



# Future of Water in Europe

Local, regional and  
global best practice

BOOK OF ABSTRACTS

5th Annual Water Efficiency Conference  
5-7 September 2018  
University of Aveiro, Portugal

**watwef**  
Conference of the Water Efficiency Network

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COVER IMAGE: a city skyline with several large water pipes above ground by Gratuit.

[http://www.freemageslive.co.uk/free\\_stock\\_image/water-pumping-jpg](http://www.freemageslive.co.uk/free_stock_image/water-pumping-jpg). Creative Commons Attribution 3.0 Unported License.

## Preface

This bi-annual conference is organised by the Water Efficiency Network. The network is a global group of academics, industry practitioners, NGOs, interest groups and members of the public who share a common interest in promoting water resource efficiency and resilience, progressive water policy, useful and usable codes and standards as well as general best practice. The network was established in 2011 with the support of the UK Government's Department for Environment, Food & Rural Affairs (DEFRA) and is still going strong thanks to its many dedicated members and technical committees.

This volume contains the papers presented at the Water Efficiency Conference (WatefCon) 2018 held on September 5-7, 2018 in Aveiro, Portugal. Over 60 submissions were received and managed via the EasyChair online conference management system. Each submission was reviewed by at least 2 scientific committee members which decided to accept 36 papers full papers and others as extended abstracts and poster submissions.

This year's proceedings also include 3 invited keynote speakers and 2 special industry sessions. The first industry session on Water Efficiency Labelling is organised in collaboration with ANQIP: Associação Nacional para a Qualidade nas Instalações Prediais together with leading experts from Europe to discuss this topical issue. The second industry session on Micro Hydro Energy Recovery and System Control towards Smart Water Grids is organised in collaboration with the EU Interreg Atlantic Area project, REDAWN: Reducing Energy Dependencies in Atlantic Area Water Networks. The REDAWN project brings together 15 partners (including the WATEF Network) from 5 countries around the European Atlantic coast to foster the adoption of hydropower energy recovery technology in built water networks in the Atlantic Area. The project is co-financed by the European Regional Development Fund through the Interreg Atlantic Area Programme. Details about the project can be found at [www.redawn.eu](http://www.redawn.eu).

I am grateful to all the contributing authors, presenters, session chairs, the keynote speakers and panel members of the industry sessions. This conference will not be a success without you all. I am also grateful to our sponsors: ANQIP, OLI, ADENE - Agencia para e Energia, HELIROMA Hot water solutions, Agencia Portuguesa do Ambiente and HEABOO disruptive techs.

My sincere thanks to this year's conference chairs: Prof Armando Silva Afonso and Dr Carla Pimental Rodrigues of ANQIP, who in addition to their editorial efforts on the proceedings have helped to make our first conference foray outside of the UK a big success. We also thank our hosts and colleagues at the University of Aveiro.

Lastly, thank you to Eleanor Eaton for going 'over and beyond' in her management of the network and its activities. And to all our technical committee chairs and members, who continue to be generous with their time, expertise and resources to ensure that the network continues to be relevant and effective in delivering our vision and aspirations.

I wish everyone a pleasant time in the charming city of Aveiro, and an enjoyable and productive conference.

July, 2018  
Bath UK

Dr Kemi Adeyeye  
Lead, Water Efficiency Network

## Editorial



This volume presents a collection of papers selected for presentation at the 5th Water Efficiency International Conference organised by the Water Efficiency Network, with the general title *Future of Water in Europe: Local, regional and global best practice*. The network aims to facilitate the promotion of water efficiency and sustainable management of urban water by bringing together academics, stakeholders and practitioners.

This conference will take place at the University of Aveiro (Portugal) and is the first held outside the UK. As in previous conferences, it is expected to make a significant contribution to the dissemination of research and innovation in the water sector, in a world where exponential urban growth and climate change are leading to increasing situations of water scarcity and flooding.

The papers selected have been grouped into eleven categories:

1. Local, regional and global case studies and good practice
2. Water efficiency in all sectors; domestic, industry, agriculture etc.
3. Water-energy, the water-energy-food nexus
4. Smart and resilient cities
5. Capacity building for climate and environmental change
6. Customer and user innovation
7. Innovation in water supply and treatment
8. Water quality, reuse and recycling
9. Environment and water infrastructure systems
10. Water governance and policy
11. Water in nature: hydrology, land use, low and high peak trends etc.

The papers were selected via a peer review process; we would like to take this opportunity to thank the scientific committee and network members for their hard work and constructive feedback to the authors of the papers. We have actively encouraged young researchers and industry to present their work, product developments and innovations in a constructive and encouraging environment. We would also like to extend our thanks to the conference sponsors, the organising committee and the keynote speakers for all their efforts and contributions toward the success of the event. We very much hope that the papers presented and discussions held at the conference will help to cross-fertilise research ideas with industrial advances in order to identify the challenges and opportunities to address water issues, at local, regional and global levels.

Conference Chairs:

Prof. Armando Silva Afonso  
Dr Carla Pimental Rodrigues  
University of Aveiro & ANQIP



## Prof. Carlos Borrego

*Full Professor of Environmental Engineering at the University of Aveiro.*



During 40 years working on environmental problems, Professor Borrego has represented Portugal on a number of national and international scientific boards and committees (EC, NATO, ESF, FCT), and evaluation panels of research institutions and projects. He was Minister of Environment, Vice-Rector of the UA, and presently is the Director of the Department of Environment and Planning. Coordinating the Research Group on Emissions, Modelling and Climate Change, he has been involved in more than 30 European projects and over 800 scientific publications on environmental impact assessment, air quality management, wind tunnel simulations, exposure to atmospheric pollutants and human health, climate change mitigation and adaptation, research and innovation for circular economy, sustainable development. As Director of the IDAD-Institute of Environment and Development, the interface unit of UA for cooperation with the Society, develops professional consulting and project activities.

### **Abstract: Climate Change, Heat Waves and Water Stress: time for change**

Climate change is one of the greatest challenges today. The current debate is not about the human contribution to global warming and climate change, but how to deal with the impacts of future climate change, namely; changes to the global water biogeochemical cycle. Rising temperatures are melting glacial ice at an unprecedented rate. Glaciers are an important source of freshwater worldwide, and some are in danger of disappearing within the 21st century. In a warmer environment, more precipitation will occur as rain rather than snow, resulting in excess water runoff that cannot be stored and therefore the decrease of soil moisture and groundwater recharge. Additionally future climate scenarios include changes in precipitation spatial (increase in equatorial regions and high latitudes; decrease in middle latitudes) and temporal patterns like periods of heavy rainfall followed by long periods of drought during spring and summer in the Mediterranean region (IPCC, 5AR, 2013). Climate change increase the risks of storms, floods, drought, water stress and fresh water scarcity, with consequences on food production, energy and other economic sectors, human health and ecosystems.

Urban areas are among the most vulnerable to climate change. Nowadays, more than half of the world population lives in urban areas and this is expected to increase to 66% (UN, World Urbanization Prospects, 2014). At the same time the number of megacities is increasing too, leading to problems like transport management, goods (materials, food, water, energy) supply, solid wastes collection and treatment, wastewater drainage and treatment, air pollution, urban heat island effect (UHIE), among others.

To create sustainable cities and communities became one of the 17 Sustainable Development Goals of the 2030 Agenda for Sustainable Development, establish by United Nations. To face global warming and climate change impacts, cities should adapt and become more resilient. Increasing blue and green infrastructure, are most recommended solutions for greening the cities, to adjust the urban microclimate reducing the UHIE, to increase the comfort and citizen's quality of life and contributing to the regulation of the urban water cycle, from demand to disposal.

## Prof. Francisco Arregui

*Researcher at ITA (formerly Instituto Tecnológico del Agua), Universitat Politècnica de Valencia*



Francisco Arregui has over 20 years of experience in the field of water metering and apparent losses assessment and reduction. His Phd, in 1998, dealt with the technical management of water meters.

Since then, he has lead numerous projects with private and public water utilities around the world, giving technical support and training on water meter management, water meter performance analysis, non-revenue water reduction strategies and water consumption patterns determination.

He has also supervised several PhDs and MSc on the topic and co-authored more than 40 technical papers and a book for IWA Publishing entitled “Integrated water meter management”. Currently, he is working in the development of cloud based software tools to support water meter management.

### **Abstract: New trends in high frequency water demand monitorization and analysis: experiences and challenges**

Water metering, data logging and transmission equipment have progressively reduced their price and increase capacity and sensitivity. Also, the latest developments in Big Data and Machine Learning techniques allow for the processing of large quantities of data. Cloud computing allow for scalable systems that can be upgraded as more computing power and storage are required. All these advances have made possible significant improvements in the understanding of water consumption that can help water utilities improve the overall efficiency of their systems. The presentation describes previous experiences and challenges faced when conducting high frequency water consumption monitorization. It also, presents the latest advances in water demand micro-component research conducted at ITA (Spain), including the new software and hardware developed.

## Prof. Francisco Nunes Correia

*Full Professor of Environment and Water Resources, IST, University of Lisbon  
Former Minister of Environment, Territorial Planning and Regional Development*



Francisco Nunes Correia got his Ph. D. in Civil Engineering at Colorado State University (USA). He is currently a Full Professor of Environment and Water Resources at Instituto Superior Técnico (IST), the main engineering school in Portugal. He is founder, former President of the Board, and now President of the General Assembly of the Portuguese Water Partnership, a platform of universities, enterprises, professional associations and governmental agencies involved in water policy and technology. Along with his academic career, he held several public positions, notably Minister of Environment, Territorial Planning,

and Regional Development of the Portuguese Government (2005-2009), President of the National Laboratory of Civil Engineering (2004--2005) and National Co-ordinator of the POLIS Programme for the urban renewal and environmental improvement of Portuguese cities (1999--2003). He was also Co-ordinator of the Portuguese National Environment Plan (1993-- 1995) and Director--General for Natural Resources (1986--1989).

He was awarded the degree of Grand Officer of the Order of “Infante D. Henrique”, an honorific decoration conferred in 2010 by the Portuguese President of Republic in recognition for the achievements as Minister. He has extensive professional experience as researcher, teacher, and consultant in the areas of water, environment and regional development. He was consultant of the World Bank in water projects in South America and participated in environmental projects in Macao (China). He was Coordinator of several European research projects, notably EUROWATER and WATER 21.

### **Abstract: Dimensions and Principles of Water Governance**

Effective water resources management requires not only appropriate technology and infrastructure, but also a model of governance, and the corresponding procedures, that contribute to lead society to the ultimate goal of sustainable development. The key elements of the water policy formulation process, and the main components and actors of this process, need to be understood to be able to establish a system of governance that is effective, efficient, and capable of promoting trust and engagement of the main actors and of society in general. With this purpose, OECD has formulated the 12 principles for good water governance, approved by the Ministerial Council of this multilateral organization in June 2015, after a long process of discussion and consultation. These principles can be used as a basis for the formulation of more purposeful and adjusted policies, or else as a framework for the inter-comparison, benchmarking and monitoring of the evolution of the water governance system in different societies. The following step, now taking place, is the definition of a group of indicators that provide an accurate view of the degree of achievement in the implementation of the various principles.

# ANQIP Industry Session 1: Water Efficient Labelling

**CHAIR – Prof. Armando Silva Afonso**



**SPEAKER – Eng. Paulo Lemos – DG ENVI, European Commission**

**Panel members:**

- Eng. Filipa Newton - Head, Water Efficiency Department at ADENE - Agency for Energy
- Eng. Paula Gomes - Head Division of Sustainable Development at DGAE - General Directorate of Economic Activities
- Dr. Carlos Velazquez - Corporate Marketing Director at Roca Group
- Dr. Yvonne Orgill - Chief Executive at Bathroom Manufacturers Association
- Eng. Kjell-Åke Henriksson - Energy Installations in JM AB

## **Key topics of discussion:**

- 1) At what point is the process of creating a European efficiency label for water using products?
- 2) Do you consider more important a label of energy efficiency, a label of water efficiency or a mixed label for water using products?
- 3) What is the importance of a unified European label for efficiency of products?
- 4) How can efficiency labelling enhance innovation and industrial development?
- 5) How to raise consumer awareness of water efficiency?
- 6) How to involve the commercial sector in promoting efficient products?



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ANQIP

# REDAWN Industry Session 2: Water Efficient Labelling

CHAIR – Prof. Helena Ramos



SPEAKERS & Panel members:

- Engr Rui Silva Santos, RSS Portugal and Miguel Zilhão, IST/RSS Portugal
- Engr Nuno Aleixo, KSB
- Dr John Gallagher, Trinity College Dublin
- Engr Pedro Perdigao, INDAQUA
- Engr Margarida Pinhão, Technilab Lisboa
- Engr Jose Saldana, Saint Gobain PAM

Find out more about  
**REDAWN**

[www.redawn.eu](http://www.redawn.eu)

This project is co-financed by the European Regional Development Fund through the Interreg Atlantic Area.





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# #1. Local, regional and global case studies and good practice + Innovation in water supply and treatment

# Risk management in water supply networks

**Fernanda Rodrigues<sup>1\*</sup>, Manuela Borges<sup>1</sup>, Hugo Rodrigues<sup>1,2</sup>**

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## ABSTRACT

Water supply networks are critical infrastructures essentials to health, safety, economic and social wellbeing that have to be maintained and preserved to ensure their proper functioning. The proper management of those infrastructures is a key point to ensure their proper functioning. Considering the importance of critical infrastructures, such as water supply networks, for the daily life of all sectors of society, the risks to which they are exposed, and the consequences of such risks must be analyzed. Thus, it is important that responsible companies for the management of these assets incorporate risk management in their activities. In the scope of risk management, this work intends to identify the vulnerabilities of water supply infrastructures, by analyzing the risks they are exposed and to identify the measures that need to be implemented or reinforced. This work analyses what initiatives exist for risk management of critical infrastructures, such as water supply networks, considering this as an essential element in the company's management activities. Risk assessment methodologies were analyzed to identify the vantages and disadvantaged of each one. As a case study, it was used the supply network of the city of Aveiro, in Portugal, which is composed by 15 reservoirs, 5 elevated and 10 supported. This network was analyzed resourcing ArcMap, ArcGIS desktop software, which allows a better understanding of how the case study works. Risk management was applied to the case study and the probability and possible consequences of six distinct categories of threats were determined in eight scenarios, allowing the analysis of risk levels of the network through the development of risk maps. Measures to improve the response or to prevent the occurrence of potential incidents were also identified.

*Keywords: Critical infrastructures, risk assessment methodologies, ArcGIS, ArcMap*

## 1. INTRODUCTION

The infrastructures safety management is a current challenge as for governments as for owners and operators of critical infrastructures [1].

The critical infrastructures systems and installations are subject to diverse and different failure modes. Thus, it is important to anticipate the possible failure modes, its probability of occurrence and the gravity of its consequences [2]. The hazards under which the critical structures are subject can be intentional, e.g. terrorism, sabotage, cyberattacks, or non-intentional as accidents, aging, natural catastrophes, etc. Hazard is defined as an element as itself or in combination with others that has the intrinsic potential to cause a risk. A situation that represent a threat level to life, health, property or environment correspond to a hazard [3].

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ISO 31000 – Risk management [4], define risk as the effect of uncertainty on objectives, where an effect is a deviation from the expected — positive and/or negative. The standard consider that objectives can have different aspects (such as financial, health and safety, and environmental goals) and can apply at different levels (such as strategic, organization-wide, project, product and process). During the risk assessment the risk can be eliminated, reduced or when it is not possible mitigation and protection measures can be implemented. The more effective way to analyze the benefits between reduce the risk and the protection measures is to implement a decision support system that integrate information about threats, vulnerability assessment and the consequences of the interruption of a service, through advanced modeling and simulation [5]. Vulnerability is the manifestation of the inherent states of the system that can affect negatively the system [6]. The ESPON Hazards project defines vulnerability as the combination of the potential damage and the response capacity, considering its versatility to recognize 3 dimensions of vulnerability: economic, social and ecologic [7]. Nowadays, different network infrastructures as transports, energy, water, communications, are intrinsically connected. This interconnection implies that changes in the capacities of one are felt in others. Those dependencies are not limited to the localization of the original incident that caused the change and the resulting effects are frequently adverse and lasting. Local changes in a network several times have regional effects or even global in certain domains [8]. Interdependencies between infrastructures and its resilience, the capacity to recover the former function after the occurrence of non-desirable events, are the key aspects in the critical infrastructures management.

The urban network of water supply is almost always composed by water abstraction sources, adductor conducts, treatment stations, and supply networks, being exposed to a great variety of risks threatening its functioning [9]. As the water is essential for Human life, the analysis, mitigation or elimination of those risks must be a priority.

This paper aims to present the risk assessment for the upcoming risk management of a water supply network applied to a case study: the Aveiro municipality water supply system, located in the midland Portugal.

## **2. METHODOLOGYCRITICAL INFRASTRUCTURES PROTECTION**

The European Programme for Critical Infrastructures Protection (EPCIP) consist on a plan that involve different tools permitting to protect European critical infrastructures. The European Directive 2008/114/EC, of 8 of December is part of the Critical Infrastructure Protection (CIP) programme in which are only considered the energy sectors (electricity, gas, oil), and transports. The Article 3 establish that each Member State shall identify potential Critical Infrastructures.

The Homeland Security Presidential Directive (HSPD-7) establish a US law to protect the critical infrastructures, introducing a structure for the Internal Safety Department (DHS) that permit to identify, prioritize and protect the critical infrastructures from terrorist attacks [10]. The critical sectors identified include among others the waste-water and the water supply system [11]. Comparing the DHS approach with the European one, EPCIP it is possible to conclude that both represent sectorial approaches. However, contrary of EPCIP, HSPD-7 focus on the resilience and the EPCIP contain a formal procedure to identify and designate the critical infrastructures, not considered in the HSPD-7.

The Canadian National Strategy for Critical Infrastructure Protection establish a structure to reinforce the resilience of critical infrastructures, being the resilience the final objective to be achieved. This objective is achieved through a plan, execution element of the national strategy that establish the actions in the area of partnerships organizations, the implementation of a management of all the risks and the information sharing [12].

## **3. CRITICAL INFRASTRUCTURES RISK ASSESSMENT METHODOLOGIES**

A successful Critical Infrastructure Protection Program depends on the effective risk assessment methodologies implemented, indispensable in order to identify threats, assess vulnerabilities and evaluate the impact on assets, infrastructures or systems taking into account the probability of the occurrence of threats. There is a significant number of risk assessment methodologies for critical infrastructures, consisting on some main elements: identification and classification of threats, identification of vulnerabilities and evaluation of impact [12]. Currently a methodology definition considering the users, the interdependencies between critical

infrastructures of different sectors and the analysis at infrastructures/systems levels and at the systems of systems level, beyond the determination of the principal elements mentioned, is necessary.

Giannopoulos et al. [12]. present a selected number of these risk assessment methodologies (RAM) and in order to obtain a structured review, the evaluation of these methodologies took place according to the following criteria: Scope of the methodology (which sector is addressed, to whom it is addressed (policy makers, researchers, operators etc.)); Objectives of the methodology; Applied techniques and standards; interdependencies coverage; is resilience addressed?; if cross-sectoral methodology, how are risks compared across sectors?. So, different Risk Assessment methodologies (RAM) were analyzed: Better Infrastructure Risk and Resilience (BIRR) developed by Argonne National Laboratory - USA Department of Energy's [13]; Protection of Critical Infrastructures - Baseline Protection Concept (BMI) developed by the Federal Ministry of Interior, the Federal Office for Civil Protection and the Disaster Response and the Federal Criminal Police Office (Germany) [12]; CARVER2, Criticality Accessibility Recoverability Vulnerability Espyability Redundancy developed by the NI Centre for Infrastructure Expertise – USA [12]; Critical Infrastructure Modelling Simulation (CIMS) adopted by Idaho National Laboratory supported by the U.S. Department of Energy [12]; Critical Infrastructure Protection Decision Support System (CIPDSS), developed in the USA that is a tool for information and decision support for the protection of critical infrastructures, is a pure risk assessment tool that accounts the probability of a threat, vulnerabilities and impact for all hazards and different types of infrastructures [14]; the Critical Infrastructure Protection modelling and Analysis (CIPMA) launched by the Australian Government in order to build the capacities for the protection of nation's critical infrastructures [12]; CommAspen is the evolution of the first version of an agent-based tool that has been developed in the 90's in order to model the interdependencies between electric power systems and other infrastructures that are essential for the US economy [15]; Counteract (Cluster of User Networks in Transport and Energy relating to Anti-terrorist Activities) developed under a FP6 funded project, focus on the transport and energy sectors and it is focused on terrorist threats [12]; DECRIS project/approach build on the existing capacities in the sectoral risk assessment methodologies that exist in Norway [16]; European Risk Assessment and Contingency Planning Methodologies for Interconnected Energy Networks (EURACOM) [17]; National Infrastructure Simulation and Analysis Centre developed the Fast Analysis Infrastructure Tool (FAIT) in US [18]; Multilayer Infrastructure Network (MIN) is a methodology that has been developed by the Purdue School of Civil Engineering in US [12]; Agent-Based Laboratory for Economics (N-ABLE) developed by NISAC (National Infrastructure Simulation and Analysis Centre) [19]; Network Security Risk Assessment modelling (NSRAM) that has been developed by the Institute for Infrastructure and Information Assurance at James Madison University [12]; RAMCAP-Plus methodology has been developed by ASME (American Society of Mechanical Engineers) [20]; Risk and Vulnerability analysis (RVA ) developed by the Danish Emergency Management Agency [21]; Sandia Risk Assessment Methodology developed by Sandia National Laboratories in US [22]; Risk Management Framework of the National Infrastructure Protection Plan (NIPP) developed by the Department of Homeland Security and the corresponding Risk Management framework in Canada [23]; in Portugal the Risk Management of the Portuguese Safety Association (GRAPS in Portuguese) based on the ISO 31000 [24].

Aiming to choose the RAM to be used in a case study, the authors considered several factors as the availability of tools for its implementation, the facility of application, and the importance given by the RAM to the interdependencies and resilience, considering that the severity of the consequences is related with these two criteria. Respecting interdependencies, for e.g. an electrical energy failure lead to consequences not only in the energy sector but also in other sectors of critical infrastructures as in the water supply or transports. Resilience permits to decrease or mitigate the consequences of adverse events being for that considered an important factor.

Methodologies as NEMO, FAIT, in spite of its interest, consist on a software that are not available. CARVER2 software is wide-ranging and considers important points referring risk assessment, namely the resilience, interdependencies and vulnerability, contrary to almost the other methodologies that do not consider resilience. This is the highlighted parameter in RAMCAP-plus methodology that develop expressions permitting to quantify the owner and community resilience being well structured and broad. In the FAIT methodology the Fastmap application permit to generate maps and reports of active risks, in real time, during an event occurrence, for e.g. floods, forest fires, tsunamis, etc.

The on/off relation possible in the NEMO methodology would be a beneficial resource for water supply networks because permit to analyze the cascade effect that one network element can cause in the others. In this methodology software SIG are used to map analyses, as it will be done in the work herein presented.

The NSRAM methodology consider the Human behavior, as for e.g. in the event of a failure, it has in consideration the effects of the maintenance personnel or the unavailability of pieces. CIPDSS methodology propose the development of decision makers profiles taking in consideration the subjective risk assessment nature.

Without needing to apply software is possible to use the EUROCAM, BIRR and RVA methodologies being composed by similar risk assessment structures. Thus, due to the existence of available tools to its application, RVA methodology was chosen in the aim of the work developed, being complemented to improve the risk assessment. RVA was complemented with ArcGIS permitting a better understanding of the potential risks consequences and through the identification of plans that permit to improve the response of the enterprise to adverse events.

## 4. METHODOLOGY

### Case study

The case study under study consist on the water supply network of Aveiro municipality that supply almost 78450 persons (according to Censos 2011[25]), is composed by 8 significant points in 5 parishes as represented in Figure 1 [26].

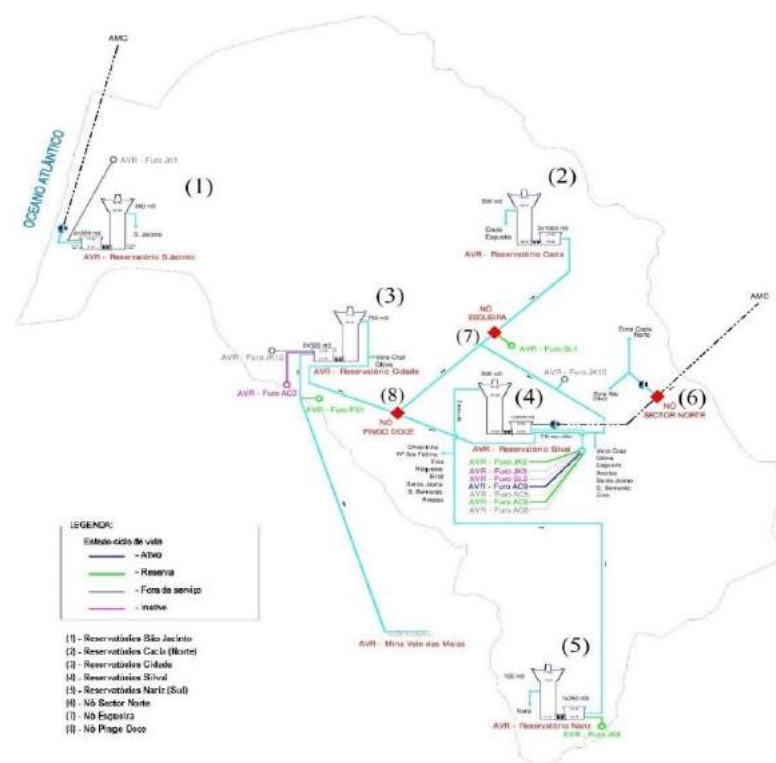


**Fig. 1 – General water supply network of Aveiro municipality**

Each one of these significant points consist on water reservoirs with different capacities:

- (1) 3 reservoirs, one with 300 m<sup>3</sup> and two with 350 m<sup>3</sup>, supplying 1000 inhabitants that increase in summer due the littoral location.
- (2) 3 reservoirs, one with 500 m<sup>3</sup> and two with 1000 m<sup>3</sup>.
- (3) 3 reservoirs, one with 750 m<sup>3</sup> and tow with 500 m<sup>3</sup>.
- (4) 4 reservoirs, three with 500 m<sup>3</sup> and one with 3500 m<sup>3</sup>.
- (5) 2 reservoirs, one with 100 m<sup>3</sup> and one with 250 m<sup>3</sup>.
- (6) Without reservoir but permitting strengthen the network
- (7) and (8) are points of operation and of control of the supply system.

## Network modeling

For the integral understanding of the network under study that is fundamental in the risk management, the software GIS, ArcGIS desktop, of ESRI – Environmental Systems Research Institute, was used.

Geographic Information System – GIS is an informatics system that capture, store, analyze and show geospatial data (Chang, 2017).

The analyses were realized resorting the ArcGIS desktop, the ArcMap that permit to show and explore sets of GIS data, to attribute symbols and do layouts of maps to print or publish. It also permits to create and edit ranges of data through the toolbox (ESRI, 2017).

Figure 2 depict the available information of the water supply network, namely the significant points, abstraction points, the pipelines and the handover points together with the pipes.

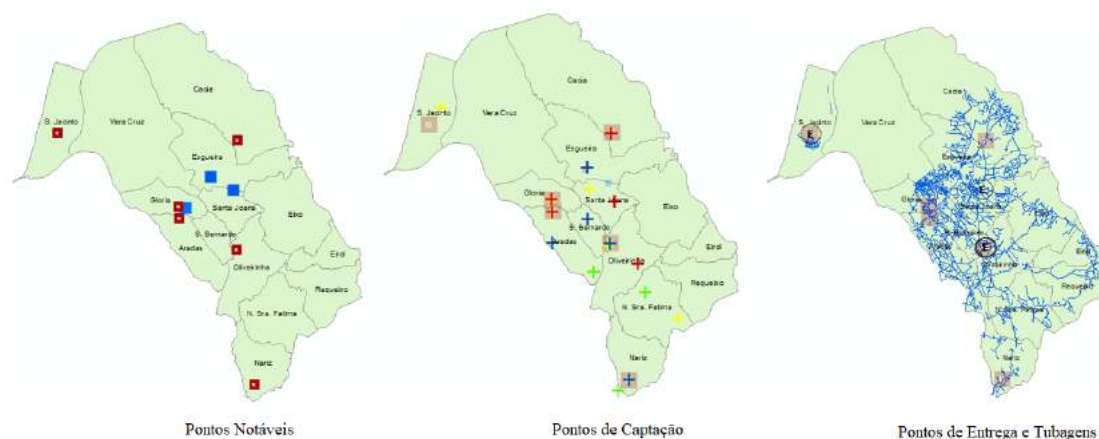


**Fig. 2 – Water supply network's elements**

Figure 3 shows the population density distribution obtained through the Censos 2011 [25] data. Finally resorting Google Earth it was possible to locate infrastructures that can be affected by the occurrence of an event in the water supply network, as public administration buildings, hospitals, health centers, schools, elderly centers, fire department, police departments, see Figure 4.

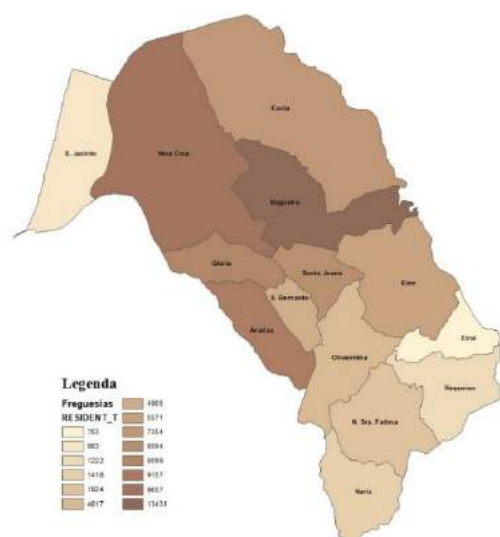


**Fig. 3 – Population density of Aveiro municipality (source [25])**

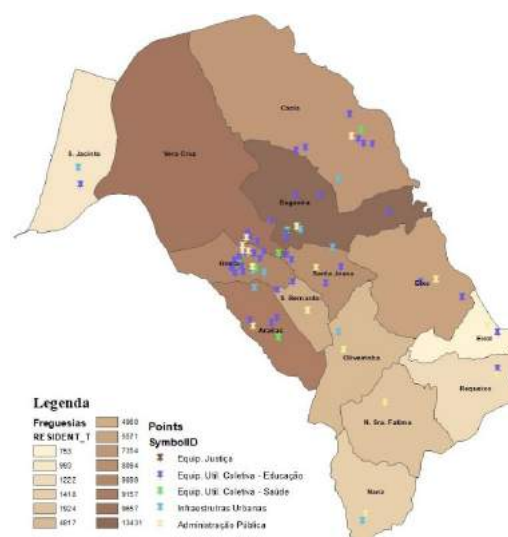


**Fig. 4 – Infrastructures that can be affected by the events affecting the water supply system**

Figure 5 represent the water supply points, which information is essential for the risk management of this critical infrastructure and the area of influence of each system of the water supply network is represented in Figure 6.



**Fig. 5 – Infrastructures Water abstraction and supply points**

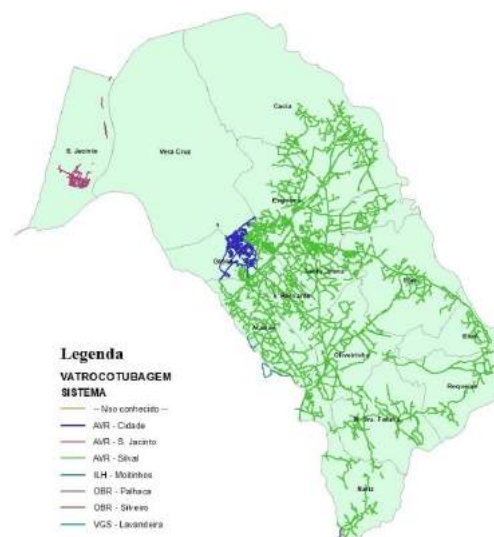


**Figure 6 – Area of influence – System**

### Risk and Vulnerability Analysis (RVA) implementation

The risk assessment of the water network was done using the Risk and Vulnerability Analysis (RVA) methodology developed in Denmark consisting on the filling of 4 templates in the Danish Emergency Management Agency (DEMA) website. In the first template, it was identified all the stockholders involved in the analyses and the critical function of the society that have to be analyzed. The second and third correspond respectively to the identification of threats and to the analyses of the treats scenarios. In the fourth, a risk profile is done as the vulnerability analyses estimation.

According to the DEMAs threats scenarios catalogue it was decided to develop 6 scenarios as depicted in Table 1, integrated in 3 types of incident/category of different treats: destruction or failure of critical society functions, crime and extreme natural phenomenon. For each one it was estimated the probability of occurrence the consequences and the vulnerability of the assets according to Tables 2, 3 and 4.

### Table 1 – Scenarios to be considered

| Scenario | Title                                                      | Threat category/Incident type                        |
|----------|------------------------------------------------------------|------------------------------------------------------|
| 1        | Electric energy failure in the significant point of Silval | Destruction or failure of critical society functions |
| 2        | Earthquake – Intensity VII                                 | Extreme natural event                                |
| 3        | Remote management failure                                  | Destruction or failure of critical society functions |
| 4        | Failure of sodium hypochlorite dosing pumps                | Destruction or failure of critical society functions |
| 5        | a) Cyberattack against IT systems (remote management)      | Other threats: Crime                                 |
|          | b) Destruction of Silval reservoir                         | Other threats: Crime                                 |
|          | c) Water contamination                                     | Other threats: Crime                                 |
| 6        | Failure in the abstraction system of Carvoeiro             | Destruction or failure of critical society functions |

The vulnerability assessment considers the preparation before the event occurrence, through the planning and the mitigation measures, the response capacity and relief during and the recovery capacity after the incident, scored according Table 5.

**Table 2 - Probability indexes**

|   |                        |
|---|------------------------|
| 1 | <b>Highly unlikely</b> |
| 2 | Very unlikely          |
| 3 | Probable               |
| 4 | Very probable          |
| 5 | Highly probable        |

**Table 3 - Consequence levels**

|   |              |
|---|--------------|
| 1 | Limited      |
| 2 | Moderated    |
| 3 | Serious      |
| 4 | Severe       |
| 5 | Critical     |
|   | Not relevant |
|   | Unknown      |

**Table 4 – Levels of risk**

|   |               |    |                |
|---|---------------|----|----------------|
| 1 | Very low risk | 9  | Medium risk    |
| 2 | Very low risk | 10 | Medium risk    |
| 3 | Very low risk | 12 | Medium risk    |
| 4 | Low risk      | 15 | High Risk      |
| 5 | Low risk      | 16 | High risk      |
| 6 | Low risk      | 20 | Very high risk |
| 8 | Medium Risk   | 25 | Very high risk |

**Table 5 – Indexes for the preparation assessment, response capacity and relief and recovery capacity**

|   |                             |
|---|-----------------------------|
| 1 | Adequate                    |
| 2 | Mostly adequate/some faults |
| 3 | Some severe faults          |
| 4 | Many severe faults          |
| 5 | Unsuitable                  |
|   | Not relevant                |
|   | Unknown                     |

According to the water consumption data, it was possible to calculate the period in which is possible to supply the population with the store water in the reservoirs, without being supplied by the abstraction points. This an essential data for the crises management as it corresponds to period in which the management enterprise has to solve the problem that hinder the reservoirs supply.

## 5. RESULTS DISCUSSION

Resourcing RVA methodology the 6 scenarios were assessed which results for scenario 1, as an example, are depicted in Table 6.

The risk matrixes permit verify that the developed scenarios have low or medium levels of risk. The risk matrix for each scenario was also developed as depicted in Table 6.

**Table 6 – Assessment results for scenario 1**

|                              |                                 |
|------------------------------|---------------------------------|
| Probability                  | 1 – Highly unlikely             |
| General consequences         | 4 - Severe                      |
| Risk                         | 4 – Low risk                    |
| Preparation                  | 2 – Mostly adequate/some faults |
| Recovery capacity and relief | 4 – Many severe faults          |
| Recovery capacity            | 1 - Adequate                    |

According to Table 7, it is possible to verify that the water supply network has high vulnerability for some scenarios. The scenario which has higher vulnerability is the cyberattacks (scenario 5 a)). It must be highlighted that for this scenario it was considered that the management enterprise has no preparation or mitigation measures. As this kind of attacks to critical infrastructure are increasing it must be a scenario that have to be deeply analyzed and considered.

**Table 6 – Matrix of Risk**

|                |                     |              |              |             |                         |              |
|----------------|---------------------|--------------|--------------|-------------|-------------------------|--------------|
| Probability    | Highly probable (5) |              |              |             |                         |              |
|                | Very probable (4)   |              |              | Scenario 4  |                         |              |
|                | Probable (3)        |              |              |             | Scenario 2 and 3        |              |
|                | Very unlikely (2)   |              |              |             |                         | Scenario 6   |
|                | Highly unlikely (1) |              |              |             | Scenario 1, 5 a) and b) | 5 c)         |
| Very high risk |                     |              |              |             |                         |              |
| High risk      |                     | Limited (1)  | Moderate (2) | Serious (3) | Severe (4)              | Critical (5) |
| Medium risk    |                     |              |              |             |                         |              |
| Low risk       |                     |              |              |             |                         |              |
| Very low risk  |                     | Consequences |              |             |                         |              |

**Table 7 – Vulnerability profile**

| <div><div></div><div></div><div></div><div></div></div><br>Very high vulnerability |                                                       | Assessment of vulnerability levels                                 |                                                                    |                                                         |
|------------------------------------------------------------------------------------|-------------------------------------------------------|--------------------------------------------------------------------|--------------------------------------------------------------------|---------------------------------------------------------|
| <div><div></div><div></div><div></div><div></div></div><br>High vulnerability      |                                                       | Preparation (plans, preventive measures, etc.)                     | Response and relief capacities                                     | Recovery capacities                                     |
| <div><div></div><div></div><div></div></div><br>Medium vulnerability               |                                                       |                                                                    |                                                                    |                                                         |
| <div><div></div><div></div></div><br>Low vulnerability                             |                                                       |                                                                    |                                                                    |                                                         |
| <div><div></div></div><br>Very low vulnerability                                   |                                                       |                                                                    |                                                                    |                                                         |
| Threats` scenarios                                                                 | Scenario 1 –<br>Electrical failure<br>Silval          | <div><div></div><div></div></div>                                  | <div><div></div><div></div><div></div><div></div></div>            | <div><div></div></div>                                  |
|                                                                                    | Scenario 2 -<br>Earthquake                            | <div><div></div><div></div><div></div><div></div><div></div></div> | <div><div></div><div></div></div>                                  | <div><div></div><div></div></div>                       |
|                                                                                    | Scenario 3 –<br>Remote<br>management<br>failure       | <div><div></div><div></div><div></div></div>                       | <div><div></div><div></div><div></div></div>                       | Unknown                                                 |
|                                                                                    | Scenario 4 –<br>Failure of dosing<br>pumps            | <div><div></div><div></div></div>                                  | <div><div></div><div></div></div>                                  | <div><div></div></div>                                  |
|                                                                                    | Scenario 5 a) –<br>Cyberattack                        | <div><div></div><div></div><div></div><div></div><div></div></div> | <div><div></div><div></div><div></div><div></div><div></div></div> | <div><div></div><div></div><div></div><div></div></div> |
|                                                                                    | Scenario 5 b) –<br>Destruction of<br>Silval reservoir | <div><div></div><div></div><div></div></div>                       | <div><div></div><div></div></div>                                  | Unknown                                                 |
|                                                                                    | Scenario 5 c) –<br>Water<br>contamination             | <div><div></div><div></div><div></div></div>                       | <div><div></div><div></div><div></div></div>                       | Unknown                                                 |



|  |                                                                                |                                                                                   |                                                                                    |                                                                                     |
|--|--------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|
|  | <b>Scenario 6 –<br/>Failure in the<br/>abstraction system<br/>of Carvoeiro</b> |  |  |  |
|--|--------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|

## 6. CONCLUSIONS

Risk management aims to minimize the impacts of potential risks that can affect a certain activity being necessary deeply know it. For critical infrastructures, the analysis of its performance when subject to events associated to potential risks, permits to identify measures that have to be implemented to minimize the respective consequences. Currently the critical infrastructures threats are increasing being essential that its management enterprises have to do a reliable risk assessment and management. Nowadays, these treats are not only due to human actions like terrorism and crimes but also to natural phenomena's that are getting more extreme consequences due to climate changes. This work aims to contribute to lead the management enterprises responsible for critical infrastructures to do a reliable risk management of their assets granting its suitable functioning specially under a damage situation. The study herein presented was developed in the water supply system of Aveiro municipality composed by 15 reservoirs, 5 elevated and 10 supported on the floor, located in 5 different parishes. The water network supply almost 78450 persons. The analyses were done resourcing the ArcMap of ArcGis desktop software that permitted to analyze the network functioning and the population depending on the water supply being possible to identify the network critical points. The risk assessment was done using the Risk and Vulnerability Analysis (RVA) methodology developed in Denmark consisting on the filling of 4 templates in the Danish Emergency Management Agency (DEMA) website. The network risk assessment permitted verify the scenarios with higher level of risk and identify the network vulnerability. After the templates filling for each scenario, a general analysis was carried out and it was identified possible measures to be implemented to improve the preparation or the enterprise response to incidents. Regarding the risk profiles and vulnerability, the risk matrix permits verify that the developed scenarios have low or medium levels of risk. This matrix also leads to the scenarios identification with higher probability of occurrence and with severe consequences permitting to prioritize scenarios in which invest in mitigation and prevention measures. Risk maps to each scenario were developed to the water network and specific ones to the most critical point of Silval. It was concluded that to decrease the vulnerability of the water supply network of Aveiro municipality a set of emergency and contingency plans must be develop: Maintenance plans; Investment plans; Contingence plans (aiming to prepare the organization to respond efficiently to emergencies and to its potential human impact); Emergency plans (systematizing a set of standards and rules to minimize the forecast catastrophe effects, managing effectively the available resources); Evacuation plan; Action plan.

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# How to estimate rainwater harvesting savings at urban level? A scale-adaptive method

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## ABSTRACT

Water is already a key resource at risk in many parts of the globe. As such, increasing water efficiency through consumption reduction or resorting to alternative water sources is a challenge in the near future. Rainwater is an alternative water source that is becoming increasingly popular in many countries. This paper presents a methodology to evaluate rainwater harvesting (RWH) potential at an urban level taking into consideration buildings characteristics and consumption pattern. The proposed methodology is applied to the city of Lisbon, Portugal, located on the Atlantic coast of the Mediterranean climate region. The estimated water savings potential varies within the city of Lisbon depending on buildings configuration, namely the relation between the number of floors and the roof area, and buildings occupancy, namely the number and size of the families, ranging from 16% to 86%. The spatial variability of the rainfall in the city of Lisbon was found to be negligible for rainwater harvesting potential evaluation.

*Keywords: rainwater harvesting systems, water savings potential, non-potable water consumption, hydrologic regime, Mediterranean region, urban planning, Lisbon.*

## 1. INTRODUCTION

Due to population growth [1], water consumption increase [2], pollution of water sources [2] and, more recently, climate changes around the world [3, 4], water has become a resource at risk. Several countries are already facing problems related to water scarcity or will face them in a near future [5, 6]. In the scope of water efficiency, rainwater has been considered an alternative source usually for non-potables uses in buildings in various contexts [7-10]. These studies show a substantial variability of water savings potential from RWH depending on the specific context of the analysis and the adopted design method. To achieve reliable results, a daily simulation of the RWH performance taking into consideration the local climate (namely the rainfall), the water consumption pattern per end-use, and the RWH system configuration (in particular the collection area and losses) is required [11-13].

At an urban level, several studies account for the spatial variation of the precipitation [14], some emphasize the real collection area derived from the building roof area [15] but the link to the buildings demographics to determine the water consumption is only found in the study by Belmeziti et al [16]. Since all these aspects are relevant for estimating RWH savings, the goals of the present paper are two-fold. First, develop a methodology to evaluate rainwater harvesting potential at an urban level that takes into consideration the rainfall and buildings spatial variability and also accounts for the buildings geometric and demographic characteristics. Second, apply the methodology to the city of Lisbon, Portugal, that is located in the on the Atlantic coast of the Mediterranean climate region.

## 2. PROPOSED METHODOLOGY

The proposed methodology is schematically presented in Fig. 1. It adopts equivalent buildings as representative of a certain city building stock and uses them to estimate the performance of a RWH system in a delimited area.

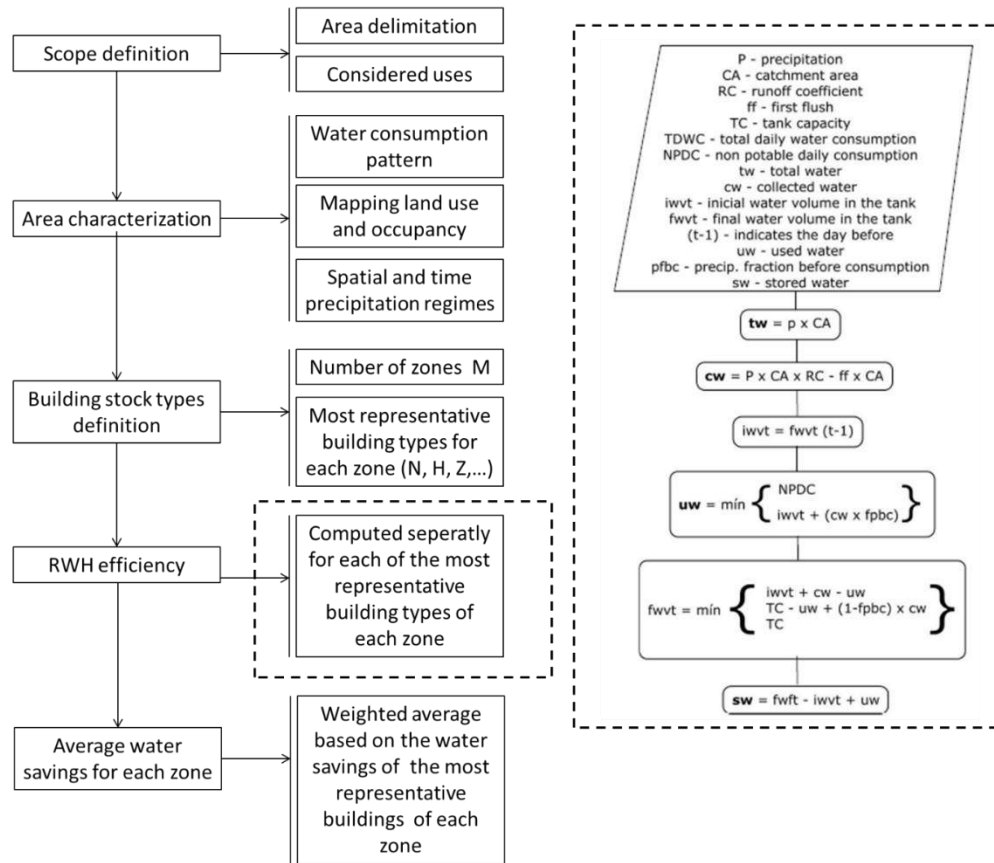


**Fig. 1: Methodology flowchart.**

Scope definition includes: (i) the definition of the spatial boundaries of the study (area delimitation); and (ii) the potential uses for the harvested rainwater (considered uses). The proposed methodology may be applied to a country, municipality, city, parish or even a neighborhood. The adopted urban area should be defined depending on the purpose of the analysis, expected accuracy of the results and available information about the characteristics of the rainfall and the buildings geometry and occupancy. The proposed methodology also considers the possibility of using rainwater in buildings and/or in public spaces. In buildings, rainwater uses vary depending on the level of demand of the target population. One may assume rainwater to be suitable for potable uses, both in residential and service buildings, but in most developed countries only non-potable uses are acceptable, typically indoor uses such as cloth washing and flushing and outdoor uses such as washings (e.g., car, garage, driveways and walkways) and watering. In public spaces, rainwater may be used for street washing and garden watering.

Area characterization includes: (i) water consumptions pattern; (ii) mapping land use and occupancy; and (iii) spatial and time rainfall regimes. The daily water consumption per capita on residential buildings varies around the globe, and is generally higher in developed countries [17]. Different studies also show that the non-potable water consumption of an average household in developed countries represents about 35% of the total indoor water consumption [6, 18]. The characterization of the urban area involves analyzing information from statistical studies, geographical information systems and local observations, in order to identify city zones that are distinct in terms of: (i) land uses proportions, for instance roads, gardens and building areas; and (ii) building characteristics and occupancy, due to different number of floors, number

of households per floor and number of occupants per household. Rainfall is variable both in time and space around the globe. In order to characterize the hydrologic regime it is important to identify the available sources of information and select the most adequate. For rainwater harvesting systems simulation, Mitchell et al. [19] recommends the use of rainfall series with a minimum of 10 years of records. Distinct rainfall series should be defined for different zones since there can be significant spatial variability of the rainfall depending on the climate and area under analysis [20].

Water consumptions pattern, land use and occupancy and rainfall regimes are balanced to determine, simultaneously, the adequate number of zones that should be considered in the analysis and the most representative building types of each zone. Each zone is characterized by its rainfall (P) and the most representative building types to keep the approach simple, while avoiding excessive averaging error. However, the methodology is adaptable to varying degrees of detail depending on the information is available. In theory, it can consider each individual building in all zones. Within each zone, the RWH potential is, therefore, assessed for each building type considered representative of the zone and extrapolated based on its relative weight in the building stock.

The RWH system is evaluated for each building type by simulating its performance on a daily basis considering: (i) the daily rainfall amount (mm); (ii) the collection area (m<sup>2</sup>); (iii) the total daily water consumption of the building (m<sup>3</sup>/day) as well as its non-potable fraction; (iv) the tank capacity (m<sup>3</sup>); and (v) the first flush and losses. The daily rainfall amount can be obtained from direct observations (records of meteorological stations), indirect observations (satellite images) or monitoring local rainfall. Building roof area of each building type representative of each zone should be characterized since it directly defines the collection area of the RWH system. This information can be obtained from GIS. The average daily water consumption per building type can be obtained based on the number of residents (occupancy) times the daily water consumption per capita. Occupancy should be estimated as the roundup integer computed from the number of dwellings per floor, the number of floors of each building type in each zone and the average family dimension in that zone. This information can be estimated consulting statistical studies and performing visits on site to characterize each building stock under analysis. Consumption pattern of each zone, including its non-potable fraction, should be assessed consulting previous studies eventually complemented by monitoring campaigns. Fig. 1 (dashed box) presents a simplified representation of the model used to simulate the performance of a RWH system. A daily scale was chosen to estimate approximately the real RWH potential because it limits the influence of the temporal variability between the rainfall and consumption. Further details on the model used can be found in Silva et al. [10]. Other parameters such as tank capacity and losses are defined according to users requests. Typically, for evaluating RWH systems potential in unconstrained scenarios, several tank capacities are tested in order to identify the optimum point. The losses are frequently quantified by a constant first flush diversion and a runoff coefficient. The runoff coefficient may vary depending on the antecedent number of dry days, roof slope, material, orientation and rainfall intensity [21].

Along with the raw data from the simulations, the outputs of the program include the following parameters: i) Full use of rainwater efficiency (FURE) = (Stored rainwater)/(Total rainwater); ii) Non-potable water savings (NPWS) = (Consumed rainwater)/(Non-potable water consumption); and iii) Total water savings (TWS) = (Consumed rainwater)/(Total water consumption). After assessing the water savings of each building type, it is possible to estimate an average water savings value of each urban zone according to Equation (1).

$$Non\ potable\ savings_{zone\ j} = \frac{\sum Quant.buildings_i \times Non\ potable\ water\ savings_i}{\sum Quant.buildings_i} \quad (1)$$

The  $\sum Quant.buildings_i$  symbolizes the representativeness that a building type has in the zone (in percentage). The  $Non\ potable\ savings_{zone\ j}$  is the final output expected for the program, since the goal is to map a certain area, being able to reproducing different RWH efficiencies in a heterogeneous city.

### 3. APPLICATION TO THE CITY OF LISBON, PORTUGAL

The proposed methodology was applied to the city of Lisbon, Portugal, considering only residential buildings and non-potable water uses in toilet flushing and laundry (Section 3.1). The city was divided in 7 different zones depending on the buildings characteristics and occupancy (Section 3.2) and possible spatial variability of the rainfall (Section 3.3). Specific RWH evaluation values obtained for each of the most representative building type of each city zone are detailed in Section 3.4.

#### 3.1 Water consumption

In Portugal, the average daily residential water consumption is 61 L per capita according to the official statistics [22]. However, according to a study from the largest water supplier in Portugal, EPAL (Empresa Pública das Águas Livres), the national average daily residential water consumption is 152 L per capita [23]. The few and limited studies regarding the residential water consumption end-use pattern in Portugal estimate the proportion of non-potable uses ranging from 25% to 40% of the total water consumption. Given the limitations (namely water end-use distribution) and dispersion (due to the location and context of the households) of the available consumption data in Portugal, a water end-use consumption characterization study was done to provide an estimation of water consumption end-use pattern in Lisbon. The study was based on inquiries requesting the participants to measure the water consumption by end-use in order to identify the non-potable uses susceptible of being replaced by rainwater. In a first stage, the study focused on a single household in order to obtain the detailed proportion of the water consumption associated to each end-use. The daily water consumption per capita by each end-use is presented in Fig. 2. Fig. 3 synthesizes these results in potable and non-potable water consumption. The second stage involved the participation of 15 households, where only the total water consumption and non-potable water consumption (washing machines and toilet flushing) were measured. The household selection covered a wide range of occupancy typologies, including households of families with children of different ages, couples, single people, pensioners and students. The evolution of the water consumption per capita during one week is presented in Fig. 4. Therefore, the evaluation of the RWH savings potential in Lisbon computed in this work assumed a total daily water consumption of 0,146 m<sup>3</sup> per capita, of which roughly 28% (0,041 m<sup>3</sup> per capita) is used in non-potable end-uses. The detailed approach of this study may be found in [24].

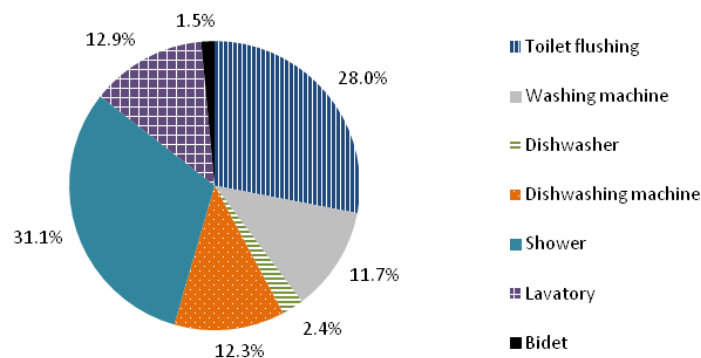


Fig. 2. Results of the first stage of the inquiries for each end-use.

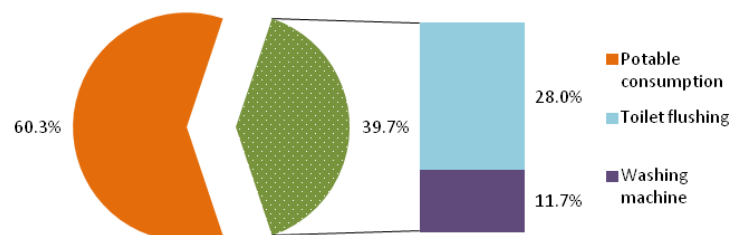


Fig.3. Results of the first stage of the inquiries for potable and non-potable consumption.

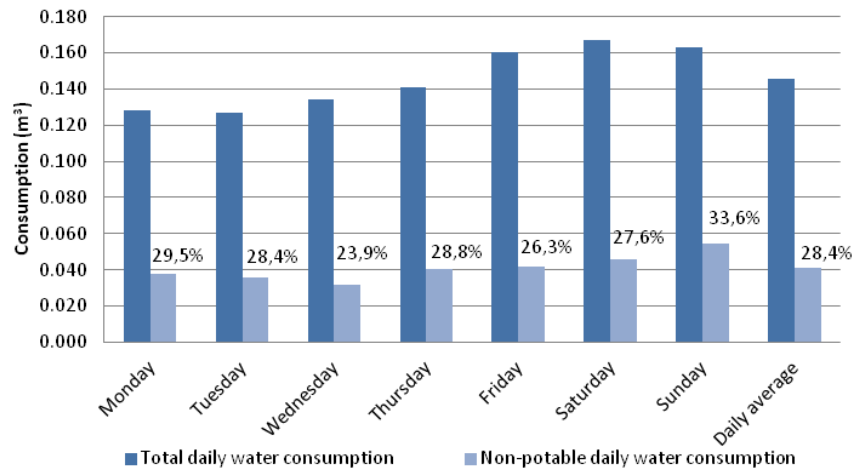


**Fig. 4: Water consumption per capita: potable and non-potable daily consumptions**

### 3.2 Urban area

The Lisbon Urban Information Center (CIUL – Centro de Informação Urbana de Lisboa) provided the Lisbon plan in GIS with the roof area of all the buildings in the city. The 2011 national census [25] and the Lisbon municipality [26] provided information regarding the number of buildings, number of residents and families in each parish. The number of buildings is organized by groups depending on the number of floors, households and residents. This enabled identifying six zones in the city of Lisbon with distinct relative proportions of buildings in terms of number of floors and estimating the average number of occupants in each dwelling type. The six zones were designated from A to E (Fig. 5) and each one represents a fairly homogenous area of the city different from the surrounding areas. Since zone E spreads over a large area of the city, it was divided into two zones, E.1 and E.2, to allow considering potential spatial variability of the rainfall. The average family dimension also shown in Fig. 5 was estimated for each zone dividing the number of residents by the number of families of all the parishes within the zone. It is possible to observe that the average family dimension increases from the city center to the city periphery. This is consistent with the municipality urban rehabilitation initiatives to revitalize and attract young couples to the city center that is mainly inhabited by older people. Table 1 summarizes all the data. The most representative types of buildings in each zone are highlighted in Table 1. Except for Zones E.1 and E.2, defined due to potential spatial rainfall variability, it is noticeable that the most representative buildings of any adjacent zones are different in terms of the number of floors.

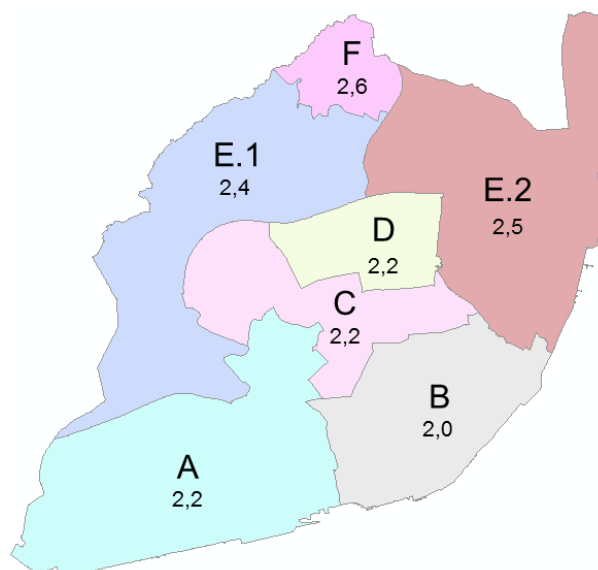


**Fig. 5: Definition of the six zones in Lisbon and average family dimension in each zone.**



**Table 1. Building characterization and number of residents in each city zone.**

| Zone         | Floors |     |     |     |     |     |     | Residents | Families | Average family dimension |
|--------------|--------|-----|-----|-----|-----|-----|-----|-----------|----------|--------------------------|
|              | 1      | 2   | 3   | 4   | 5   | 6   | ≥7  |           |          |                          |
| A            | 30%    | 23% | 17% | 14% | 8%  | 3%  | 5%  | 103 796   | 47 308   | 2,2                      |
| B            | 15%    | 15% | 19% | 22% | 16% | 7%  | 6%  | 125 398   | 61 419   | 2,0                      |
| C            | 9%     | 7%  | 9%  | 19% | 17% | 11% | 28% | 74 799    | 34 135   | 2,2                      |
| D            | 8%     | 16% | 25% | 21% | 11% | 5%  | 15% | 31 812    | 14 403   | 2,2                      |
| E.1          | 16%    | 31% | 6%  | 6%  | 8%  | 6%  | 27% | 101 808   | 43 121   | 2,4                      |
| E.2          | 14%    | 30% | 11% | 10% | 11% | 5%  | 20% | 92 607    | 36 824   | 2,5                      |
| F            | 35%    | 24% | 8%  | 10% | 7%  | 4%  | 12% | 22 480    | 8 684    | 2,6                      |
| Lisbon total |        |     |     |     |     |     |     | 552 700   | 245 894  | 2,2                      |

### 3.3 Hydrologic regime

In order to account for possible spatial variability of the rainfall, the hydrologic regime was characterized separately for each city zone defined on Fig. 5. Unfortunately, the stations in Lisbon area with daily rainfall data do not have data from the same period of time. Alternatively, to evaluate the influence of the rainfall in the RWH performance, the 53 years daily rainfall series dataset (1950/51 to 2002/03) in a 2° grid covering all Portuguese mainland developed by Belo-Pereira et al. [27] was used. The city of Lisbon is limited by 5 grid points, namely P173, P174, P175, P185 and P186 (Fig. 6), that were selected to characterize the hydrologic regime of each city zone. Since the dataset was developed resorting to several sources and involved interpolation and gap filling, its consistency was checked against the rainfall records of the Sacavém de Cima meteorological station [28]. The length of the rainfall records of the Sacavém de Cima meteorological station extends from 1980/81 to 2001/02 and the correlation between both data sources is of 0,87. Given the high correlation, it was considered that the Belo-Pereira et al. (Belo-Pereira et al., 2011) dataset is a good approximation of the real rainfall regime and is suitable to be used in the present study.

The total annual rainfall between 1950/51 and 2002/03 is presented in Fig. 7 and no statistical evidence of any trend was found. In that way, although some studies show that there will be a variation in the hydrologic regime due to climate changes [29], in the present research these values were considered to represent the hydrologic regime in the near future and no climate changes scenarios are taken into account.

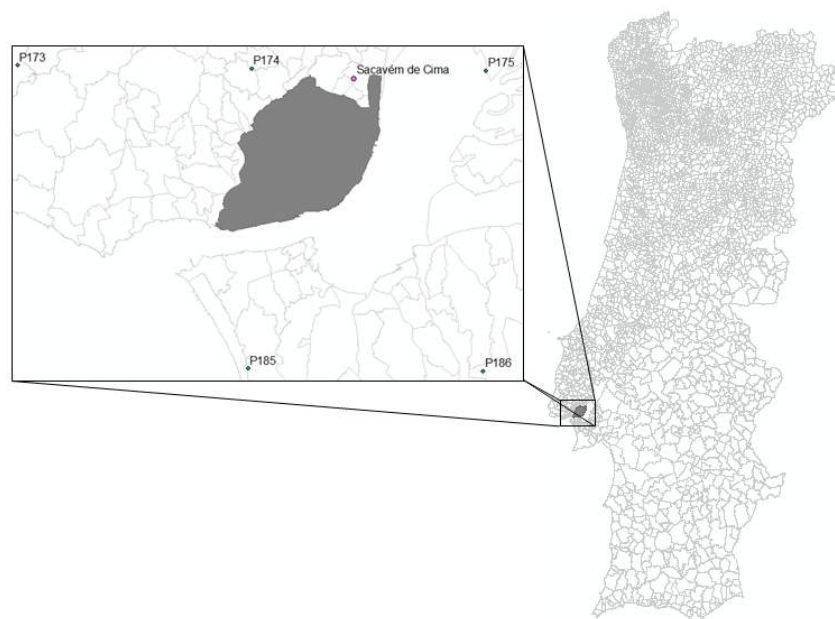


**Fig. 6. Location of P173, P174, P175, P185, P186 and the Sacavém de Cima meteorological station.**

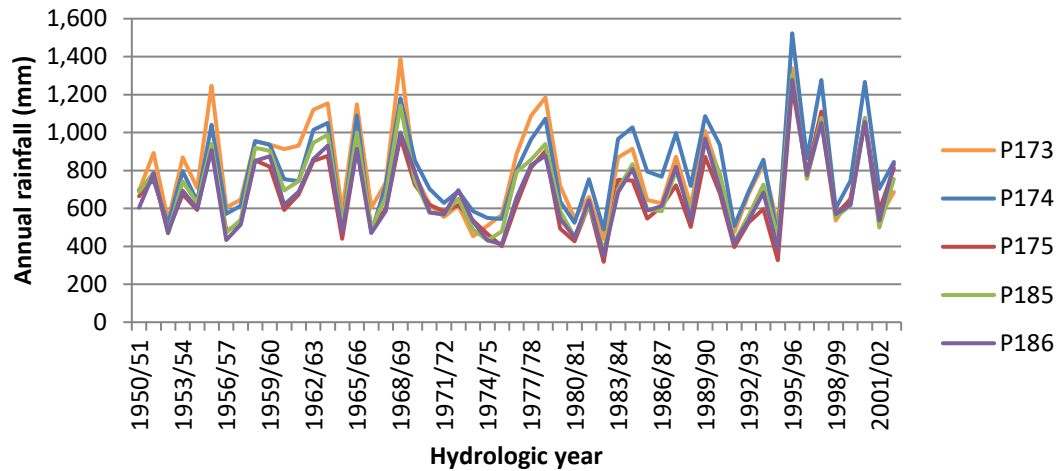


**Fig. 7. Annual rainfall in the five grid points of Lisbon from 1950 to 2001.**

The rainfall in the centroid of each city zone was determined by interpolating from the 5 grid points using an inverse distance weighting method. Fig. 8 shows the boxplot of the monthly rainfall in each of the city zones. It is possible to observe that the amount and variability of the rainfall in each month is similar in all zones. From October to April, the wet period in Portugal, the median monthly rainfall is always between 50 and 100 mm. Between May and September, the dry season, this value is below 50 mm and around 2 mm in July and August. It can be concluded that, in the city of Lisbon, the temporal variability of the rainfall is far more relevant than the spatial variability.

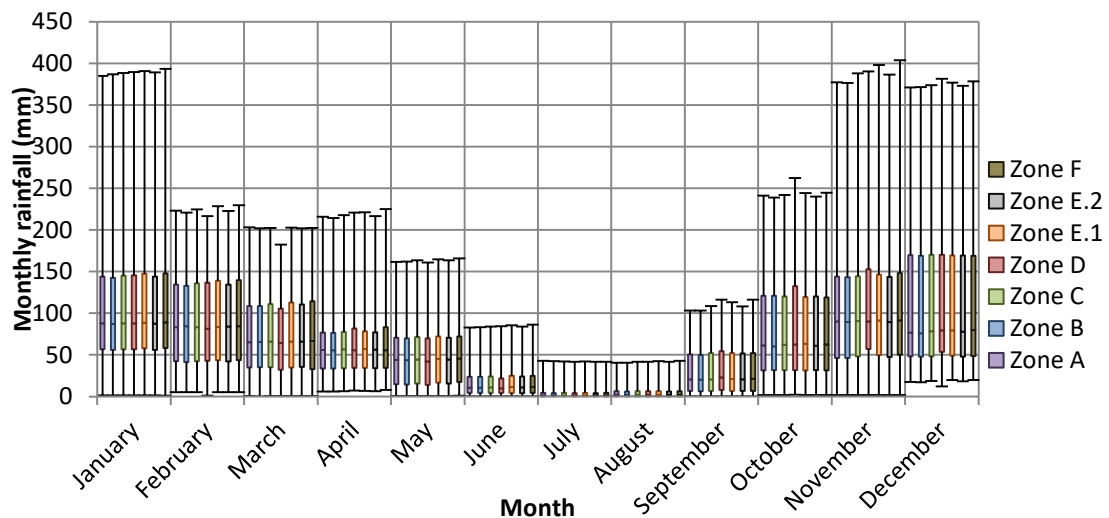


**Fig. 8: Rainfall distribution along the year in the different zones of Lisbon.**

### 3.4 RWH evaluation

Table 1 synthesizes the roof area of the most representative buildings in each city zone and also the respective estimated number of residents. Visits to each zone allowed the identification of the average number of dwellings per floor in each building type. This information was then used to estimate the total occupancy of the buildings and, consequently, the water demand of each case (Table 2). RWH system performance was evaluated separately for each building type through the calculation of three parameters defined in the Methodology Section. Following Farreny et al [21], the relation between the pitched roofs orientation and the wind direction was neglected and a runoff coefficient of 0,80 was adopted. Considering the events with rainfall

height over 1 mm, it was observed that only 30% of the total water precipitated occurs in events with a rainfall height up to 5 mm. Therefore, since the large majority of the buildings in Lisbon have pitched clay tile roofs, a 0,80 runoff coefficient can be regarded conservative based on the runoff equations developed by Farreny et al [21]. The first flush was assumed to be 1 mm based on the findings by Amin et al. [30]. Tank capacities of 0,1 m<sup>3</sup>, 0,5 m<sup>3</sup>, 3 m<sup>3</sup>, 5 m<sup>3</sup>, 7,5 m<sup>3</sup>, 15 m<sup>3</sup>, 30 m<sup>3</sup>, 50 m<sup>3</sup>, 65 m<sup>3</sup> and 75 m<sup>3</sup> were tested for all cases.

**Table 2. Roof area, number of residents and water consumption of the most representative buildings in each city zone.**

| Zone | Roof area (m <sup>2</sup> ) | Number of floors | Number of dwellings/floor | Number of families | Average family dimension | Estimated number of residents | Number of residents | Average daily water consumption (m <sup>3</sup> )/building | Average daily non-potable water consumption (m <sup>3</sup> )/building |
|------|-----------------------------|------------------|---------------------------|--------------------|--------------------------|-------------------------------|---------------------|------------------------------------------------------------|------------------------------------------------------------------------|
| A    | 31,68                       | 1                | -                         | 1                  | 2,2                      | 2,2                           | 3                   | 0,438                                                      | 0,123                                                                  |
| A    | 158,60                      | 2                | 2                         | 4                  | 2,2                      | 8,8                           | 9                   | 1,314                                                      | 0,369                                                                  |
| B    | 125,90                      | 3                | 2                         | 6                  | 2,0                      | 12                            | 12                  | 1,752                                                      | 0,492                                                                  |
| B    | 229,35                      | 4                | 2                         | 8                  | 2,0                      | 16                            | 16                  | 2,336                                                      | 0,656                                                                  |
| C    | 151,63                      | 4                | 2                         | 8                  | 2,2                      | 17,6                          | 18                  | 2,628                                                      | 0,738                                                                  |
| C    | 227,90                      | 8                | 2                         | 16                 | 2,2                      | 35,2                          | 36                  | 5,256                                                      | 1,476                                                                  |
| D    | 127,19                      | 3                | 2                         | 6                  | 2,2                      | 13,2                          | 14                  | 2,044                                                      | 0,574                                                                  |
| D    | 264,97                      | 4                | 2                         | 8                  | 2,2                      | 17,6                          | 18                  | 2,628                                                      | 0,738                                                                  |
| E.1  | 24,76                       | 2                | -                         | 1                  | 2,4                      | 2,4                           | 3                   | 0,438                                                      | 0,123                                                                  |
| E.1  | 198,55                      | 9                | 2                         | 18                 | 2,4                      | 43,2                          | 44                  | 6,424                                                      | 1,804                                                                  |
| E.2  | 55,00                       | 2                | -                         | 1                  | 2,5                      | 2,5                           | 3                   | 0,438                                                      | 0,123                                                                  |
| E.2  | 420,68                      | 8                | -                         | 23                 | 2,5                      | 57,5                          | 58                  | 8,468                                                      | 2,378                                                                  |
| F    | 55,48                       | 1                | -                         | 1                  | 2,6                      | 2,6                           | 3                   | 0,438                                                      | 0,123                                                                  |
| F    | 102,81                      | 2                | -                         | 1                  | 2,6                      | 2,6                           | 3                   | 0,438                                                      | 0,123                                                                  |

Note: The buildings without value for the number of dwellings per floor are houses with only one family, excluding the 8 floors' building in zone E.2 which has 2 dwellings per floor in the ground level and 3 dwellings per floor in the remaining floors.

#### 4. RESULTS AND DISCUSSION

Table 3 resumes the optimum tank capacity chosen for each building type of each city zone and the corresponding non-potable water savings that were used to compute an average value of non-potable water savings for each city zone (Figure 9). The non-potable water savings in each zone only consider the buildings with more representativeness. These values were calculated applying equation (1), presented in Proposed Methodology section, based on the non-potable water savings obtained in each building type per zone. As these values are a weighted average of the values obtained per building, they are lower than the maximums shown in Table 3.

It is possible to state that the non-potable water savings obtained in this analysis should be taken into account in new buildings because in several cases, almost 50% of the non-potable water consumption can be replaced by rainwater.

#### 5. CONCLUSION

This communication presents a methodology to evaluate the potential of rainwater harvesting in heterogeneous urban areas by taking into consideration differences in the rainfall regime, building characteristics, occupancy and water use pattern. The practical application of the methodology was demonstrated through its application to the city of Lisbon.

The potential reduction in potable water consumption by using rainwater was evaluated for Lisbon using the proposed methodology and limiting the scope to residential buildings. Since

the rainfall regime was found to be roughly uniform throughout the city of Lisbon, the definition of zones with possible different potential performance of the RWH system was conducted based on the building characteristics and occupancy.

**Table 5. Non-potable water savings per building.**

| Zone | Num. floors | Tank capacity (m <sup>3</sup> ) | Non-potable water savings (%) |
|------|-------------|---------------------------------|-------------------------------|
| A    | 1           | 3                               | 34                            |
| A    | 2           | 30                              | 53                            |
| B    | 3           | 15                              | 34                            |
| B    | 4           | 30                              | 44                            |
| C    | 4           | 15                              | 29                            |
| C    | 8           | 15                              | 22                            |
| D    | 3           | 15                              | 31                            |
| D    | 4           | 50                              | 46                            |
| E.1  | 2           | 3                               | 29                            |
| E.1  | 9           | 7,5                             | 16                            |
| E.2  | 2           | 7,5                             | 54                            |
| E.2  | 8           | 30                              | 26                            |
| F    | 1           | 15                              | 57                            |
| F    | 2           | 30                              | 86                            |

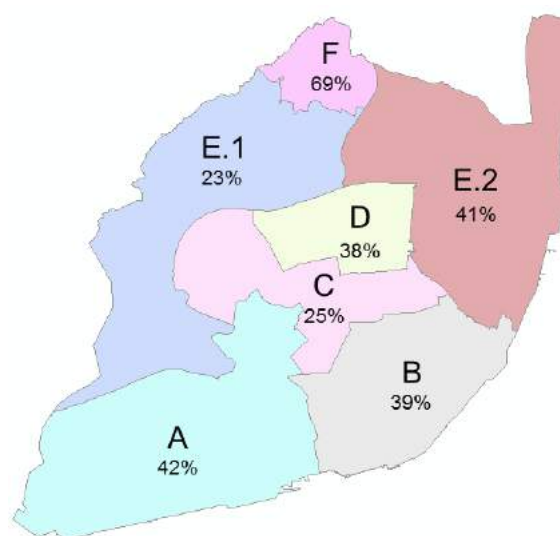


**Figure 9. Average non-potable savings in each city zone.**

In none of the zones was it possible to collect all the rainwater required for the non-potable consumption, being 86% the maximum value obtained. This implies that, after discounting the losses and first flush, the rainwater collected at the buildings roofs is not sufficient to meet the non-potable water demand. When calculating the weighted potential non-potable water savings, this value reduces to 69%. Nevertheless, there is the potential for least half of the non-potable water needs to be replaced by rainwater, which is encouraging for a large scale installation of a RWH system in the city.

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# Assessment of the national water and energy saving potential of greywater reuse – Israel as a case study

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<sup>2</sup>Greywater Reuse Coalition

## ABSTRACT

Onsite greywater treatment and reuse produces a viable alternative for high value potable water exactly where it is needed – on location in high density urban settings where consumption growth rates are highest. Greywater recycling is broadly perceived to be of substantial benefit in alleviating water scarcity. However, concerns regarding greywater reuse economic viability versus desalination have been raised. This work presents the results of analysis, based on the use of standard greywater reuse models applied to the current Israeli Water authority's long term water master-plan. Quantitative projections on the impact of greywater treatment and reuse at the national level on future desalination needs are presented *versus* the current water authority model. The analysis demonstrates that there are substantial economic, water and energy benefits at the national level if greywater reuse is widely adopted.

*Keywords: greywater reuse, water saving, energy saving, water scarcity*

## 1. INTRODUCTION

Increasing water scarcity in many countries leads to development of new water sources. The costs of developing and exploiting these new resources and the energy required for their operation are becoming higher as water deficit rises. In many cases, urban water demand comprises a significant part of the overall regional water demand. Indeed, today many large urban areas, even in regions that were traditionally considered as water ample, suffer from water scarcity. Therefore, lowering the urban water demand has recently become an important issue for water utilities and regulatory bodies. This could be achieved by a combination of different measures such as: increasing water supply systems efficiency (reducing water losses in the distribution system), installation of water efficient appliances (flow reducers, dual flush toilets, water-efficient washing machines, etc.), rising public awareness to water saving (targeted public campaigns), and using/reusing "new" alternative water sources (e.g. rainwater harvesting greywater reuse). When considering urban water reuse, especially for non-potable uses, on-site greywater reuse has the potential to play a significant role.

Indoor domestic water demand (excluding garden irrigation and other external uses) in developed countries usually lies in the range of 100-180 L·c<sup>-1</sup>·d<sup>-1</sup> (litre/(capita·day)) or 36-66 m<sup>3</sup>·c<sup>-1</sup>·y<sup>-1</sup>, comprising ca. 70% of the total urban water demand [1]. Besides minor quantities, most in-house consumed water is transformed into wastewater, which can be classified into two major categories:

- 1) Greywater, originating from all domestic "water generating" appliances except toilets, comprising 60-70% of the in-house water demand;
- 2) Blackwater, originating from toilets, comprising 30-40% of the in-house water demand.

Toilet flushing and garden irrigation are the main possible uses for on-site greywater reuse, and if widely implemented, significant water saving could be achieved.

The current study analyses the potential of water and energy saving on a national scale if onsite greywater reuse becomes a common practice using Israel as a case study country, representing countries suffering from water scarcity. In order to overcome the acute water shortage, the country has developed a massive seawater desalination scheme that currently supplies about 70% of its urban water demand. Hence, the marginal water to which the analysis is referring to, is desalinated seawater which is the most expensive water source in the country [2].

## 2. ANALYSIS

The following key points will be addressed in the presentation:

- The cost of GWR will be borne by the taxpayer, but will still reduce the average family cost of living in the medium and long term. Due to net saving on the water and sewage bills.
- The analysis assumes that the following legislation will be adopted:
  - GWR mandated in all new construction from 2012.
  - Shower, bath, hand basin and laundry greywater is recycled.
  - Main reuse for toilet flushing with secondary reuse of garden irrigation.
- It is demonstrated that adopting this path would create substantial savings in money, resources and environmental costs to the state of Israel, specifically:
  - Reduce national water consumption by 150 – 250 million m<sup>3</sup>/y by 2050.
  - Reduce national energy consumption by 1 – 2 TW·h/y by 2050.
  - Reduce the number of new desalination plants to be constructed by 1-2 (13-14 plants instead of 15) plants planned for 2050 [3].
  - Avoid the release of 10 - 20 million tons of CO<sub>2</sub> by 2050.
  - Lead to cumulative savings of 8-16 billion US\$ by 2050.
- Desalination is an essential cornerstone in Israel's current and future water economy, but it must be a last resort due to its very large footprint in capital and ongoing costs, energy consumption and environmental impact.
- GWR is a lower cost solution over desalination and must be preferred where it is an option.
- The impact of GWR on availability of wastewater for centralised reuse in agriculture is minimal, reducing the compound annual growth rate of wastewater availability from 2.1% to 1.7%.

Fig.1 depicts the population growth in Israel, where it can be seen that by 2050 the population will double the one in 2010. Figure 1 also shows the significant effect of increasing uptake of greywater reuse practice in the specific urban water consumption. Figures 2 and 3 shows the water saving potential of graywater reuse and the consequential national costs savings due to averted seawater desalination capacity.

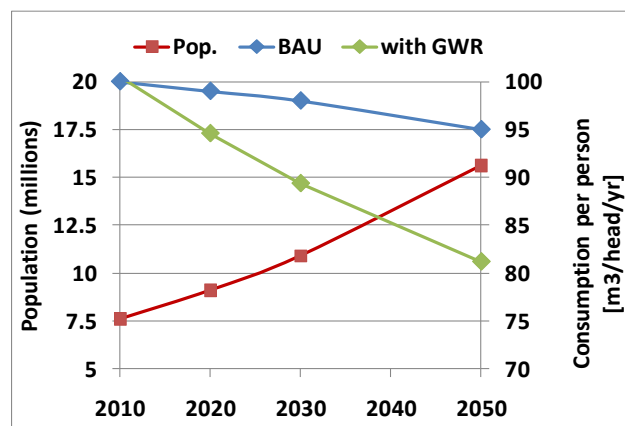


Fig 1. Projected population growth and specific water consumption with and without GWR



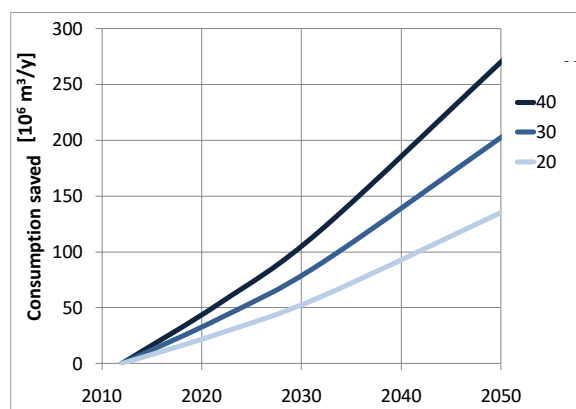


**Fig 2. Annual national water saving by GWR, assuming GWR is mandated in all new construction from 2012**

Bands are different levels of recycling efficiency

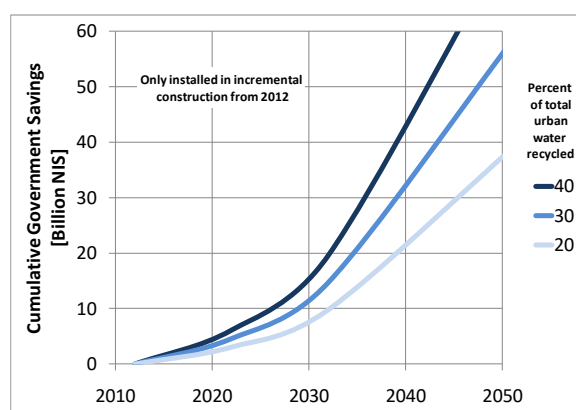


**Fig 3. Cumulative monetary savings due to GWR, assuming it is mandated in all new construction from 2012.**

Bands are different levels of recycling efficiency

### 3. CONCLUSION

The monetary saving by wide-spread introduction of onsite greywater treatment and reuse schemes is primarily enabled by reductions in infrastructure spending on water production and distribution since greywater reuse produces a viable alternative for high value potable water exactly where it is needed – on location in high density urban settings. By comparison, desalination, which is the mainstay of Israel's national plan to mitigate current and future water scarcity produces water at sea level and tens of kilometers away from the consumer in a process which requires of the order of 4 times more energy per cubic meter produced than greywater reuse. Onsite decentralised greywater recycling should be given national priority as a measure to reduce and complement the pressing need for seawater desalination.

### ACKNOWLEDGEMENTS

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## COMPETING INTERESTS

Both authors do not have any competing interests.

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# Optimization of a water supply system using genetic algorithms

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## ABSTRACT

Water supply systems are required to transport vast quantities of water over large geographical areas. In order to transport water to consumers a series of pumps are required and huge amount of energy is consumed in the process, increasing GHG emissions and with great energy cost. In this work we explore the capabilities of genetic algorithms to provide a better and more efficient way to operate pumps, optimizing pump scheduling and minimizing costs, i.e. reducing energy consumption and GHG emissions. In general, it is found that after optimizing the pump scheduling savings up to 17 % can be achieved, however, since the optimal solutions depend on the water supply system and the daily demand, the daily savings can oscillate significantly.

*Keywords: Water supply systems, pump scheduling, optimization, genetic algorithm, energy cost, EPANET*

## 1. INTRODUCTION

Water supply systems are crucial to deliver water to populations, but also require high demand of energy. In Portugal a total of 650 water pumping stations, 1726 reservoirs and 158 water treatment stations can be found, connected by 17018 kilometers of water mains [1]. The energy consumption is mainly in the form of electricity which is used in the water pumping operation. It is evident that the priority of water companies and municipalities is to guarantee the security of the supply, but also to decrease energy consumption and water wastes, aiming to obtaining a more efficient and sustainable supply system.

One way to reduce energy consumption is to development intelligent algorithms to provide indication of how pump scheduling can operate in a more cost efficient way by increasing pumping during off-peak electricity tariff periods [2,3].

In this paper the authors propose to optimize the water pumping schedule of a WSS – water supply system and to find the optimal switching on/off pump sequence throughout 24h, aiming to minimize the cost of pumping operation and therefore minimizing the pumping energy consumption, by using genetic algorithms. In this work real consumption data was considered, however, this methodology can also be applied to a water consumption prediction model by coupling the optimization module.

## 2. METHODOLOGY

### 2.1 Water supply system case study

In this paper, the case study belongs to AdA - Águas do Algarve (<http://www.aguasdoalgarve.pt>), the water company from Algarve region in Portugal. The case

study is composed by four pumping stations connected to four storage tanks (one tank for each pumping station): two of them with a set of 2 pumps each and the other two with a set of 4 pumps each (Figure 1). The system therefore establishes several constraints regarding the limit of pumps that can work at the same time in a pumping station, so that redundancy is assured. In order to model the water system, the hydraulic simulator EPANET 2.0 is used for its versatility. The main inputs required in EPANET 2.0 are: i) network structure (pumps, pipes, nodes, junctions, and tanks characteristics, as also terrain topography), ii) hydraulic constraints, iii) electricity tariff, iv) water demands and tanks initial conditions, iv) operation rules (e.g. tank level limits, pressure triggers). And the main outputs used from EPANET 2.0 are: i) water flows, ii) tank levels, iii) hydraulic constraints compliance, v) electricity consumption in pumping operation.

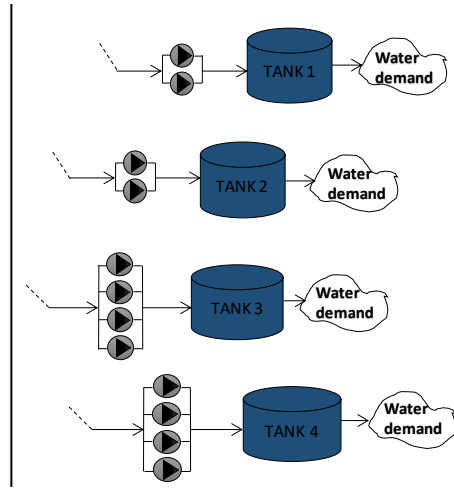


Fig. 1. Scheme of the case study.

## 2.2 GA Algorithm

There are several types of optimization methods that can be applied to find optimal pump schedules. Water network modeling is analytical complex and the optimization search space is neither mathematically convex, differentiable, or continuous. In these cases, metaheuristic methods become useful since are capable of find a good approximate solution to the real optimum in a reasonable amount of iterations.

Genetic algorithms (GA) [4] has been widely used in the scientific research community and has proven to be well suited to solved this kind of problems. Genetic algorithms work by using a chromosome structure that is composed by the decision variables which are the pump switches in this study (in this case the definition of each pump switch on/off). Each candidate solution is defined by a set of decision variables that correspond to an individual, and the set of individuals assessed by the GA is known as the population. The feasibility of each individual is evaluated by the simulation model of the water network developed in EPANET. Each candidate solution is evaluated in terms of water system compliance.

Consider the optimization objective to minimize the cost of operating the pumps ( $F$ ) supplying the demanded water throughout 24h (one day), as defined in equation set (1) to (5).

$$\text{minimize:} \quad F = \sum_{h=0}^{h=23} T(h, d, s) P(h, e_i, w_p) \quad (1)$$

$$\text{subject to, } \forall h \in [0, 24[: \quad w_p(h) \geq w_p^d(h) \quad (2)$$

$$w_n(h) \geq w_n^d(h) \quad (3)$$

$$w_t(h) \geq w_t^d(h) \quad (4)$$

$$w_t^{l,min} \leq w_t^l(h) \leq w_t^{l,max} \quad (5)$$

where the used parameters are as follows:

$T$  – electricity tariff (Eur/kWh)

$h$  – time, in hours, throughout 24h

$d$  – day of the week (weekday, weekend, holyday), which influences the tariff

$s$  – season (Winter, Spring, Summer, Autumn), which influences the tariff

$P$  – pumping electrical energy consumed (kWh)

$e_i$  – energy consumption of pumping per each pump used,  $i$ , (kWh/m<sup>3</sup>). This depends on the water flow in the pump and on the pump head and speed (calculated in EPANET)

$w_{p,n,t}$  – water flow throughout the pump ( $p$ ), node or junction ( $n$ ), or tank ( $t$ ) (m<sup>3</sup>/h)

$w^d$  – water flow demand to the pump ( $p$ ), node or junction ( $n$ ), and tank ( $t$ ) (m<sup>3</sup>/h)

$w_t^l$  – water level in the tank ( $t$ ). It must be between specified limits ( $min$ ,  $max$ )

Information regarding the constrains or any physical restriction violation, which could lead to the water system failure, is very important and are included in the state information provided by the simulation model. In terms of constrains, besides hydraulic compliance, and water demand compliance, we also consider specified minimum and maximum operational limits for levels in the water tanks. These limits are parameters that the user can be modified, but in this study they were provided by the water utility that manage this case study - Águas do Algarve (Table 1) (*the volume of the tanks are omitted due to confidentiality issues concerning the system*).

**Table 1. Water level tank constrains**

| Water Tank | Minimum level [m] | Maximum level [m] |
|------------|-------------------|-------------------|
| Tank A     | 1.80              | 5.10              |
| Tank B     | 1.80              | 2.85              |
| Tank C     | 1.80              | 3.75              |
| Tank D     | 1.80              | 4.60              |

The constrains are evaluated for each candidate solution and a penalty factor is attributed to the cost value of a solution, if a solution fails to comply with these constrains (equation 6).

*Updated objective function ( $F^*$ ) by a penalty factor:*

$$F^* = F + \sum w_t^l(h), \quad \forall h \in [0, 24[ \mid (w_t^{l,min} \geq w_t^l(h) \vee w_t^{l,max} \leq w_t^l(h)) \quad (6)$$

The penalty factor is a weighted function so that faulty solutions are more or less penalized based on how much they deviate from the physical restrictions of the WSS network.

The GA algorithm works as follows; (1) The initial population is generated randomly and then evaluated independently. Individuals that fail to comply the physical restrictions of the WSS network are penalized. (2) A selection procedure selects a percentage of the best solutions to generate the offspring population, using crossover and mutation operators. In this work uniform crossover and creep mutation operators were considered. (3) Subsequently, the offspring population is evaluated and a selective mutation procedure is followed for individuals having high penalty factors, aiming to increase convergence. (4) Afterwards, these mutated individuals are evaluated and returned back to the offspring population, and the best individuals from the offspring population are reinserted to the main population. This procedure is done through a series of interactions and continuous to loop until a maximum number of generation is reached, or after a total number of interactions without any improvement.

The GA algorithm output will consist of two scenarios; i) level-driven and ii) cost-driven solution. The level-driven solution is driven to search solutions that minimizes cost but at the same time that the tank level at the end of the 24h is maintained above the initial level at 0h. The cost-driven solution is purely driven by cost minimization. Obviously, the level-driven solution will have a higher daily cost, however, the cost-driven solution will let the levels below the initial level at the beginning of the day, which inevitably will result in a higher daily cost for the following day since it will require to pump more water so that tank levels must stay above the minimum defined in table 1.

### 3. RESULTS AND DISCUSSION

In this chapter we present the results of the optimization of the case study detailed previously. Figure 2 and 3 shows the water consumption for each four tanks (A, B, C and D), water level and pumping scheduling during 24h (XX axis).

There are two solutions provided: i) is a tank leveled solution, i.e. the optimization algorithm is driven to search solutions that minimizes cost but at same time that the tank level at the end of the 24h is maintained above the initial level at 0h; and ii) is a solution purely driven by cost minimization.

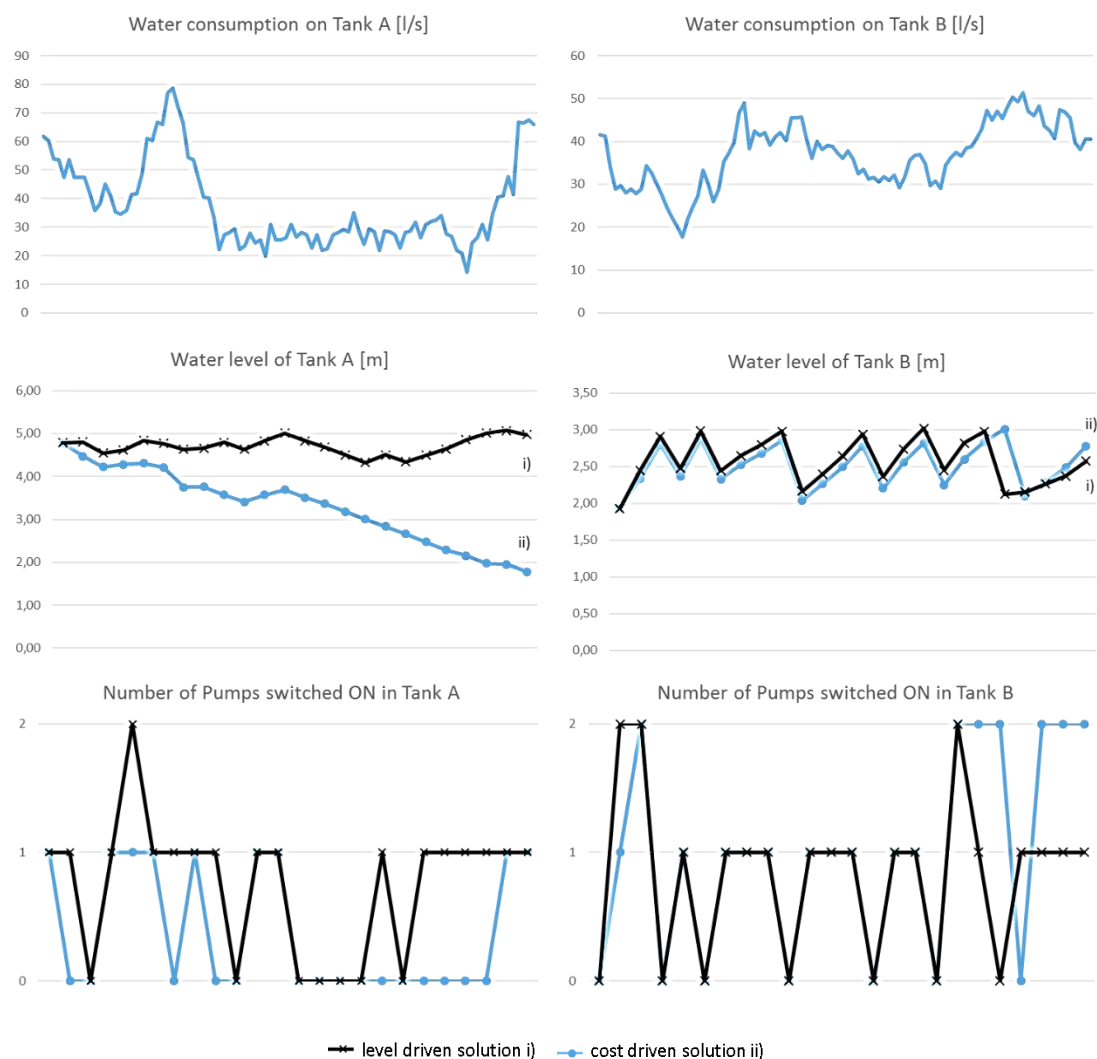


**Fig. 2.** Water demand in the tank A and B (above), tank levels for solutions i) tank levelled and ii) cost minimized (middle), and pump switching (below), along 24h.

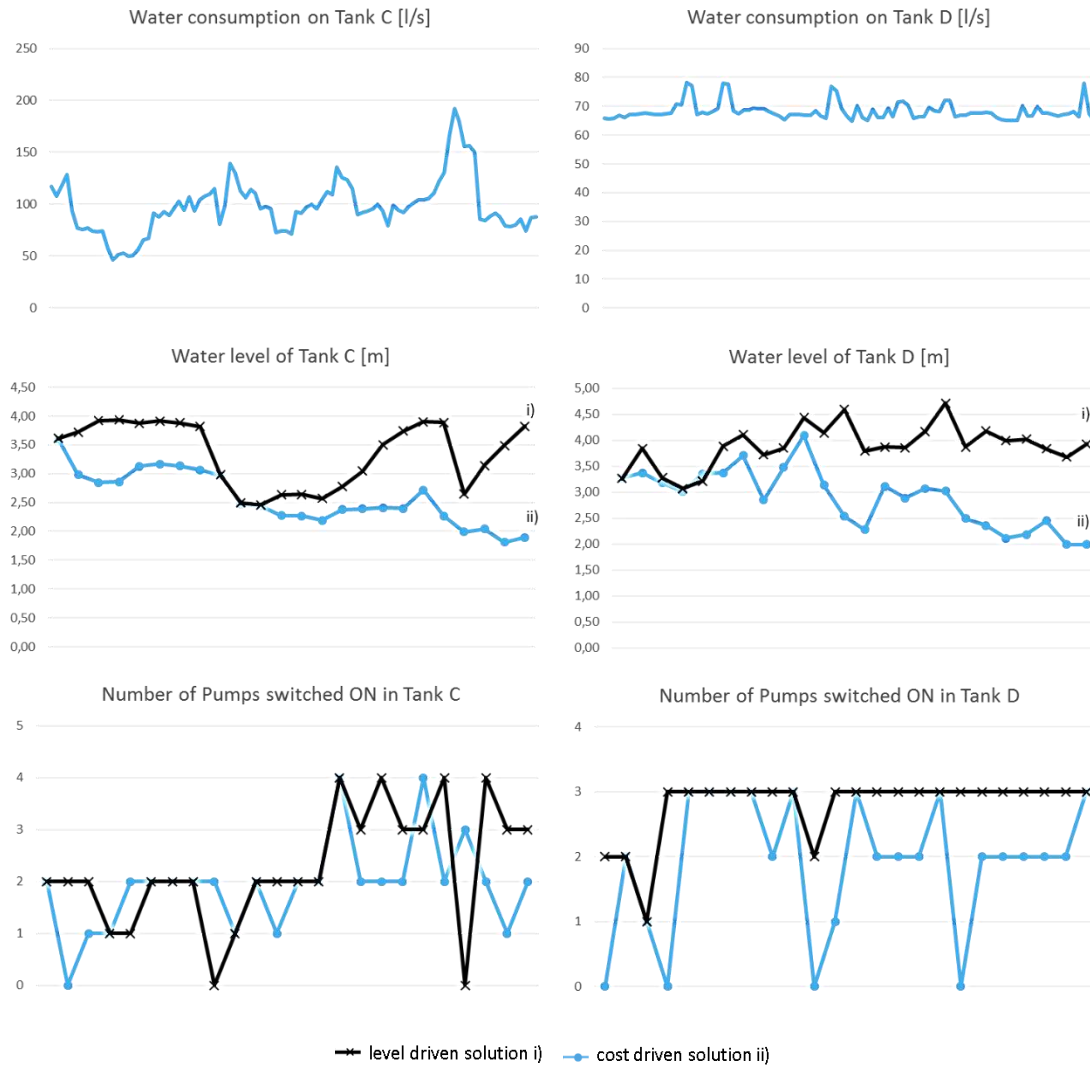


**Fig. 3.** Water demand in the tank C and D (above), tank levels for solutions i) tank levelled and ii) cost minimized (middle), and pump switching (below), along 24h.

In order to minimize cost (as in solution ii)) there are two options, which can be considered together: the use of the pumps only when the electricity tariff is low, and the use of the water stored in the tanks, i.e. not needing to switch on pumps. On the other hand, solution i) tries to use all the resources in solution ii) described before, but enforces the water level to be above the initial level by switching on pumps to cover this constraint. Obviously, this approach will have a higher cost than solution ii), but the benefit is that the tanks are not depleted for the next day.

These results were obtained after a total of 140 iterations, initially population of 80 individuals and a percentage of 25% for the offspring crossover and mutation. The total cost for this 24h simulation was 332.90€ for the level-driven solution and 271.81€ for the cost-driven solution. According to default operation regime currently in operation at Águas do Algarve, the same day had a cost of 300.60€. This shows that the GA algorithm provided solutions with improvement up to 10%. Nevertheless, the level-driven solution resulted in a 10% increase in comparison with the default operational regime currently in used by Águas do Algarve, however, this can be explained since this solution has a more conservative approach than the operational regime currently in used. Due to the design of this solution, it was initially expected that the daily cost could be higher than the currently regime in used, but is expected to allow a cost reduction in the long term.



#### 4. CONCLUSION

During this work a Genetic Algorithm (GA) was applied to a water supply system consisted of four tanks and a total of twelve pumps, belonging to Águas do Algarve. The output of the GA algorithm consisted in two solutions i) level-driven and ii) cost-driven. The algorithm output was compared with the currently pumping rules used by Águas do Algarve. During this work real demand patterns were used during a period of 24h.

Results show that for this case study of 24h energy reduction of 10 % were possible by using the GA algorithm result for the pumping scheduling in comparison with the currently in use operational pumping procedures. However, since the optimal solutions depend on the water supply system and the daily demand, the daily savings can oscillate significantly.

#### ACKNOWLEDGEMENTS

We acknowledge AdA – Águas do Algarve and AdT – Águas do Tejo Atlântico for providing information regarding the numerical model of the network in EPANET software as well as real data from demand patterns for the case study.

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# Establishing a National Benchmark for Residential Water Use in New Zealand: Methodology and Preliminary Results

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## ABSTRACT

Freshwater is considered New Zealand's greatest natural asset and essential to our socio-cultural, economic and environmental well-being. Freshwater availability in New Zealand has been ranked fourth amongst OECD countries. However, across New Zealand's 16 regions water stress is experienced in most catchments for part the year, due to the spatial and temporal variation in water availability.

Approximately eight percent of New Zealand's weekly water allocation is for domestic water supply. Whilst the volume of water that is consented for domestic abstractions is well understood, the actual consumption of domestic water in New Zealand households is not. Residential water metering is practiced in a few areas of New Zealand, where water is charged volumetrically. However, for most regions residential water use is charged as a targeted rate, with little consideration of the volume consumed per household.

This paper presents the methodology and preliminary findings of a nationwide residential water use study. Residential water meters are to be installed in approximately 380 homes across New Zealand to capture daily consumptive water use over a 12-month period. Of these homes, 190 are to be installed with high resolution meters which allow end-use disaggregation of a household's water use. The aim of this research is to compile and compare data around residential water use across all regions to create a benchmark for residential water use in New Zealand. At the household level, this information can be used to target sustainability initiatives for the efficient use of water in the home. At the wider district and regional level, this information informs debate around residential water metering and the wide-reaching issue of residential water demand and consumption.

*Keywords: Residential, Water, Use, Benchmark, Metering, End-use, Demand, Management*

## 1. INTRODUCTION

Freshwater is considered New Zealand's greatest natural asset [1], and essential to our socio-cultural, economic and environmental well-being [2].

New Zealand has over 425,000 kilometers of rivers and streams, more than 50,000 lakes and 249,776 hectares of wetlands [2]. New Zealand's low population density and high average rainfall mean the freshwater availability per capita is higher than most countries [3]. Subsequently, freshwater availability in New Zealand has been ranked fourth amongst OECD countries [4]. Approximately 711 billion meters cubed of freshwater is stored in groundwater aquifers, 440 billion meters cubed flow through the streams and rivers, and 230 billion meters cubed is contained within lakes across the country [3].

However, as a nation New Zealand experiences water stress in most catchments for part of the year due to the spatial, temporal and climatic variation in water availability across New Zealand's 16 regions.

Approximately eight percent of New Zealand's weekly water allocation is for domestic water supply [5]. Whilst the volume of water that is consented for domestic abstractions is well understood, the actual consumption of domestic water in New Zealand households is not. Residential water metering is practiced in few areas of New Zealand, where water is charged volumetrically. However, for most districts, household water use is charged as a targeted rate, which is a component of a household's rates bill [6]. For the 2016-17 period, the cost to provide drinking water services to residential properties throughout New Zealand was on average \$424, for those districts that were un-metered [7]. Understanding how consumers perceive their own water use is an important factor when analysing residential water use.

In New Zealand, case studies of residential water end-uses have been conducted for the Kapiti Coast, and Auckland areas. In 2007, 12 homes in the Kapiti Coast were monitored over an eight-month period. The average water use during the winter period was measured to be 168.1 L/p/d [8]. In Auckland, 51 homes were monitored in four-week intervals, with two summer monitoring periods, and one winter period. The average per person water use was measured to be 149 L/p/d in summer compared with 161 L/p/d in winter, excluding outdoor water use. When outdoor water use was included, the average summer water use increased to 188 L/p/d, and average winter increased to 175 L/p/d [9]. Both the Kapiti and Auckland studies found showers, washing machines and toilets were responsible for most of a household's water use.

A similar study in the Gold Coast of Australia aimed to identify peak day and peak hour demand, and measured an average household water use of 145.3 L/p/d. The study found that the three appliances responsible for around 70% of household water use were the showers, taps and washing machines [11].

The household water use in 'standard' new single-family homes, and new 'high-efficiency' homes was investigated and compared with the findings from a previous residential end-use study. Results found a significant reduction in indoor household water use in newer and high-efficiency homes. Outdoor water use in new homes did not show a clear reduction [12].

There is currently no national benchmark for residential water use in New Zealand. This research helps to fill this gap in knowledge.

## **2. METHODOLOGY**

### **2.1 Sample Selection**

To determine the appropriate sample size across the 67 districts of New Zealand, the total number of connections was required. Data pertaining to the number of connections was derived from the National Performance Review data for the 2015 -2016 period [6]. Where supplementary information was required for some districts, the number of connections were estimated based on total connections and/or the number of dwellings from the 2013 New Zealand census dataset.

The sample was consequently allocated at random based on the total estimated number of residential water connections. The variation between household water use in a previous study of Auckland's household water use was also factored in to the sample selection [9]. The objective for this research was 95% confidence level that the estimates of total water consumption will be within 5% of the true value.

A 20% response rate was anticipated. Information packs have been mailed to over 2,000 randomly selected consumers throughout New Zealand, to date. Information packs were customized for each specific district to suit the needs of the relevant district council/water service provider. The study group to date consists of varying household typologies (although there are no medium or high-density dwellings included) and have some water uses common in every house (toilets, showers etc.). Others, such as washing machines and dishwashers, are not found in every home.

## 2.2 Measurement Methodology

This research adopted a three-tiered approach to understanding residential water use. The three research phases are as follows:

- Phase 1: approximately 2,000 households are to be mailed a paper-based survey
- Phase 2: approximately 190 of these households had a meter installed capable of reading daily consumption
- Phase 3: another 190 households had a meter installed capable of end-use disaggregation

To date, most of participating district councils are transitioning from the surveying phase to meter installation, both daily and end-use capable meters are currently being installed across New Zealand. Data will be collected for a 12-month period.

### 2.2.1 Resident water use survey

A comprehensive residential water use survey was sent to over 2,000 homes throughout New Zealand. Questions pertaining to five key themes were covered in the survey; these included human, behavioral, building, outdoor and water end-use focused questions.

Surveying households in this manner allowed an inventory of end-uses to be compiled. Factors such as the number of water end-uses and whether an appliance was rated for efficiency were collected. Social aspects around how residents in metered and non-metered areas of New Zealand perceived their households water usage were collated. All household information was acquired under an appropriate confidentiality agreement.

### 2.2.2 Daily consumptive water metering

Of the 2,000 residents that were initially surveyed, approximately 190 of these homes have been, or are in the process of being, installed with a meter that will collect daily readings (Itron Aquadis or Itron Intelis). Metering will be in place for 12-months and will allow a comparison of household water use data with external influences, such as; climate, socio-demographic characteristics, household income, and house and section size.

### 2.2.3 Water end-use disaggregation

To monitor the end-uses of individual appliances in each dwelling, a method called Flow Trace Analysis is used. This technique requires logging of high frequency data at 10 second intervals. A single high-resolution meter is installed at the water supply point of entry of each house. This method was piloted successfully in the Water End-use Efficiency Project [8].

Approximately 190 homes across New Zealand have been, or are in the process of being, installed with a higher resolution meter (Actaris CT5-S20). The minimum requirements for these meters were 34 pulses per litre and ten-second intervals. This level of data collection allows us to investigate the end-uses of appliances in each of the homes.

## 2.3 Site Visits and TraceWizard Analysis

To understand how each household appliance uses water, an initial site visit is required. The purpose of the site visits is to systematically create a water use fingerprint for every water using appliance in the dwelling. This was achieved by running each of the water using appliances in isolation for one minute. This created the baseline fingerprint in the dataset. The fingerprint data is then assigned to a fixture using the Trace Wizard software package, developed by Aquacraft Inc. and information pertaining to the run time, per appliance, collected during the site visit.

A visual example of this fingerprint assignment is shown in Figure 1. A unique fingerprint has been created for a range of appliances in the dwelling. Once a fixture is assigned a unique flow profile, the Trace Wizard software can assign all future water events with that profile. An

example from Figure 1 is the washing machine that is correctly identified twice in the time series. It is important to note that whilst every appliance is run in isolation for the purposes of the initial flow trace identification, once an appliance has been assigned a flow trace the Trace Wizard software can identify 13 simultaneous water use events. For example, at 15:41:50 the software has assigned the flow trace to both the washing machine and a concurrently used toilet in the dwelling.

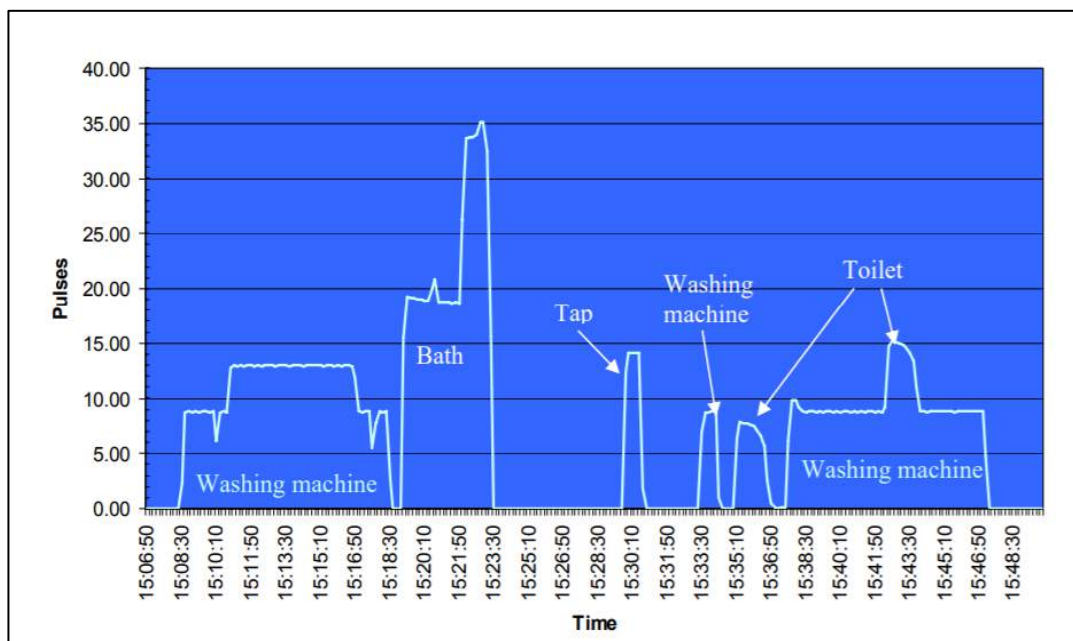


Figure 1 Example of the assignment of fingerprints

The site visits also allowed an interview of household residents to gain valuable background information of their houses water use and to collect additional demographic information.

Flow profiles at 10 second intervals are in the process of being collated for each individual household. At present, data collection is scheduled to be complete in May 2019.

### 3. RESULTS AND DISCUSSION

Results from the water end-use survey sent to residents across New Zealand are presented. Further results from a previous BRANZ water end-use study in the Auckland region are presented [9], alongside preliminary results from this research, to demonstrate the methodology.

#### 3.1 Nationwide Social Survey

##### 3.1.1 Sector, home ownership and demographic representation

A 12% survey response rate has been observed to date. Of the 240 returned surveys, 201 have consented to water monitoring.

Sector groups, home ownership structure and household demographics have been collated for all respondents and can be seen in Figure 2. Over half of the survey respondents to date have originated from provincial sectors, characterised by having populations of between 20,00 and 90,000. The rural sector (populations below 20,000) makes up the second largest contributing group to the sample at 29% of respondents. Metro centers (populations exceeding 90,000) represent 14% of respondents. At the national scale, the proportion of district councils that are classified as provincial is 46%, rural represents 38%, and metro 16% [10]. Thus, the sector contributions are largely representative.

In regard to the home ownership structure in Figure 2B, the majority of the sample are freehold homeowners at 61%. Homeowner's with mortgages represent the second largest group at 30%, followed by renters at 7%, and those classified as 'other', which refers to such agreements as leaseholds, for example. When compared to national homeownership structures, it is noted that the rental proportion of the sample is much lower than the national rental average of 34%. Further, the proportion of the sample that own their own home (freehold and/or with a mortgage) is over represented at 91% compared with 67% nationally.

The over representation of home ownership could, in part, be due to the demographics of the sample. As can be seen in Figure 2C, the largest proportion of respondents are retirees, at 40%. The 2013 New Zealand census found that older people aged between 65 and 79 years had a home ownership rate of 77% and are more likely to own their own homes (with or without a mortgage). According to the 2013 New Zealand census, 14% of New Zealand's population was retired. Thus, the sample has a much higher proportion of retired people than the general population. An additional factor that is potentially having an impact on the demographic of survey respondents to date is location. As Figure 2A shows, the majority of respondents were from rural and provincial areas of New Zealand. Larger urban areas generated more survey responses from younger demographics. This is not surprising as the larger urban areas have Universities and greater job opportunities compared to rural areas.

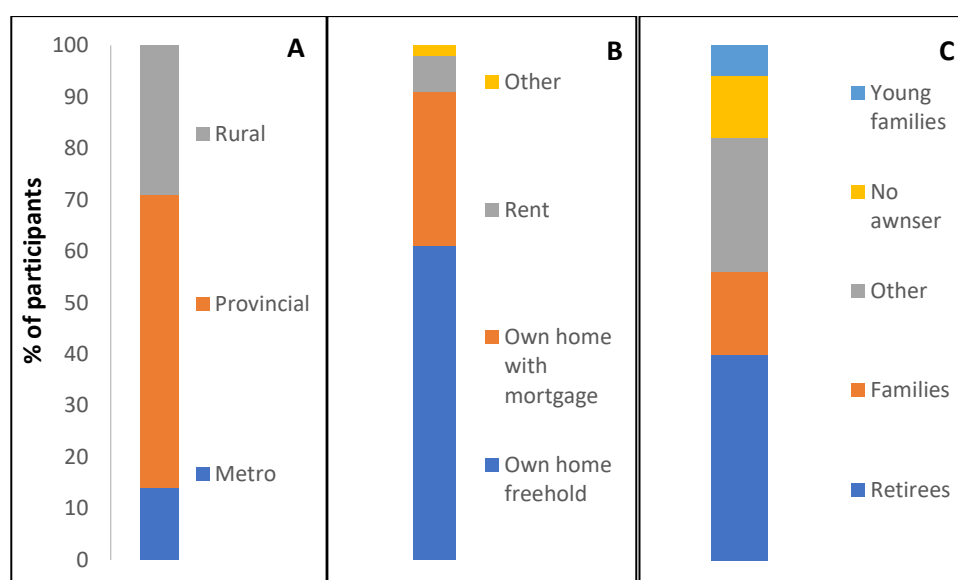


**Figure 2 Proportion of different sectors (A), home ownership structures (B) and demographics (C) on the preliminary results**

### **3.1.2 Preliminary Survey Results**

One of the key results from the survey was the variation in how people perceived their household water use. As discussed, most New Zealanders water use is not metered, and consumers are charged for water services in their annual council rates. It is clear from Figure 3, that most New Zealanders surveyed were unaware of how much water their household used. Occupants were asked to categorise their household water-use as high, medium or low, and were asked to estimate how many litres per day their household would use on average.

Figure 3 shows that the majority of survey respondents estimated themselves to be medium users of water. However, within this category estimates ranged from under 100 L/d to over 2,000 L/d. Further highlighting a lack in awareness around residential water use across New Zealand. For comparison, the average summer and winter residential water use from a similar study conducted in Auckland was 422L/d and 425L/d respectively [9].

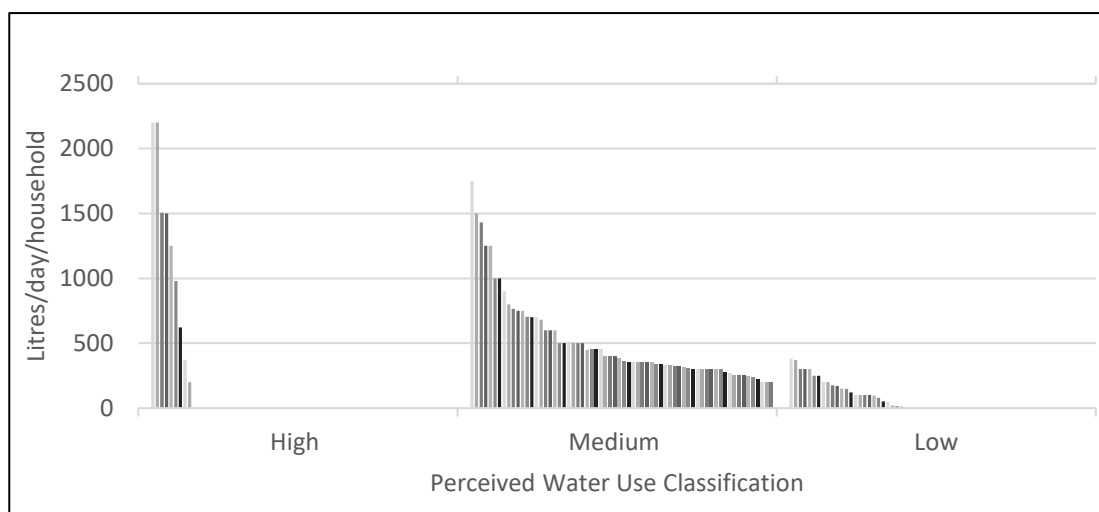


**Figure 3 Perceived household water use across New Zealand.**

It became clear during the surveying that a large proportion of respondents were unaware or unaffected by the Water Efficiency Labeling Scheme (WELS) that was adopted in New Zealand in 2010. Under the scheme certain water using appliances are rated based on their water efficiency. Information is provided to consumers on a products water consumption with the aim of aiding consumers to make more water efficient purchases. Survey respondents were asked to note their appliance WELS ratings, is applicable. Of the 240 preliminary surveys analyzed only 14% of respondents provided WELS information. A follow up site visit to twelve preliminary households confirmed that consumers are less aware of the WELS rating when compared to its energy counterpart the Energy Rating Label. A potential cause for this relates back to how water is charged for in New Zealand. All New Zealanders are charged for energy based on how much they use and are incentivized to be energy efficient through their energy bills through potential monetary savings. As discussed, this is not the case with water in most areas of New Zealand, and thus drivers to promote water efficiency are lacking in comparison.

### 3.2 Daily Consumptive Water Use

The daily water uses profile of a five-person dwelling in the Auckland region of New Zealand can be seen in Figure 4 [9]. Daily water use data were collected for the month starting 10<sup>th</sup> June 2008. Clear spikes in water use can be seen throughout the month. For example, a peak of 3,129 L/day is visible on the 21<sup>st</sup> June. On average the daily water use for the June-July period for this dwelling was 825L/day. According to findings of an Auckland Water Use in Households study completed in 2008, the average household water use of the 51 sample homes is 425L/day for the same period.

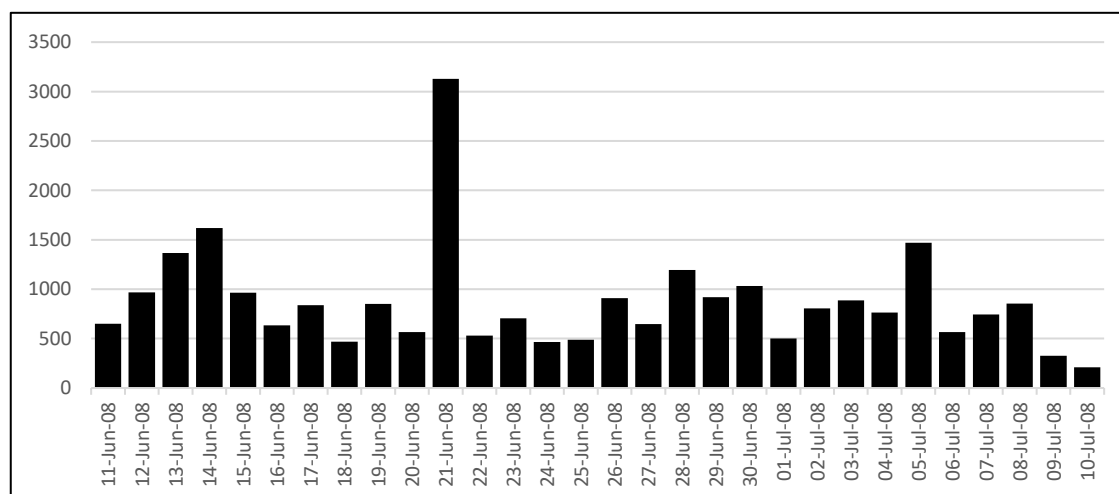


**Figure 4 Daily water use profile of a dwelling in the Auckland region of New Zealand**

Preliminary results for four dwellings monitored during the January 2018 period can be seen in Figure 5. Three of the homes are based in a district that meters residential properties and charges volumetrically on this basis (dwelling, A, B and C). Dwelling D is located in a district with no residential metering and water is charged for as a component of the district council's annual rates. The average daily water use can be seen alongside the number of people present in the household. Based on these households it appears that water use increases with the number of residents in the dwelling. However, more data is needed to support this assumption.

Additional information from the surveying and on-site interviews can aid in interpreting changes in observed water use. In this instance, both dwelling A and D are two-person households. Dwelling A is in a metered area of New Zealand, whilst dwelling D is located in a non-metered area of New Zealand. It can be seen in Figure 5 that dwelling A has a slightly higher average water use for the January 2018 period. The occupants of dwelling A are a working couple, whilst one of the occupants of dwelling D is retired and one a full-time worker. Based on the assumption that a semi-retired household would use more water, as they are more frequently at home, Figure 5 shows that this is not the case based on this preliminary data. Dwelling A can be seen to have slightly higher water use than dwelling D for the same period. To understand the drivers of household water use the ability to contextualise water use against occupant behaviour is an important factor. Based on the resident surveys, dwelling A report a much higher water use for garden irrigation than dwelling D. At present, outdoor water use in New Zealand, and the variation between seasons, is poorly understood. This residential water use project aims to provide some valuable information on outdoor water usage across demographics, regions and based on occupant behaviours.

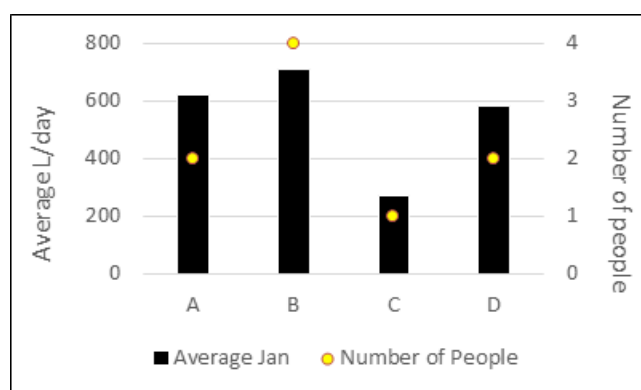


**Figure 5 Average water use for the January 2018 period across four metered dwellings**

Data collected at the daily level can be used to create a monthly water use profile. This level of data collection can also be used to understand peak demand (monthly, daily or peak times throughout the day). Over the 12-month monitoring period, information pertaining to peak periods will be collated and compared against regions, demographics and household typologies, as well as external influences.

Figure 6 expands the daily data for dwelling A (Figure 5 above). A time series of the 11<sup>th</sup> January 2018 is presented, as this was the peak water usage day (in contrast, dwelling B, C and D had peak water usage on the 29<sup>th</sup>, 26<sup>th</sup> and 24<sup>th</sup> January, respectively). There is clear peak in water use between 2pm and 6pm, with a prominent spike at 5pm. There is minimal water usage between 8am and 2pm.



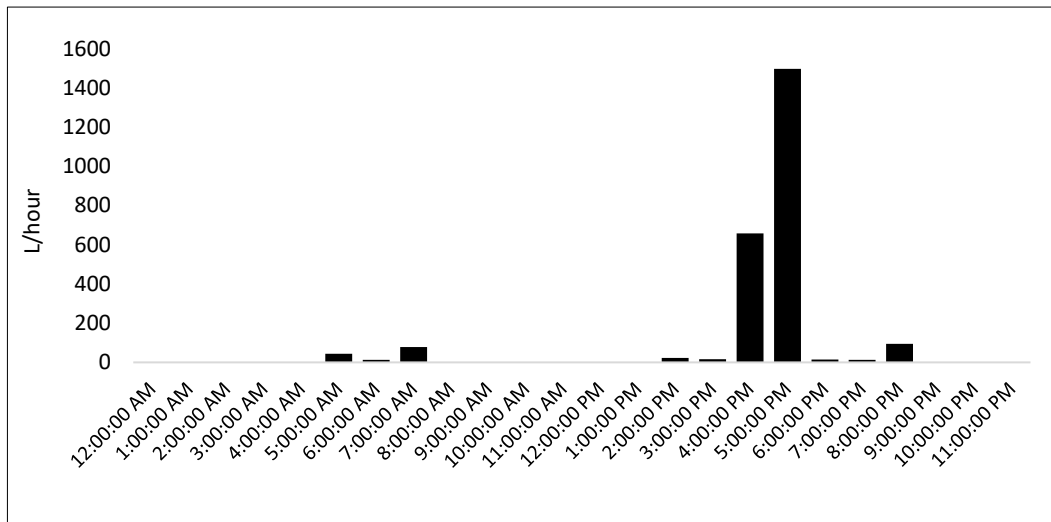


**Figure 6 Time series of a peak day's water use for a metered dwelling**

### 3.3 Household End-use Disaggregation

Whilst the daily water use data can go some way in quantifying water use and understanding water use demand in a dwelling, in regard to volume, it is not capable of exploring *how* water demand is being used in the dwelling, thus unable to help target water efficiency strategies at the household (and appliance) level. Using the Trace Wizard software, the daily water use profiles can be analysed at the end-use level to determine which appliances in a dwelling are consuming the most water, and to understand the behavioural influences on water usage.

Figure 7 shows the end-use disaggregation of the daily water use profile in Figure 4. Whilst Figure 4 shows how much water is being used throughout the month, the results of the end-use disaggregation can show *how* this water is being used.

It can be seen in Figure 7 that most of water usage on the peak day of the 21<sup>st</sup> June 2008 is for garden irrigation. Subsequent spikes in water use can also be seen on the 14<sup>th</sup> June 28<sup>th</sup> June and 5<sup>th</sup> July 2008, all of which are Saturdays. Analysis of the monthly profile for this dwelling shows an increase in water usage at the weekends, particularly for irrigation. The end-use disaggregation method is able to detect leaks in a household, and so it can be used to estimate water loss as well as consumption. A decreasing leak can be seen between the 28<sup>th</sup> June and the 3<sup>rd</sup> July. Leaks can have a major effect on household water consumption, especially if left undetected.

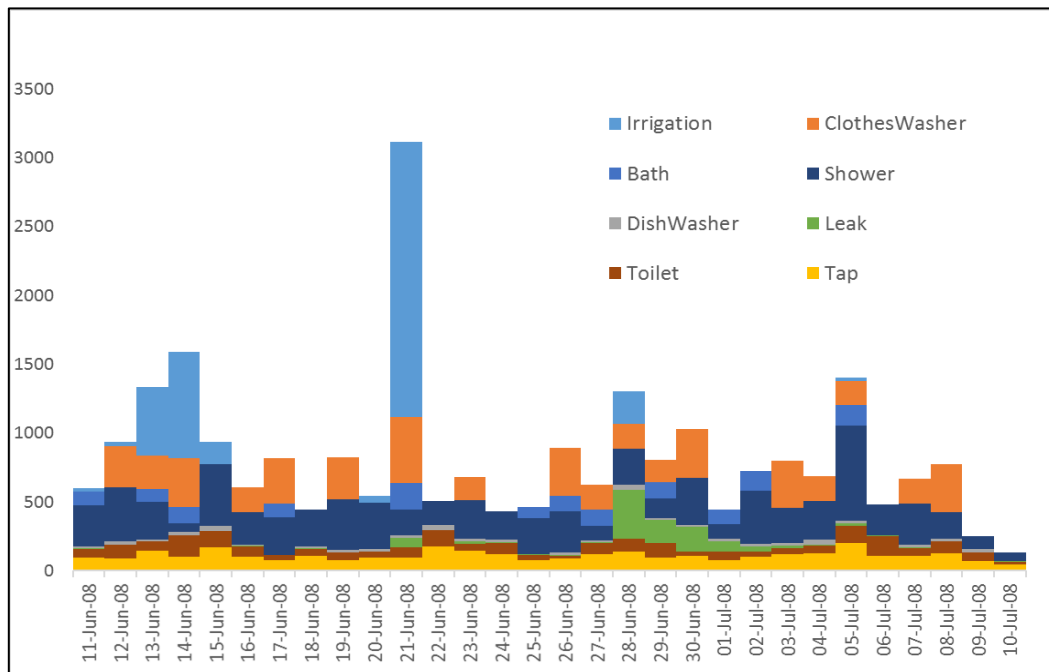


**Figure 7 End-use disaggregation of the daily water use profile of a dwelling in the Auckland region of New Zealand**

By collecting this information at the household level, an understanding of how appliances affect residential water use can be created. Further, an inventory of appliance types, and consumer behaviour in regard to usage and decision makings can be created and used to help target water use at the appliance level throughout New Zealand.

#### 4. CONCLUSION

This paper has explored a methodological approach to establish a benchmark for residential water use in New Zealand. To date a national water benchmarking has not been undertaken before. Our research will create a national benchmark for water use that can be used to compare residential water use across metro, provincial and rural regions, various climate zones, and several demographics groups. The information will be used to target sustainability initiatives (at different scales) for the efficient use of water within residential dwellings. At a district and regional scale to help inform the debate around residential water metering and water conservation campaigns.

The resident surveys highlighted that there is wide scale uncertainty around household water use, and an unfamiliarity of the national water efficiency labeling scheme. The surveys provide high-level understanding of water use behaviors, demographics, and fittings and appliances used to contextualize the metered daily and end-use water consumption data. This information will be valuable in understanding how consented residential water supply is actually consumed in New Zealand.

Preliminary results give a unique and insightful look in to how water is used across various districts of New Zealand. High resolution water metering for water end-use disaggregation has provided insight into when water is use used at the seasonal, weekly, daily and hourly timescales. The metering methodology has also provided insight into where water is use. Obtaining this accurate end-use information allows the identification of opportunities in which

water can be used more efficiently in areas of New Zealand that are not currently metered. This adds a layer of data and analysis that is currently lacking in New Zealand.

## ACKNOWLEDGEMENTS

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## #2. Customer and user innovation

## **Public awareness of and attitudes towards water use and its conservation**

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### **ABSTRACT**

Understanding how the public views water use and its conservation is crucial to the effective management of water resources. More often than not such research is limited by geographical location. Therefore, with behaviour change playing an ever greater role in the management of water resources, there is a growing need to better understand how the public views water use and its conservation in particular locations. This is crucial to the development of more informed and robust policy decisions. As a result, this paper presents the findings of a small-scale research project that sought to expand the geographical scope upon which our understandings of water use and its conservation are based i.e. the county of Buckinghamshire in the United Kingdom. Questionnaires were administered to 60 members of the general public, with the issues of awareness and attitudes towards water; current consumption behaviours; and potential barriers to increasing domestic water efficiency being explored. The results of the study are shown to support previous research findings in the area of public awareness of water use and its conservation, most notably in relation to being unaware of consumption levels and the impact gender can have on engagement. It is concluded that the findings of the study support further the need for not only ongoing research but awareness campaigns targeted at changing social norms toward the need for water efficiency, with these appearing to be associated with low awareness of environmental issues more generally.

*Key Words: water use, water conservation, public awareness, Buckinghamshire, United Kingdom.*

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## 1. INTRODUCTION

Whether viewed as a natural resource, commodity or basic human right, we cannot exist without water (Adeyeye, 2014a; Beal & Stewart, 2011; Ginis, 2005; Juniper, 2013). This suggests that water should be treated with great respect, and caution applied to water resource use, yet until recently people have been naïve in their interactions with water (Allan, 2011). Citizens in developed nations are often unaware of global water supply issues, and are shielded by their government's ability to provide a consistent, safe, water supply. This sense of security is becoming increasingly scrutinised as climate change, population increase and more affluent lifestyles begin to threaten existing access to safe water supplies (Environment Agency, 2011; Medd & Chappells, 2008; ONS, 2012; Sharp *et al.*, 2011; Spinks, Fielding, Price, Russell & Mankad, 2011).

Surprisingly for some, the United Kingdom (UK) is one nation showing signs of water stress, which can in part be attributed to the paradox that exists between perceived and actual water resources. The UK is often perceived as a nation with an abundance of water, yet the reality is at times significantly different. With regions varying in terms of climate, socio-economic composition and growth potential, there are areas of the UK, such as the south and south east of England that are exhibiting signs of water stress (DEFRA, 2008a; Edwards & Martin, 1995). As a result, water supply and its security is becoming an issue of growing concern in the UK, with calls for changes in behaviour and lower levels of water consumption being increasingly made (DEFRA, 2011, DEFRA, 2008a; Environment Agency, 2008).

An important focal area for change is household water consumption. In particular, Herrington (1999) identified water consumption in England as increasing year on year, with the current average use being at 150 litres per person per day (Staddon, 2010a). This is not only a concern in terms of usage, but also because household consumption has subtler indirect impacts. For example, hot water usage in UK homes accounts for over 5% of total UK greenhouse gas emissions, equivalent to 35 million tonnes of pollution per year (DEFRA, 2008b). Water treatment and quality control also contributes to emissions and this is amplified by the fact all UK mains water is supplied to drinking quality level, despite less than 10% of mains water actually being utilised for drinking (NHBC Foundation, 2009; Orgill, Woolliscroft & Brindley, 2014). Overall, the water industry consumes 3% of total energy used in the UK, an especially significant figure when the connection between water and energy usage has not been widely acknowledged by consumers (CCW, 2015; Staddon, 2010b).

Water and energy usage are two important environmental issues, yet it can be argued consumers have not given equal attention to both resources. For instance, research by DEFRA (2007) into public attitudes and behaviours towards the environment, can be noted as highlighting that just under 50% of respondents stated they didn't pay much attention to the amount of water used at home. However, when compared to energy usage, only 23% of respondents concluded the same. This potential difference in attitudes between water and energy is a concern. Adeyeye (2014a) builds upon this and notes several UK government incentive schemes for promoting energy efficiency, but no equivalent scheme for water (Robinson & Adeyeye, 2014).

In the context of current UK policy, DEFRA's vision for the future 2030 targets increased consumer knowledge of household water use; the promotion of more sustainable behaviours; and a new average daily consumption figure of 130 litres per person per day (DEFRA, 2008a; DEFRA, 2008b). Therefore, understanding public awareness of and attitudes toward water use and its conservation is vital to achieving these visions, as the success of water initiatives often rely upon public engagement and support (Bell & Aitken, 2008; Dolnicar & Hurlimann, 2011; Knamiller & Sharp, 2009). Understanding how individuals perceive water use is also essential to the success of water demand management strategies (Edwards & Martin, 1995; Jenkins & Pericli, 2014; Jorgensen, Graymore & O'Toole, 2009; Medd & Shove, 2005; Steg & Vlek, 2009).

When seeking to understand water use attitudes, it is important to note the geographical context or location of the such research, which may in turn affect its applicability. Australia has been a hotbed for water use research due to pronounced water security issues (Syme, Shao, Po & Campbell, 2004; Rathnayaka *et al.*, 2014; Willis, Stewart, Panuwatwanich, Capati &

Giurco, 2009). Also attitudes and awareness to water use will inevitably shift over time, with this thus necessitating the need for research to be updated in order to facilitate the development of effective water demand management strategies (Adeyeye, 2014a; DEFRA, 2008a; DEFRA, 2011; Jenkins & Pericli, 2015; Medd & Shove, 2005; NHBC Foundation, 2011; Welte & Anastasio, 2010). Therefore, this study aims to not only update and enhance our knowledge and understandings of public awareness and attitudes toward water use, but to also expand the geographical context upon which from such understandings emerge.

## 2. METHODOLOGY

From an overarching perspective, the research undertaken for this study adopted a qualitative approach, implemented through the administration of a questionnaire to individuals over the age of 18 living in the county of Buckinghamshire. Questionnaires were administered to individuals in the key population centres of Aylesbury, Milton Keynes and High Wycombe. 20 questionnaires were administered in each location.

60 participants completed questionnaires; 30 males, 30 females. The two most common age groups were 18-30 and 51-60 year olds. Both were overrepresented when compared to the Buckinghamshire's population. Age distribution of participants is acknowledged as being distorted thus limiting the ability to assess the impact of age. However, the heavy weighting of 18-30 year olds is argued as being value particularly as previous research by Consumer Council for Water has identified this group as a priority group for further research (CCW, 2015).

From a general perspective, the questionnaire focused on exploring awareness and attitudes toward water; current consumption behaviours; and potential barriers to increasing domestic water efficiency. To aid data collection, the questionnaire was split in three sections. The first section focused on collecting data relating to gender, age, household size, tenure, engagement with environmental issues, and awareness of water use and its conservation as an issue. Section two subsequently focused on exploring respondent's awareness of water use and saving measures, with questions focusing on whether they had a water meter, how much water their household used, how much water they used per day, what the average per capita consumption in the UK was, what every day domestic activities they thought used the most water, and what water saving or storage devices they had in their household. The final section then sought to explore water use behaviour in relation showering, brushing teeth, and gardening, with attention also focusing on exploring respondents perceptions of water sufficiency in UK, how important they thought water use was in comparison with other environmental issues, whether or not they would be willing to change their behaviour to reduce their water usage, and what broad approaches would motivate them the most to save water i.e. financial, technological, education, and/or regulation.

The majority of questionnaire responses returned quantitative data that was analysed with the aid of Microsoft Excel software. In particular, Chi-squared tests, T-Tests and regression analysis were utilised for statistical analysis (Rogerson, 2011).

## 3. RESULTS AND DISCUSSION

To aid discussion of the results, the study findings have been split into nine sub-sections. Initially, the focus is on exploring a range of issues that serve to shape perceptions of and attitudes towards the importance of water use and its conservation. In particular, the first two sections focus on the exploring the impact of gender, households size, tenure. Following sections then focus on exploring the knowledge and uptake of water saving technologies and devices, awareness of water use, and engagement with water meters. Following these sections attention then turns to discussing that public awareness of environmental issues and its association with awareness. The final two sections focus on exploring the impact of financial concerns and the relative importance of water usage in comparison to the consumption of other utilities.



### 3.1 The impact of gender and household size

Previous research identifies priority groups to be the target of water usage and efficiency campaigns, with common variables and their impact worthy of research (Hurlimann, Dolnicar & Meyer, 2009; Jenkins & Pericli, 2015; Spinks *et al.*, 2011). One such variable is gender. In a 2015 by CCW, young males were subsequently identified as a priority group for awareness campaigns. Study results support this finding, with it being found that twice as many females than males were interested in learning more about personal water consumption, but with equal numbers in each group feeling they could save more. This suggests awareness campaigns should seek to think carefully about how gender potentially influences engagement with water efficiency initiatives.

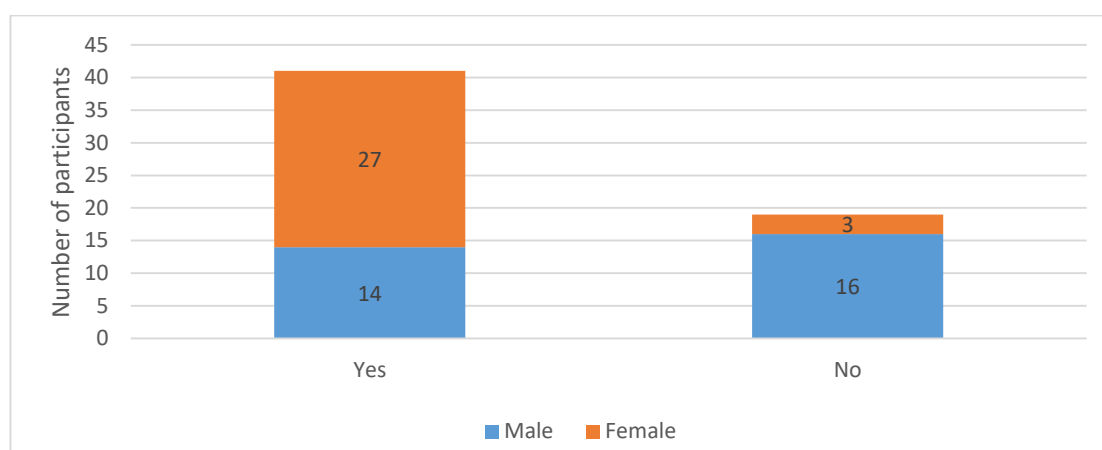


**Fig. 1. Interest in learning more about personal water consumption**

Household size (number of occupants) was another variable tested, with it being found that this variable did not have an impact on responses. This counters previous research in Australia and South Korea by Willis *et al.* (2009) and Lee, Park and Jeong (2012) respectively. Subsequently this finding is argued to underscore the importance of not only treating this result with caution because it differs to that of previous research but the continued need to ensure research takes place in many national and geographical contexts so as to afford us the opportunity to construct as detailed understanding of the variables that effect water use and attitudes to its conservation in different national contexts.

### 3.2 The impact of tenure on water use

Tenure was tested for influence on responses due to importance in previous research (Randolph & Troy, 2008; Willis *et al.*, 2009). Results suggest tenure didn't impact responses, perhaps a counter-intuitive finding. Tenants in rented properties for example, will have less say in household fittings and will not be in a position to invest in water-saving technologies – a point supported by one participant's comments.

However, one question where tenure was found to statistically significant was for ownership of water butts, as 'owned outright' (59.1%) and 'owned mortgage' properties (50%) had considerably higher ownership than rented properties (13.3%). This could impact external water consumption, and further research into the role of tenure is recommended to clarify influence.

### 3.3 Knowledge and uptake of water saving technologies and devices

Study results also highlighted areas for increased household water efficiency, which are essential to uncover (Jorgensen, Graymore & O'Toole 2009). 36.7% of participants were found to be unaware of internal water-saving technologies in their household, suggesting that household water audits could play a key role in identifying those properties where water efficiency could be achieved though the fitting of low cost water efficiency devices such as tap aerators (Tam & Brohier, 2014). Support this argument is that the study found that 30% of

participants thought they didn't have them in their home, and had never considered installation. One participant explicitly concluded that they had *"never heard of them"*.

Personal washing habits offer an opportunity to reduce consumption, with regular baths and long showers prevalent amongst respondents. The majority of participants stated water power was more important than time spent showering, and this could be important when trying to reduce water consumption. If modern aerators were installed that reduced flow volume but not the power 'feel', individuals could reduce shower time (NHBC Foundation, 2009; NHBC Foundation 2015). The introduction of 'eco-baths' would also assist in reducing water consumption from bathing habits.

The study also identified the potential to reduce external water usage by improving the uptake and fitting of water butts, as 70% of participants never used one. One in four participants regularly watered a garden during dry periods, and one in ten did so without using a water butt.

### 3.4 Public awareness and understandings of water use

Arguably the most critical finding from this study was that participants knew where they consumed the most water, but had little idea of actual consumption rates. Bathroom activities and white goods were considered the heaviest users (The Water Calculator, 2016; Waterwise, 2016). Actual water consumption showed no consensus in responses, and many estimates were surprisingly low (see Figure 2). If people don't know their real consumption rate and associated impacts, their motivation to adjust behaviours will be limited. This point highlights the need for awareness campaigns. This finding supports, and is supported by, the work of Randolph and Troy (2008) who identified that water demand management strategies would benefit from increased consumer understanding of usage (see Adeyeye, 2014a; De Franca Doria, 2010; Dolnicar & Hurlimann, 2011).

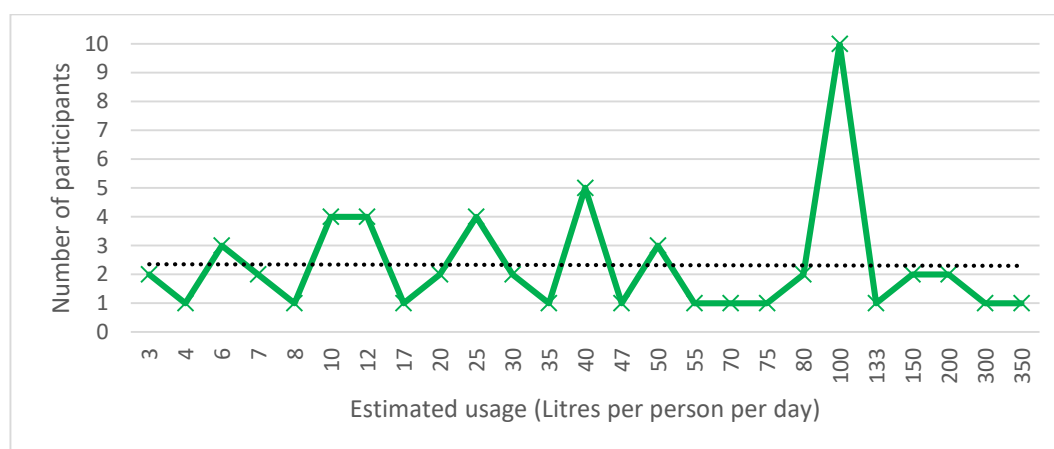


**Fig. 2. Respondent estimation of household water consumption**

When the influence of social norms was explored, in particular the influence of family and friends in altering consumption patterns, it was found that 45% of participants responded that this would affect their behaviour to some extent, providing support for the power of social influence on behaviours.

### 3.5 Water meter engagement

Engagement with water meters can influence awareness of water consumption (see CCW, 2015; DEFRA, 2008; DEFRA, 2011; Edwards & Martin, 1995; Knamiller & Sharp, 2009; Van Vliet, Chappells & Shove, 2005). However, this study found that 83.3% of participants either didn't have or had never checked their water meter. Despite this finding indicating a level of disengagement, and thus a possible explanation of poor understanding of water use, it is important to acknowledge that not all research supports the ability of metering to reduce consumption (Gadbury & Hall, 1989; Macleod, 1979; Staddon, 2010a).

### 3.6 Public awareness of water use and water conservation

Participant's engagement with current environmental affairs was found to be poor, with only 28.3% saying they regularly thought about with environmental issues. 30% of respondents were also found to never have encountered the topics of water use and water conservation prior to this study. This suggests awareness could be acting as a barrier to increased water efficiency, which is a particular issue that influences the success of water demand management strategies (see Ajzen & Fishbein, 1980; DEFRA, 2008b; DEFRA, 2011; Jenkins & Pericli, 2014). This is also a concern when considering the apparent influence engagement with current environmental affairs had on responses.

Participants were asked whether information on water usage was widely accessible and easy to understand. 41.7% believed information was inaccessible, highlighting a further barrier to raising awareness (Steg & Vlek, 2009). Interestingly, a separate finding countered the perceived importance of public awareness, as participant's ranked 'increased awareness' as the lowest motivator for saving water. This could be explained by adapting Burch's model of conscious competence for skill acquisition, where participants were 'unconsciously incompetent' (GTI, 2016). Awareness was ironically not seen as an issue because individuals were unaware of any knowledge deficiency.

Personal experiences were touted as one potential influence of consumption rates, and one in five participants had experienced at least 24 hours without water (Campbell, Johnson & Larson, 2004; Jenkins & Pericli, 2014; Medd & Chappells, 2008). Results showed personal experiences had some influence on responses, and further research is recommended as a result.

The study also found that only 31.6% of participants indicated that they were currently concerned about water use and water conservation, suggesting water wasn't a priority issue for many. This was supported by 45% of participants feeling that the UK had an abundant water supply (DEFRA, 2008b; DEFRA, 2011; Environment Agency, 2008; Juniper, 2013). One quarter of participants strongly agreed that they had the right to access as much clean water as desired, and a further one in three agreed. These attitudes are potential barrier to improving water efficiency, but were found to be contradicted by 71.6% of participants being open to the idea of changing water use behaviour.

A question originally posed by Randolph and Troy (2008) was replicated for this study, and results provided further empirical support for positive attitudes towards water efficient behaviours. 21.7% of participants believed they could do 'a lot more' to save water, 55% 'some more' and 20% 'a little more'. Only 3.3% thought they could do nothing more, highlighting scope to improve household water efficiency.

### 3.8 Financial disincentives and behaviour

Alongside the influence of social norms on water efficiency, financial motivations were explored. Of the four scenarios provided to participants, financial constraint was considered the greatest motivator for reducing consumption. In further questioning, 21.7% strongly agreed and 46.6% agreed that increasing water bills would increase awareness of water consumption. It is concluded that finances play an important role in consumption behaviours, supporting existing research (DEFRA, 2008a; Jenkins & Pericli, 2014; Jenkins & Pericli, 2015; Zetland, 2011). Hassel and Cary's (2007) rational-economic model is further supported by above findings, and suggests awareness campaigns should concentrate on financial and (where applicable) performance benefits (or parity) when attempting to reduce household water consumption. However, it is important to acknowledge that price increases alone are unlikely to effectively manage domestic water demand (Randolph & Troy, 2008).

### 3.9 Water, the poor relative!

41.7% of participants believed the UK had more important environmental issues than water, and a further 36.7% were undecided. Many participants were found to be more concerned about their energy consumption, believing energy efficiency was easier to achieve than water efficiency. A large number of participants were also undecided or equally concerned. This partially supports previous research by DEFRA (2007). Part of the attitude gap between energy

and water could be due to the passive nature of many water-saving technologies. For example, click taps and flow restrictors may be installed prior to occupancy and new tenants may be unaware of their presence and purpose. The NHBC Foundation (2015) found water efficiency measures were installed four times more often than energy equivalents in affordable new homes, providing some evidence for awareness issues of water efficient fittings. Adeyeye (2014a) noted a lack of promotional schemes for water efficiency products when compared to energy, and this offers further explanation for findings.

It is possible that energy receives more attention than water because of the cost differences in accessing each resource. As noted previously, money had the greatest perceived influence on behaviour, with energy tending to be more expensive (Adeyeye, 2014b). Water pricing does not accurately reflect its true value. To tackle this issue, public awareness campaigns should target the role of water efficient fittings and clarify their performance parity, alongside environmental benefit. Passive technologies are currently at risk of being undervalued, under-installed and misunderstood, with 36.7% of participants without (or unaware of) internal water-saving technologies.

The connection between water use and other environmental impacts should be more clearly communicated (Adeyeye, 2014b; Staddon, 2010b). The NHBC Foundation (2011) found “*For every pound the household paid for its water use (comprising water bill and energy bill for hot water), almost 2kg of CO<sub>2</sub> was emitted*”. If energy is considered more important by the general public (as results suggest), then the connection between hot water use and energy consumption offers a way to utilise this sensitisation.

#### 4. CONCLUSIONS

A key finding of this study was that awareness rather than attitudes are potentially the key barrier to improving household water efficiency. As such, it is recommended that awareness campaigns are enhanced, and concentrate on water use in ‘real terms’ to assist information transfer to the general public. Quick wins identified should be central to future campaigns, alongside the financial and performance benefits (or parity) of water-saving technologies. Clear communication from water providers as identified in The Water Act (DEFRA, 2014) will be paramount in efforts to increase household water efficiency.

It is further recommended that educational campaigns are introduced, and efforts to inform individuals should receive greater attention. For example, the EU water label and other similar information schemes should be explored (Orgill, Woolliscroft & Brindley, 2014; The Water Label Company Ltd, 2016). Shedding light on social norms and average consumption levels could mitigate some of the heaviest consumers, but also risks alienating efficient individuals. People are generally open to learning more about water consumption, and this pro-environmental spirit should be utilised in efforts to increase efficiency.

The availability of water efficiency information is currently a problem that needs to be addressed by the water industry. When designing new water demand management strategies, information dispersal should be central to discussions. Additionally, promotional campaigns for water-saving technologies should be considered (Adeyeye, 2014b).

Finally, caution should be exercised when applying international research to the UK. The economic, climatic and demographic differences between nations limits the wider validity of research. It is therefore argued that further research is urgently needed within the UK to assist water conservation efforts.

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# Thermal and flow distribution of showerheads as a method for understanding water user preferences

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## ABSTRACT

Water efficient products such as showerheads provide a useful means to manage and deliver water use efficiency. They are now prevalent in the market, however there remains gaps in the understanding of these products in terms of user interaction and use and the extent of how these affects user perception, and experience. These unknowns still exist since user experience of eco products influences the extent to which they consistently achieve water use efficiency beyond the short term.

This study was therefore undertook to study important parameters that define the technical efficiency of showerheads as it is associated with the perceived performance and experience of (and therefore the satisfaction with) showerheads. Technical parameters were measured in a laboratory environment and the findings were triangulated against in-home user feedback.

This study is significant because it presents a useful methodology for understanding user preferences for such water products, as well as the degrees of affordance that need to be factored into their design, deployment and use.

*Keywords: Flow distribution, Thermal range, Showerheads, Water efficiency, Water user*

## 1. INTRODUCTION

This unsustainable water use relative to population growth is an increasing cause for concern and attention. Water use habits have also evolved in line with sociological and economic factors, and less in line with environmental/resource constraints. Although water challenges are less apparent in developed countries, particularly due to advancements in municipal water supply systems, the need for water use efficiency remains important. Technological solutions, behavioural interventions and financial incentives targeted at users has been shown, to varying degrees of success, to help deliver water use efficiency in homes (e.g., [1-4]). In addition to water efficient behaviours, promoting use of water efficient fixtures have been successful in some communities resulting in up to 35% of indoor water savings [5].

Water technologies and products are useful for achieving targeted water savings in domestic and personal water use. Taps, showers, baths and toilets are necessary for sanitation and health but can also promote water waste due to poor design, installation and use. However, some like Lee and Tansel [5] have found that the satisfaction levels of the participants in water efficiency trials including retrofitted high efficiency fixtures were closely correlated with the achieved water savings.



Therefore, this study focuses on the technical efficiency of showerheads as a determinant for its efficiency in-use. It presents laboratory findings of temperature and flow distribution of showerhead as an indicator of the potential to propagate due to water loss, and the perceived satisfactions that could potentially be derived by the user as a result of using these products.

A sample of 10 showerheads was used in this study. All the showerheads were water efficient discharging water at between 5-11 litres per minute (Table 1).

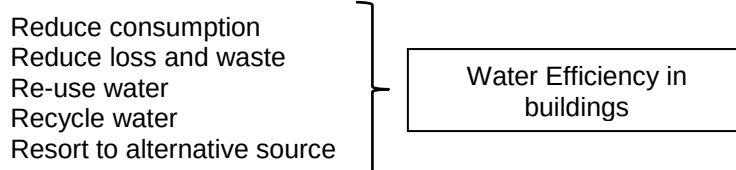
**Table 1. Characteristics summary of the showerheads in the sample.**

| Ref No.                                       | S-01                                                                                | S-02                                                                                | S-03                                                                                | S-04                                                                                | S-05                                                                                | S-06                                                                                 | S-07                                                                                  | S-08                                                                                  | S-09                                                                                  | S-10                                                                                  |
|-----------------------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
| Shape                                         | Round                                                                               | Oblong                                                                              | Round                                                                               | Round                                                                               | Round                                                                               | Round                                                                                | Round                                                                                 | Rectangle                                                                             | Curved rectangle                                                                      | Round                                                                                 |
| Height                                        | 90                                                                                  | 157                                                                                 | 106                                                                                 | 100                                                                                 | 100                                                                                 | 106                                                                                  | 135                                                                                   | 67                                                                                    | 65                                                                                    | 135                                                                                   |
| Width                                         | 90                                                                                  | 82                                                                                  | 106                                                                                 | 100                                                                                 | 100                                                                                 | 106                                                                                  | 135                                                                                   | 182                                                                                   | 120                                                                                   | 135                                                                                   |
| Height incl. handle                           | 215                                                                                 | 270                                                                                 | 239                                                                                 | 230                                                                                 | 230                                                                                 | 239                                                                                  | 246                                                                                   | 227                                                                                   | 219                                                                                   | 246                                                                                   |
| Sprout Type                                   | Recessed twin                                                                       | Recessed twin                                                                       | Recessed twin                                                                       | Protruding single soft rubber                                                       | Protruding single soft rubber                                                       | Recessed twin                                                                        | Recessed twin                                                                         | Triple central, recessed twin                                                         | Recessed twin                                                                         | Recessed twin                                                                         |
| Sprout Layout                                 | 3 x 3 double sprout clusters                                                        | Two long double-sprout oval rows                                                    | Two concentric double sprout circles                                                | Central core and radial rows                                                        | Central core and radial rows                                                        | 3 x 3 double sprout clusters                                                         | Random x 3 clusters                                                                   | Central triple clusters, random rows                                                  | Random                                                                                | Random x 3 clusters                                                                   |
| Working pressure (bar)                        | 0.3 - 5.0                                                                           | 1.5 - 5.0                                                                           | 0.35 - 5.0                                                                          | 0.3 - 5.0                                                                           | 0.3 - 5.0                                                                           | 1.0 - 5.0                                                                            | 0.35 - 5.0                                                                            | 1.5 - 5.0                                                                             | 0.35 - 5.0                                                                            | 0.35 - 5.0                                                                            |
| Regulated flow rate @ 2 bar pressure (l/m)    | 8.7                                                                                 | 8.7                                                                                 | 7.9                                                                                 | 13.2                                                                                | 12.9                                                                                | 5.1                                                                                  | 7.6                                                                                   | 7.4                                                                                   | 8.3                                                                                   | 7.6                                                                                   |
| Measured Regulated flow rate @ 2 bar pressure | 10.3                                                                                | 7.2                                                                                 | 7.2                                                                                 | 9.2                                                                                 | 8.7                                                                                 | 5.1                                                                                  | 11.3                                                                                  | 7.2                                                                                   | 8.1                                                                                   | 9.6                                                                                   |
| Number of functions                           | 1                                                                                   | 4                                                                                   | 1                                                                                   | 3                                                                                   | 1                                                                                   | 1                                                                                    | 2                                                                                     | 2                                                                                     | 1                                                                                     | 2                                                                                     |
| Mode of operation                             | Colliding twin jets                                                                 | Colliding twin jets                                                                 | Colliding twin jets                                                                 | Mixing with Air                                                                     | Mixing with Air                                                                     | Colliding twin jets                                                                  | Colliding twin jets                                                                   | Colliding twin jets                                                                   | Colliding twin jets                                                                   | Colliding twin jets                                                                   |
| Image                                         |  |  |  |  |  |  |  |  |  |  |

Studies such as this contribute to the better understanding of sustainability mismatch in water efficient products against user preferences and use behaviours. The laboratory and user experiments on showerheads makes it possible to further determine factors that promote the efficiency of design and use of the showerhead; in turn promoting sustainable development.

## 2. RESEARCH CONTEXT

There 5R principle (below - [6]) is typically proposed for achieving water, and energy efficiency as shown below.



Domestic buildings which typically include individualised, and multiple architectural spaces such as kitchens and bathrooms provide the opportunity and scope for targeted water efficient

product solutions, and this has been the case. A wide range of different types of taps, showers etc. are now readily found in the market with increasing additional functionalities, and characteristics, all designed to meet user needs, preferences, and demands as highlighted by market studies of various kinds. Showerheads in particular have become increasingly complex over time and this in turn informs their water use consumption. Even eco- or water efficient-showerheads come in varying types and offer different flow rates/patterns, pressure, temperature ranges etc. as shown below.

#### **Type of shower heads [7]:**

- Single head: This type of showerhead may have a single setting or more than one setting. Settings often include more and less focused sprays and a pulsating spray.
- Multiple-head Shower: These fixtures may have two or more spray nozzles connected to one pipe. They can easily replace a single head fixture.
- Cascading Showerhead: They often are mounted overhead such that the water drops straight down. They typically give a softer spray and have diameters of 6 to 8 inches.
- Shower Panel or Shower Tower: These are designed to spray water from more than one location having more than one showerhead. They may operate sequentially.
- Rain Systems: Rain systems simulate rain by allowing water to fall from an overhead fixture.
- Body Spas: Body spas consist of multiple showerheads and are described by some as the vertical equivalent of a spa. The showerheads may be activated sequentially or intermittently.

Biermayer [7] also postulated that the amount of water used by showers could be reduced in several ways if information were available regarding both the water efficiency and performance of showerheads.

- Results of testing showerheads can provide an enforcement function, whereby showerheads that exceed the standard for water flow are identified and removed from the market.
- Showerheads that use even less than the standard and also provide a good shower experience can be identified and promoted.
- Providing consumers with information about which showerheads they are most likely to find satisfactory will encourage them to switch to effective low-flow showerheads and discourage them from installing non-compliant showerheads.
- Identifying low-flow showerheads that provide an adequate shower also may prevent consumers from purchasing multi-head shower fixtures.
- Additional research into ways to encourage consumers to turn off the water while lathering also could save water.
- Perceived or real safety considerations may prevent utilities from promoting very low-flow showerheads and therefore, these issues must be researched.

A previous study by Adeyeye *et al.* [8] showed that the environmental performance of resource using products such as showerheads, are affected by product design and use. Use factors are also influenced by the extent to which the product satisfies user performance expectations in addition to meeting environmental benchmarks and standards. Therefore, it is important to understand water efficient product design and performance standards individually and in conjunction with user preferences in order to determine the extent to which it is wholly water efficient.

This study aims to satisfy this assertion by presenting product performance findings of 10 water efficient showerheads in conjunction with user feedback on the specific criteria being studied. The 10 showerheads were supplied by the same manufacturer and 12 volunteer participants participated in a 12 week study where they were able to use each showerhead at home for one week. They completed a feedback sheet of each showerhead after their first and last use during the week. Therefore, it is possible to compare their initial and final feedback. Conclusions are then presented to highlight the importance of the showerhead performance characteristics in informing the user perception and feedback of the product.

### 3. THE EXPERIMENTAL SETUP

A study by McClelland *et al.* [9] used focus groups to address the issue of a 'good shower'. They found that the main requirements were temperature stability, adequate water volume and distribution, and perceived skin pressure. Alkhaddar *et al.* [10] followed up these findings with laboratory experiments which proposed useful measurement methods as well as determined the relative dependencies of performance metrics such as flow rate and skin pressure. This study builds on this work. The research design is summarised as below (Figure 1).

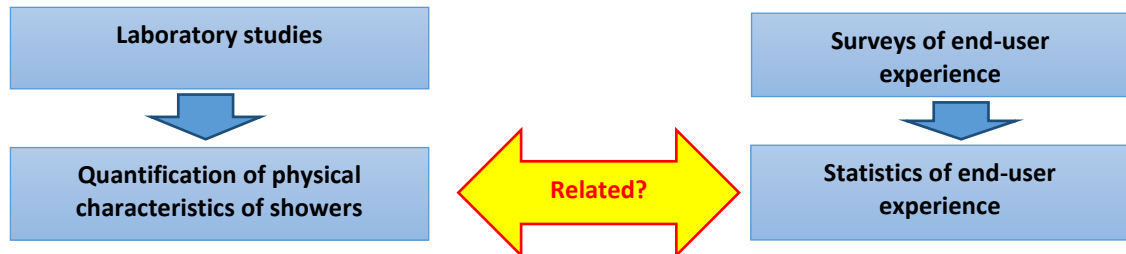


**Fig. 1. Research design.**

Figure 3 shows the laboratory setting and the schematic configuration of the instrument setup in the shower cubicle. The cubicle has provision for three shower heads to be mounted at the same time. The mounting position for this study is indicated in the figure and the mounting wall is referred to as the north wall for the purpose of orientation.

#### 3.1 Showerhead Spray diffusion/ distribution

The measurement of the showerhead spray diffusion and distribution is derived from the method employed by Alkhaddar *et al.* [10] and a comparison is shown in Figure 4. Alkhaddar *et al.* [10] assumed that the spray has a circular pattern and the spray centre coincides with that of the collector unit. As such, their collector system consists of nine radial zones with water collected and measured for each zone to give a distribution map of the spray. In reality, the spray pattern is not symmetrical in the radial direction due to spray-hole asymmetry or simply the presence of showerhead installation angle. This means that a collector system of circular zone may not truly map the actual spray distribution.

Refinement to the circular zone design is needed, ideally with each circular zone subdivided into smaller zones. This would however significantly increase the manufacturing and operational difficulties. The spray collector design adopted in the current study overcomes the asymmetry issue by using a series of plastic containers (cups) arranged in a configuration as shown in Figure 2. A precision template is laser-cut out of an 8 mm Perspex sheet, ensuring repeatability and consistency of container positions between tests of different shower heads. The position of the collector unit in the shower cubicle can be seen in Figure 3. Initial trials show that the centre of the shower spray is generally not the same as the centre of the container array, depending on the showerhead being tested. For consistency and improved spray area coverage, each shower head is tested three times with the template placed at a distance of 0.55 m, 0.60 m and 0.66 m from the north wall, respectively. In addition to increased spray area being measured, the gapping area between the container arrays is also covered. The spray collector unit serves to obtain the flow distribution and temperature variations across the spray. The unit collects water over a fixed time of 60 seconds. Over this time, a sufficient amount of water is collected without overflowing any of the cups. The volume of water in the cups can be easily derived using a digital scale while the water temperature at each cup is obtained by means of a thermal camera. Four thermal images are taken for each test, each covering 1/4th of the container array.

#### 3.2 Showerhead temperature range

Thermal imaging is now widely used in the construction industry and for the purposes of this study temperature differentials can be used to define temperature ranges and heat transfer from water being dispensed from the showerhead. Thermal imaging cameras work by recording Infrared Radiation (IR) which directly relates to the objects' temperature. The thermal imaging

camera used for this study is Thermo View Ti30 by Raytec, which comes with a software tool that converts recorded thermal images into temperature.

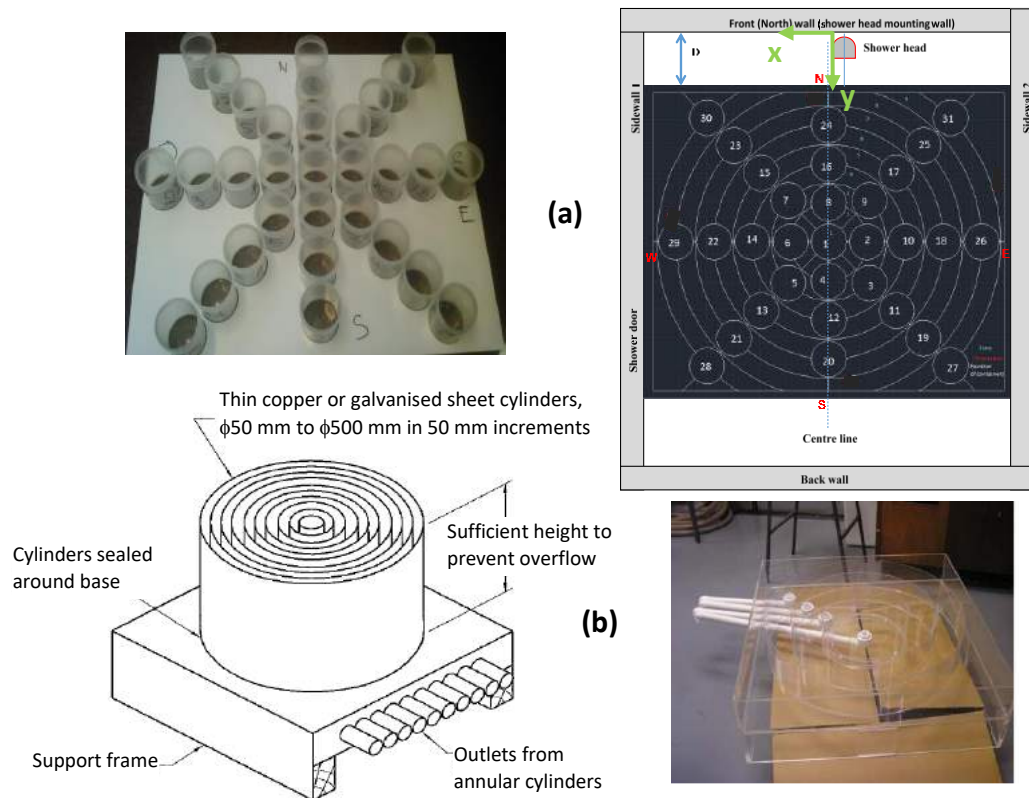


Fig. 2. Spray collector units (a) current study, with plan view and (b) Alkhaddar *et al.* [10].

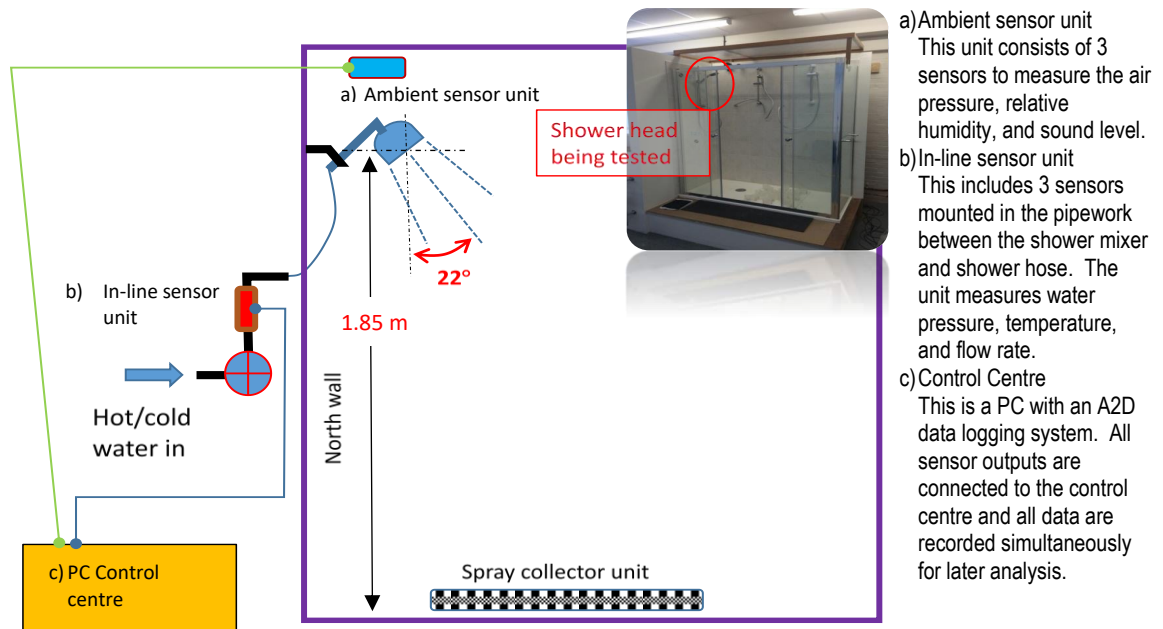


Fig. 3. The shower cubicle and instrumentation layout.

#### 4. USER FEEDBACK

As stated, participants of the 12 week shower challenge were asked to complete a feedback sheet which documented their showering habits as well as their feedback against a metrics of 23 different questions and a choice of 5 responses. The feedback sheet was explained to participants at a commencement workshop to ensure that the feedback questions are interpreted correctly when completing the feedback sheets.

Two stages of feedback were obtained: one on receipt of the showerhead at the beginning of the trial week, and second at the end of the trial week after the final showering event before the swap. Relevant excerpts of the average user feedback is presented due to the space constraints of this paper (Table 2). A further paper will better articulate the findings based on participant demographic and discuss correlations against other user and showerhead metrics.

In summary, it was found that users were able to discern differences in the showerhead performance in terms of the consistency of flow and temperature as well as the spray coverage. Further, user judgemental and experiential perceptions of the showerheads differed throughout the trial. Therefore, and depending on the showerhead, the mean value for the showerhead increased or decreased throughout the trial. This showed that there could be significant differences in findings from water efficiency studies that are based on experiential data compared to other 'passive' methods.

Feedback are provided on a scale of 1 to 5, and the notional mean for acceptable, positive feedback was defined as 3.5 in line with the median, rather than the arithmetic mean which is not robust for outliers and variance. On consistency of water flow, the majority of the showerheads performed the notional mean. With the exception of showerheads 1 and 10, all the showerheads were rated higher at the end of trial week compared to the beginning of the week. Showerhead 7 received the same overall mean value for both feedback stages. It should be noted that showerheads 7 and 10 are identical in all aspects except colour (*see images in Table 1*). This was done as an additional indicator of consistency in the user feedback of each product.

**Table 2. Average feedback summary from study participants.**

|                                           |                          | S-1   | S-2   | S-3   | S-4   | S-5   | S-6   | S-7   | S-8   | S-9   | S-10  |
|-------------------------------------------|--------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| The water flow was consistent             | Start of Week            | 4.67  | 4.55  | 4.11  | 4.60  | 4.38  | 4.33  | 4.75  | 4.67  | 4.50  | 4.75  |
|                                           | End of Week              | 4.56  | 4.67  | 4.38  | 4.70  | 4.55  | 4.44  | 4.75  | 4.83  | 4.60  | 4.58  |
| I like the coverage of the spray          | Start of Week            | 4.22  | 4.25  | 4.00  | 4.30  | 4.23  | 3.44  | 4.25  | 4.00  | 4.20  | 4.50  |
|                                           | End of Week              | 3.67  | 4.42  | 4.38  | 4.40  | 4.55  | 3.44  | 4.63  | 3.83  | 4.40  | 4.42  |
| The water temperature was consistent      | Start of Week            | 4.00  | 4.27  | 4.00  | 4.20  | 4.38  | 3.33  | 4.38  | 4.17  | 4.10  | 4.50  |
|                                           | End of Week              | 4.00  | 4.42  | 4.00  | 4.20  | 4.36  | 3.44  | 4.13  | 4.08  | 4.00  | 4.42  |
| This showerhead meets all my expectations | Start of Week            | 4.00  | 4.55  | 3.89  | 4.00  | 4.08  | 3.67  | 4.13  | 3.83  | 4.20  | 4.25  |
|                                           | End of Week              | 3.89  | 4.33  | 3.75  | 4.20  | 4.09  | 3.44  | 4.00  | 3.83  | 4.10  | 4.33  |
| I will be happy to buy this showerhead    | Start of Week            | 2.67  | 2.27  | 2.33  | 2.70  | 2.62  | 2.67  | 2.75  | 3.00  | 2.70  | 2.67  |
|                                           | End of Week              | 2.11  | 1.83  | 2.38  | 2.90  | 2.73  | 2.78  | 2.75  | 3.25  | 2.40  | 2.83  |
| This showerhead was enjoyable to use      | Start of Week            | 2.78  | 3.09  | 3.00  | 3.60  | 3.08  | 2.89  | 3.75  | 3.50  | 3.30  | 3.92  |
|                                           | End of Week              | 2.89  | 3.17  | 3.00  | 3.30  | 3.00  | 2.56  | 4.25  | 3.58  | 3.00  | 3.83  |
|                                           | Total (top 3 criteria)   | 25.12 | 26.58 | 24.87 | 26.40 | 26.45 | 22.42 | 26.89 | 25.58 | 25.80 | 27.17 |
|                                           | Average (top 3 criteria) | 4.19  | 4.43  | 4.15  | 4.40  | 4.41  | 3.74  | 4.48  | 4.26  | 4.30  | 4.53  |
|                                           | Total                    | 34.23 | 36.6  | 34.73 | 37.8  | 37.12 | 31.66 | 39.02 | 37.07 | 36.4  | 39.67 |
|                                           | Average                  | 3.42  | 3.66  | 3.47  | 3.78  | 3.71  | 3.17  | 3.90  | 3.71  | 3.64  | 3.97  |

User feedback on the spray coverage were more varied. Most of the showerheads received higher ratings at the beginning of the week compared to the second feedback at the end of the week. All except showerhead 6 (*see images in Table 1*) which was rated lower than the notional

average at 3.4. Showerhead 6 is a round showerhead with recessed twin sprout types laid out as 3X3 double sprout clusters. This shower delivered the least regulated flow rate of 5.1 l/min @ 2 bar pressure of all the showerheads. Although showerheads 1 and 8 performed better, their ratings dropped at the end of the trial week compared to the initial feedback. Showerhead 1 is also round, whilst 8 is rectangular. The design of showerhead 1 is similar to that of 6, but with more sprouts. Whilst showerhead 8 has triple central, recessed twin arranged from the centre in triple clusters and random rows (see images in Figure 1). They deliver regulated flow rates of 8.7 and 7.4 l/min @ 2 bar pressure respectively. All 3 showerheads work by delivering colliding twin jets of water that turn into thousands of tiny droplets. At the end of the trial week, showerheads 1, 6 and 8 received good feedback for consistency of water flow at mean values of 4.56, 4.44 and 4.83 respectively. However, this fell to mean values of 3.67, 3.44 and 3.83 for flow distribution.

The preceding feedback did not apply to the temperature consistency delivered by the showerheads. All the showerheads were rated well above the notional mean, except showerhead 6. Showerheads 1, 3, 4 and 9 stayed within the same feedback range at the start and end of the trial week. However, the mean rating for showerheads 5, 7, 8 and 10 dropped at the end of the trial week. Showerhead 5 is also round but distinct in its mode of operation. Showerhead 5 has 1 function unlike the similar showerhead 4 which has 3 functions. Like showerhead 4, it has a protruding sprout arranged in radial rows around a central core. Their mode of operation is also significantly different from the others as they are the only two showerheads that mix water with air – hence some participants complaining that they are noisy.

Participants stated that most of the showerheads met their expectations except for 6 which fell just below the notional mean. However, most of the participants – mean 1.83 – stated that they will not buy showerhead 2, the most expensive multifunctional showerhead in the sample. It should be noted that most of the participants did not identify that it had multiple functions until they were told at the end of the challenge as these functions were not obvious or intuitive. Showerheads 7 and 10 ranked highest for enjoyability – they were the largest showerheads in the sample and had just 2 functions which were obvious and easy to use.

In considering the flow, distribution, and temperature of the showerheads in this study sample, showerheads 7 and 10 were ranked highest by the participants, followed by 2, 5, 4, 9, 8, 1, 3 and 6 in that order. These findings compared with that in Adeyeye *et al.* [8] prove the importance of user perceptions and feedback of design and performance considerations in determining the degrees of suitability, adoption, satisfaction and water use efficiency of water products such as showerheads.

## 5. LABORATORY RESULTS

As the spray water is collected in individual cups at known positions over a fixed time of 60 seconds, the relative volume of spray water at these positions can be calculated with respect to the total amount of water released from the showerhead, which is recorded by the data logging system. Figure 4 gives an example of the spray water distribution in different directions (Refer to Figure 2, **North-South**, **East-West** etc.). Note that the spray water measurement is repeated 3 times for each showerhead with the spray collect unit respectively placed at 0.55m, 0.60m and 0.66m from the north wall. There is good consistency between the 3 tests. It is clear that the centre of the spray is not easily identifiable during the experiment. It can however be estimated using the measured spray volumes. With the positions of the cups defined in terms of x-y coordinate (refer to Figure 3), the centre of the spray can be calculated in the form of centre of gravity of the measured masses:

$$x_c = \frac{\sum V_i x_i}{\sum V_i}, \quad y_c = \frac{\sum V_i y_i}{\sum V_i}$$

Where  $\{x_i, y_i, V_i\}$  represent the position  $(x_i, y_i)$  and volume  $(V_i)$  of i-th cup. Not all cups are included in the calculation. A measurement is included if  $V_i \geq 0.3V_{max}$ , where  $V_{max}$  is the maximum volume per cup collected in a showerhead test. This is based on the fact that all showerhead tests have a spray collector coverage of at least 70% of the total spray. The approach has the effect of alleviating potential bias and inaccuracy caused by low spray water area that extends to outside the bounds of the collector unit.

An examination of the spray volume measurement indicates that the per-cup volume is up to 4% of the total spray volume. For purpose of mapping the spray distribution, the measured per-cup volumes are grouped into 5 ranges of 0.001-0.5%, 0.5-1%, 1-2%, 2-3% and 3-4%. These are colour-coded and shown along with the cup positions, thus providing a visual indication of the varying spray intensity over the spray area.

Figure 5 shows the results for showerheads 1, 4, 6, and 10. It was shown in Section 4 that 4 and 10 were among the showerheads that attracted the highest overall ratings in user feedbacks while 1 and 6 were among those that received the lowest. The mapping provides an insight into three aspects of the spray, i.e., spray form or pattern, magnitude and variation of spray intensity and effective spray area or coverage. It can be seen that the spray form is generally non-symmetrical with respect to the centre of the spray irrespective of the showerhead design. The dashed curves approximately enclose the central areas where the collected spray water exceeds 1%. It can be seen that showerhead 10 shows a pattern that is the nearest to radial asymmetry. The percentage volume of water collected in each cup can be viewed as the intensity of the flow at the cup position. A higher intensity of spray means a higher flow rate and velocity over the cup area. A higher flow velocity in turn means a greater impact force felt on the body due to the momentum principle. As the distance from the centre of the spray increases, the spray intensity reduces.

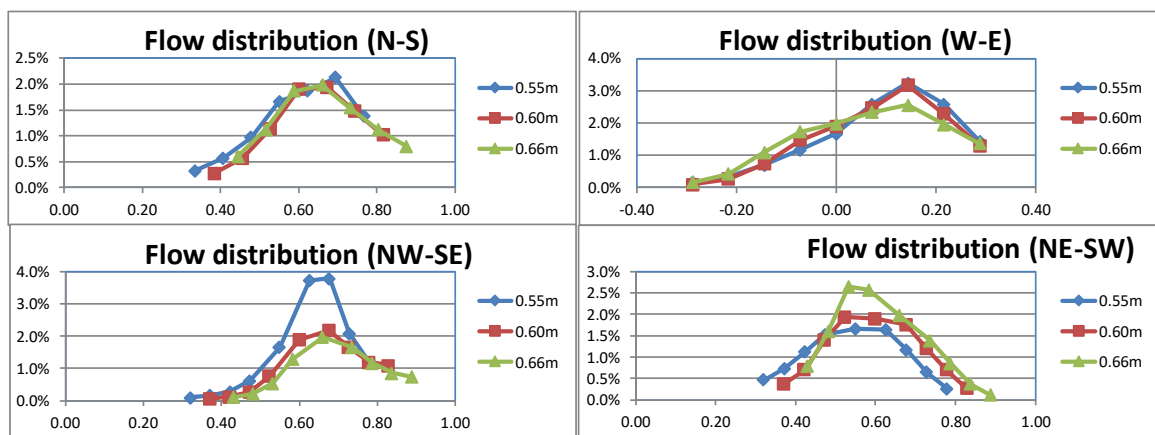


**Fig. 4. Variation of spray volume as a function of floor position for showerhead S-1.**

Similar to spray volume distribution, the temperature of the spray may also be mapped as shown in Figure 6. Again, the temperature is grouped into 5 zones between maximum and minimum readings. It is interesting to note that the temperature variations follow a similar pattern as the spray volume distribution. There is a drop of about 2°C between adjacent zones, indicating significant heat transfer from the spray to the surrounding air. It can also be seen that showerhead 6 contains only two cups in the two highest temperature zones, indicating that heat transfer of this showerhead is faster than others. This means that this particular showerhead, while being most water efficient, offers poor spray intensity and heat retention. Temperature variation for showerhead 1 shows no obvious difference to 4 and 10 apart from the stated asymmetry. Other factors may be in the play for the poor ratings of showerhead 1.

### 5.1 Limitations

The limitations of this study are the purposive sampling of the showerheads i.e. from the same manufacturer and the sample size of the study – 6 men and 6 women. However, the objective of the study was to investigate a range of water efficient showers types i.e. design, modes, functions, and this was achieved in spite of the showerhead samples being sourced from a single manufacturer. Also, the methodological aim was for depth rather than breadth hence the participant sample size. The challenge of recruiting and maintaining participants for studies such as this is also well documented. Nevertheless, the future studies will aim to further test and corroborate findings against a wider product and user sample range.



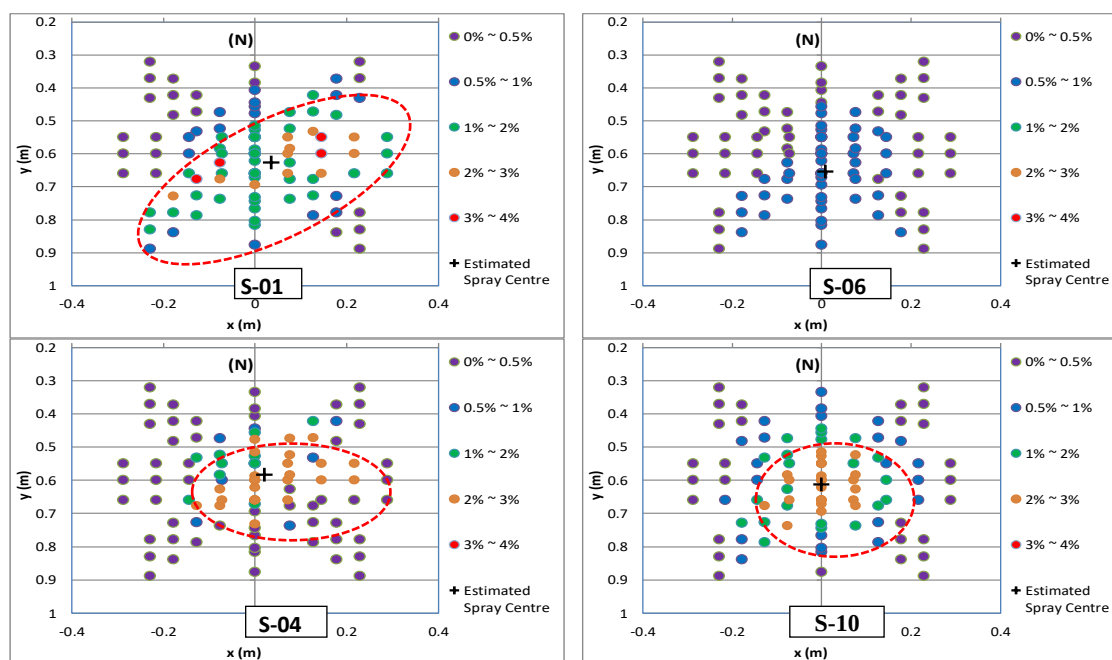


**Fig. 5. Spray distribution for showerheads 1 & 6 of low overall ratings, 4 & 10 of high overall ratings.**

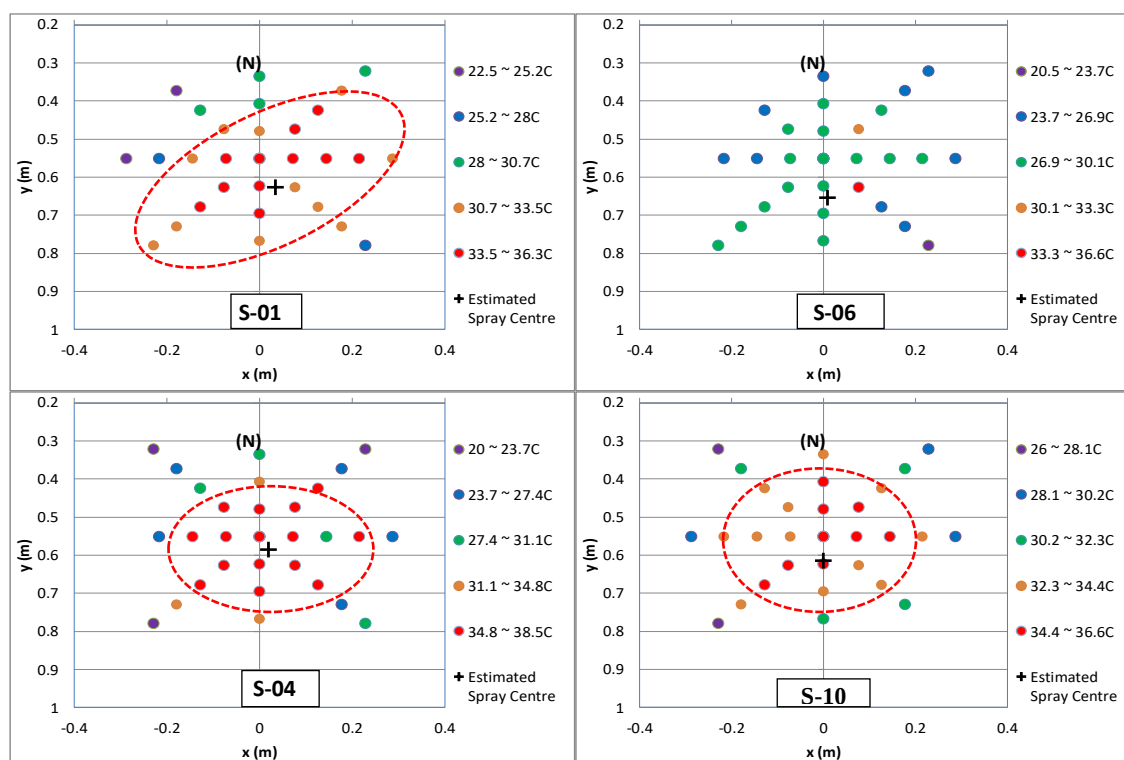


**Fig. 6. Spray temperature distribution for showerheads 1 & 6 of low overall ratings, 4 & 10 of high overall ratings.**

## 6. DISCUSSION AND CONCLUSION

Functionality matching as judged by the user, against his/her goal with the product [11] should be considered and understood when promoting water efficiency through the use of products such as showerheads. Functionality mismatch i.e. the desired functionalities and delivered functionalities, can occur and affect context in which the product is used [11], and can result in



what can be referred to as unwanted or anticipated side effects [12]. This paper builds on Adeyeye *et al.* [8] in studying the sustainability mismatch between design/performance metrics of the sampled showerheads on one hand, and user feedback of experience on the other.

The first part of the results evaluated user feedback on flow and temperature parameters as two main parameters that can be used to understand user preference of one product against another, but also to understand how this preference is defined by their experience of the product. From the user feedback, the 10 showerheads can be clustered into two distinct groups; preferred and not preferred. Showerheads, 1, 3, 6 appeared to be distinctly non-preferred compared to the others. Showerheads 1, 3 and 6 have similar designs, with less sprouts compared to the others, and produce finer water flow i.e. deliver water as fine sprays.

The user feedback were then checked against findings from laboratory tests. This confirmed that the less rated showerheads can suffer from poor spray delivery along with temperature drops greater than other showerheads. Showerhead 1 for instance, seems to suffer from asymmetrical uneven spray distribution which may have contributed to its poor ratings. These showerheads can also suffer temperature variations following a similar pattern as the spray volume distribution. A drop of about 2°C between adjacent zones was found, indicating significant heat transfer from the spray to the surrounding air. Therefore, the evidence from this product and user sample, can help to conclude that both volumetric and temperature distributions of the spray play a part in deciding the overall experiential performance of such products from the users' perspective. This means that the design of water efficient showerheads should avoid poor spray intensity and heat retention.

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# Showerheads experience: Statistical analysis of the individual behaviour of the users

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## ABSTRACT

The water user embodies different physical, social and psychological factors, which in turn inform their water behaviours and the extent to which they engage with solutions aimed at water efficiency. Therefore, products designed to be resource efficient, such as the showerhead, needs to consider the affordances of user interactions and experience in order to ensure that their design, performance and environmental intents are achieved.

This paper sits within a wider body of work which aims to understand the technical efficiency of showerheads as well as the extent to which it is efficient-in-use based on other qualitative metrics such as the user, perceptual and experiential factors. The work presented in this paper uses statistical methods to investigate the correlations and differences between water use factors such as duration and volume (discharge), against user and water efficient showerhead types.

The significant findings are that while users may adjust the duration of their shower events according to the volume discharge of the showerhead, increasing the duration slightly with decreasing discharge, this does not hinder the water savings potential from the discharge reduction. Further, the showerheads discharge is the underlying motivation for the water consumptions differences between males and females. Bearing in mind the limitations of the sample, the female participants were found to consume more water on average than the male participants in these cases, indicating distinct gender behaviour change relative to the showerhead discharge. However, the sample size limits extensive statistical conclusions and needs to be further explored for conclusive results.

Still the initial findings in this paper contributes insights into how quantitative methods and analysis are beneficial for understanding the qualitative implications of water efficiency interventions; such the tendency for users to make behavioural adjustments according to the perceived performance of water efficient products.

**Keywords:** shower duration, showerhead discharge, water efficiency, water user behaviour

## 1. INTRODUCTION

The drivers for indoor use include household composition, presence of water saving devices and a range of socio-economic factors [1]. Jorgensen *et al.* [1] therefore proposed a model which suggests that demographics, dwelling characteristics (including house size, water using appliances and type) and household composition (number of people and ages) impact directly on consumption, conservation intention, trust and perceived behavioural control and on the range of attitudes, perceptions and habits. They found this to be in keeping with other studies

findings where housing type and size has been found to have the largest influence on water use, along with the direct impact of climate and seasonal factors.

This aligns with previous studies, like [2, 3], which found that the user's decisions, behaviours and habits have a major effect on resource use be it energy or water. Berk *et al.* [4] also found people with a higher income, more education and a higher status job were more likely to engage in water saving practices. Although, it was further found that this could be linked to being able to afford the purchase and use of water saving technologies rather than behaviours per se. Conversely, Lee *et al.* [5] found location, function, and personal preferences are major factors in determining water demand.

Residential water demand can be classified as indoor and outdoor water use. Lee *et al.* [5] found that, approximately, 50 percent of the residential water demand in Miami is for indoor use. As study by Beal *et al.* [6] and [7] found that shower use contributes an average of around 30% of the total household consumption in Australia and UK. If indoor and outdoor water demand proportion may vary substantially with location, the relative proportion of shower water consumption is more consistent in developed countries. Beal *et al.* [6] also found a trend toward greater water use in showers amongst older, smaller households and younger, larger families. This makes engineered/ higher efficiency water using devices such as water efficient showerheads an important strategy for delivering effective reductions in water consumption [8]. Most 'water saver' showers achieve savings by introducing air or atomising the water drops to improve wetting for a given flow rate. For the user, the experience is not entirely compromised, as it is similar to that of a 'power shower' but with less water used per minute compared to 12-20 litres from non-efficient showers [9].

This paper sits within a wider body of work which aims to understand the technical efficiency of showerheads as well as the extent to which it is efficient-in-use based on other qualitative metrics such as the user, perceptual and experiential factors. The work presented in this paper uses statistical methods to investigate the correlations and differences between water use factors such as duration and volume (discharge), against user and water efficient showerhead types. In addition to the statistical findings, this paper is significant because it provides insights into how quantitative methods and analysis can be beneficial for understanding the qualitative implications of water efficiency interventions; such the tendency for users to make behavioural adjustments according to the perceived performance of water efficient products.

## 2. METHODOLOGY

A statistical approach was adopted to analyse the user data collected and explored in a showerhead study during which users' trialled 10 showerheads in 10 weeks and filling up a water diary (Table 1). Other aspects, including subjective comfort related information, were elicited from the users and further detail can be found in Adeyeye *et al.* [10]. Statistical tests were applied to evaluate:

- i) If there are differences in the shower event durations and amounts of water used as a result of using the different showerheads.
- ii) The possible explanations underlying the distinct behaviours from the various users when using the same showerhead.

In the first option, each user is considered independent, while in the second, each showerhead is analysed separately. The methodology comprises the following steps:

- i) Data preparation, including the codification of the non-numerical information in the dataset.
- ii) Preliminary data analysis and assumption checking.
- iii) Testing the difference between the shower events durations and volumes changes.

The results of the tests were evaluated using the usual 0.05 significance level and all non-significant cases are highlighted in *italic* on the tables. As any mathematical tool, the statistical tests required that non-numerical characteristics have to be converted into numeric. This conversion will have influence in the results, particularly when the classes are ordinal and not

categorical. Even regarding the later, if the continuous variable reveal an order between the categories, that may affect the results.

Herein, Tables 1 and 2 were used to code the non-numerical information in the dataset collected by Adeyeye *et al.* [10]. This coding process was done using an expert approach whilst respecting the order of the classes whenever applicable. The users, the showerheads, the days of the week and the weeks were also coded sequentially, but not shown herein due to space constraints.

**Table 1. User characteristics coding.**

| Gender                       |   | Weight                        |   | Relationship                    |   |
|------------------------------|---|-------------------------------|---|---------------------------------|---|
| Female                       | 1 | 51-55kg                       | 1 | Single, never married           | 1 |
| Male                         | 2 | 56-60kg                       | 2 | Cohabiting                      | 2 |
| Age                          |   | 66-70kg                       | 3 | Divorced                        | 3 |
| 25 - 34                      | 1 | 71-75kg                       | 4 | Married or domestic partnership | 4 |
| 35 - 44                      | 2 | 76-80kg                       | 5 | Employment                      |   |
| 45 - 54                      | 3 | 90kg +                        | 6 | Student                         | 1 |
| Ethnicity                    |   | Height                        |   | Employed (part -time)           | 2 |
| Asian/Asian British          | 1 | 151-155cm (to 5ft 1inches)    | 1 | Employed and student            | 3 |
| Mixed/Multiple ethnic groups | 2 | 156-160cm (to 5ft 3inches)    | 2 | Employed (full-time)            | 4 |
| Polish Catholic & Jewish     | 3 | 166-170cm (to 5ft7inches)     | 3 | Income                          |   |
| White                        | 4 | 171-175cm (to 5ft 9 inches)   | 4 | £20,000 - £29,999               | 1 |
| Education                    |   | 176-180cm (to 5ft 11inches)   | 5 | £30,000 - £39,999               | 2 |
| Currently studying           | 1 | 180cm and more (6ft +)        | 6 | £40,000 - £49,999               | 3 |
| Professional qualification   | 2 | Religion                      |   | £50,000 - £59,999               | 4 |
| Further Education/ College   | 3 | All                           | 1 | £60,000 or more                 | 5 |
| Bachelor Degree              | 4 | No religion                   | 2 |                                 |   |
| Postgraduate degree          | 5 | Christian (all denominations) | 3 |                                 |   |

**Table 2. Showerhead and shower events characteristics coding.**

| Shape              |   | Colour         |   | Purpose                 |   |
|--------------------|---|----------------|---|-------------------------|---|
| Rectangular        | 1 | Chrome         | 1 | Refresh                 | 1 |
| Round              | 2 | Grey & Chrome  | 2 | Relax/ Refresh          | 1 |
| Oblong             | 3 | White & Chrome | 3 | Hygiene                 | 2 |
| Curved rectangular | 4 | Height         |   | Hygiene/ Refresh        | 2 |
| Sprout             |   | 135-150        | 1 | Hygiene/Other           | 2 |
| Protruding single  | 1 | 151-170        | 2 | Relax                   | 3 |
| Recessed twin      | 2 | 171-200        | 3 | Hygiene/ Refresh/ Relax | 3 |
| Spray              |   | Distance       |   | Hygiene/ Relax          | 3 |
| Colliding twin jet | 1 | 0-20           | 1 | Time of the day         |   |
| With air           | 2 | 21-50          | 2 | Morning                 | 1 |
|                    |   | 51-75          | 3 | Afternoon               | 2 |
|                    |   | 76-150         | 4 | Evening                 | 3 |

Tables 3 and 4 present the mean duration and water consumption of the shower events for each user and showerhead tested. It is noticeable that only one user experienced all showerheads. Therefore, the sample size and composition varies for each user or showerhead.

**Table 3. Mean duration (min) of the shower events for each user and showerhead.**

| User | S-01  | S-02  | S-03  | S-04  | S-05  | S-06  | S-07 | S-08  | S-09  | S-10  | Mean         |
|------|-------|-------|-------|-------|-------|-------|------|-------|-------|-------|--------------|
| 1    |       | 4.43  | 5.58  | 5.67  | 5.43  |       | 6.00 | 6.67  | 8.14  | 4.60  | <b>5.81</b>  |
| 2    | 6.60  | 6.50  |       | 6.17  | 6.00  | 5.67  |      | 6.00  | 6.00  | 6.00  | <b>6.12</b>  |
| 3    |       |       |       |       | 30.00 | 8.60  |      | 8.60  |       |       | <b>15.73</b> |
| 4    | 35.67 | 29.29 | 32.00 |       | 27.56 | 27.50 |      | 33.33 |       | 32.50 | <b>31.12</b> |
| 5    | 14.50 | 27.50 | 21.17 | 31.43 | 26.67 | 27.14 |      | 27.14 | 28.33 | 27.50 | <b>25.71</b> |
| 6    | 4.68  | 4.31  | 4.64  | 4.05  | 4.68  |       | 4.00 | 4.69  | 4.43  | 4.40  | <b>4.43</b>  |
| 7    |       | 7.56  |       | 8.83  |       | 9.83  | 8.33 | 9.00  | 9.14  |       | <b>8.78</b>  |
| 8    | 8.17  | 8.92  | 9.00  | 8.86  | 9.50  | 7.13  | 8.75 | 18.07 |       | 9.14  | <b>9.73</b>  |
| 9    | 11.14 | 7.43  | 8.00  | 8.29  | 7.57  | 9.17  | 7.50 | 9.50  | 7.43  | 9.29  | <b>8.53</b>  |
| 10   | 4.10  |       | 4.00  | 4.29  | 3.68  | 4.40  | 4.63 |       | 4.29  | 6.57  | <b>4.49</b>  |
| 11   | 9.00  | 9.00  |       | 10.25 | 8.60  |       | 6.20 | 10.25 | 8.71  | 9.25  | <b>8.91</b>  |

| User        | S-01         | S-02         | S-03         | S-04        | S-05         | S-06         | S-07        | S-08         | S-09        | S-10         | Mean         |
|-------------|--------------|--------------|--------------|-------------|--------------|--------------|-------------|--------------|-------------|--------------|--------------|
| 12          | 7.80         | 7.00         | 6.80         | 6.80        | 5.80         | 6.80         | 7.67        | 5.50         |             | 9.00         | <b>7.02</b>  |
| <b>Mean</b> | <b>11.29</b> | <b>11.19</b> | <b>11.40</b> | <b>9.46</b> | <b>12.32</b> | <b>11.80</b> | <b>6.64</b> | <b>12.61</b> | <b>9.56</b> | <b>11.83</b> | <b>10.81</b> |

**Table 4. Mean water consumption (l) of the shower events for each user and showerhead.**

| User        | S-01          | S-02         | S-03         | S-04         | S-05         | S-06         | S-07         | S-08         | S-09         | S-10          | Mean          |
|-------------|---------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|---------------|---------------|
| 1           |               | 31.89        | 40.20        | 52.13        | 47.23        |              | 70.20        | 48.00        | 65.96        | 44.16         | <b>49.31</b>  |
| 2           | 67.98         | 46.80        |              | 56.73        | 52.20        | 28.90        |              | 43.20        | 48.60        | 57.60         | <b>51.25</b>  |
| 3           |               |              |              |              | 261.00       | 43.86        |              | 61.92        |              |               | <b>87.58</b>  |
| 4           | 367.37        | 210.86       | 230.40       |              | 239.73       | 140.25       |              | 240.00       |              | 312.00        | <b>250.72</b> |
| 5           | 149.35        | 198.00       | 152.40       | 289.14       | 232.00       | 138.43       |              | 195.43       | 229.50       | 264.00        | <b>205.56</b> |
| 6           | 48.15         | 31.04        | 33.44        | 37.26        | 40.72        |              | 45.20        | 33.74        | 35.87        | 42.24         | <b>38.39</b>  |
| 7           |               | 54.45        |              | 81.27        |              | 50.15        | 94.17        | 64.80        | 74.06        |               | <b>66.64</b>  |
| 8           | 84.12         | 64.20        | 64.80        | 81.49        | 82.65        | 36.34        | 98.88        | 130.08       |              | 87.77         | <b>84.97</b>  |
| 9           | 114.77        | 53.49        | 57.60        | 76.23        | 65.87        | 46.75        | 84.75        | 68.40        | 60.17        | 89.14         | <b>71.34</b>  |
| 10          | 42.23         |              | 28.80        | 39.43        | 32.00        | 22.44        | 52.36        |              | 34.71        | 63.09         | <b>44.85</b>  |
| 11          | 92.70         | 64.80        |              | 94.30        | 74.82        |              | 70.06        | 73.80        | 70.59        | 88.80         | <b>77.32</b>  |
| 12          | 80.34         | 50.40        | 48.96        | 62.56        | 50.46        | 34.68        | 86.63        | 39.60        |              | 86.40         | <b>57.84</b>  |
| <b>Mean</b> | <b>115.18</b> | <b>75.95</b> | <b>66.48</b> | <b>87.82</b> | <b>99.88</b> | <b>61.10</b> | <b>73.28</b> | <b>98.68</b> | <b>73.75</b> | <b>103.60</b> | <b>86.85</b>  |

Assuming the shower events as independent cases allows the use of the totality of the 621 observations to assess differences in means. This implies that the intrinsic habit of the users is less relevant to explain the shower events than the other characteristics recorded.

### 3. RESULTS AND DISCUSSION

Parametric or non-parametric tests were carried out in order to compare if the mean values between two distributions are statistically distinct. An important aspect of the selection of parametric or non-parametric tests is checking if the data meets the assumptions underlying the former. Parametric tests are considered more powerful than non-parametric, but require the data to be normally distributed across each group and to be without outliers.

The usual parametric tests to compare means are the T-test, for comparing only two groups, and the Analysis of Variance (ANOVA), for comparing three or more groups. However, both the Shapiro-Wilk and Kolmogorov-Smirnov (more adequate for our case since the sample size in category is less than 50) tests reveal that the duration and the water consumption of the shower events are not normally distributed for several users and showerheads. Tables 5 and 6 present the results for user 1 and showerhead 1.

**Table 5. Duration and water consumption normality test results for user 1.**

| Variable              | Showerhead | Kolmogorov-Smirnov <sup>a</sup> |    |       | Shapiro-Wilk |    |       |
|-----------------------|------------|---------------------------------|----|-------|--------------|----|-------|
|                       |            | Statistic                       | df | Sig.  | Statistic    | df | Sig.  |
| Duration (min)        | 2          | 0.360                           | 7  | 0.007 | 0.664        | 7  | 0.001 |
|                       | 3          | 0.484                           | 12 | 0.000 | 0.465        | 12 | 0.000 |
|                       | 4          | 0.293                           | 6  | 0.117 | 0.915        | 6  | 0.473 |
|                       | 5          | 0.421                           | 7  | 0.000 | 0.646        | 7  | 0.001 |
|                       | 7          | 0.414                           | 7  | 0.001 | 0.630        | 7  | 0.001 |
|                       | 8          | 0.285                           | 6  | 0.140 | 0.711        | 6  | 0.008 |
|                       | 9          | 0.504                           | 7  | 0.000 | 0.453        | 7  | 0.000 |
|                       | 10         | 0.367                           | 5  | 0.026 | 0.684        | 5  | 0.006 |
| Water consumption (l) | 2          | 0.360                           | 7  | 0.007 | 0.664        | 7  | 0.001 |
|                       | 3          | 0.484                           | 12 | 0.000 | 0.465        | 12 | 0.000 |
|                       | 4          | 0.293                           | 6  | 0.117 | 0.915        | 6  | 0.473 |
|                       | 5          | 0.421                           | 7  | 0.000 | 0.646        | 7  | 0.001 |
|                       | 7          | 0.414                           | 7  | 0.001 | 0.630        | 7  | 0.001 |
|                       | 8          | 0.285                           | 6  | 0.140 | 0.711        | 6  | 0.008 |
|                       | 9          | 0.504                           | 7  | 0.000 | 0.453        | 7  | 0.000 |
|                       | 10         | 0.367                           | 5  | 0.026 | 0.684        | 5  | 0.006 |

\*. This is a lower bound of the true significance.

## a. Lilliefors Significance Correction

**Table 6. Duration and water consumption normality test results for showerhead 1.**

| Variable              | User | Kolmogorov-Smirnov <sup>a</sup> |    |       | Shapiro-Wilk |    |       |
|-----------------------|------|---------------------------------|----|-------|--------------|----|-------|
|                       |      | Statistic                       | df | Sig.  | Statistic    | df | Sig.  |
| Duration (min)        | 2    | 0.367                           | 5  | 0.026 | 0.684        | 5  | 0.006 |
|                       | 4    | 0.268                           | 6  | ,200* | 0.862        | 6  | 0.197 |
|                       | 5    | 0.322                           | 8  | 0.014 | 0.753        | 8  | 0.009 |
|                       | 6    | 0.251                           | 8  | 0.148 | 0.924        | 8  | 0.459 |
|                       | 8    | 0.492                           | 6  | 0.000 | 0.496        | 6  | 0.000 |
|                       | 9    | 0.228                           | 7  | ,200* | 0.934        | 7  | 0.582 |
|                       | 10   | 0.192                           | 8  | ,200* | 0.926        | 8  | 0.477 |
|                       | 11   | 0.175                           | 3  |       | 1.000        | 3  | 1.000 |
|                       | 12   | 0.233                           | 5  | ,200* | 0.884        | 5  | 0.329 |
| Water consumption (l) | 2    | 0.367                           | 5  | 0.026 | 0.684        | 5  | 0.006 |
|                       | 4    | 0.268                           | 6  | ,200* | 0.862        | 6  | 0.197 |
|                       | 5    | 0.322                           | 8  | 0.014 | 0.753        | 8  | 0.009 |
|                       | 6    | 0.251                           | 8  | 0.148 | 0.924        | 8  | 0.459 |
|                       | 8    | 0.492                           | 6  | 0.000 | 0.496        | 6  | 0.000 |
|                       | 9    | 0.228                           | 7  | ,200* | 0.934        | 7  | 0.582 |
|                       | 10   | 0.192                           | 8  | ,200* | 0.926        | 8  | 0.477 |
|                       | 11   | 0.175                           | 3  |       | 1.000        | 3  | 1.000 |
|                       | 12   | 0.233                           | 5  | ,200* | 0.884        | 5  | 0.329 |

\*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

As such, only non-parametric tests were used in the analysis, namely the Mann-Whitney U test, for comparing two groups, and the Kruskal-Wallis test, for comparing three or more groups.

### 3.1 Analysing each user separately

The user profiles are as shown in Table 7. Kruskal-Wallis test reveal that for the different showerheads, the duration and water consumption are statistically distinct for users 1, 2, 5, 8 and 10. For users 4, 6, 7, 9 and 12 the duration is not statistically distinct but the water consumption is. No statistically significant difference was found either for duration or water consumption for users 3 and 11 (Table 8). Some of these results require due consideration of the sample size and composition, namely the case of user 3 which only tested 3 of the showerheads divided by 12 shower events.

The results regarding the duration are the most relevant, since the water consumption is estimated based on the reported duration of the shower events. Since the water pressure at the shower may be distinct from what was assumed, the actual value of the water consumption may be biased. Still, this bias is constant for all showerheads tested by each user, meaning the water consumption difference is correct. Therefore, since we are testing if there are statistically significant differences, the results are valid nevertheless.

Focusing on the duration results, it is observed that the majority of the users do not change their showering pattern, enabling the lower discharge showerheads to produce a statistically significant reduction in water consumption. The sample size is limited for generalization purposes, but these results are indications that these water efficient devices provide most users an equivalent level of comfort so that they do not change their showering habits.

**Table 7. User profile**

| Users | Gender | Age     | Highest qualification      | Height                      | Weight  | Income             | Ethnicity                    | Relationship                    | Religious beliefs | Employment                        |
|-------|--------|---------|----------------------------|-----------------------------|---------|--------------------|------------------------------|---------------------------------|-------------------|-----------------------------------|
| 1     | Female | 35 - 44 | PG degree, Doctorate       | 156-160cm (to 5ft 3inches)  | 51-55kg | £40,000 - £49,1003 | Polish Catholic & Jewish     | Married or domestic partnership | All               | Employed (full-time)              |
| 2     | Female | 25 - 34 | Bachelor Degree            | 151-155cm (to 5ft 1inches)  | 51-55kg | £20,000 - £29,1004 | White                        | Married or domestic partnership | No religion       | Employed (full-time)              |
| 3     | Female | 35 - 44 | PG degree, Doctorate       | 171-175cm (to 5ft 9 inches) | 71-75kg | £60,000 or more    | White                        | Married or domestic partnership | No religion       | Employed (full-time)              |
| 4     | Female | 35 - 44 | PG degree, Doctorate       | 151-155cm (to 5ft 1inches)  | 56-60kg | £20,000 - £29,1003 | White                        | Single, never married           | No religion       | Employed (full-time)              |
| 5     | Female | 45 - 54 | PG degree, Doctorate       | 156-160cm (to 5ft 3inches)  | 56-60kg | £20,000 - £29,1000 | White                        | Divorced                        | No religion       | Employed (part-time)              |
| 6     | Female | 25 - 34 | PG degree, Doctorate       | 151-155cm (to 5ft 1inches)  | 90Kg +  | £30,000 - £39,999  | White                        | Married or domestic partnership | No religion       | Employed and studying (part-time) |
| 7     | Male   | 35 - 44 | PG degree, Doctorate       | 171-175cm (to 5ft 9 inches) | 76-80kg | £60,000 or more    | Mixed/Multiple ethnic groups | Married or domestic partnership | Christian         | Employed (full-time)              |
| 8     | Male   | 25 - 34 | PG degree, Doctorate       | 180cm and more (6ft +)      | 76-80kg | £20,000 - £29,999  | White                        | Single, never married           | Christian         | Employed (full-time)              |
| 9     | Male   | 25 - 34 | Currently studying         | 166-170cm (to 5ft7inches)   | 76-80kg | £20,000 - £29,1001 | White                        | Married or domestic partnership | No religion       | Student                           |
| 10    | Male   | 45 - 54 | Professional qualification | 166-170cm (to 5ft7inches)   | 71-75kg | £60,000 or more    | White                        | Married or domestic partnership | No religion       | Employed (full-time)              |
| 11    | Male   | 35 - 44 | Professional qualification | 171-175cm (to 5ft 9 inches) | 66-70kg | £60,000 or more    | Asian/Asian British          | Married or domestic partnership | No religion       | Employed (full-time)              |
| 12    | Male   | 35 - 44 | Further Education/ College | 176-180cm (to 5ft 11inches) | 66-70kg | £50,000 - £59,999  | White                        | Married or domestic partnership | No religion       | Employed (full-time)              |

**Table 8. Kruskal-Wallis test results assessing the influence of the showerhead on the duration and water consumption of the shower events for each user.**

| User | Variable                      | Duration (min)        | Water consumption (l) |
|------|-------------------------------|-----------------------|-----------------------|
| 1    | Total N                       | 57                    | 57                    |
|      | Test Statistic                | 25,342 <sup>a</sup>   | 33,561 <sup>a</sup>   |
|      | Degree Of Freedom             | 7                     | 7                     |
|      | Asymptotic Sig.(2-sided test) | 0.001                 | 0.000                 |
| 2    | Total N                       | 47                    | 47                    |
|      | Test Statistic                | 19,303 <sup>a</sup>   | 43,429 <sup>a</sup>   |
|      | Degree Of Freedom             | 7                     | 7                     |
|      | Asymptotic Sig.(2-sided test) | 0.007                 | 0.000                 |
| 3    | Total N                       | 12                    | 12                    |
|      | Test Statistic                | 4,780 <sup>a,b</sup>  | 5,313 <sup>a,b</sup>  |
|      | Degree Of Freedom             | 2                     | 2                     |
|      | Asymptotic Sig.(2-sided test) | 0.092                 | 0.070                 |
| 4    | Total N                       | 39                    | 39                    |
|      | Test Statistic                | 11,354 <sup>a,b</sup> | 25,457 <sup>a</sup>   |
|      | Degree Of Freedom             | 6                     | 6                     |
|      | Asymptotic Sig.(2-sided test) | 0.078                 | 0.000                 |
| 5    | Total N                       | 61                    | 61                    |
|      | Test Statistic                | 29,373 <sup>a</sup>   | 42,383 <sup>a</sup>   |
|      | Degree Of Freedom             | 8                     | 8                     |
|      | Asymptotic Sig.(2-sided test) | 0.000                 | 0.000                 |
| 6    | Total N                       | 67                    | 67                    |
|      | Test Statistic                | 6,190 <sup>a,b</sup>  | 23,105 <sup>a</sup>   |
|      | Degree Of Freedom             | 8                     | 8                     |
|      | Asymptotic Sig.(2-sided test) | 0.626                 | 0.003                 |
| 7    | Total N                       | 47                    | 47                    |
|      | Test Statistic                | 5,865 <sup>a,b</sup>  | 20,133 <sup>a</sup>   |
|      | Degree Of Freedom             | 5                     | 5                     |
|      | Asymptotic Sig.(2-sided test) | 0.320                 | 0.001                 |
| 8    | Total N                       | 77                    | 77                    |
|      | Test Statistic                | 25,939 <sup>a</sup>   | 43,775 <sup>a</sup>   |
|      | Degree Of Freedom             | 8                     | 8                     |
|      | Asymptotic Sig.(2-sided test) | 0.001                 | 0.000                 |
| 9    | Total N                       | 66                    | 66                    |
|      | Test Statistic                | 8,460 <sup>a,b</sup>  | 24,729 <sup>a</sup>   |
|      | Degree Of Freedom             | 9                     | 9                     |
|      | Asymptotic Sig.(2-sided test) | 0.489                 | 0.003                 |
| 10   | Total N                       | 67                    | 67                    |
|      | Test Statistic                | 15,754 <sup>a</sup>   | 34,394 <sup>a</sup>   |
|      | Degree Of Freedom             | 7                     | 7                     |
|      | Asymptotic Sig.(2-sided test) | 0.027                 | 0.000                 |
| 11   | Total N                       | 36                    | 36                    |
|      | Test Statistic                | 12,177 <sup>a,b</sup> | 13,817 <sup>a,b</sup> |
|      | Degree Of Freedom             | 7                     | 7                     |
|      | Asymptotic Sig.(2-sided test) | 0.095                 | 0.055                 |
| 12   | Total N                       | 45                    | 45                    |
|      | Test Statistic                | 11,416 <sup>a,b</sup> | 26,542 <sup>a</sup>   |
|      | Degree Of Freedom             | 8                     | 8                     |
|      | Asymptotic Sig.(2-sided test) | 0.179                 | 0.001                 |

a. The test statistic is adjusted for ties.

b. Multiple comparisons are not performed because the overall test does not show significant differences across samples.

### 3.2 Analysing each showerhead separately

Against the showerhead types (Table 9); the Mann-Whitney U test reveal that the duration and water consumption for males and females are statistically distinct for showerheads 1, 4, 6, 9 and 10. No statistically distinct water consumption was found for showerheads 2, 3, 5, 7 and 8 (Table 10). The fact that both the duration and water consumption results are the same for all



showerheads is explained by the perfect correlation between duration and water consumption (water consumption is equal to the duration times the showerhead discharge). As such, if one is statistically distinct the other will be also and vice-versa. Both results were presented here just for consistence with the presentation of the results in the previous section.

**Table 9. Showerhead types**

| Ref No.                                    | S-01                                                                              | S-02                                                                              | S-03                                                                              | S-04                                                                              | S-05                                                                              | S-06                                                                               | S-07                                                                                | S-08                                                                                | S-09                                                                                | S-10                                                                                |
|--------------------------------------------|-----------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|
| Shape                                      | Round                                                                             | Oblong                                                                            | Round                                                                             | Round                                                                             | Round                                                                             | Round                                                                              | Round                                                                               | Rectangle                                                                           | Curved rectangle                                                                    | Round                                                                               |
| Height (mm)                                | 90                                                                                | 157                                                                               | 106                                                                               | 100                                                                               | 100                                                                               | 106                                                                                | 135                                                                                 | 67                                                                                  | 65                                                                                  | 135                                                                                 |
| Width (mm)                                 | 90                                                                                | 82                                                                                | 106                                                                               | 100                                                                               | 100                                                                               | 106                                                                                | 135                                                                                 | 182                                                                                 | 120                                                                                 | 135                                                                                 |
| Height incl. handle (mm)                   | 215                                                                               | 270                                                                               | 239                                                                               | 230                                                                               | 230                                                                               | 239                                                                                | 246                                                                                 | 227                                                                                 | 219                                                                                 | 246                                                                                 |
| Regulated flow rate @ 2 bar pressure (L/m) | 8.7                                                                               | 8.7                                                                               | 7.9                                                                               | 13.2                                                                              | 12.9                                                                              | 5.1                                                                                | 7.6                                                                                 | 7.4                                                                                 | 8.3                                                                                 | 7.6                                                                                 |
| Number of functions                        | 1                                                                                 | 4                                                                                 | 1                                                                                 | 3                                                                                 | 1                                                                                 | 1                                                                                  | 2                                                                                   | 2                                                                                   | 1                                                                                   | 2                                                                                   |
| Image                                      |  |  |  |  |  |  |  |  |  |  |

As in the previous section, some of the results have to be looked with due consideration regarding the sample size and composition for each showerhead. Particularly showerhead 7, which was only used by two females and all the males. This bias explains the contradiction with the results obtained for showerhead 10, for which the only difference is the colour.

**Table 10. Mann-Whitney U test results assessing the influence of the users gender on the duration and water consumption of the shower events with each showerhead.**

| Showerhead | Variable                      | Duration (min) | Water consumption (l) |
|------------|-------------------------------|----------------|-----------------------|
| 1          | Total N                       | 56             | 56                    |
|            | Mann-Whitney U                | 142.000        | 142.000               |
|            | Test Statistic                | 142.000        | 142.000               |
|            | Standard Error                | 56.811         | 56.811                |
|            | Standardized Test Statistic   | -3.520         | -3.520                |
|            | Asymptotic Sig.(2-sided test) | 0.000          | 0.000                 |
| 2          | Total N                       | 78             | 78                    |
|            | Mann-Whitney U                | 792.500        | 792.500               |
|            | Test Statistic                | 792.500        | 792.500               |
|            | Standard Error                | 99.576         | 99.576                |
|            | Standardized Test Statistic   | 0.326          | 0.326                 |
|            | Asymptotic Sig.(2-sided test) | 0.744          | 0.744                 |
| 3          | Total N                       | 55             | 55                    |
|            | Mann-Whitney U                | 297.000        | 297.000               |
|            | Test Statistic                | 297.000        | 297.000               |
|            | Standard Error                | 58.693         | 58.693                |
|            | Standardized Test Statistic   | -1.363         | -1.363                |
|            | Asymptotic Sig.(2-sided test) | 0.173          | 0.173                 |
| 4          | Total N                       | 63             | 63                    |
|            | Mann-Whitney U                | 207.000        | 207.000               |
|            | Test Statistic                | 207.000        | 207.000               |
|            | Standard Error                | 72.226         | 72.226                |
|            | Standardized Test Statistic   | -3.987         | -3.987                |
|            | Asymptotic Sig.(2-sided test) | 0.000          | 0.000                 |
| 5          | Total N                       | 71             | 71                    |
|            | Mann-Whitney U                | 476.000        | 476.000               |
|            | Test Statistic                | 476.000        | 476.000               |
|            | Standard Error                | 83.846         | 83.846                |
|            | Standardized Test Statistic   | -1.407         | -1.407                |
|            | Asymptotic Sig.(2-sided test) | 0.159          | 0.159                 |

| Showerhead | Variable                      | Duration (min) | Water consumption (l) |
|------------|-------------------------------|----------------|-----------------------|
| 6          | Total N                       | 49             | 49                    |
|            | Mann-Whitney U                | 143.500        | 143.500               |
|            | Wilcoxon W                    | 468.500        | 468.500               |
|            | Test Statistic                | 143.500        | 143.500               |
|            | Standard Error                | 49.488         | 49.488                |
|            | Standardized Test Statistic   | -3.162         | -3.162                |
|            | Asymptotic Sig.(2-sided test) | 0.002          | 0.002                 |
| 7          | Total N                       | 48             | 48                    |
|            | Mann-Whitney U                | 223.500        | 217.500               |
|            | Test Statistic                | 223.500        | 217.500               |
|            | Standard Error                | 47.919         | 48.101                |
|            | Standardized Test Statistic   | -1.304         | -1.424                |
|            | Asymptotic Sig.(2-sided test) | 0.192          | 0.154                 |
| 8          | Total N                       | 72             | 72                    |
|            | Mann-Whitney U                | 577.500        | 577.500               |
|            | Test Statistic                | 577.500        | 577.500               |
|            | Standard Error                | 88.102         | 88.102                |
|            | Standardized Test Statistic   | -0.778         | -0.778                |
|            | Asymptotic Sig.(2-sided test) | 0.437          | 0.437                 |
| 9          | Total N                       | 57             | 57                    |
|            | Mann-Whitney U                | 52.500         | 52.500                |
|            | Test Statistic                | 52.500         | 52.500                |
|            | Standard Error                | 60.777         | 60.777                |
|            | Standardized Test Statistic   | -5.570         | -5.570                |
|            | Asymptotic Sig.(2-sided test) | 0.000          | 0.000                 |
| 10         | Total N                       | 72             | 72                    |
|            | Mann-Whitney U                | 379.000        | 379.000               |
|            | Test Statistic                | 379.000        | 379.000               |
|            | Standard Error                | 83.128         | 83.128                |
|            | Standardized Test Statistic   | -2.370         | -2.370                |
|            | Asymptotic Sig.(2-sided test) | 0.018          | 0.018                 |

## 5. CONCLUSION

This paper uses statistical methods to investigate the correlations and differences between water use factors such as duration and volume, against user and water efficient showerhead types.

Some of the users (5 in 12) were found to adjust the duration of their shower events to the volume discharge of the showerhead; increasing the duration slightly with decreasing discharge. Still, the p-values of the duration were always found to be larger than for the discharging, indicating that the more water efficient showerheads still resulted in statistically significant water savings. This was further strengthened by the fact that the shower events of another 5 out of the 12 was not statistically distinct for the various showerheads, indicating that the potential water savings could be effectively achieved in almost its full potential. The remaining 2 users, for which neither the duration nor the water consumption was found statistically distinct for the various showerheads, one case (user 3) is explained by the fact that it only used three of the showerheads and the other (user 11) presents non-statistically significant results for the water consumption by a very small margin (p-value=0.055). Applying a less stringent significance criteria to user 11 (e.g., 10% error - p-value=0.1), both the duration and water consumption differences would be classified as statistically significant.

The trends in the analysis for each showerhead are less noticeable. Apparently, the showerheads discharge is the underlying motivation for water consumption differences between males and females, with higher and lower discharges (extremes) resulting in statistically significant mean values. Bearing in mind the limitations of the sample, females were found to consume more water in average than males in these case, indicating distinct gender behaviour change to the showerhead discharge. Still, other factors may play a role, for instance comparing showerheads 1 and 2 one could hypothesize the influence of the shape, but the sample size limits the statistical conclusions.

Water savings are possible using water efficient showerheads for the large majority of users, since the eventual duration adjustment from behavioural change may affect but do not hinder the potential savings completely. There seems to be distinct behaviour from males and females to the different showerheads, particularly when the discharge is high or low, but this needs to be further explored in the future for conclusive results.

The findings need to be regarded as preliminary due to the dataset limitation (sample size), but they provide useful insights into how quantitative methods and analysis are beneficial for understanding the qualitative implications of water efficiency interventions; such the tendency for users to make behavioural adjustments according to the perceived performance of water efficient products.

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# Non-household market opening in the English water sector: a step closer to service innovation?

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<sup>5</sup>Arup

## ABSTRACT

Six months after non-household (nHH) wholesale/retail separation ('market opening') came into force (1<sup>st</sup> April 2017), have any improvements been made in service innovation for customers in the water sector in England? This paper will offer an answer to this question based on recent work facilitated by the Watef Service Innovation Technical Committee (SITC). To do this the SITC and participants at a highly interactive Watef masterclass, explored first-hand accounts from different organisations (Business Stream, Waterwise, Utility Week) that were involved in, affected by or observed nHH market opening in the English market, alongside statistics from England's nHH water market operator MOSL (Market Operator Services Ltd). In contrast to the Scottish experience with market opening (from 2008), the English market responded quickly with more nHH customers switching in the first six months than in the first few years in the Scottish context. However, few small to medium enterprises (SMEs) were aware of the ability to switch and less switched compared to large multi-site companies who were more prompt in taking advantage of the ability to switch. A range of associated and un-associated retailers entered the market and began to compete to win benefits relating to the 2.5% net margin allowed on services (in contrast to the revised higher, but variable, margin in Scotland), which prompted a focus on added value and in particular encouraging water efficiency through new models of service innovation. Workshop findings indicated retailers and supporting organisations are refining and testing further service innovation approaches in an emerging market that will continue to evolve over the coming years.

*Keywords: innovation, market opening, non-household, retail separation, service, water efficiency*

## 1. INTRODUCTION

The approach of water trading and opening water markets have received increasing attention in a range of contexts over the last ten years, as water managers become ever mindful of water stress and scarcity and uncertainty over future supply-demand balance scenarios (Giannocco et al., 2013). Water rights trading is distinctly different to separating wholesale and retail water markets and whilst the former is established practice in countries such as Australia, Northern USA, some South American Countries and only Spain in Europe, the latter has received limited attention in the literature (Giannocco et al., 2013; Calatrava and Martinez-Granados, 2017). This is primarily due to a tendency for public authorities (such as municipalities or councils) to be responsible for water management, with the distinct exception of water management in the UK, which is a privatized sector. Water rights trading experiences reveal that such trading rarely

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leads to the benefits simulated using modelling techniques due to a range of factors from the geographical to the cultural (Bauer, 1997; Tisdell and Ward, 2003). Even in Spain, water trading in the Segura River Basin, one of the most water-scarce regions in Spain and Europe, achieved only limited success with only small volumes being traded (Calatrava and Martinez-Granados, 2017).

Opening the water market has received distinctly less attention than energy market opening, as the former has rarely been trialed. Experience from the energy sector shows that a range of approaches have been used in different contexts with differing results. Economic inefficiency, uncontrollability and disharmony have been reported in Russia (Lisin et al., 2017), but innovative models of reform in Brazil have reduced speculation and volatility to prioritize security of supply (Tankha, 2017). In the UK, the Competition and Markets Authority conducted an investigation (2014-2016), which was criticized for many biases regarding representation of vertical integration, reasons for new entrants (favourable government policies including exemptions rather than market-driven) and shifting the focus of problems on to customers rather than the large energy companies by blaming weak customer engagement for low switching rates (Amountzias et al., 2016).

With a newly open non-household water market in the UK (Scotland in 2008, England in 2017; Ward et al., 2016), what has wholesale-retail separation brought to the fore? A recent report on lessons for England based on the Scottish experience highlighted: awareness as the biggest barrier to engagement with the market; customers were not necessarily aware they could renegotiate with their existing supplier rather than switching; the market met the needs of large businesses not small to medium enterprises (SMEs); least engaged customers still viewed the sector as a monopoly; some customers preferred a broker to do the switch for them due to perceptions of ease of switching and the most engaged customers still struggled to find information on price and service comparisons (CCWater, 2016). So after market opening in England (April 2017) how have things changed? Have any improvements been made in water efficiency or service innovation for customers in the water sector in England? This paper will offer an answer to this question based on recent work facilitated by the Water Efficiency Network Service Innovation Technical Committee<sup>1</sup> (SITC).

## 2. METHODOLOGY

To answer the above question and explore what had happened in the first seven months of market opening, the SITC organized a highly interactive WATEF network masterclass. This presented first-hand accounts from different organisations (Business Stream, Waterwise and Utility Week) that were involved in, affected by or observed nHH market opening in the English market. The masterclass also hosted a workshop with participants to explore perspectives on the future of the water retail market – loosely orientated around challenges and opportunities.

### 2.1 First-hand accounts of the English (and Scottish) water retail market

The first part of the Watef Water Retail Separation Masterclass (23-11-2017) consisted of three keynote presentations from a diverse range of professionals. After an opening to the day from Martin Shouler (Arup), Lois Vallely (Features Editor, Water Retail and Utility Week publications) presented on '236 days later', giving an excellent overview of the reasons for market opening, whether it had been a success and what could be improved. Next, Trevor Nelson (Regulation and Compliance Manager, Business Stream) provided a first-rate background to opening in Scotland and how Business Stream journeyed from that market into the English market, contributing perspectives on licensing, acquisitions, solutions and governance. Finally, Aaron Burton (Waterwise) presented on delivering water efficiency in retail competition, sharing analytical insights into water efficiency services provided by retailers, social media and reported experience to date. He also highlighted emerging initiatives such as the Waterwise Retail Forum and the Waterwise Retail League Table.

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<sup>1</sup> <https://www.watefnetwork.co.uk/51-557>

## 2.2 Collaborative exploration of English water market opening challenges and opportunities

The second part of the masterclass consisted of several interactive exercises to get the participants thinking broadly about water systems, water efficiency and service innovation all in the context of market opening – reflecting on experiences to date and exploring future directions. Activities included:

- A question and answer session after the keynote presentations;
- A warm-up exercise where participants constructed a model of a 'resilient' water supply network (Figure 1);
- An innovation ranking exercise (using Digital Disruptor cards provided by Arup<sup>2</sup> - Figure 2) to catalyse thinking about themes (big/open data, artificial intelligence, satellites, sensors, augmented reality);
- Break-out sessions to address questions such as:
  - o How far can sector separation drive service innovation?
  - o How can service innovation drive water efficiency?
  - o Is retail separation the beginning of true competition and will it deliver true value?

After discussions around the tables, everyone reconvened to compile and compare responses and summarise the main thoughts around the room. Outputs from the day included recorded presentations and a digital story, which can be found on the Watef Network website<sup>3</sup>.



**Fig. 1. Masterclass participants constructing a model 'resilient' water network**



**Fig. 2. Participants at the Masterclass in discussion using ARUP's Digital Disruptors for the Water Sector**

<sup>2</sup> <https://www.arup.com/perspectives/themes/water/how-can-the-water-sector-embrace-digital-disruption>

<sup>3</sup> <https://www.watefnetwork.co.uk/51-557>

### 3. RESULTS AND DISCUSSION

To synthesize the presentations, discussions and culmination of all the exercises undertaken during the masterclass, this section begins with an overview of the keynotes, followed by a summary of the breakout groups and then ends with a reflection on where service innovation is in the context of market opening.

#### 3.1 First-hand accounts of the English (and Scottish) water retail market

In her presentation, Lois first highlighted some useful summary statistics, such as there being 1.2 million business customers, 22 retailers, 16 wholesalers and over 1000 brokers all competing for water service provision contracts. She also highlighted that the main drivers of market opening were to drive down prices, improve water efficiency, encourage innovation and improve customer service. Furthermore, using figures from MOSL (Market operator Services Ltd) she was able to reveal that during the first seven months of opening (01-04-17 to 01-11-17) the number of water supply point switches (roughly translated as double the number of business customers) was at just over 71, 000. Following this up with a look at MOSL data closer to a year after opening, identified that in February 2018 100,000 switches had taken place, representing around 3.8% of the total eligible supply points base (2.7 million) (smsplc, 2018). Lois followed this with an overview of some market research undertaken for her publications, which showed that there had been a mixed reaction to market opening. Around 7% of those surveyed expressed that they thought it had been very unsuccessful, but there was a relatively even distribution of opinion across the Successful, Unsuccessful and Neither successful or unsuccessful categories, with the latter receiving about 42% of votes (Figure 3). 75% of survey participants highlighted billing as one of the main issues after market opening (Figure 4) and billing errors was the biggest issue (Figure 5), with comments such as:

*"Appalling billing and customer service standards of virtually all the retailers. Utterly woeful"*

*"Poor quality of data on CMOS – assuming that is the true reason....."*

A summary of the issues was provided and included the lack of standardization in wholesale charges, the retail margin, service to smaller businesses (SMEs), lack of innovation, lack of focus on service, wholesalers being slow to adapt their mindset, lack of clear processes for retailers and wholesalers to interact and confidence in the market being undermined, with customer engagement and customer awareness being areas of deficit. The lack of focus on service and lack of innovation seem to indicate there is still much work to be done around broader service innovation.

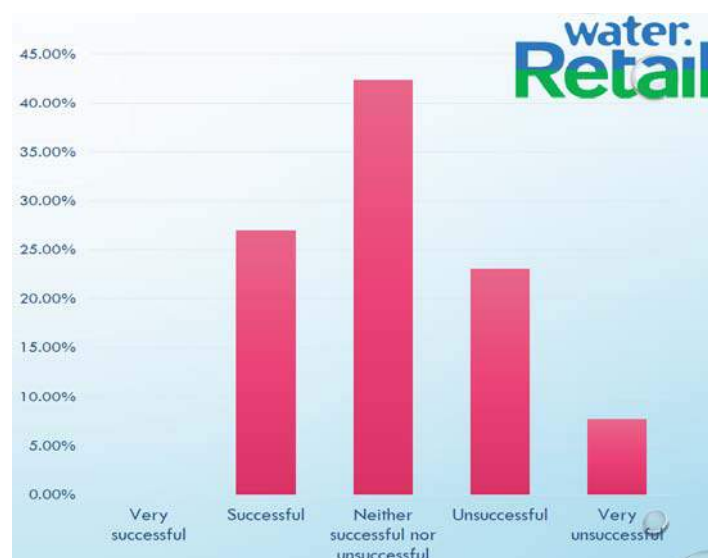


**Fig. 3. Percentage of those surveyed who thought market opening had been a success or not**

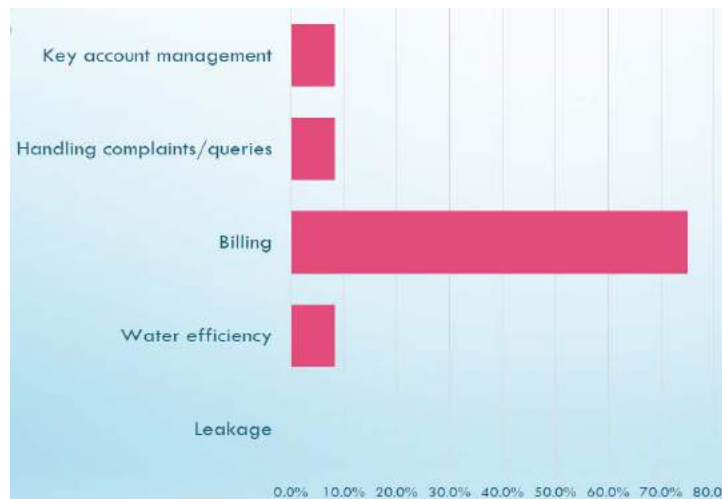


**Fig. 4. Percentage of those surveyed raising issues with service on market opening**

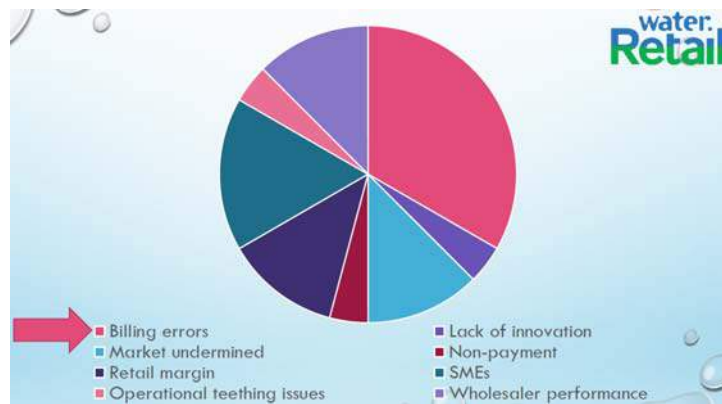


**Fig. 5. Key areas for improvement perceived by survey participants**

Moving on to the next keynote, Trevor also provided some introductory statistics, showing that since opening 24 billion litres of water had been saved (£53.8 million), alongside 42,000 tonnes of carbon (£7 million in energy) and a 28% increase in customer satisfaction. He then gave a background to Scottish opening, describing the journey from 2005 to 2009 when the Water Services (Scotland) Act 2005 required wholesalers to operate at an arm's length, to not have an unfair advantage, to not affect competition and to create a level playing field. This was achieved through robust and demonstrable separation, a governance structure to ensure independence and for retailers to be fully financed on a commercial basis. Business Stream originated within Scottish Water, but for the aforementioned reasons had to obtain a retail licence, which required it to restructure its board, borrow finances on a commercial basis, separate physically and separate IT systems and then construct service agreements with Scottish Water. As a company, it then focused on water and wastewater infrastructure and management solutions such as plant hire, trade effluent, water efficiency and leak detection. The Scottish market consisted of 200,000 supply points, 15 retailers (after consolidation), but only the one wholesaler (Scottish Water). In 2009 to 2014 came the Cave Report, the Water Act 2014 and the drive towards market opening in England. Between 2014 and 2017 the English market was set up based on the Scottish experience under a shadow market model. Business Stream then acquired an English retail license, Southern Waters' nHH customer base, developed its existing processes and services, gained market accreditation and began pre-market switching. Issues that arose, similarly to those raised by Lois, included market complexity, quality of data and low margins. Since English opening, there has been switching, but mainly larger business customers, there has been bi-lateral interaction, retailer



consolidation and new entrants and some customers choosing to self-supply. A range of associated and un-associated retailers entered the market and began to compete to win benefits relating to the 2.5% net margin allowed on services (in contrast to the revised higher, but variable, margin in Scotland), which prompted a focus on added value and in particular encouraging water efficiency through new models of service innovation.

Moving to focus on this water efficiency drive, the final presentation from Aaron made visible the Water Efficiency Strategy for the UK (launched in June 2017) and summarized the water efficiency in retail competition water supply value chain. The Strategy recommends that there must be steps taken to work with nHH retailers to deliver water efficiency, identify capacity gaps, and provide an independent assessment framework to inform consumer choices, clarify market codes and operations and ensure water efficiency continues to be delivered even as the sector becomes more fragmented. Aaron highlighted some of the challenges as water companies having outcome delivery incentives from Ofwat linked to nHH water efficiency that need to be delivered in the current price review period (before 2020), access to data to support demand forecasting and water resources planning and that water could become bundled as the cheapest service (alongside energy and telecoms) to achieve higher margins. He then provided an analysis of water efficiency services provided by the retailers (Figure 6), which revealed that a high proportion delivered smart metering and online billing, but only a small proportion delivered integrated water management. Business Stream offered the highest diversity of services, with Anglian Water Business close behind and PEEL offering the least (Figure 7). However, there was variation between information provided on retailer websites and it was acknowledged that the information can be hard to find, being hidden amongst blogs, adverts and cases studies – there was no standard or accreditation for water efficiency reporting and therefore difficult to compare across retailers, representing a potential area of opportunity. Aaron moved onto reported experience to date synthesizing that 43% of businesses are now aware they can change retailer, but that 39% were unlikely to switch or negotiate a better deal (as they did not feel they used enough water to save money). Despite this, roughly a quarter had switched or were in the process of doing so, with one organisation with a £1 million water bill quoting a £5K saving. Finally, Aaron talked about (i) the Waterwise Leadership Group, to influence commitments to water efficiency; (ii) the Waterwise Retail Forum to support retailers in diversifying water efficiency service building on best practice and brokering opportunities to lead to a standard method for measuring and monitoring water efficiency, demand forecasting and water resources planning and (iii) the League Table, which is a common approach applied in other sectors for customers to compare different retailer services.

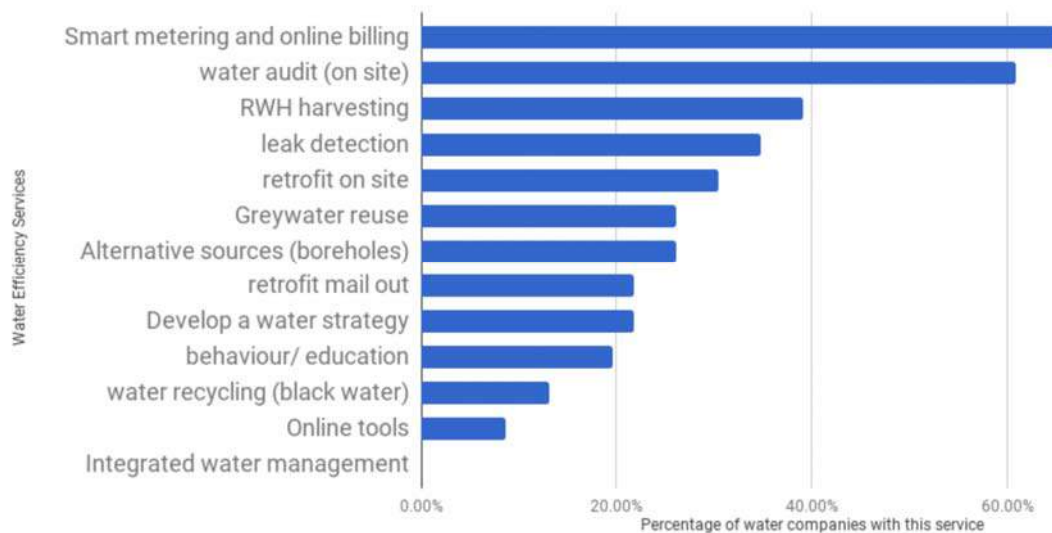


**Fig. 6. Water efficiency services provided by water retailers**

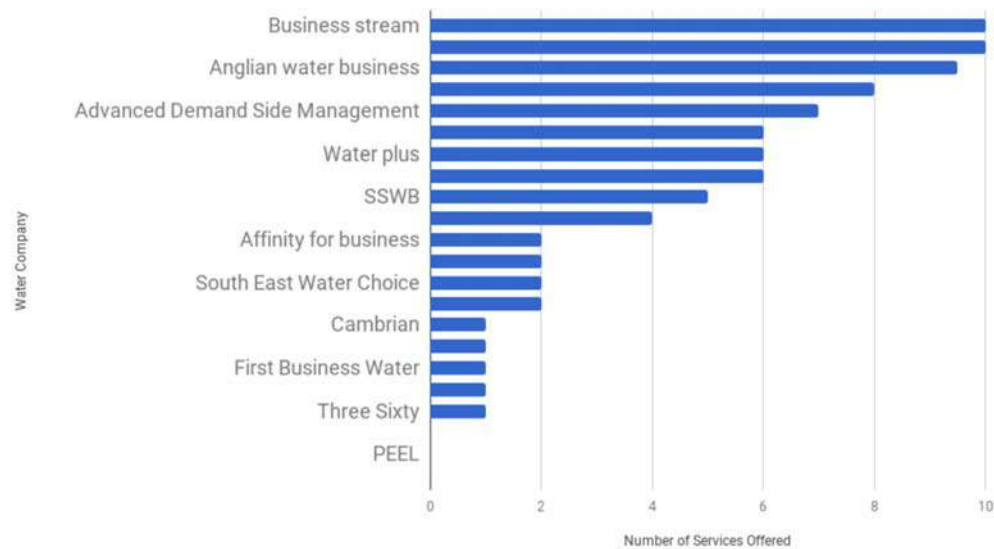


**Fig. 7. Number of water efficiency services offered by water retailers**

### 3.2 Collaborative exploration of English water market opening challenges and opportunities

Our synthesis of the Digital Disruptor cards showed that participants ranked digital water metering as the most important, followed by social media, open data, demand-side internet of things, remote system management and real-time response. They agreed that these were all important technologies for underpinning customer choice and in engaging customers across the generations on services with which they may be unfamiliar. Such innovations could assist with smarter billing, something that was seen as requiring improvement (refer to section 3.1).

In the round table discussion a range of themes were discussed in relation to the previously mentioned questions. Noteworthy points in the discussions included:

- It is difficult to reveal the true value of water even after wholesale-retail separation (price, cost, demand, regulation, market forces, competition etc. do not help);
- Retailers selling services rather than water – then if they sell a service that does not require water there would be extensive water efficiency gains;
- Iterative communication and improvement as being vital for driving water efficiency, water conservation and stewardship;
- Being better at raising awareness of ability to switch as well as pushing water efficiency;
- Benchmarking against other retailers and associated discounts to drive innovation;
- There is more room for open data, analytics, prediction and real-time approaches;
- Ways of interacting need improvement and need to be more rapid (e.g. webchat);
- Separation of surface water and sewage costs to encourage more water reuse;
- Standards and accreditation in water efficiency could improve services offered;
- Billing system optimization being key to keeping service levels high;
- Need a 'Fitbit for water' and to explore block chain approaches;
- Comparison tools could be improved (especially web-based);
- Bundles of services could represent a good option.

In summarizing the discussions, it became clear that the size of businesses was an important factor and the focus in the six months since opening had been on winning business from large companies, with smaller firms being somewhat overlooked. This led the SITC to consider further the remit of service innovation and to reflect back on the service innovation journey since the Committee was established in 2014, which is presented in the following final section.

### 3.3 Reflections on service innovation in the context of English water market opening

In contrast to the Scottish experience with market opening (from 2008), the English market responded quickly with more nHH customers switching in the first six months than in the first few years in the Scottish context. However, few small to medium enterprises (SMEs) were aware of the ability to switch and less switched compared to large multi-site companies who were more prompt in taking advantage of the ability to switch. In 2016, the SITC published a paper, in which it highlighted ten do's and don'ts from the European Commission in relation to SMEs and service innovation (Ward et al., 2016). As SMEs seem to have been largely overlooked on English market opening, the Committee decided to reflect on whether these do's and don'ts fit the experiences observed. Observations and comments are summarized in Table 1, which are indicated as positive improvement by a plus sign, no improvement or static situation with a forward slash and a negative situation with a minus sign (including combinations of each). As Table 1 shows, there has been positive action with regards with Do's, but a lack of action on ensuring the Don'ts are not done. Waterwise's recommendations around forums and league tables could help improve things further (refer to section 3.1).

**Table 1. Mapping EC recommended Do's and Don'ts to service innovation after English market opening**

|                                                                                   | Observed (+, /, -)                                   | Comment                          |
|-----------------------------------------------------------------------------------|------------------------------------------------------|----------------------------------|
| <b>Do</b>                                                                         |                                                      |                                  |
| Focus on knowledge innovation                                                     | + Yes                                                |                                  |
| Support transformation                                                            | / Could be improved                                  |                                  |
| Support clusters & networks                                                       | + licencing & data reporting<br>- service innovation | Waterwise's proposals could help |
| Search for next best practice                                                     | + To a certain extent                                |                                  |
| Capitalise on regional competences                                                | - Not really                                         |                                  |
| Launch large-scale demonstrations                                                 | - Not really                                         |                                  |
| <b>Don't</b>                                                                      |                                                      |                                  |
| Focus purely on research & technological innovation                               | - Too much focus on water efficiency devices         |                                  |
| Support individual specialised firms                                              | + Not done                                           |                                  |
| Copy-paste best practice                                                          | +Trying to be avoided                                |                                  |
| Follow without reflecting                                                         | - Needs to improve                                   |                                  |
| Avoid specific targets                                                            | - Need to set targets                                |                                  |
| Launch pilots in isolation                                                        | - Need to improve visibility                         |                                  |
| <b>Additional support</b>                                                         |                                                      |                                  |
| <i>For companies</i> – innovation clinics, management guidance, access to finance |                                                      | Waterwise's proposals could help |
| <i>For sector</i> – design centres, living labs, cluster support                  |                                                      | Waterwise's proposals could help |
| <i>For market</i> – awareness raising, cooperation incentives                     |                                                      | Waterwise's proposals could help |

As well as a focus on SMEs, participants and the Committee also considered the range of associated and un-associated retailers that entered the market and began to compete to win benefits relating to the 2.5% net margin allowed on services (in contrast to the revised higher,

but variable, margin in Scotland). The entry of these retailers prompted a focus on added value and in particular encouraging water efficiency through new models of service innovation. Business Stream appeared to be a leader in this area, evidenced through Waterwise's analysis and Waterwise's recommendations around some sort of forum and league table structure seem to fit well with the EC's dos as represented in Table 1. Reflections and adjustments to the new open water market in England will continue to emerge as the sector further works to maximize benefits to economy, society and environment and to achieve resilient outcomes.

In bringing all of this discussion together the Committee reconsidered the questions posed at the beginning of this paper:

- After market opening in England how have things changed?
  - o It is too early to have witnessed any major changes beyond those represented by a new water provision structure of water wholesalers and retailers for nHH customers. There has been a degree of switching and renegotiation with existing suppliers, but very limited innovation around services provided beyond those already offered additionally by existing established retailers. There is much more work to be done in relation to the list of custo raised in section 3.2 and in Table 1.
- Have any improvements been made in water efficiency or service innovation for nHH customers in the water sector in England?
  - o There have been water savings, cost savings and energy savings made in relation to nHH customers switching to retailers who have helped improved their water efficiency. Whether this has been done through 'quick wins' of simply cutting consumption/finding leaks etc. or through more innovative service provision is hard to determine. However, it is clear that there are products, processes and services emerging that will help to redefine service innovation for water efficiency over the coming years.

#### 4. CONCLUSION

The Water Efficiency Network Service Innovation Technical Committee investigated the state of play in the newly opened English water market through an all-day Masterclass that was held in November 2017, just over six months after wholesale and retail water operations were separated. Masterclass findings indicated that retailers and other organisations are refining and testing further service innovation approaches, which may be facilitated by non-governmental organisations such as Waterwise, in an emerging market that will continue to evolve over the coming years.

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#### COMPETING INTERESTS

None

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# **Provision of Free Public Drinking Water in UK Cities**

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## **1. INTRODUCTION**

Bristol Water and the International Water Security Network have identified public drinking water offerings as a potential solution to various environmental and social problems. This project explores the benefits from and obstacles to providing publicly available water, which may exist as drinking water fountains or alternatives such as the Refill scheme, where “drinkers” can obtain free water from participating business. A desk study investigating public water offerings in multiple locations in the UK, in Europe and Worldwide was created to obtain a greater understanding of the current state of drinking water fountains. Key areas of interest included design types, maintenance, funding, partnerships, locations and risks and vulnerabilities. Follow on research will be conducted via two questionnaires, the first of these for drinking water providers in a range of cities and areas who successfully provide public drinking offerings. This survey will reveal the successes and barriers encountered whilst implementing a network of drinking water fountains so that Bristol can learn from these experiences and emulate their accomplishments. The second questionnaire will explore the water drinking culture amongst the people of Bristol by investigating their perceptions which drive different drinking water behaviours. Whether through a new generation of public water fountains or through innovations like “Refill Bristol”, provision of free public drinking water is an important challenge for cities around the world.

## **2. HISTORY**

Populations of major cities in the UK exploded during the industrial revolution in the nineteenth century, consequently increasing the demand for public water supply. In response, the Metropolitan Free Drinking Fountain Association, a philanthropic society that built free public drinking fountains around London for the poor, was established in 1859. Hydrating the underprivileged was not the only motivation for installing these fountains. The Metropolitan Free Drinking Fountain Association was founded by the Quakers, a Christian group that abstained from alcohol, who wanted to provide an alternative to the sinful beer and spirits sold in pubs (Salzman, 2017). This gained support from respected figures such as Prince Albert and the Archbishop of Canterbury. Temperance organisations, such as the United Kingdom Alliance, also saw promise in drinking water fountains and commissioned their own opposite pubs in an attempt to change public behaviour. As a result, in 1872, London had 300 drinking fountains, and this increased to approximately 800 in 1879 (Phurisamban and Gleick, 2017).

## **3. CURRENT STATE OF PROVISION IN THE UK**

On the whole, the availability of public drinking water fountains in the UK is poor. For example, areas such as Greater Manchester, Merseyside and South Yorkshire, homes to millions of people, have no public drinking fountains whatsoever. Despite predominately featuring in cities and towns throughout the UK since the industrial revolution, councils in these areas have removed drinking fountains “a few years ago due to health risks and

damage” (Davis, 2017). However, with the impacts of plastic waste now widely publicised and becoming a major cause for concern by many members of the public, government initiatives and independent campaigns such as Refill are now gathering momentum. This could potentially cause the return of drinking water fountains on a nationwide scale.

In the city of Bristol there are currently 24 drinking water fountains, some of which have existed since the mid-nineteenth century. King (2014) performed a survey on these and the only one which was fully functioning was the fountain in the Promenade in Clifton Down. The majority of these fountains were not defaced, although litter was an issue at some sites.

Bristol has two other public drinking water fountains, one in the Millennium Square, constructed in 2015, and another in Queens Square, introduced in 2016. The fountains are popular, within four months of installation 12,736 litres of water were withdrawn, equating to 60,000 drinks (Bristol Water, 2018). The fountain in the Millennium Square uses bright visuals and interesting water facts to stand out and draw attention. This is considered a useful tactic to encourage interaction and future involvement (Arroyo et al., 2012).

In addition to these fountains, over 200 businesses in Bristol offer free tap water offerings to the public. These initiatives are part of Bristol Refill schemes in an attempt to reduce plastic waste and the consumption of sugary drinks. Refill Bristol’s success has encouraged 18 other cities and areas in the UK to get involved and install Refill stations within businesses. This includes Brighton, Bath, Bradford on Avon, Durham and the North East and Devon.

Bristol Refill have partnered with Bristol Water, At-Bristol, Bristol 2015’s Green Council Partnership’s Water Group, FRANK Water, Go Green, Bristol Council, Bristol Waste and Eunomia Research & Consulting Ltd to make this possible. This range of support has assisted with funding and campaigning to make these schemes a success. In an interview with The Guardian, Ben Newby of Bristol Water spoke about the support needed for such schemes (Davis, 2017). “If we tried to do it (introduce drinking water fountains) on our own it would never have happened,” said Newby. “You have got to have that buy-in because otherwise all you do is face barriers.” Collaboration with partners with the same objectives is therefore essential in projects like these.

In the northeastern city of Hull, Yorkshire Water partnered up with several organisations to install three drinking water fountains in Hull’s new city centre. Yorkshire Water claim that the equivalent to 29,000 bottles of water was consumed from these fountains in their first 4 months of operation (Yorkshire Water, 2018). With the help from partner organisations, Yorkshire Water intend to use the water fountains to reduce the amount of single-use plastics in Yorkshire by a third. There is no online information on how the fountains were installed or who the partners were.

The location of the fountains were positioned in conjunction with existing running trails so that thirsty runners can rehydrate for free. A “City Oasis Walks” map has also been created and can be downloaded onto a mobile phone to explore the marina. This is intended to encourage more people to exercise (Yorkshire Water, 2017). Display water fountains with a light show were also installed near to the drinking water fountains in an attempt to attract more people.

At this moment in time, there are 111 available drinking fountains across London’s councils which are free to use. These are predominantly in parks and open spaces and have existed for some time. More recently, 700 Refill stations have been established in London in collaboration with cafes, restaurants and other businesses. The Refill campaign have partnered with Thames Water, the Zoological Society of London and the charity City to Sea to achieve this, and together they plan to introduce drinking water fountains to popular locations

within the capital. London Mayor Sadiq Khan has publicly backed this scheme and has pledged £750,000 over three years with the hope of reducing plastic waste from single-use plastic water bottles (Davis, 2018). Khan has pledged a further £6 million to environmental enhancements around London and this will include more drinking fountains, but only if the pilots are successful.

Provisional trials of these drinking fountains are underway as 20 pilot fountains are to be set up to gauge their success. The first of these was set up in mid-March of 2018 in Carnaby Street in the West End. Two more are to be installed in Liverpool Street station and another in Flat Iron Square in Southwark. These pilot fountains will feature flow meters and street surveys will be conducted to investigate whether these fountains will change public behaviour. There is limited information on how these fountains have been set up and where they are getting their water from.

Although drinking fountains have become redundant in modern times in Belfast, the city council are planning to reintroduce them for their environmental and social benefits (Belfast City Council, 2012). Six historic drinking fountains remain, like relics, and are now redundant and decommissioned. Only two working drinking fountains are still in use. Belfast City Council (BCC) plan to refurbish the old existing fountains and replace any lead piping which would otherwise pollute the water supply. These will need historic building consent for reconstruction, if they are listed. If it is not possible to refurbish unused drinking fountains, new ones will be established in parks and green spaces which are easily accessible for all, on running routes and in surveillance areas to deter vandalism.

If new drinking fountains are to be installed, two types will be considered, the 'stoop and drink' fountain and the bottle filling fountain. BCC prefer the bottle filling station as they believe it will be perceived as safer to drink from and more convenient to use.

BCC are looking for a fountain that is simple and cheap to maintain, so is vandal proof, not vulnerable to corrosion and has easy access to plumbing. The fountain must also be very hygienic, easy to clean and have a covered spout to avoid contamination. An inbuilt and easy to replace water filter and the ability to turn off in the winter are also considered necessary. BCC are open to the inclusion of sparkling water as well as natural water, after the success of public sparkling water fountains in Europe.

BCC estimate that the total cost of the drinking fountain unit and installation in a location close to an existing mains water supply would range from £2,500- £4,000. BCC recognise that if a fountain were to be built in a location with no water supply in close proximity then costs would increase substantially. Maintenance costs are estimated at £1,000- £2,000 per fountain. Additional costs may include the construction of an access path if one does not already exist.

Potential barriers highlighted by the BCC include maintenance, which BCC believe would have to be carried out every two days, not including forced repairs. Health and safety would also be a major concern, as the threat of waterborne diseases, contamination and pollution from external sources could potentially harm members of the public. This would be awful for any individual and potentially have very expensive repercussions for the council. Vandalism is another worry for BCC, as this would be costly, cause delays to the service and may deter future use from the public.

However, these plans are yet to be put into action, mainly due to funding. Green Party councillor Georgia Milne is currently discussing the prospects of drinking fountains and similar refill schemes to those currently in England and Wales to BCC. This meeting took place on



the 1st of February 2018 and Milne's motion is now being referred to the People and Communities Committee (Scott, 2018).

#### 4. CONCLUDING COMMENTS

The availability of drinking water fountains varies considerably between cities and again between region. Although the UK and Europe both have a network of drinking water fountains which were established in their history, only cities in Europe have opted to maintain them. On the whole, the UK has let its fountains go into disrepair, mostly due to a lack of funding as the necessity for fountains were replaced with bottled water. Conversely, in Europe, the historical importance and hot temperatures experienced in cities have made drinking fountains a vital part of their cities infrastructure. Outside of the European continent, cities also seem to follow the same reasoning, if they are essential for residents and tourists, then their upkeep will have been maintained.

However, with the mounting impacts of plastic waste from single-use plastic bottles, many local governments have started new initiatives to reintroduce drinking fountains or water stations to reduce pollution. More evidence regarding increasing the availability of water to reduce health problems such as obesity, particularly in children, is also causing prompting local councils to consider fountains. These factors have sparked new interest in campaigns and ideas that people have started to get behind and now governments and responsible businesses are starting to fund.

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# #3. Capacity building for climate and environmental change

# Urban resilience to climate change: the role of water efficiency

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## ABSTRACT

Increasing attention is being paid to the potential impacts of climate change on urban environments. According to the United Nations, about 54% of the planet's population currently lives in cities, but it is expected that this percentage will rise to 66% in 2050.

For this reason, climate change impacts in urban areas and buildings will be very significant. Urban life will have to adapt and create resilience to more extreme weather conditions, which are likely to put strain on existing infrastructures such as water supply, drainage, health and energy. Therefore, it is imperative to assess the effects of these changes in the systems of water supply in buildings, as well as study mitigation measures to be implemented in new constructions or in building rehabilitation.

Water efficiency in buildings can not only contribute to the mitigation of this problem as a result of the water-energy nexus, but can also contribute to adaptation and increase of resilience of buildings through measures such as the use of rainwater harvesting systems, reduction of consumption in areas affected by heat waves, etc. The installation of rainwater harvesting systems in buildings can also contribute to an increased resilience in urban areas, due to the damping of the peak flows in periods of intense precipitation.

This paper presents a reflection on the impact of the climate change in buildings and urban areas and on the possible contributions of water efficiency measures to mitigate these effects and to increase the resilience of cities.

*Keywords: Climate change; adaptation and resilience; mitigation measures; water efficiency in buildings.*

## 1. INTRODUCTION

Over the 21st century, climate change will continue under a range of possible greenhouse gas emission scenarios [1] and by the end of this century global average temperature will rise 2.6 to 4.8 °C higher than at present, and sea levels will be 0.45 to 0.82 meters higher [2], significantly affecting coastal areas. More frequent and intense extreme weather events will result in a higher incidence of floods and droughts around the planet. Prolonged droughts will also reduce groundwater recharge and the subsequent impacts on water and sanitation services constitute a clear danger for development and health [3,4].

According to the United Nations, about 54% of the planet's population currently lives in cities, but it is expected that this percentage will rise to 66% in 2050 given that the projections show

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that urbanization combined with the overall growth of the world's population could add another 2.5 billion people to urban populations by 2050 [1]. For this reason, climate change impacts in cities and buildings will be very significant and urban life will have to adapt and create resilience to more extreme weather conditions, which is likely to put strain on existing infrastructures such as water supply and drainage.

Foremost, it is necessary to implement mitigation measures, consisting in intervention to reduce the sources or enhance the sinking of greenhouse gases but, at the same time, adjustments will be necessary in order to prevent or moderate the damage, increasing "resilience", that is, the capacity to manage harmful events, disturbances or trends, responding in ways that the buildings maintain their essential function, identity and structure [2].

In addition to a possible contribution to the mitigation of the phenomenon through the reduction of energy consumption, as a result of the water-energy nexus, building installations of water supply and drainage should contribute to the adaptation to these climatic changes and to the acquisition of more resilience in the buildings. It is very important to know what can be done to improve the traditional systems and solutions in order to maximize the resilience of the buildings, and what needs to be done differently to ensure that buildings can handle in the future the impacts of climate change.

## **2. IMPACTS OF CLIMATE CHANGE IN THE BUILT ENVIRONMENT AND MITIGATION STRATEGIES**

An important impact of climate change that is expected to intensify in the next decades is the increased intensity and frequency of heavy rainfall and other extreme weather events, such as heat waves [5]. Changes in precipitation are expected to differ from region to region, with some areas becoming more humid and others drier, increasing more over the precipitation in high latitude regions and decreasing in most subtropical areas [6,7].

Regarding the European continent, southern and central Europe face increasingly more frequent heat waves, forest fires and droughts as well as the Mediterranean area, which is becoming gradually dry and thus even more vulnerable to droughts [8,9]. Northern Europe is getting increasingly wet and winter floods are likely to become more common. Being exposed to heat waves, floods or rising of the sea level, urban areas are often ill-equipped to adapt to climate change [10].

Changes in mean precipitation will impact groundwater recharge rates which may affect the water supply [11,12] and, in semi-arid and arid areas, salinization of shallow groundwater will intensify due to increased evaporation and water uptake by vegetation. With higher temperatures, there will be an increased demand for cooling (and hence power) in the summer and a decreased demand for heating in winter. On the other hand, more frequent and intense winter rains lead to flooding in riverine areas and overloading of public drainage systems [13,14].

Primary mitigation strategies comprise carbon efficiency, energy efficiency of technology, system and infrastructure efficiency and service demand reduction through behavioral changes. In the world, it is estimated that the building sector contributes as much as a fifth of total global annual greenhouse gas emissions, making buildings the largest contributor to global greenhouse gas emissions and also consuming more than 32% of global final energy [2]. The major causes of this contribution are the extensive use of fossil fuel-based energy for thermal comfort, lighting, water heating, water supply and drainage, electrical equipment and appliances, as well as in the production of construction materials [15].

Given the massive growth in new construction, if nothing is done, greenhouse gas emissions from buildings will more than double in the next 20 years [16]. Considering their whole life cycle (construction, operation or use and demolition), to obtain a significant reduction of CO<sub>2</sub> emissions, effective measures must be taken during its use or operation phase, because it represents 80-90% of the total energy consumed throughout its entire life cycle.

The use of green roofs on buildings, for example, can bring great advantages, not only in terms of mitigation of energy requirements for thermal comfort but also in terms of increased resilience and adaptation, since it reduces the flow of surface water and increases the number of green infrastructures in urban areas as well as all its associated benefits. Hard engineering solutions will continue to play a role in adapting to climate change, but will also improve forecasting and preparedness, along with risk avoidance through planning controls [13].

Taking into account the water-energy nexus, reduction of water consumption in the building cycle is also reflected in significant energy efficiency, considering the reduction of energy needs to heat sanitary hot water and to pressurize water in buildings and also in the public systems, in abstraction, pumping and treatment of water and wastewater. Therefore, the nexus between water efficiency and energy efficiency should be one of the most important aspects that must be noted when considering the contribution of buildings to mitigation strategies.

A study developed in a medium-sized city in Portugal (Aveiro) by ANQIP, a Portuguese association for quality and efficiency in building installations, found that energy savings due to the use of efficient products (classified in the category “A” of the ANQIP labeling scheme for water efficiency) allow for a reduction in emissions higher than 100 kg of CO<sub>2</sub> per capita and per year, in relation to the present scenario, taking into account only the heating of domestic hot water in buildings and energy consumption in public networks [17]. It should be noted that in Portugal, energy consumption for heating domestic hot water represents over 30% of the total housing energy consumption.

Table 1 summarizes the savings obtained per component of the urban water cycle, per person and per household, considering an average value in Portugal of 2.3 persons per house and emissions of CO<sub>2</sub> weighted in 240 g/kWh. It is considered that these results can be extrapolated to other urban contexts, and may even be more relevant in cities with high-rise buildings, since in these cases pressurization needs in this type of building are significant [17]. There are other studies carried out in Portugal on this subject [18-20] that reinforce the results of this one.

**Table 1. Estimated energy savings and CO<sub>2</sub> reductions with the use of water efficient products in buildings**

| Component of the urban water cycle                    | Annual energy savings and CO <sub>2</sub> reductions with the use of water efficient products |                                     |                  |                                     | Percentage of the total (%) |
|-------------------------------------------------------|-----------------------------------------------------------------------------------------------|-------------------------------------|------------------|-------------------------------------|-----------------------------|
|                                                       | Per person (kWh)                                                                              | Per person (kg of CO <sub>2</sub> ) | Per family (kWh) | Per family (kg of CO <sub>2</sub> ) |                             |
| Building system (only sanitary hot water heating)     | 368                                                                                           | 88.3                                | 846              | 203.1                               | 87.0                        |
| Public system of water supply                         | 32                                                                                            | 7.7                                 | 74               | 17.7                                | 7.6                         |
| Public system of drainage and treatment of wastewater | 23                                                                                            | 5.5                                 | 53               | 12.7                                | 5.4                         |
| <b>TOTAL</b>                                          | <b>423</b>                                                                                    | <b>101.5</b>                        | <b>973</b>       | <b>233.5</b>                        | <b>100.0</b>                |

The reuse of greywater and rainwater harvesting can also contribute to reducing energy consumptions. Compact installations for direct reuse of greywater (toilet and washbasin combined, for example), reducing water consumption in the building, also lead to the saving of water and energy in the urban water cycle. As rainwater harvesting systems also reduce water consumption in houses, they additionally entail reductions in water flows and energy consumptions in public networks. Although rainwater harvesting systems demand a pressurization system in the building, the corresponding energy consumption is equal to or less than those that occur when the supply derives from the public network.

With regard to large installations for greywater reuse, with a centralized "conventional" treatment to regenerate these effluents, we find that the energy consumed in the treatment makes the system "neutral" from an energy standpoint, i.e. the energy expended in the treatment of greywater, about 1.8 kWh/m<sup>3</sup>, is close to the energy saved in the urban water cycle. However, since the temperature of greywater from showers, for example, is generally above 30 °C, the utilization of this thermal energy for pre-heating hot water will allow a saving of about 3 kWh/m<sup>3</sup>, making these installations advantageous not only from the point of view of saving drinking water, but also from an energy standpoint [18].

### 3 THE ROLE OF WATER SUPPLY AND DRAINAGE SYSTEMS IN BUILDINGS WITHIN PROCESSES OF ADAPTATION AND INCREASED RESILIENCE

Buildings face great risks of damage from the projected impacts of climate change, having already experienced a substantial increase in extreme weather damage in recent decades. More than half the urban areas projected for developing countries by 2030 have yet to be built, offering great potential for integrated adaptation planning, but special attention should be paid also to existing buildings. Furthermore, it would be of great interest to encourage good practice by incorporating climate change responses within engineering standards.

It would be extremely important to elaborate suitable construction and weather sensible planning projects in order to promote the design of buildings and public spaces that are capable of dealing with the effects of climate change without significant damage. The use of green roofs on buildings, for example, can bring great advantages, since it reduces the flow of surface water and increases the number of green infrastructures as well as all its associated benefits.].

In addition to the contribution that buildings can make to mitigate the impacts of climate change on urban areas, for example reducing flood peaks through green roofs and gardens [21] or reducing energy needs through water efficiency, it is important specify the role of the water supply and drainage systems in buildings in relation to the resilience and adaptation of the building itself.

There are two impacts of climate change that bind directly with building networks of water supply and drainage: the increased intensity of heavy rainfall and extreme heat waves. Table 2 summarizes the main measures to be adopted concerning the building installations of water supply and drainage with a view to promoting the adaptation and resilience of buildings against these impacts of climate change.

**Table 2. Measures to be adopted for promoting the adaptation and resilience of buildings against the impact of climate change**

| Type of impact of the climate change  | Measures to be adopted to promote adaptation and resilience of the building                                                                                                                                                                                                                                                      |                                                                                                                                                                                                                                                                                                                                 |
|---------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                       | New buildings                                                                                                                                                                                                                                                                                                                    | Existing buildings                                                                                                                                                                                                                                                                                                              |
| Increased intensity of heavy rainfall | <ul style="list-style-type: none"> <li>- Review of design standards with integration of new weather data or higher safety coefficients;</li> <li>- Construction of green roofs (preferably mandatory);</li> <li>- Installation of rainwater harvesting systems (preferably mandatory).</li> </ul>                                | <ul style="list-style-type: none"> <li>- Review the sizing of the rainwater drainage pipes, especially stacks and drains (in gravity systems) and analysis of the need for new emergency overflow outlets (specifically in siphonic systems);</li> <li>- Installation of rainwater harvesting systems (if possible).</li> </ul> |
| Extreme heat waves (water scarcity)   | <ul style="list-style-type: none"> <li>- Review of design standards considering greater capacity in water tanks (when they exist in the building);</li> <li>- Installation of rainwater harvesting systems and/or greywater reuse systems;</li> <li>- Application of water efficient products (preferably mandatory).</li> </ul> | <ul style="list-style-type: none"> <li>- Conducting water efficiency audits;</li> <li>- Installation of rainwater harvesting systems and/or greywater reuse systems (if possible);</li> <li>- Exchange of the devices installed by more efficient ones or application of reducers of flow or volume.</li> </ul>                 |

In the case of increased intensity of heavy rainfall, it will be necessary to adjust the design standards for new buildings and review the design of rainwater drainage in existing buildings. The latter aspect is more delicate with regard to rainwater siphonic systems [22], whose capacity to respond to unforeseen flow increases is smaller, since it is known that, in these systems, a flow slightly above the design flow is sufficient to cause a rapid increase in the depth of water in the roof.. The placement of more emergency overflow outlets could be the solution. The review of the design standards shall include new weather data and/or higher safety coefficients.

Regarding extreme heat waves and the inherent risk of water scarcity, the adjustment of the standards is again necessary, with regard to reviewing the sizing of water tanks and increasing efficiency in the use of water in buildings. Rainwater harvesting and the reuse of greywater shall be promoted, being the first solution particularly suited to answer the many impacts of climate change because it simultaneously reduces the flood peaks in urban areas and promotes additional water storage in buildings.

The construction of green roofs combined with rainwater harvesting systems in buildings can boost the advantages of each of these technologies [23,24], whereby their combination should also be considered a very promising solution to face climate change and increase sustainability in cities [25,26]. When designing a rainwater harvesting system combined with a green roof structure, several factors should be taken into account, such as the roof runoff coefficient [27]. The runoff coefficient is a dimensionless parameter that represents the relationship between the total runoff volume from the roof and the total amount of precipitation in a certain time period [28] and, in impervious roofs, it has a value near one. In the case of green roofs, average annual values of 0.5 for extensive green roofs (green roofs with a maximum depth of about 150 mm) and 0.3 for intensive green roofs generally adopted.

In fact, these values depend on the characteristics of the roof, like the type of plants used and the characteristics of the substrate and are very dependent of the climatic conditions in the region, especially by temperature and precipitation diagrams. In Mediterranean climates, monthly runoff coefficients are particularly important for sizing the storage tanks of rainwater harvesting systems [28], in view of the existence of long dry periods, extending in general throughout the summer period. The monthly runoff coefficient represents the relation between the total runoff volume from the green roof measured during a given month and the total amount of precipitation on the roof in that month, added to the volume of eventual watering done in that period. In other climates, such as in central and northern Europe, where precipitation periods occur in almost all months, the sizing of the storage tanks is often done on the basis of annual average runoff coefficients.

From the perspective of integrating green roofs with rainwater harvesting systems, some studies have been developed on a conventional extensive green roof system in Oporto city (Portugal) [29]. These studies have revealed low values of runoff coefficient but allowed the development of an expression to predict the monthly runoff coefficients for this type of conventional green roof [29].

The extensive pilot system adopted (Figures 1 and 2) followed the typical extensive green roof structure: geotextile membranes, a water holding capacity layer using expanded clay, and the growing substrate with 10 cm height, composed of a mixture of expanded clay and organic matter [29]. The pilot green roof was established with three different common aromatic plant species: *Satureja montana*, *Thymus caespititius* and *Thymus pseudolanuginosus*. These plants are autochthonous in Portugal and in other countries with Mediterranean climates.



**Fig. 1 – Green roof experimental set up [29]**



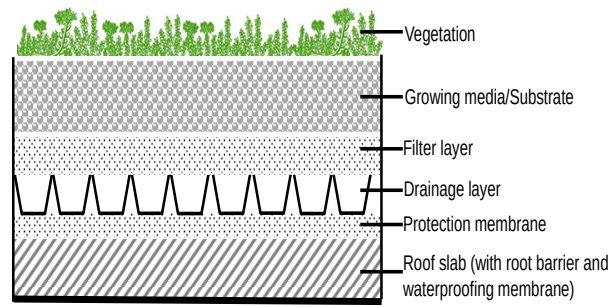


**Fig. 2 – Green roof schematic representation [29]**

The main goal of the research developed in Oporto was to obtain a practical mathematical expression that allows, with acceptable approximation, determination of average values of the monthly runoff coefficient for a specific extensive green roof. Measurements made in the pilot green roof allowed for the development of the following expression for monthly runoff coefficient prediction [29]:

$$C_M = \frac{0.016(P_M - R_M)}{(2T_M - T_{M-1})^{1.2}} \quad (1)$$

where:

- $C_M$  = Runoff coefficient of month  $M$
- $P_M$  = Precipitation of month  $M$  (mm)
- $R_M$  = Watering of month  $M$  (mm)
- $T_M$  = Mean air temperature of month  $M$  (°C)
- $T_{M-1}$  = Mean air temperature of month  $M-1$  (°C)

The obtained expression, which depends significantly on temperature in previous periods and precipitation, has similarities with the well-known Turc formula, widely used in hydrological studies to determine flow deficit, which can be considered an indicator of its consistency. Assuming its validity in different climatic conditions, the formula was applied to 12 weather stations of Portugal where it is possible to get temperature and precipitation values (Figure 3), seeking to get theoretical values for the monthly runoff coefficients for green roofs with characteristics similar to those of the pilot system, in locations with different climatic characteristics [30].

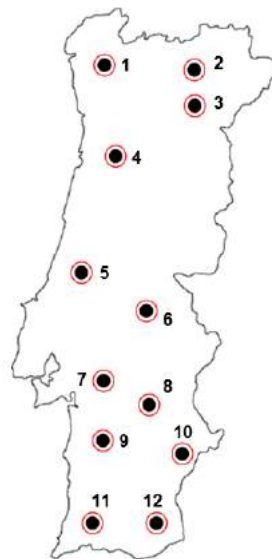


**Fig. 3 – Portuguese weather stations with information available [30]**

It should be noted that northern Portugal has a significant Atlantic influence, where the Mediterranean climate is less dominant. This is the case of stations 1 and 2. Station 3, although located also in the north of Portugal, is situated in the Douro valley, which has a very specific local climate.

The results obtained on the basis of the average values calculated from the records available for the hydrological year 1980/1981, until 2015/2016 are shown in Figure 4 [30]. These values correspond to a minimum of 0.04 and a maximum of 0.14 and it should be noted that these values are clearly lower than the average annual runoff coefficients proposed in the literature for green roofs in central/northern European countries, which sometimes are close to 0.3 for intensive green roofs and 0.5 for extensive green roofs.

Interestingly, in the two weather stations with Atlantic climatic influence the observed results are significantly different from the others, and it is notorious that the results follow similar patterns in the weather stations with dominant Mediterranean climates.

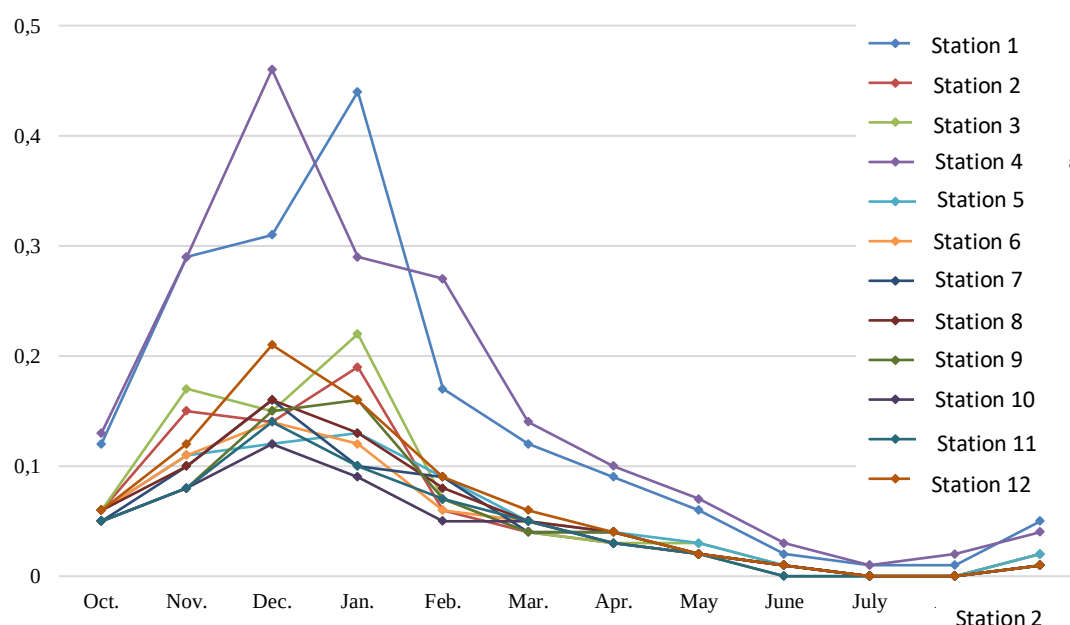


**Fig. 4 – Monthly runoff coefficient for the different stations (2015-2016) [30]**

## 4 CONCLUSIONS

Dealing with climate change is one of the major challenges facing mankind in the 21st century. It is necessary simultaneously to implement mitigation measures, consisting of intervention to reduce the sources or enhance the sinking of greenhouse gases and adjustments to the climate and its effects. This intervention seeks essentially to prevent or moderate the damage, which is known as processes of adaptation and increasing resilience.

Buildings play an essential role in these processes, not only in relation to mitigation measures, but also to the need to be adapted and acquire higher resilience. Building installations for water supply and drainage make specific contributions in all these processes, and can significantly contribute to mitigation; they are also essential to processes of adaptation and increasing resilience, in the face of some of the projected impacts of climate change.

Review of design standards and the increase of water efficiency in buildings should be considered priority measures, but some solutions – such as green roofs or rainwater harvesting systems in buildings – can contribute greatly to a very appropriate response to the impacts of climate change. These solutions should be widely generalized, preferably with a mandatory character in some regions.

The integration of green roofs with rainwater harvesting systems seems also a promising solution, but the design combined of these solutions depends heavily on the characteristics of

the green roof and the particularities of local or regional climates, whereby further research in this field is needed. In Mediterranean countries the cost of these solutions may be significantly higher, although their technical and economic viability may also be interesting given the growing scarcity of the resource and the need for adaptation and increased resilience to climate change effects.

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# End-of-life of a Sustainable Drainage System: Assessment of Potential Risk of Water Pollution through Leaching of Metals

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## **ABSTRACT**

Sustainable Drainage systems (SuDS) have emerged as very effective and highly attractive approach for storm peak control, pollution retention and biodegradation, water quality improvement and groundwater re-charge via use of micro-scale integrated management practices. One of the SuDS devices widely used to infiltrate, store and treat surface runoff which allows it to recharge groundwater is the pervious paving systems (PPS). Previous studies have demonstrated relatively high removal efficiencies of 98.7% of total hydrocarbons, 95% of suspended solids, 93% of lead and 89% of COD etc. Although a few of the studies have evaluated the performance of the PPS system at end-of-life such as the hydrological performance, pollutants retention, pollutants biodegradation etc., none has assessed the potential groundwater and soil pollution by pollutants such as metals at end-of-life. Thus, the aim of this study was to evaluate potential risks associated with the decommissioning and beneficial use of wastes generated during the dismantling of the PPS. The method involved the determination of leachable concentrations of 14 metals in the PPS samples made up of Pavement blocks (P), Aggregates Alone (AA), Aggregates and Dust (AD), Dust alone (D) and Geotextile fibre which, were analysed and compared to appropriate risk-based regulatory threshold limits. The results showed that the measured concentrations of all the metals were below the appropriate risk-based regulatory threshold values for irrigation purposes as specified by FAO and USEPA. Furthermore, results all indicate that the dismantled materials can be reused as recycled aggregates for other civil construction purposes as they were all below EU LFD WAC for inert waste. This has potential to increase recycling of aggregates from construction and demolition wastes among EU Member States and minimize dependence on virgin aggregates and hence, reduction on exploitation of natural resources and sustainability of the PPS system.

*Keywords: [Water pollution, Metals, Leaching, SuDS, Sustainability]*

## **1. INTRODUCTION**

There is no doubt that increasing global urban development, population and climate change will continue to exert more pressure on the built environment more than ever.

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By 2050, it is estimated that 70% of global population of 9.8 billion will live in cities, up from current 49 % today [1]. This entails massive additional infrastructural development to cope with the influx into the cities. In order to ensure an ecologically sustainable development to cater for the growing building and infrastructural needs, sustainable construction has become one of the major considerations for Building Professionals globally. Currently, there is a growing emphasis on the re-modelling of urban spaces to help revitalise the City Centres [2] and also to reduce impact of flash flooding due to unpredictable and extreme weather conditions which, Climate Scientist have predicted will exacerbate with time [3]. Apart from City Centres, residential areas are also trending similarly, for instance, in London, approximately two-thirds of front gardens have been paved over mainly for off-road vehicular parking [4]. Likewise, there was an increase in the development of paved surfaces on front gardens in a sub-urban area of Leeds due to urban creep by up to 13% [5]. In 2011, the number of houses which converted front gardens into paved surfaces for car parking almost doubled in the past 20 years, from just 16% of houses in 1991 to 30% in 2011 [6]. These cities depend largely on the urban landscape of which pavement structures are important components as sustainable urban drainage devices [7; 8] and an embodiment of urban culture [9]. These pavement structures are Low Impact Development (LID) features designed to mimic the predevelopment hydrology of a milieu by using design techniques which infiltrate, filter, store, evaporate, and also detain runoff at source [10]. LIDs, also known as Sustainable Drainage systems (SuDS), have emerged as very effective and highly attractive approach for storm peak control, pollution retention and biodegradation, water quality improvement and groundwater re-charge. SuDS are sustainable techniques amongst other things offering holistic solutions to challenges posed by climate change, emerging organic contaminants and water pollution.

One of the SuDS devices widely used to infiltrate, store and treat surface runoff which could allow groundwater recharge (if designed to infiltrate stormwater directly into soil) is the pervious paving systems (PPS). Due to its multi- benefit attributes, PPS has been used in different applications such as, rainwater recycling with ground source heat pump (GSHP) technology for improved environmental performance of new domestic building developments, tanked sub-base storage system for rainwater harvesting, mitigation of urban heat island effect and avoidance of elevation of temperature of receiving water bodies etc.

The structure of PPS has also been shown to possess the capacity for the retention and biodegradation of urban pollutants for the improvement of discharge water quality. Some of the urban pollutants include, polycyclic aromatic hydrocarbons (PAHs), total petroleum hydrocarbons (TPH), heavy metals, particulates, microbes and emerging organic pollutants. Previous studies have demonstrated relatively high removal efficiency of these pollutants by the PPS. They include the removal efficiency of 98.7% of total hydrocarbons [11], 95% of suspended solids [12], 93% of lead and 89% of COD [13] etc. One of these pollutants, metals, are naturally occurring elements widely distributed in the environment due to their multiple applications in different sectors such as industrial, medical, agricultural and domestic. Their toxicity is a function of numerous factors such as the dose factor, age, genetics, chemical species, route of exposure and nutritional status of those exposed to them [14]. Due to their high level of toxicity, metals such as mercury, lead, arsenic, cadmium, chromium etc. are

regarded as systemic toxicants that can cause multiple organ damage even at low concentration levels and therefore, are of environmental and health concern. Whilst several elements have been characterised, some of them such as arsenic, lead, mercury, cadmium etc. have been classified by the US Agency for Toxic Substances and Disease Registry (ATSDR) as priority pollutants due to their toxicity [15].

However, when PPS structures are installed, they are also subject to routine maintenance to ensure the integrity of the infrastructure and extended design life span. While some studies in the UK have demonstrated that the PPS systems can function satisfactorily without any maintenance for over 10 years [16; 17; 18], others reported PPS operating without maintenance for over 20 years [19; 20; 21]. Although a few of the studies have evaluated the performance of the PPS system at end-of-life, such as the hydrological performance [22]; pollutants retention [7]; pollutants biodegradation [24] etc., none has assessed the potential groundwater and soil pollution by pollutants such as metals at end-of-life during decommissioning. Furthermore, as a SuDS device, there is the need to put the waste generated during decommissioning of the PPS to beneficial use at end-of-life for sustainability. In the present context, end-of-life is defined as the phase when the PPS which was previously in service was dismantled.

Thus, the aim of this study was to evaluate potential risks associated with PPS during decommissioning and the beneficial use of wastes generated during dismantling of the PPS.

## **2. METHODS**

This study is a field-based research set on an 11-year old parking lot built as an experimental test bed with each single bay of dimensions 2400mm x 4800mm [25]. Leachable concentrations of 14 metals in the PPS samples made up of Pavement blocks (P), Aggregates Alone (AA), Aggregates and Dust (AD), Dust alone (D) and Geotextile fibre, were analysed and compared to appropriate risk-based regulatory threshold limits. The regulatory threshold limits included the Food and Agriculture Organization (FAO) Wastewater quality guidelines for agricultural use and, US EPA Guidelines for Water Reuse: Recommended water quality criteria for irrigation. It was thought that if these metals leach onto adjoining farmlands during decommissioning, they may be taken up by plants including food crops during agricultural activities and may eventually end up in the food chain which could become an issue of health concern. Furthermore, the leachable concentrations were compared with regulatory threshold limits used by some EU Member States for the control of pollution from aggregates to ensure that infiltrated leachates do not contaminate groundwater resources. Some EU Member States such as Austria, Czech Republic and France, rely fully or partly on the EU Landfill Directive (LFD) Waste Acceptance Criteria (WAC) for inert waste as the basis for their leaching criteria for use of waste aggregates [26]. These also have associated financial implication hence, the need to carry out the evaluation.

### ***2.1 Leachate analysis***

On completion of sample collection, they were delivered to an analytical laboratory with an extensive range of accredited analytical services for detailed analyses. In the UK, the laboratory operates a fully documented quality management system accredited by

The United Kingdom Accreditation Service (UKAS), to the ISO/IEC 17025 standard. They also hold UKAS accreditation to the Drinking Water Inspectorates' Drinking Water Testing Specification (DWTS) for drinking water testing and, the Environment Agency of England & Wales (EA) Monitoring Certification Scheme (MCERTS).

In summary, the soluble and suspended species were leached from waste into water. The procedure is based on BSEN 12457-3:2000 and consists of a two-stage batch test at different liquid-to-solid ratios. The sample material, which originally or after pre-treatment, had a particle size below 4mm, was brought into contact with water under defined conditions. The solid residue was separated by filtration and the leachate tested for temperature, conductivity and pH to give an indication of leachate conditions.

### **3. RESULTS**

The results obtained from this study showed that the measured concentrations of all the metals were below the appropriate risk-based regulatory threshold values for irrigation purposes as specified by FAO and USEPA. This suggests that there is no potential pollution of water resources such as groundwater, surface waters, rivers or aquifers. In terms of assessment using regulatory threshold limits for the control of pollution from aggregates to ensure beneficial use of aggregates is not compromised, results all indicate that the dismantled materials can be reused as recycled aggregates for other civil construction purposes. Results were all below EU LFD WAC for inert waste and therefore, may be reused without any environmental concerns. This has potential to increase recycling of aggregates from construction and demolition wastes among EU Member States and minimize dependence on virgin aggregates and hence, reduction on exploitation of natural resources and sustainability of the PPS system.

### **ACKNOWLEDGEMENTS**

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# Green Roof Policies for stormwater retention in cities around the world – A Literature Review

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## ABSTRACT

Stormwater management is one of the biggest challenges faced by urban environments nowadays. Accelerated urbanization has increased the impermeable surfaces in cities and reduced the areas of natural soils available to absorb rain, resulting in more frequent flood events and the uncontrolled discharge of untreated water into rivers.

Green roofs play an important role in this context, since they are able to provide water management benefits that address local authority concerns and regulations relating to water issues, specially when installed over occupied spaces in cities, where recovering the original soil is not possible anymore. As a consequence of these benefits many cities worldwide started to develop green roof policies to promote water management. Examples are the cities of Portland, New York, Washington DC and Toronto, just to mention a few. The aim of this paper is to present a literature review on green roof policies for water management, in order to understand the different policy models implemented by cities with different characteristics and present conclusions for future actions in the Portuguese context.

*Keywords: stormwater management, green roofs, sustainability, nature based solutions*

## 1. INTRODUCTION

The water cycle has been drastically impacted by urbanization. As a consequence of that in the last decade the importance of stormwater management in urban areas has increased significantly. Stormwater runoff from urban roofs makes a significant contribution to sewerage-derived flooding and urban water quality problems. In most urban cities, roofs may account for approximately 40 – 50% of the impermeable urban surface area (Stovin, 2013).

The ability of green roofs to withstand rainwater makes it possible to reduce water pressure in the urban drainage system and the impact of precipitation peaks and flood phenomena, which are likely to be more frequent in the future. In addition to the water retained in the green roof system (more or less depending on the type of green roof), there is also a phenomenon of delayed delivery or surplus water, thus achieving a reduction effect of the delivery of flows to the urban drainage system, and can greatly improve the management of rainwater in cities.

This reduction of water volumes in the sewage infrastructure can be reflected in cost savings. In addition, green roofs absorb and filter pollutants from rainwater, contributing to the improvement of the quality of the flow released. Excess water draining from a green roof can be stored and used in the building itself. In Germany, thanks to these benefits, some buildings that included green roofs were able to completely disconnect from the rainwater system (Ngan, 2004).

Despite the benefits presented it is important to note that for the urban scale the only way to achieve such benefits for stormwater retention with green roofs would be through a large

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scale implementation. Because of that many cities around the world have adopted incentive policies for green roofs.

In the portuguese context, untill the date, there is no city with a green roof policy. The city of Porto, however, have developed in the past year “The Fifth Façade Project”, a project between the Portuguese Association for Green Roofs and the Porto City Council that aims to define which policy model would be more suitable to include green roofs in the urban strategy of the city. Nevertheless, cities as Lisbon suffer from serious problems related to stormwater retention and would undoubtedly benefit from an incentive policy for green roofs.

The objective of this paper is to present a literature review on green roof incentive policies for stormwater retention around the world, in order to understand the different policy models implemented by cities with different characteristics and present conclusions for future actions in the Portuguese context.

## 2. METHODOLOGY

The methodology used in this paper focused on gathering, reading and analysing more than 100 green roof policies documents during the period between january and august 2017, in order to select which cities have GR policies for stormwater retention around the world and the nature of such policies.

The starting point for the identification of the cities with green roof policies was the databases available on the IGRA (International Green Roof Association) and WGIN (World Green Infrastructure) websites. Then, a research was done using different keywords such as “green roof policies” or “green roof stormwater”, just to mention a few.

Once identified a city with a green roof stormwater policy the research became more specific and the keywords more detailed (in example “Portland stormwater management policy” or “New york legislation for green roofs”). Whenever available the laws were reviewed, but in most cases the legislation documents was not available. Only documents in English, Spanish and Portuguese were analysed.

From this literature review 65 cities were identified as having green roof policies (figure 1), from which 18 present stormwater issues as its main motivation. The database of cities including green roof policies is available at the official website of the Portuguese association for green roofs ([greenroofs.pt](http://greenroofs.pt)).

## 3. RESULTS AND DISCUSSION

The majority of the cities identified use a combination of different green roof policies. Five different kind of policies were identified:

### **Reduction in taxes fees:**

Indirect financial incentives usually represent reductions in rates or taxes. Reducing wastewater rates is one of the most common examples. Since green roofs control rainwater retention, they reduce runoff at the local level, reducing the flow volume and the amount of flows entering the urban drainage system, resulting in a discount for the owner or, in some cases, the total exemption of certain tariffs.

### **Persuasion:**

Cities may include green roofs in their planning instruments but only encouraging and mentioning it as an important ecological instrument. Actions of environmental education and

disclosure related to green cover are also essential persuasion measures in any strategy to include green cover in urban planning.

### Mandatory

Another form of green roof policy that have been increasingly adopted in modern cities corresponds to its mandatory inclusion in the planning instruments of cities.

For example, some policies may require green roofing in all public buildings, or in other cases there may be an organization by areas where in some areas all new buildings are required to include green roofs.

### Direct financial incentives:

Direct financial incentives usually correspond to subsidies made available to owners who include green roofs on their properties. These subsidies would vary considerably according to their purpose and the reality of the place where they were applied. They are generally implemented at the municipal level but there are also cases of incentives supported by central governments

The amount of the allowance is usually determined in two ways: the owner receives a certain cash value per square meter (m<sup>2</sup>) of green cover or a percentage of the work is paid to the owner

### Constructin bonus

Authorities may include green roofs in their planning instruments in a variety of ways, such as on the basis of ecological compensation (eg through the possibility of building more floors if a building includes a building site).

Figure 1 presents the list and mapping of cities with green roof policies identified in the literature review



Figure 1: List and mapping of cities with GR policies around the world

Table 1 presents a resume of the information about the 18 cities identified with green roof stormwater policies

| City               | Year of policy | Kind of policy                                                | Description of the policy                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|--------------------|----------------|---------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Hanover, Germany   | 1982           | Persuasion<br>Mandatory<br>Reduction in rainwater rates       | Hanover is a city with a long tradition of encouraging green roofs. As early as 1987 the city included the advantages of green roofs in the environmental section of its urban development plan.<br>In 1994 precise specifications were included in the Hanover Municipal Guidelines for Green Roofs in Urban Deveopment Plans. Environmental standards for construction in municipal areas have come to state that all roofs considered flat (with a slope of less than or equal to 20%) of new buildings should include green roofs. From 2001 owners of buildings with green roofs received a 50% reduction in rainwater rates. The city also focused on offering green roofs advice to builders, investors and building owners as a means of spreading the benefits of technology and thus facilitating awareness of the importance of its mass implementation. (IGRA, 2011). |
| Karlsruhe, Germany | 1980's         | Reduction in stormwater rates                                 | According to the height of the substrate<br>The main objective of the policy was the improvement of the cities climate and the reduction of the heat island effect                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Stuttgart, Germany | -<br>1980's    | Persuasion<br>Mandatory<br>Reduction in rainwater rates up to | Inclusion in the plans of the city<br>Requiring that all flat roofs (up to 12 degrees of inclinations) include green roofs<br>Direct incentives for existing buildings or for new buildings located in areas where GR were not required according to urbanism plans                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |

|                           |      |                                                                       |                                                                                                                                                                                                                                                                                                                                                                                           |
|---------------------------|------|-----------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                           |      | 50% for buildings<br>Direct financial<br>incentives                   | Between 1986 and 2009 approximately 430 projects and 66.000 m <sup>2</sup> of GR were financed by the government. The subsidy was around 17.90 € /m <sup>2</sup> (50% of the cost materials and installation), with a minimum of 12 cm of substrate). The owner should keep the GR for at least 10 years. In 2014 the incentive program has undergone an update (IGRA 2004; Lawlor 2006). |
| Munich                    | -    | Persuasion<br>Financial incentives<br>Reduction in<br>rainwater rates | Inclusion in the soil use plan<br>Financial incentives for the voluntary installation of GR<br>Reduction in rainwater rates for the owners of buildings with a GR                                                                                                                                                                                                                         |
| Munster,<br>Germany       | -    | Reduction in<br>rainwater rates for<br>buildings with GR              | The city offered 80% reduction in rainwater rates if the building included GR                                                                                                                                                                                                                                                                                                             |
| Cologne,<br>Germany       | -    | Reduction in<br>rainwater taxes                                       | The reduction was only guaranteeing certain performances standards, based on allocation of financial subsidies for its construction (Lawlor, 2006).                                                                                                                                                                                                                                       |
| Hamburg,<br>Germany       | -    | Financial support<br>Reduction in<br>rainwater taxes                  | The Hamburg Ministry of Environment and Energy offers financial support for the creation of green totalling 3 million by the end of 2019. Owners can receive subsidies to cover up to 60% of installation costs and are still subject to a reduction of 50% in rainwater tariffs (Lawlor, 2006; Growing Green Guide, 2013)                                                                |
| Rotterdam,<br>Netherlands | 2008 | Financial incentives                                                  | In 2008 the city of Rotterdam started a program of financial incentives for the installation of GR, having as one of the main objectives the management of rainwater. The green roof incentive program began                                                                                                                                                                              |

|                     |      |                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|---------------------|------|----------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                     |      |                      | as part of the city's water plan, which listed other measures to mitigate the effect of climate change. By 2014 the city already had 200 GR, equivalent to an area of 200.000 m2 (IGRA, 2014).                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Copenhagen, Denmark | 2004 | Persuasion Mandatory | The city of Copenhagen has started to encourage green roofs around 2008 as a way to improve stormwater management. In 2009, with responsibility for the UN Climate Change Conference COP15, which discussed the strategies to be adopted to combat the effects of global warming, the focus on green roofs have intensified. An incentive policy for green roofs in Copenhagen was adopted in 2010 and today Copenhagen has a mandatory policy for green roofs. (Growing Green Guide, 2013; IGRA, 2012).                                                                                                                                                  |
| Bolzano, Italy      | -    | Persuasion policy    | Bolzano introduced a policy in 2004 that supports sustainable solutions for rainwater management, among which are the green roofs. The policy was accompanied by model projects, the adoption of the italian guide for the construction of green roofs and education and information strategies on the subject. (IGRA, 2004).                                                                                                                                                                                                                                                                                                                             |
| New York City, USA  | 2007 | Persuasion policy    | New York started to develop a green roof incentive policy in 2007, especially with the motivation to improve rainwater management. Later, the promotion of green roofs in the city began to take into account other benefits, such as promotion of biodiversity. (Lawlor, 2013)                                                                                                                                                                                                                                                                                                                                                                           |
| Chicago, USA        | 2000 | Mandatory            | The incentive policy to encourage green roofs in Chicago started in 2000 with the main objectives to reduce the heat island effect and help the management of rainwater. The city started to demand that all the replaced roofs respond to the minimum standards of solar reflectivity and emission, which was favorable to the proliferation of the green roofs. In addition, Chicago's rainwater regulations promote green roofs, as all projects with more than 1.393 m2 should have a rainwater maintenance plan, which in turn must include volume and flow controls. Green roofs are one of the measures to meet those requirements. (Lawlor, 2013) |
| Portland, USA       | 1996 | Reduction in         | Portland's green roof incentive program began in 1996 when green roofs began to be used as a part of a strategy to reduce the polluted urban runoff that hits rivers. In addition to providing indirect                                                                                                                                                                                                                                                                                                                                                                                                                                                   |



|                     |      |                                                          |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|---------------------|------|----------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                     |      | stormwater rates<br>Bonus construction                   | incentives by reducing storm water rated to owners who included green roofs, the city had a green roofing incentive policy based on the award of a “construction bonus” (reflected in the possibility of building more floors in a building) to owners who included green roofs in their buildings. (Lawlor, 2013)                                                                                                                                                                                                                                                                                                                                                                                                                        |
| Seattle, USA        | 2009 | Persuasion policy                                        | The city of Seattle pushed for the implementation of green roofs through two main avenues: one of them was the adapted rainwater code in 2009, where green roofs were included as one of the best practices to be used to reduce the impermeous surfaces of cities and the amount of water to be managed after precipitation phenomena. The other was the Seattle Green Factor, adopted in 2006. The Seattle Green Factor is a document that aims to increase the quantity and quality of the city's green areas while allowing designers and owners flexibility to meet the standards of development. Green roofs were included as one of the measures to be used to meet the development standards required in the plan. (Lawlor, 2013) |
| Palo Alto, EUA      | 2012 | Financial subsidies<br>for their installation            | By 2012 the city of Palo Alto adopted a policy to encourage green roofs based on the allocation of financial subsidies for its installation, with the aim of improving rainwater management. (Green Roofs for Healthy Cities, 2014)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| Atlanta, EUA        | 2013 | Persuasion policy                                        | In 2013, the Atlanta Hydroelectric Basin Management Department revised the stormwater management ordinance to increase the promotion of green infrastructure in the city's new and developing projects. Green roofs are one of the techniques mentioned in the document to mitigate these type of problems. (Lawlor, 2013; Green Roofs for Healthy Cities, 2014)                                                                                                                                                                                                                                                                                                                                                                          |
| Minneapolis,<br>EUA | 2005 | Reduction on the<br>city's mandatory<br>sanitation rates | Since 2005, the city of Minneapolis has a policy that says that any building that contributes to improved stormwater management, for example through the implementation of green roofs, receives a discount on the city's mandatory sanitation rates. (Lawlor, 2013; Growing Green Guide 2013)                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Toronto,<br>Canada  | 2009 | Mandatory policy                                         | Toronto was the first city in North America to develop a mandatory policy for green roofs, preceded by a vast study about the benefits and economic returns that the application of this technology would bring to the city. (Lawlor, 2013; Growing Green Guide 2013)                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |

|                      |      |                   |                                                                                                                   |
|----------------------|------|-------------------|-------------------------------------------------------------------------------------------------------------------|
|                      |      |                   |                                                                                                                   |
| Vancouver,<br>Canada | 2001 | Persuasion policy | Since 2001 Stormwater management planning for GVRD includes green roofs. (Lawlor, 2013; Growing Green Guide 2013) |

Table 1 Information about the GR stormwater policies identified

The majority of the cities identified use a combination of different policies. The main policies identified were persuasion, and reduction in stormwater fees (9 cities each), followed by direct financial incentives and mandatory (5 cities each). The least implemented policy, according to the literature review, was the bonus construction policy, mentioned only by the city of Portland.

### Relevant data

The analysis of the different green roof policies for stormwater retention reinforced the importance of some parameters that should be taken into account in the Portuguese context, such as:

1. The definition of the green roof performance, related to the amount of water it can hold (depending, among other issues, on the depth of the substrate), and to the type of vegetation used (more effective in filtering pollutants).
2. The use of green roof guidelines for project, construction and maintenance of green roofs
3. Maintenance control

Although these are important aspects to take into account when defining a green roof policy for stormwater management, it is important to note that each case is a case and the definition of a green roof policy for a city should include a global view of its problems and a deep understanding of its context, in order to define which parameters would be more priority and what would be the best model to encourage a large scale implementation of green roofs.

## 4. CONCLUSION

Stormwater retention will remain a priority in the political agenda of urban centers for the next years. Specific for the Portuguese context it will be important to define innovative and creative ways to deal with this situation. Green Roofs can play an important role in this issues, as it was reinforced by some case studies presented in this article.

From the literature review analysed in this study it was possible to identify some aspects that would be relevant for the implementation of a green roof policy in the Portuguese context, such as: the performance of the green roofs, the use of guidelines and the fiscalization of the maintenance of green roofs.

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# Water efficiency and drainage in challenging environments

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## ABSTRACT

The UN recognises that water, sanitation and hygiene (WASH) is a basic human right, but does not recognise drainage as such. Without drainage, settlements flood, leading to impacts on quality of life and human health. This impacts the most vulnerable and poorest of populations who live in informal settlements or favelas and refugee camps. Further layers of complexity are added with the incidence of disease vectors such as mosquitoes which can carry malaria and viruses associated with Zika, dengue or chikungunya and the wasting of water in climates where drought is prevalent. This paper reports on projects in Brazil and the Kurdistan Region of Iraq in which Sustainable Drainage Systems or SuDS are proposed to address issues associated with excess surface water and lack of greywater management in these most challenging of environments. SuDS mimic nature by infiltrating water, providing storage and slow conveyance in order to attenuate the storm peak, improve water quality and provide amenity and biodiversity. Encouraging water to percolate underground reduces standing water between dwellings and on the street, with the potential to reduce mosquito breeding sites, thus reducing their impacts on human health. Residents can be encouraged to dispose of their greywater in biofilters and at the same time grow ornamental plants or fruit and vegetables thus making the most use of water which would otherwise be wasted. Whilst community engagement in informal settlements or favelas is required to improve their quality of life, refugee camps are set up formally by host governments and the United Nations High Commissioner for Refugees (UNHCR) with WASH already installed. There is thus potential to influence policy, encouraging the installation of drainage at the same time as WASH, possibly providing the first step to recognise drainage as a human right.

*Keywords: Sustainable drainage systems (SuDS); greywater management; disease vectors; informal settlements; favela; refugee camp*

## 1. INTRODUCTION

It is explicitly recognized in Resolution 64/292, 2010 (United Nations General Assembly) that access to clean, safe drinking water and sanitation is a human right, and that they are the foundation enabling the ability to achieve all human rights. Particularly focused on developing countries, the Resolution requests that States invest in supporting activities such as capacity-building and transfer of technology to enable the provision of a clean, safe, accessible and affordable drinking water supply as well as providing sanitation for all. However, these aims do not mention “floods” or “drainage”, implying that drainage and resilience to flooding is not necessarily a human right. In 2007, dwellings in Villa Flores, Costa Rica were flooded with wastewater, but the Constitutional Chamber of Costa Rica associated this with poor maintenance of the sewerage system, violating the population’s constitutional right to health [1]; drainage was not addressed in this document.

Overcrowding and increased urbanisation have caused problems with flooding and contamination worldwide, in developed, developing and underdeveloped cities alike. However, exacerbating this, particularly where “precarious settlements” which are informal,

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and also formal settlements set up temporarily for refugees, are involved, is lack of greywater management, leading to its disposal in the street. This situation results in contaminated streams and standing water surrounding dwellings (see Fig 1). In areas where disease vectors such as mosquitoes are a problem, for example in the favelas of NE Brazil, this wastewater provides breeding grounds for these insects and can potentially increase the incidences of infections such as zika, dengue or chikungunya [2].



**Fig. 1. Contaminated wastewater flowing between dwellings in a favela in NE Brazil.**

Whilst Fig 2 shows that the proportions of people living in the slums of Brazil were in decline, reducing from almost 40% in 1990, nonetheless, more than 20% still lived informally in 2014. The situation in Iraq is different in that the sharp increase from under 20% up until 2000 to over 50% in 2010, with a slight decline to below 50% in 2014, is probably a reflection of the migration of refugees, mainly from Syria, into the country, as well as provision being made for Iraqi nationals displaced by war in internally displaced persons (IDP) camps. Whilst there are many such camps distributed across the country, nearly 20 IDP camps are located around Baghdad, according to the UNHCR [3]. However, the majority of both the refugee and IDP camps are to be found in the north east of the country, in the Kurdistan Region of Iraq (KRI) where there are some 40 IDP and 8 refugee camps.

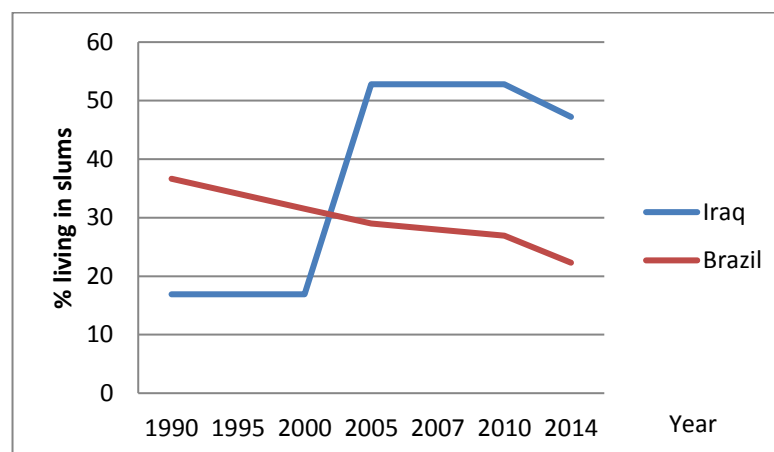


**Fig. 2. Proportion of Iraqi and Brazilian urban populations living in slums (UN-Habitat definition) from: World Bank, United Nation's Millennium Development Goals database [4]**

Whilst refugee camps are initially set up in KRI by UNHCR and the Kurdistan Regional Government (KRG), they are subsequently managed by local agencies. WASH is designed into the camps as a matter of course [5], and whilst 'Drainage' is identified as a component in WASH, it is constructed last, if at all, resulting in costly retrofits which still prove ineffective once problems with wastewater (combination of grey and surface waters, sometimes even

containing sewage) and flooding occur. These water flows are directed “to another environment” [6] by constructing large drainage ditches to the boundaries of the camp, whilst open concrete drains and pipes are also used. Water could instead be encouraged to infiltrate into the ground, which would be more environmentally sustainable; if this were coupled with greywater reuse it would reduce surface water flows, suggesting that Sustainable Drainage Systems, or SuDS, may provide some answers to these issues. SuDS mimic natural systems by encouraging infiltration of water into the ground, its retention or detention, and its slow conveyance to the receiving waterbody [7]. Whilst the main benefits of SuDS are encapsulated in the SuDS Square which balances reduction in water quantity, improvement of water quality, provision of amenity and promotion of biodiversity [8], there are other benefits to using this approach (see: [9]). If designed properly, and with awareness of local conditions, SuDS can be installed into the most challenging of environments: informal settlements and refugee camps.

The aim of this paper is therefore to investigate whether SuDS approach can be used in the challenging environments of favelas and refugee camps to reduce surface water flows and manage greywater.

## 2. MATERIAL AND METHODS / EXPERIMENTAL DETAILS / METHODOLOGY

This study is based in the NE of Brazil in Fortaleza and also in the Kurdistan Region of Iraq. The location of both sites is shown in Fig 3.

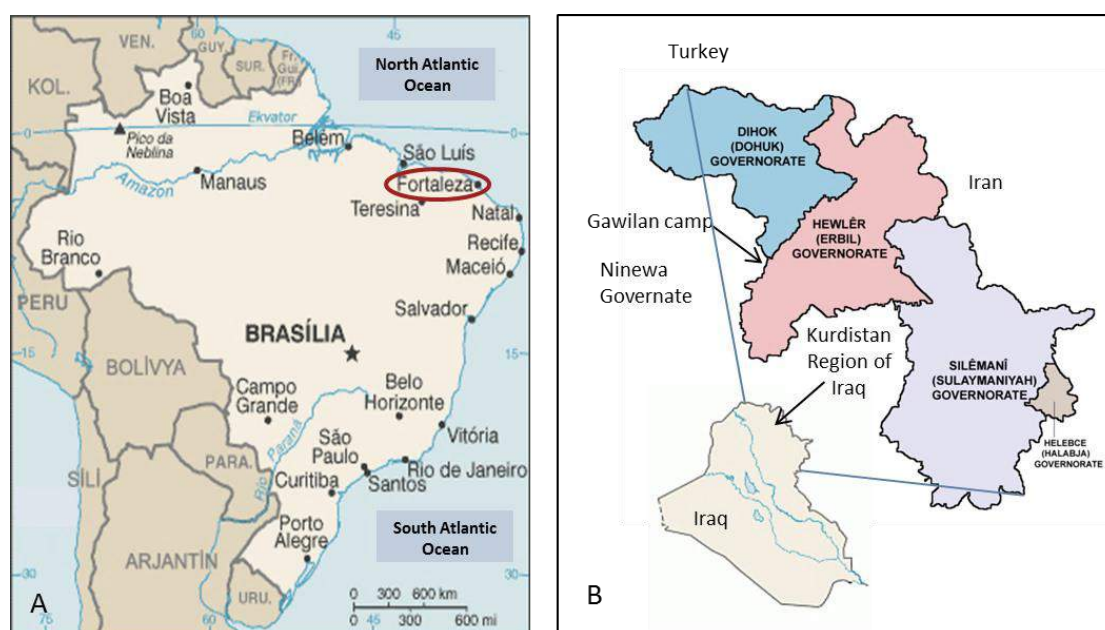


**Fig. 3. Study site locations. A.) Fortaleza, Brazil. B.) Gawilan refugee camp, Kurdistan Region of Iraq**

### 2.1 Fortaleza, Brazil

With no vaccine developed yet for the Zika virus, the focus of this study is to investigate the potential of reducing sites where the *Aedes* mosquito species which carries the virus, can breed by examining whether a type of SuDS solution could tackle both short term pluvial flooding and also the long-term lack of management of greywater by “drying wet environments” [10] and “drainage of mosquito breeding sites” [11]. The Zika virus was first reported in May 2015 [10] in Brazil, and [12] estimated a total of between 440,000 and 1,300,000 cases of Zika in 2015. By early 2016, cases of Zika were reported in 22 states across Brazil. Since 2015, of the 5,280 suspected cases of microcephaly, and 108 associated deaths, most were from the Northeast of Brazil. Whilst attention shifted away from Zika when



it was thought the pandemic was over, dengue and chikungunya are still rife, according to the [13], for example, incidences of chikungunya rose from 469 in 2016 to 1158 in 2017 in Ceará alone. Since both dengue and chikungunya are carried by the same insect vector as Zika, the likelihood of another Zika outbreak is fairly strong.

According to [14], these problems are generally associated with urban areas, particularly those where the poor live, hence the focus on favelas in NE Brazil. Fortaleza is the state capital of Ceará, located in Northeastern Brazil, on the North Atlantic coast; as the fifth largest city in Brazil, it has an estimated population of more than 2.5 million.

It is well-known that there are problems associated with the storage of water *inside* homes in open containers, but very little has been done to investigate how lack of drainage *outside* the home exacerbates mosquito breeding.

In November 2017, a field visit to two favelas in Brazil were carried out conducted by community leaders and local officials. These visits were observational, to ascertain whether standing water was a problem, and whether there was any evidence of mosquito breeding. A further visit is planned in June 2018 in which more detailed mapping of drainage (formal, if any and informal), environmental characteristics such as topography, soil type etc. will be carried out.

## 2.2 Gawilan Camp, Kurdistan Region of Iraq

The Gawilan refugee camp is located in Ninewa Governate in the Kurdistan Region of Iraq. The camp opened in September 2013 with 2,810 individuals and a planned capacity of 29,000 [15]. According to the UNHCR [16] in January 2018, there were 8,624 people living in Gawilan, most of who are Syrian refugees.



**Fig. 4. Location of households surveyed and water sampling sites.**

In consultation with camp officials and management, an area of Gawilan camp was identified as having concerns regarding flooding and greywater disposal. This area will be the location of a SuDS demonstration site, in which native vegetation, the local topography, infiltration and conveyance will be used in a SuDS Management Train (see: [7;8]) to ensure that none of the water currently flowing through this area will leave the site. Construction is due to begin in March 2018, but water samples, flows and volumes have been monitored as a Before-After-Control-Impact (BACI) approach at the 3 sites shown on Fig 4, and it is planned to monitor seasonally after construction has been completed in order to assess the efficiency of the

system (see Fig 5 and Table 1). Permission has been obtained from the local government to overfly the area regularly with a drone to monitor waste water flows.



**Fig. 5. Monitoring of the site pre-construction of SuDS demonstration site.**

**A. Monitoring of pH**

**B. Collection of water sample at the end of a concrete channel**

**Table 1 shows the parameters measured during the water sampling campaign.**

In order to engage with the local community and gauge any interest in SuDS, a preliminary survey of 10 households overlooking the SuDS site was carried out by means of a questionnaire and structured interviews (see Fig 4). Households chosen were 300m away from the demonstration site as their WASH practices were likely to affect the receiving environment, and they would also be the most impacted by changes to their environment. Explanation of the project was achieved with an Arabic/English translator and images of SuDS devices. Data was also collected on their current water, sanitation and hygiene (WASH) practices and the generation of greywater and its management at the household level. Further information will be collected regarding flooding, but the fact that it is a problem was shown on 19-20 February 2018, when [17] reported more than 200,000 people affected in IDPs in KRI and many shelters damaged during heavy storms.

### 3. RESULTS AND DISCUSSION

#### 3.1 Field visit: Fortaleza favelas, Brazil

Fig 6 clearly illustrates the problems with drainage in the favelas visited. Streams of greywater were seen in the streets, problems with litter and [2] reported puddles of standing water containing many 100s of mosquito larvae in one of the favelas. Should this open, outside water be encouraged to infiltrate into the ground, using SuDS techniques such as gravel-filled swales, and biofiltration using native vegetation, the potential breeding sites for disease vectors would be considerably reduced, leaving other issues, such as storage of water in open containers in dwellings to be managed more effectively.





**Fig. 6. Open greywater flows in two favelas visited in Fortaleza. A. a stream of greywater in the street. B.) litter and greywater between homes.**

### 3.2 Gawilan camp, KRI

Fig 7 shows streams of greywater flowing in concrete channels from the camp, through the SuDS demonstration site and to the boundary fence of the camp. Furthermore, a number of deep-stagnant pools have also formed within the camp confines. The Figure also illustrates problems associated with litter, and this is further shown in Fig 5 when water samples were collected for analysis.



**Fig. 7. A and B.) Greywater flowing in separate, open concrete ditches as it leaves the camp. C.) The ditches ending at the perimeter of the camp and discharging into an area of wetland which is currently of little value and may present issues around safety and human health. D.) Areas of standing water and litter before construction of the SuDS demonstration site.**

Results of the water quality analysis showed no concerns regarding many of the chemical constituents. As, Co, Pb and Hg were all below the limits of detection, and Cr, Mn, Ni, Zn and Fe were all below [18] guidelines so are not discussed further.

However, in comparison with [18] guidelines, there were concerning levels of BOD<sub>5</sub>, COD in the streams entering the areas (Table 2), although both reduced at the outlet. Bacteria,

expressed as both most probable number (MPN) and total bacterial count (TBC) was of concern at all 3 sampling sites (Table 2). The results for bacteria may indicate mixing of black or toilet water in the wastewater streams, allowing it to flow in open channels through the camp and then into the wider environment is a serious issue that needs to be tackled. In comparison with other standards, turbidity was also extremely high (Table 2), probably reflecting the high bacterial counts: those given by [19] are for lakes and streams, and should the water from the outlet reach local water bodies, the impacts could be quite severe.

**Table 2 Results of pre-construction monitoring of water samples from the Gawilan camp SuDS demonstration site**

|                  | <i>units</i> | <i>sample 1</i> | <i>sample 2</i> | <i>outlet</i> | <i>standards</i> |
|------------------|--------------|-----------------|-----------------|---------------|------------------|
| <i>Turbidity</i> | NTU          | 213             | 468             | 473           | <50 [17]         |
| <i>BOD5</i>      | ppm          | 353             | 470             | 59.1          | 50 [16]          |
| <i>COD</i>       | ppm          | 668             | 966             | 202           | 250 [16]         |
| <i>MPN</i>       | CFU/100ml    | 2000            | 18000           | 2300          | 400 [16]         |
| <i>TPC</i>       | CFU/100ml    | 1700            | 1000            | 2000          | 400 [16]         |

### 3.2 Results of questionnaire survey

All the households in the survey had access to a toilet, a shower and water for the kitchen, the latter either drained out into an open drain or was directed underground in a pipe. In terms of sources of water to the house, 9 households had a tap inside whilst the remaining one had a roof tank. Four of the households recycled their dirty grey water by watering plants, but it was more common among households to dispose of their dirty grey water after use.

All of the households surveyed were aware of the drainage systems in the camps. They rarely overflowed according to residents, the majority saying that they had only seen them over flow once in a year. During winter however, there was the most surface water on the roads and drains with 1 respondent stating there was a lot of surface water on the roads and drains all the time. On whether the drains smelt, the majority of respondents said that the drains smelt about once a month.

## 4. CONCLUSION

Many streams and puddles of greywater were observed in the favelas in NE Brazil, some of which contained mosquito larvae. Whilst the specific species was not identified, nonetheless these could potentially be carrying a variety of viruses including those causing zika, dengue or chikungunya. There is therefore an opportunity to design SuDS into these settlements to encourage such water into the ground, and also to encourage residents to make use of the greywater, for example by watering plants, rather than by disposing of it on the street.

In the refugee camps, some people did water plants with their greywater, but the concrete channels carried enough water to represent a hazard to health, also the case of the area in which it was discarded, shown by high bacterial counts and turbidity. This area will be developed as a SuDS demonstration site in order to encourage future refugee and IDP camps to include drainage, specifically SuDS in their planning and construction.

## ACKNOWLEDGEMENTS

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## COMPETING INTERESTS

The authors declare no competing interests.

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# #4. Environment and water infrastructure systems

# Building-integrated wastewater recycling: from toilet water to salads

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## ABSTRACT

The global water shortage results in an emerging need for novel, more efficient water management systems particularly for urban regions where a high amount of fresh drinking water is wasted. Within the project ROOF WATER-FARM a building integrated water recycling concept was developed which aims to save water in office buildings and housing complexes by the separate collection and afterwards biological treatment of the various wastewater streams. Moreover, the combination with hydroponics (soilless plant cultivation) allows producing fresh food, whereby water for irrigation purposes as well as transport costs for vegetables will be saved. Within the research work presented novel combined wastewater treatment systems consisting of a pre-filtration system and a membrane bioreactor were developed which enable the generation of high quality natural liquid fertilizers from blackwater for use in plant breeding. A demonstration plant was constructed where operational conditions, removal of organic compounds and bacteria as well as phosphorous and nitrogen recovery efficiency of black water from a building complex (50 inhabitants) were investigated. Within a test period of four month, fluid fertilizer could be generated that was hygienically safe and rich on nutrients. The organic load could be reduced by a factor of 10 to a mean value of 205 mg/L. Despite of relative high concentrations of plant damaging nitride and differing nutrient compositions compared to a conventional fluid fertilizer the average fruit mass was even slightly higher (lettuce) or only 18 % less (cucumber) compared to the fruit mass of lettuce and cucumber which were conventionally fertilized.

*Keywords: black water, grey water, water recycling, building integrated, fluid fertilizer, process water, membrane bioreactor, decentralized waste water treatment plant (DWTP)*

## 1. INTRODUCTION

The establishment of centralized municipal wastewater treatment in Europe in the beginning of the last century was a response to epidemics, whereas later efforts starting in the 1960's focused on the problems of eutrophication in receiving water bodies [1]. Important technologies for the removal of nutrients mainly phosphorous (P) and nitrogen (N) have been developed [2], considering nutrients as problematic substances. This paradigm is still effective, but more and more broadens up towards the recovery of nutrients [3].

Worldwide, three million tons of phosphorous per year are excreted by humans, which represents 21 % of the total amount of artificial phosphorus fertilizer production (14.9 million tons P per year) [4]. When discharging the toilet wastewater to municipal wastewater treatment plants (WWTPs), nitrogen mainly releases to the atmosphere and the majority of phosphorous accumulates in sewage sludge. In 2011 approximately 600,000 tons of sewage sludge were utilized for farming in Germany (representing 29 % of overall annual dry sewage sludge production in Germany). However, in Germany a draft law was adopted, according to which the soil-related use of sewage sludge has to stop by 2025. The main argument for this decision is

that the environmental risk deriving from sludge trace components such as heavy metals or pharmaceuticals is considered too high. As Germany is highly dependent on phosphorous imports [5], new paths for the low cost recycling of nutrients from wastewater must be implemented over the next decade [6].

By establishing the sustainable development goals (SDGs) in 2015, the United Nations identified wastewater recycling as one of the main global development objectives for the near future (see SDG 6a [7]). The separating of wastewater sources with regard to the respectively valuable components probably play an important role in this. In combination with decentralized WWT systems this approach can have ecological, energetic, and economic advantages compared to conventional centralized systems due to the higher flexibility, the accessibility of treated process water and the opportunity to be directly connected to plant cultivation systems even in urban regions [5, 8].

As a result from global population growth and unsustainable soil management the demand for arable land is constantly rising. Until 2050, when two-thirds of the predicted 9.55 billion world citizens will live in urban areas [9], the land occupied by cities will increase from 250 to 420 million hectare (ha), if urbanization will continue to grow at the current rate. These factors in addition to the globalized food production result in an on-going deforestation rate of around 13 million ha  $y^{-1}$  [10]. In response to the described problems related to globalized food production, various urban farming methods are emerging in cities like Berlin, Barcelona, Milan or New York [11,12]. These urban plant cultivation systems such as roof top greenhouses have to be supplied with irrigation water, nutrients, and energy which most suitable will be generated on site.

“Cities are nutrient hotspots” [3]. Hence, decentralized ecological sanitation concepts that not only deliver process water for irrigation but also integrate nutrient recovery for the production of fertilizer must be one main task of sustainable urban planning and policy making [13].

Against this background the overall goal of the research work presented was the development and implementation of a technological process for the production of hygienic safe, ecological harmless, and plant available fluid fertilizer from toilet water (also referred to blackwater, BW). The work was carried out within the scope of the ROOF WATER-FARM project (see section 2.1) which aims to develop technologies for a more ecological, integrated and self-sufficient urban resource management concept that brings food production back to the center of people's life.

## **2. MATERIAL AND METHODS / EXPERIMENTAL DETAILS / METHODOLOGY**

### **2.1 The ROOF WATER-FARM Project**

ROOF WATER-FARM demonstrated paths towards innovative city water management and urban food production [14]. Potentials and risks of redesigning across sectors of infrastructure were explored and communicated.

Over a period of 3.5 years, five project partners representing all relevant fields, namely wastewater technology, farming, urban planning and innovation management, investigated opportunities for building-integrated water treatment systems to irrigate and fertilize roof-top greenhouses. Technologies for water treatment and plant/fish production were examined at a demonstration and test site in Berlin-Kreuzberg (figure 1). The research focused on a hygienically safe usage of rainwater, greywater (household wastewater without toilet water) and blackwater as both a strategy for city water management and a potential for urban food production.

The objectives of ROOF WATER-FARM were as follows:

- developing cultivation technologies of water-based plant and fish production combined with decentralized water treatment technologies for rainwater, greywater and blackwater
- testing hygienic safety of the cultivation including significant micro-pollutants (selected pharmaceuticals)



- assessing product quality according to relevant national and European requirements and
- extracting and testing liquid fertilizer (NPK) production.

Furthermore, basing on preliminary findings, the transferability of the ROOF WATER-FARM concepts into the urban area was examined. Structural variants of plant and fish production in greenhouses were projected for the scale of a building unit, and scaled up for urban spaces at large.

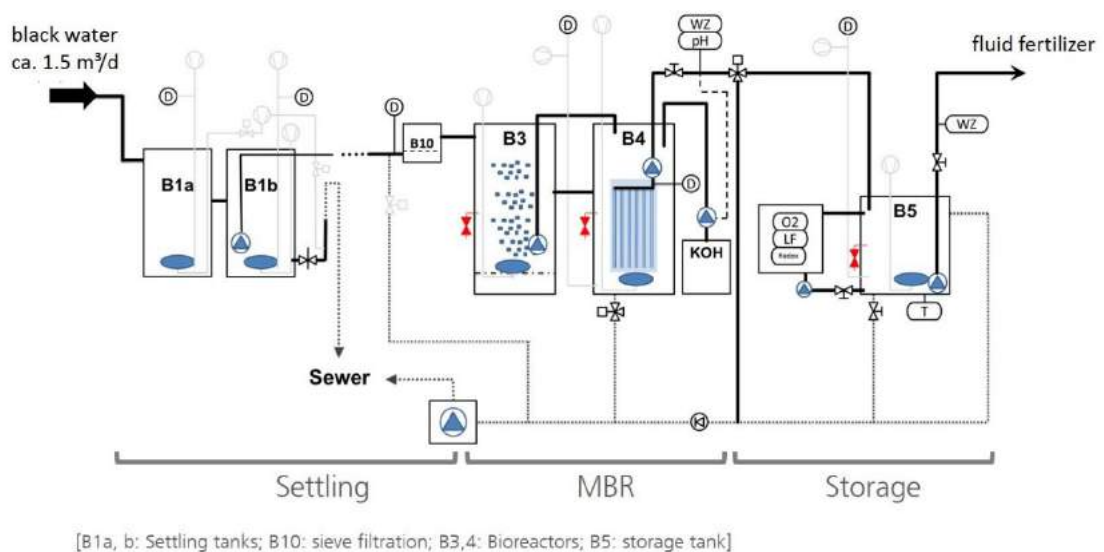
Over the course of the project, the researchers developed process-related communication and training tools for building-integrated wastewater treatment systems and urban food production.



**Fig.1. Photos of the ROOF WATER-Farm system (from left to right and top down: test site, greenhouse, blackwater treatment plant and grey water treatment plant [biological fluidized bed processes])**

## 2.2 Black water treatment system

Besides a long-term successfully operating grey water treatment plant, the project partners of ROOF WATER-FARM developed and integrated a blackwater treatment plant (BWTP), which was installed at the inner courtyard of an apartment complex, where 6-liter water flush toilets generate 50 person equivalents (PE) of wastewater. The BWTP consists of a settling tank followed by a 1 mm sieve and a 1.2 m<sup>3</sup> aerobic membrane bioreactor (MBR equipped with an ultrafiltration membrane (siClaro FM 611, MARTIN Membrane System AG) (figure 2).



## Fig.2. Flow scheme of the black water treatment plant [15]

The reactor was operated with sludge wastage rates equivalent to a solids retention time (SRT) of 55 days, and treated between 500 and 1000 L of blackwater per day. The operational parameters are given in table 1. The effluent flow of the MBR was routed by a three-way actuated valve that directed the effluent either to a 1 m<sup>3</sup> storage tank (from where it was pumped to the greenhouse when required) or to the sewer.

**Table 1. Specifications and operational parameters of pilot-scale MBR for blackwater treatment (SAD<sub>M</sub>: Membrane area specific aeration demand, SAD<sub>P</sub>: Permeate volume specific aeration demand)**

| Operational parameter         | Value           | Unit                                                 |
|-------------------------------|-----------------|------------------------------------------------------|
| module type / material        | flat sheet /PES | -                                                    |
| surface area                  | 6,25            | m <sup>2</sup>                                       |
| average flux                  | 3               | LMH                                                  |
| permeation / relaxation cycle | 12 / 3          | min                                                  |
| SAD <sub>P</sub>              | 230             | m <sup>3</sup> .air.m <sup>-3</sup>                  |
| SAD <sub>M</sub>              | 1.15            | m <sup>3</sup> .air.m <sup>-2</sup> .h <sup>-1</sup> |

The food production part of the system consisted of a non-climatized greenhouse with two 5.6 m<sup>2</sup> ebb-and-flow growing beds. The system was continuously operated from April to August 2017 in two phases. During this period, six batches of MBR effluent were produced and used as nutrient solution in the hydroponic system. Each batch was generated over a period of two weeks. In the first phase (April-May) lettuce (*Lactuca sativa* var. *crispa*) was grown. During this phase, the MBR was operated without pH control in order to assess the effects of eventual high nitride concentrations on the development of crops with a short growth cycle. In the second phase (May-August) cucumber (*Cucumis sativus*) was grown; during this period, the pH of the MBR was controlled by automatic dosing of 50 % KOH, with a pH setpoint of 7.5. All crops were grown in rockwool substrate.

During both crop cycles, an identical ebb-and-flow bed with the same number of plants was operated in parallel as a control, for which a conventional synthetic fertilizer (CANNA Aqua Vega, CANNA Deutschland GmbH) was used to prepare the nutrient solution according to fertilization guidelines for the respective crop. The effectiveness of the BWTP's effluent as a nutrient solution was assessed by the comparison between the yield and characteristics of the products of the two beds.

## 2.3 Laboratory analysis

Sample aliquots for the determination of NH<sub>4</sub>-N, NO<sub>3</sub>-N, NO<sub>2</sub>-N, PO<sub>4</sub>-P and heavy metals were filtered utilizing cellulose acetate filters with 0.45 µm pore size (Sartorius). For the measurement of COD (chemical oxygen demand), TN and TP samples were first homogenized with an Ultraturrax T-25 disperser (IKA). The Samples were analyzed according to the standard methods listed in table 2.



**Table 2. Methods for laboratory analysis of COD, nutrients, and heavy metals**

| Parameter          | Method                      | Norm              |
|--------------------|-----------------------------|-------------------|
| COD                | dichromate                  | ISO 6060-1989     |
| TNb                | peroxydisulfate             | EN ISO 11905-1    |
| NH <sub>4</sub> -N | indophenol blue             | ISO 7150-1        |
| NO <sub>3</sub> -N | 2,6-dimethylphenol          | ISO 7890-1-2-1986 |
| NO <sub>2</sub> -N | diazotization               | EN ISO 26777      |
| TP                 | phosphorous molybdenum blue | ISO 6878-1-1986   |
| Heavy metals       | ICP-OES                     | --                |

### 3. RESULTS AND DISCUSSION

This section presents the characteristic of the effluent produced by the blackwater treatment system in six charges during a continuous and steady operation period of four months. Besides COD and nutrients, potentially harmful plant contaminants such as heavy metals were determined. In order to evaluate the microbiological risk for humans, hygienic parameters were measured. The plant yield of lettuce and cucumber is determined for various quality of fluid fertilizers: (i) MBR effluent with relatively high nitride concentration, (ii) MBR effluent with moderate nitride concentration, and (iii) conventional fluid fertilizer.

#### 3.1 COD removal and nutrient enrichment

The main challenge within the development of the BWTP comprises both the removal of the organic carbon and conservation of the nutrients contained in blackwater. Figure 3 shows that the produced MBR effluent contains nearly the same amount of phosphorous and 1.7-fold of nitrogen compared to conventional fluid fertilizer. Whereas the deviation range of the different nitrogen species is quite large, a fertilizer with relatively constant total nitrogen concentration can be produced.

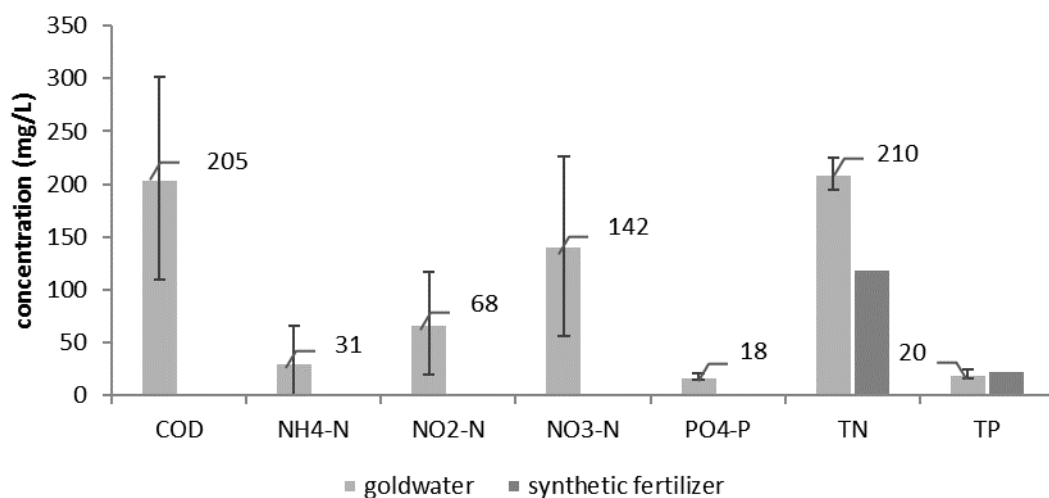


**Fig. 3. Concentration of COD, phosphorous and nitrogen measured in the MBR effluent (refer to goldwater) at the outlet of the membrane tank (mean value of charge 1 to 6) in comparison to conventional fluid fertilizer (Aqua Vega, Canna)**

The most critical component is nitride, which might be plant damaging depending on the concentration and the type of plants. As can be seen in figure 4, in charge 4 to 6 the concentration of nitride could be drastically reduced due to a KOH pH control.

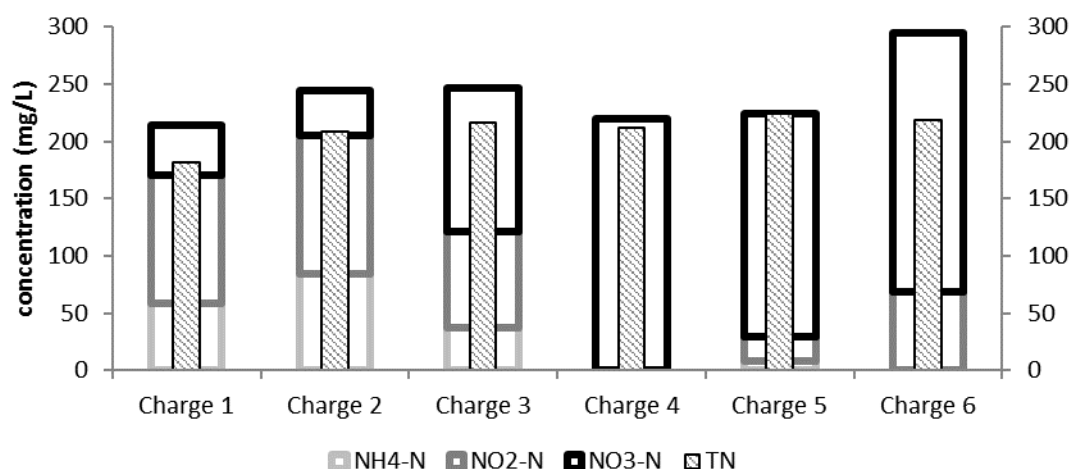


**Fig. 4. Nitrogen composition of the MBR effluent measured at the outlet of the membrane tank (single measurements of one charge, charge 1 to 3 without pH control, charge 4 to 6 with pH control)**

Although the concentration of nitride in the BWTP effluent was high due to the lack of pH control, figure 5 shows that the average mass of lettuce was similar for both types of fertilizer. However, the average mass of cucumbers produced by the bed operated with BWTP effluent was observed to be in average 18 % inferior to that of the control, even though the nitride concentration was considerably reduced because of pH control. This result indicates that the nitrite concentration was likely not the reason for the differences. The reduced yield of cucumber could have resulted from a shortage of micronutrients such as zinc, manganese or boron.

Furthermore, the COD could be reduced to the median value of 205 mg/L, ca. one tenth of the concentration in the influent raw blackwater. The removal of organic compounds is quite important since otherwise undesired microbiological degradation processes probably occur whereby producing toxic metabolic products.

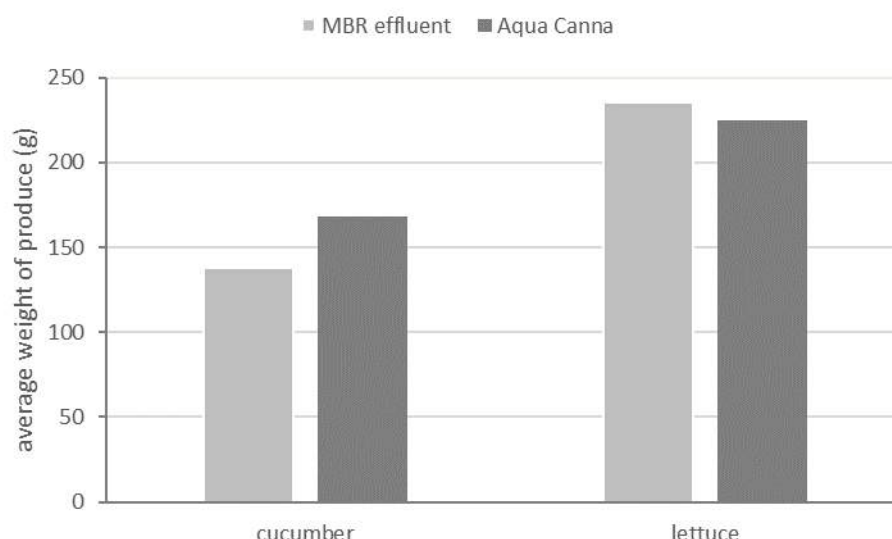


**Fig. 5. Average fruit mass per lettuce and cucumber for the produced MBR effluent and Aqua Vega, Canna**

### 3.2 Hygienic parameters

The initial blackwater flow is highly contaminated with bacteria so that it is necessary to ensure the microbiological harmless of the produced MBR effluent through appropriate monitoring of representative bacteria such as *E.coli* and *Pseudomonas aeruginosa*. Table 3 shows the hygienic parameters for the first three batches of MBR effluent. Each sample was directly taken from the storage tank.

**Table 3. Colony forming unit (CFU) of *E.coli* and *Pseudomonas aeruginosa* measured in three batches of MBR effluent**

| Parameter                     | Batch 1 | Batch 2 | Batch 3 | Unit       | Norm              |
|-------------------------------|---------|---------|---------|------------|-------------------|
| <i>E.coli</i>                 | 90      | 320     | < 20    | CFU/100 mL | DIN EN ISO 9308-1 |
| <i>Pseudomonas aeruginosa</i> | 340     | < 100   | 9500    | CFU/100 mL | DIN EN ISO 16266  |

Whereas the concentration of *E.coli* correspond to the concentration of conventional fluid fertilizers and thus, can be considered as microbiological harmless, the relatively high concentration of pseudomonads indicates an undesired microbiological re-contamination during the storage time. For this reason and due to the fact that membrane defects might overlooked a further post-filtration step after the storage tank, e.g. sandfilter is recommended. The relatively high concentration of *Pseudomonas aeruginosa* in batch 3 probably results from such membrane defects.

### 3.3 Heavy Metals

The metal concentration of the MBR effluent was determined periodically in order to check if the threshold values of hydroponics according to the EU Drinking Water Directive [16] were reached. Table 4 presents the results of heavy metal concentrations in the MBR effluent.

**Table 4. Concentration of heavy metals measured in one representative sample of MBR effluent**

| Parameter | Value  | Threshold [16] | Unit |
|-----------|--------|----------------|------|
| Lead      | 0.02   | < 0.01         | mg/L |
| Cadmium   | < 0.02 | < 0.005        | mg/L |
| Copper    | 0.08   | < 2            | mg/L |
| Zinc      | 0.48   | -              | mg/L |

The lead and cadmium concentration of the produced MBR effluent exceeded the thresholds. However, the low accuracy of the measurement method does not allow the precise determination of the heavy metals but deliver a more or less rough estimation. In contrast to these results the heavy metal concentrations in the hydroponic, which is supplied with the produced MBR effluent meets all border values. Besides this, it is still open if the application of such a strict legislation like the drinking water directive is necessary for the production of fertilizer.

## 4. CONCLUSION

The production of fluid fertilizer from blackwater has proven an appropriate way to save nutrients and water. However, since the possible uptake of micro-pollutants by the cultivated plants might lead to concerns for the end consumers, the researches aim to conduct further analytical studies to establish a reliable data basis and to understand deeply the accumulation processes of representative plants.

At present, the blackwater treatment process requires highly experienced stuff in order to operate the membrane bioreactor. Thus, novel technologies which need less maintenance has

to be implemented to allow the widespread dissemination of the BWTP technology. Within further research projects the authors want to investigate chemical and mechanical technologies such as hydrolysis and membrane applications (without bioreactor) aiming to a fully automated BWT process which can be driven by a housekeeper or the residents themselves.

In order to bring the food to the German market, business models have to be developed, which involve all stakeholder such as house owner, representatives of the local administration, and the legislation. Currently, the researchers carry out recommendations for actions, which on the one hand should support the responsible authorities to extend existing regulations allowing explicitly the use of treated toilet wastewater for plant production. On the other hand, they should help interesting investigators to technically implement the ROOF WATER-FARM concept.

Besides the German market, the project consortia attempts to establish ROOF WATER-FARM pilot plants as case studies in international metropolitan areas such as São Paulo and arid regions in Egypt which both suffer from emerging water and food shortages resulting in an urgent demand of sustainable wastewater treatment systems and water saving farming concepts.

## ACKNOWLEDGEMENTS

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## Hydropower energy recovery in water pipe networks: spatial regression analysis using GIS, assessing the correlation between energy recovery potential and geographical data

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### ABSTRACT

There are known locations in water pipe networks (WPNs) with excess head or pressure. In water distribution networks there are locations of special infrastructure such as break pressure tanks or pressure reducing valves (PRVs) which are used to prevent pipes bursting and reduce water leakage losses. In wastewater networks, there are locations at inlets and outlets to wastewater treatment plants. One of solutions to reducing the energy dependency of WPNs is by recovering a portion of this dissipated energy wasted at locations of excess head or pressure, through the implementation of micro-hydropower technology (MHP). While the potential of MHP energy recovery in WPNs is a suitable solution to improve the energy efficiency of the water sector, it has seen limited exploitation in practice due to a number of technical and non-technical issues. Non-technical issues include a lack of awareness about the scale of the existing resource available in WPNs. A spatial regression analysis has been performed in this study in an attempt to build a regression model which would enable the extrapolation and evaluation of the potential for MHP energy recovery in areas without data. The data about water and wastewater infrastructure was available for regions of Ireland and Wales. The results of the analysis for the Irish data showed correlation with population data of  $R^2=0.26$  for a subset of PRVs, for a linear model. On the other hand the Welsh data did not show any significant correlation with population data,  $R^2\approx 0$ . The regression analysis with topographical data did not show any notable correlation with the potential of sites of either Ireland or in Wales. The implication of this is that the localized population and terrain variability around the sites do not explain the variation of the MHP potential in water networks well, and that the previous extrapolations of the potential of MHP technology in the literature by population can be erroneous.

*Keywords: hydropower energy recovery, water pipe networks, micro-hydropower turbines, spatial regression analysis, geographical information systems*

### 1. INTRODUCTION

The supply of treated water and wastewater management are very expensive and energy intensive processes, which are followed by a large amount of inherent CO<sub>2</sub> emissions. Globally, 2–3% of energy usage is reported to be associated with the production, distribution and treatment of water [1]. In many western countries which represent the world's leading economies, the water industry is among the most energy-intensive industries. Thus for example in the United Kingdom the water industry is the fourth most energy-intensive industry responsible for 5 million tonnes of CO<sub>2</sub> emissions annually and consuming 7.9 TWh of energy in 2006–7 [2],[3] In smaller economies, such as that of Ireland, the operation of the water industry has been reported to cost over €600 million annually [4]

Many methods for improving the sustainability of water services have been investigated and proposed by numerous researchers. One of these methods is the concept of hydropower energy recovery which utilises excess pressure or head present in some parts of water pipe networks (WPNs) for generating the energy by means of the MHP technology. One of the first published research in this area was carried out by Williams [5]. He noticed that there are many

locations in networks where control valves are in place to manage the downstream pressure and that MHP turbines can replace or be installed in parallel to these valves, to perform the same task of reducing the pressure while adding the additional benefit of generating electricity. Since then this concept has been addressed by numerous researchers across the world. These researches included studies on pressure reducing valves (PRVs), control valves (CV), break pressure tanks (BPTs), storage/service reservoirs (SRs) and wastewater treatment plants (WWTPs) which present the most promising locations for energy recovery [6],[7].

Despite this most of the potential in WPNs remains untapped. There are several technical and non-technical barriers which prevent widespread exploitation of this type of potential. The presence of flow variations in water distribution pipes which reduces turbine efficiency and makes MHP projects less economically viable is one of them [8], [9]. One more technical barrier is the need for pressure control at the locations where the downstream pressure has to be managed [10]. For very small potentials which are very common for energy recovery sites, conventional turbines such as Kaplan, Francis etc. usually cannot be scaled down in an economically viable way. However the low-cost Pump-As-Turbine (PAT) technology presents a more economically viable solution, especially for the sites with smaller potential, but the lack of performance curves for these devices makes their application much more difficult [11], [12]. Non-technical barriers are perhaps even the larger reason for the insufficient implementation of this technology. One of these is lack of incentive for this type of technology, especially after the recent withdrawal of the Renewable Feed-In-Tariffs (REFITs) for this type of technology in many European countries [13]. The water legislation which does not lend itself to easy implementation of this technology also represents one of the barriers. One more non-technical issue includes a lack of awareness about the scale of the existing resource available in WPNs for this technology and its corresponding environmental and economic impact.

There are only few published articles which try to assess the total potential of this technology on a wider geographical coverage e.g. on a country level [16], [17], [18]. Most of the articles assess the potential of only few potential sites in detail [14], or they are focused only on one type of water infrastructure e.g. BPTs [15]. The reason for this is that in order to assess the total potential, a lot of data is required for all WDNs and in some cases data is not available or does not exist. Also without the hydraulic models of WDNs, one cannot tell if the set of sites under consideration, represents all sites in the network, and water utilities are often not willing to share their network data.

However, some examples of successful studies exist such as Bousquet et al. [16] who developed a methodology to assess the hydropower potential of WWNs in Switzerland. They identified 41 potential sites with the energy recovery potential bigger than 50 MWh, 19 of which are found to be economically viable, representing 9.6 GWh/year of recovered energy.

More recently Gallagher et al. [17] identified 238 potential sites from the regions of Ireland (mainly Dublin area) and Wales. The results of the study are the most feasible sites in Ireland and Wales, with the potential to generate an estimated 17.9 GWh per annum. Corcoran et al. [18] also studied a bigger set of sites, 95 of them in total. The study covered regions of Ireland and Wales. Most of the sites analysed in this study overlap with those from Gallagher et al. [17]. The study did not point out what is the total potential of all sites, it was focused more on finding the most promising ones and showing the influence of flow variations on the generated energy. One more study aimed to assess the energy recovery potential of the water supply part of the networks (without water distribution part) of Piemonte region (northern-west Italy) [19] identifying only potential locations for energy recovery at inlets and outlets of SRs in the WSNs. In absence of the real measurements of flow and pressure at SR locations, a special methodology was developed to assess the potential, and finding determined that 5 out of 6 sub-regions had potential in the range from 14-26 MW and that one sub-region does not have any potential. However, this research was based on too many theoretical assumptions, so the obtained potential can be taken into account more as the theoretical than the real potential.

To date no study has attempted to spatially extrapolate the potential of MHP technology to an area which would also include regions without data. This research aims to investigate the correlation between the MHP potential of the sites with some geographical data which are available for the whole area of interest, in order to develop a regression model which would be

used to extrapolate the potential to regions without data. Spatial analysis of the sites using GIS (Geographical Information Systems) based software ArcMap was carried out for this purpose.

## 2. METHODS

### 2.1. Studied sites

In this study, the same set of the potential energy recovery sites is used as in the study of Gallagher et al. [17]. The set includes 51 potential energy recovery sites in Ireland and 187 sites in Wales. These sites mostly represent WDN infrastructures such as PRVs in the first place, CVs, BPTs and SRs, but there is also several WWTPs. Most of the Irish sites are situated in Dublin County, 36 out of 51 sites, while the Welsh sites are more uniformly deployed across Wales. The locations of all the sites are displayed in Fig. 1. For each of the sites the following data was available: Mean annual flow and pressure data, for the year 2011; Site type (e.g. PRV, BPT, SR or WWTP); Place name, county and country; Longitude and latitude coordinates.

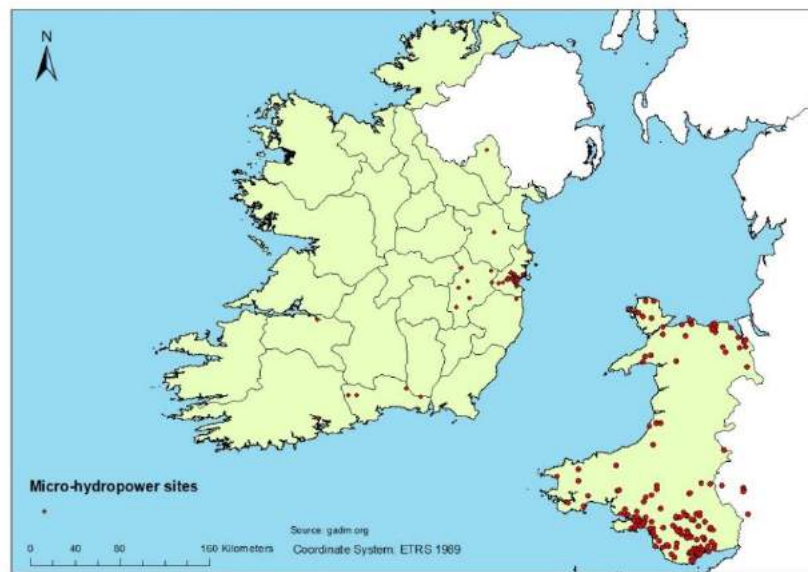


**Fig. 1. Locations of potential micro-hydropower energy recovery site in Ireland and Wales**

The data for this study was obtained from Dublin City Council, for Irish sites, and from Dwr Cymru/Welsh Water for the Welsh ones.

### 2.2. Calculating potential energy

There are many factors that can influence the energy recovery potential of a site in a WPN. In the first place, these are flow and pressure variations that occur at the site which are mainly determined by the demand of downstream consumers in case of WDNs, or amount of wastewater in case of WWNs. The diurnal flow and pressure patterns were available for only few sites, so the mean annual flow and pressure values were used to assess the power potential of all sites. Also, the selection of turbine type can influence the potential significantly. In order to be able to compare the influence of spatial geographical data on the power potential of the sites (the spatial regression analysis explained in the next subsection) the overall efficiency of the system (turbine, generator, transformer) was estimated as a constant,  $\eta = 65\%$ , similar to that used by previous studies [17], [18]. The potential for energy recovery of a site with the installation of the MHP turbine can be quantified by using the equation 1:

$$P = \rho g Q H \eta \quad (1),$$

where  $P$  = power output (kW);  $Q$  = flow rate through the turbine ( $\text{m}^3/\text{s}$ );  $\rho$  = fluid density ( $\text{kg}/\text{m}^3$ );  $g$  = acceleration due to gravity ( $9.81 \text{ m}/\text{s}^2$ );  $H$  = hydraulic head (potential energy per unit of water weight) available at the turbine (m);  $\eta$  = overall efficiency of the system, estimated at 65%.



## 2.3 Spatial regression analysis

This research is a part of the REDAWN project ([www.redawn.eu](http://www.redawn.eu)). One of the aims of this project is to quantify the total potential for the MHP technology in WPNs in the whole Atlantic area (AA) region of Europe. Obtaining the data about all potential energy recovery sites (all locations in WPNs with excess pressure) in the AA would be impossible. As it can be seen in Figure 1, for this study, data was available only for the part of Ireland and part of Wales. To accomplish this aim a regression model which would allow for data to be extrapolated is needed. In other words, a correlation between the potential and some spatial characteristic has to be found, where the spatial characteristic have to be known in both areas, where we have the data and where we do not.

The use of spatial regression models is common in other fields such as air quality modelling [20], [21]. The methodology called Land Use Regression (LUR) is used to explain variations in the concentrations of the air pollutants [22]. The basic concept of this methodology is that concentrations of pollutants are measured at a set of monitoring sites, which are used as the dependent variables in the regression model. LUR uses buffering (if vector-based model is used) to determine the proximity of pollution sources such as roads or industrial lands etc., to the monitoring sites. The obtained values are used as the independent variables in a regression model to explain the variation of pollutant concentrations at the monitoring sites. The built regression model is then used to evaluate the concentrations of pollutants at other locations of interest.

In an analogy with the air quality models, the dependant variables in our case would be the power potential quantified using equation 1, at the sites presented in Fig 1. Apart from this analogy and the general concept of spatial regression analysis, everything else is different. Phenomena that influence the potential for energy recovery in WPNs are of course completely different from the ones that influence the air pollution. The real challenge in the case of the potential for energy recovery in WPNs is finding the spatial variables which would explain the variations of the power potential without having the hydraulic model of networks to which these sites belong. As it can be seen in the equation 1 the two variables that dictate the potential of a site are the flow in a pipe and available head that can be extracted.

### 2.3.1. Population

The total flow of a WDN corresponds to the number of people for whom the network supplies the water. The same way flow in a pipe where a PRV or an SR are situated corresponds to the number of consumers downstream from the pipe. Of course, without having the hydraulic model of the network we cannot know which part of the network i.e. areas of land are downstream of the pipe. Which type of WDN infrastructure is in place at a pipe can somewhat explain the quantity of the flow in the pipe. Thus pipes where SRs are in place, will have much larger flow than the ones where PRVs are installed, because the SRs are commonly situated in the most upstream part of a network, and their flow corresponds to a much bigger population than the one which passes through a PRV. In this study, the buffer analysis is used to extract population in a proximity to the potential sites to see if it can explain the variations in their potential for energy recovery. A model is created using model builder wizard, within ArcMap for this purpose. The extraction procedure is illustrated in Fig 2. The population within the grid cells which just partially intersect the buffers is calculated by using the equation 2:

$$\frac{\text{Part of the cell overlaid with the buffer}}{\text{Area of the cell}(1 \times 1 \text{ km})} \times \text{population within the cell} \quad (2).$$

In order to use the same reference system for both, Irish and Welsh sites the European Terrestrial Reference System (ETRS89) was used as it is the EU-recommended frame of reference for geodata for Europe [23]. The best resolution for the population data that was found, is in the form of a grid, with a cell size of 1x1 km<sup>2</sup>. The source of the population shapefile was the Eurostat website, which is the statistical office of the European Union ([ec.europa.eu](http://ec.europa.eu)). The buffer analysis was conducted for a few buffer sizes to investigate which size gives the best correlation with the MHP potential of the sites. The buffers of 1km, 3km and 5km in diameter were used. Besides the buffer based scale for the population variables in the

regression analysis one more scale was used and that is a 1x1km population grid cell in which a site takes place (see Fig. 2).

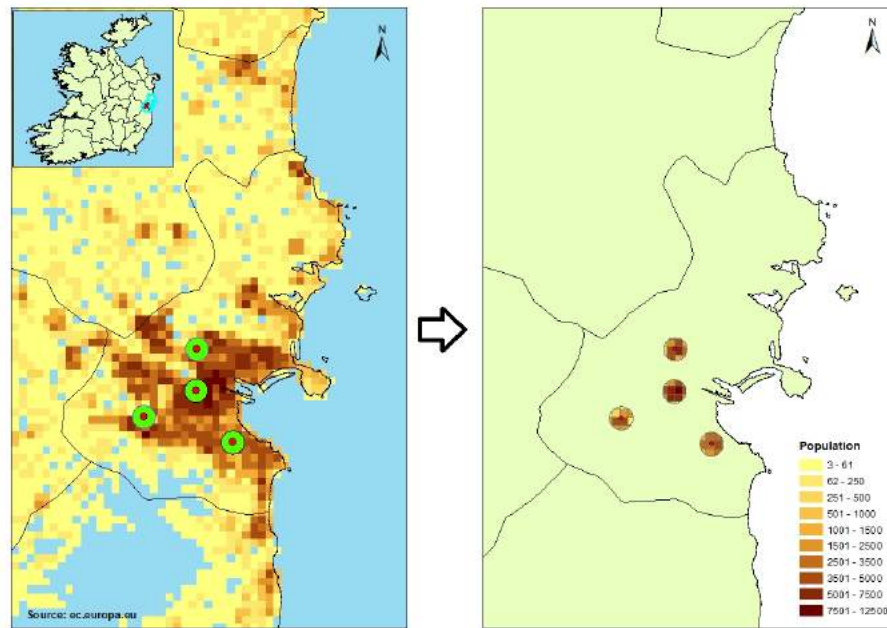


Fig. 2. Extraction of the population data within the 3km buffers for 4 sites in Dublin

### 2.3.2. Topography

It is well known that the terrain variability of a WDN is the main cause for excess pressures in it, and therefore the potential for energy recovery therein may be related to topography. In WDNs which are characterised by hilly terrain the most critical point with the minimum pressure does not need to be the one which is the furthest away from the source, unlike in networks which are situated on a flat terrain (see Fig. 3). Also in a network which has a large difference in elevation between its source and the rest of the network there is a large potential for energy recovery because a large part of the network has excess pressures. Many authors have proven that there is a correlation between the network's terrain characteristic and its potential for energy recovery [24], [15]. Tricarico et al. [24] created a performance indicator of the main network characteristic, which corresponds to available head in a network:

$$I_{Net} = \frac{H_{Tanks,max} - Z_{min}}{L_{Tot,Net}/N_{Tanks}} \quad (2)$$

where  $H_{Tank,max}$  is the maximum level of tanks in the network,  $Z_{min}$  is the minimum elevation,  $L_{Tot,Net}$  is the total length of the network and  $N_{Tanks}$  is the number of tanks present in the system. They showed that an increase in  $I_{Net}$  corresponds to an increase in the energy that can be recovered by means of PATs.

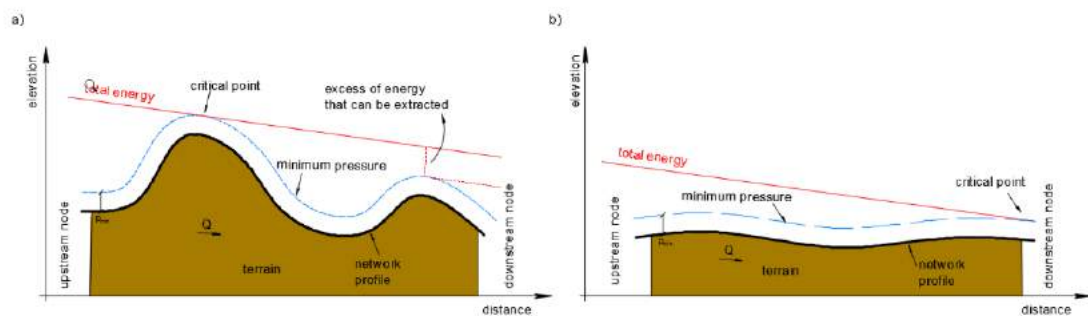


Fig. 3. Influence of terrain variability on the excess of pressure in WDNs

For the purpose of the spatial analysis of terrain conducted in this study, the Digital Elevation models (DEMs) of Ireland and Wales were gathered and used as the input data. The DEMs which were used in the analysis were acquired from the United States Geological Survey (USGS) [25]. These DEMs have the resolution of 1x2 arc second which is around 30x60m. Similar to the extraction of the population variables, a model was created in model builder wizard within ArcMap to perform the buffer analysis. This model clipped the DEMs using the buffers created around the sites, as it is illustrated in Fig. 4.

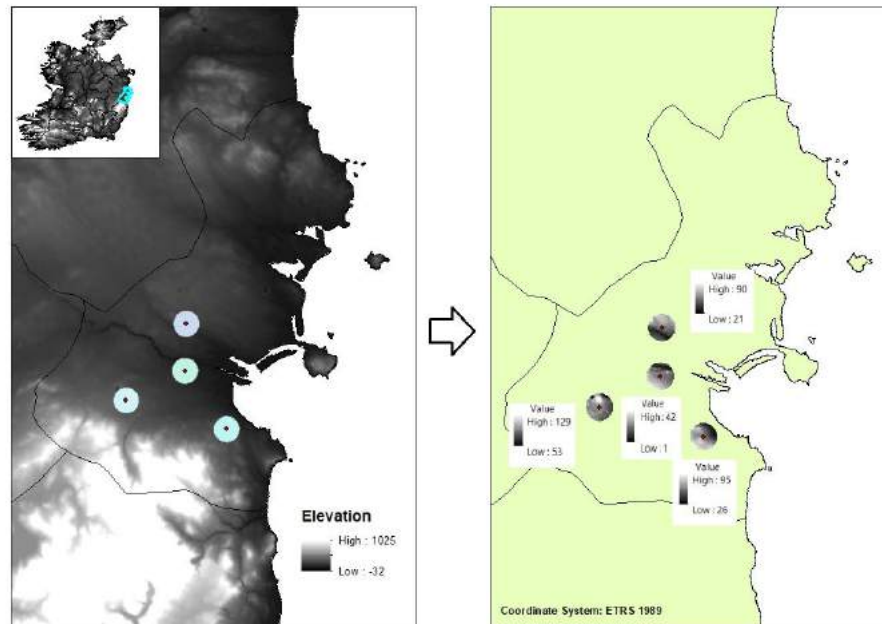


**Fig. 4. Extraction of the DEM within the 3km buffers for 4 sites located in Dublin**

The model also calculated the standard deviation (SD) of each newly created DEM (products obtained by clipping the original DEM of Ireland and Wales using the buffers created around the sites, see Fig. 4) which was used as the measure of terrain variability in the regression analysis. Similar to the extraction of the population data, different buffer sizes are used, namely 0.5km, 1km, 3km and 5km in diameter. Besides the SD of DEM buffers, one more variable was used to represent the terrain variability and that was the slope of terrain at the locations of energy recovery sites. For this purpose, the DEMs of Ireland and Wales were transformed to slope rasters and the slope values were extracted for each site.

The results of regression analysis between the energy recovery potential of sites and the variables that represented the population or the terrain variability are presented in section 3.

### 3. RESULTS AND DISCUSSION

As it was mentioned at the beginning of section 2, in this study we used the same set of the water and wastewater infrastructure that represent the potential energy recovery sites, as in the study of Gallagher et al. [17]. In the study of Gallagher et al. [17] a lot of characteristics of the potential sites, like the total potential of all sites in each country, or the total potential of each type of water and wastewater infrastructure, was already presented and is not repeated here. The distribution of the potential for energy recovery of the Irish and Welsh sites is presented in Fig. 5a and b, respectively. This figure can give us better insight into the potential of the sites and better explain why some filters were applied in the following subsections on the set of sites in an attempt to improve the regression model.

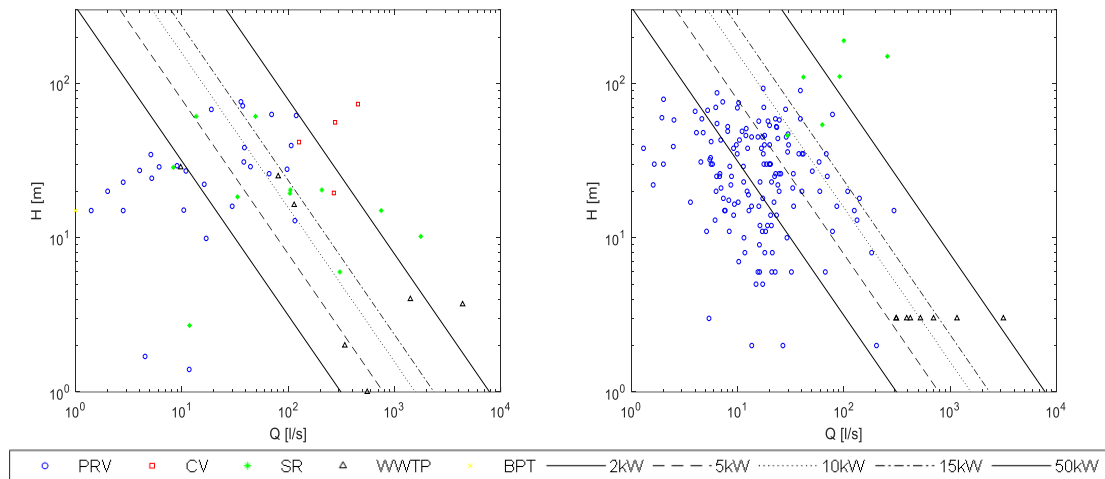


Fig. 5: Distribution of the potential for energy recovery, a) Irish sites; b) Welsh sites

### 3.1. Regression with population data

The data about population inside the buffers of different sizes was extracted in the way explained in the subsection 2.3.1 and correlated with the potential of the sites. Linear Least-Squares Regression (LLSR) analysis was undertaken to examine how well the population variables explain the variations in the potential of the sites. The results of the analysis are presented in Table 1. The initial dataset where all sites were included did not show almost any correlation with the population data inside the buffers, especially in the case of Welsh sites (see Table 1, alternative 0). The reason why the initial set of the Welsh sites includes 165 out of 187 sites is that the rest take place in rural areas without data about the population. Consequently, some filters were applied to see if the correlation would improve. Firstly, the WWTP sites were excluded from the set. The reasoning, that this filter might improve the correlation is that the buffers of 1 to 5 km around a WWTP, usually would not include all population whose sewage is processed by the plant. This filter slightly improved the correlation for the Irish data, but the correlation for the Welsh sites remained unchanged. In Fig. 5 it can be seen that all the WWTP sites have flow larger than 100 l/s which confirms the previous statement. The same reasoning can be applied for the SR sites, because these sites take place in the most upstream part of the water network and consequently their pipes carry a large volume of the water, and buffers of 1 to 5 km would probably not suit these either. As it can be seen in Fig. 5 all 4 CV sites in Ireland had very high flows so these were also excluded. There is only one BPT site with a very small potential, which takes place in Ireland so it was also excluded. As the result of filtering the LLSR analysis was undertaken only for the PRV sites, but PRV sites represent 2/3 of all sites in the dataset. The buffers of 1 to 5 km were most logical in their case because PRVs are usually located at inlets of District Meter Areas (DMAs) which represent smaller parts of a WDN, to reduce pressure in that part of a network and consequently leakage. In Table 1, it can be seen that  $R^2$  has increased 2 to 5 times depending on the buffer diameter for the Irish sites, while in the case of Welsh sites  $R^2$  underwent insignificant increase (see Table 1, alternative 2). This somewhat can be explained with that the Welsh set of PRVs is much bigger than the Irish one (152 versus 28), and that the Welsh set includes PRVs from multiple WDNs while 26 out of 28 of Irish PRVs take place in Dublin County. Because almost all Irish PRVs are located in Dublin County which represents very densely populated area their average population density in the 1km buffer is 3507 while it is 1351 in case of Welsh sites. Therefore the Welsh PRV sites were filtered to include only those which take place in Cardiff County. As the result, we got the set of 15 PRV sites with the average population density in the 1km buffer of 3810, but the correlation did not improve. A few more filters were applied as it can be seen in Table 1, but the  $R^2$  has not been improved. It can be also noticed from the results in the Table 1, that in 6 out of 7 alternatives  $R^2$  decreases with the size of the buffer for the Irish sites.

With a visual examination of the sites, it was noticed that there are several PRVs which are located very close to each other e.g. in the same grid cell and consequently these have almost the same population within the buffers but that their potentials can differ significantly. Taking this into account the sites which are located in the same grid cell were grouped and the sum of

their potential was correlated with the population of the cell. The result of this regression analysis for the Irish set of PRVs is presented in the Fig. 6. As it can be seen from Fig. 6 the correlation has slightly improved from  $R^2=0.214$  (alternative 2, Table 1) to  $R^2=0.26$ . The same analysis was undertaken for the Welsh sites but it gave insignificant improvements.

**Table 1. Results of Linear Least-Squares Regression analysis of energy recovery potential of the sites with population inside buffers of 1,3 and 5km in diameter, for Irish and Welsh sites**

| alternative | Filters applied                  | R squared |       |       |              |       |       |       |              |
|-------------|----------------------------------|-----------|-------|-------|--------------|-------|-------|-------|--------------|
|             |                                  | Ireland   |       |       |              | Wales |       |       |              |
|             |                                  | 1km       | 3km   | 5km   | No. of sites | 1km   | 3km   | 5km   | No. of sites |
| 0           | none                             | 0.063     | 0.038 | 0.023 | 51           | 0.01  | 0.011 | 0.009 | 165          |
| 1           | type≠WWTP                        | 0.098     | 0.062 | 0.035 | 44           | 0.01  | 0.011 | 0.009 | 158          |
| 2           | type=PRV                         | 0.214     | 0.193 | 0.148 | 28           | 0.002 | 0.003 | 0.008 | 152          |
| 3           | type=PRV & County=Dublin/Cardiff | 0.183     | 0.161 | 0.118 | 26           | 0.016 | 3E-04 | 0.044 | 15           |
| 4           | type=PRV & Power<15kW            | 0.003     | 0.019 | 0.061 | 22           | 0.015 | 0.014 | 0.022 | 147          |
| 5           | type=PRV & 2<Power<50kW          | 0.216     | 0.185 | 0.157 | 14           | 0.004 | 0.001 | 2E-04 | 89           |

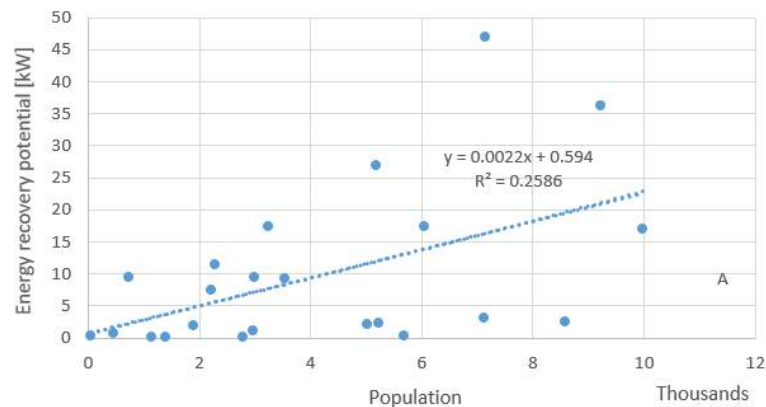


**Fig. 6. Energy recovery potential as the function of population within 1km buffer for the set of Irish PRV sites**

### 3.2. Regression with topography data

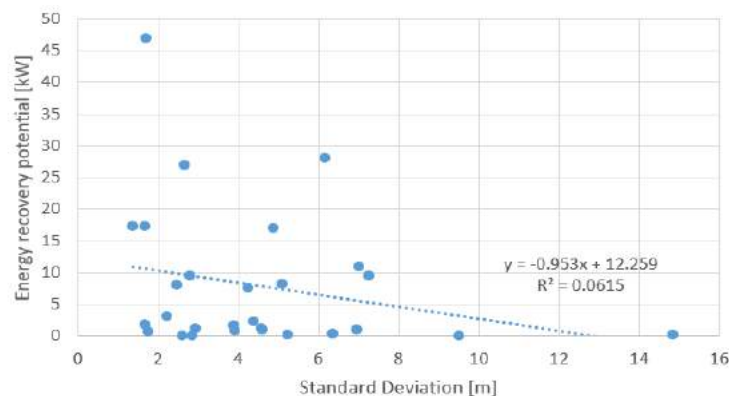
The procedure explained in the subsection 2.3.2 was undertaken to obtain variables which describe terrain variability. After extracting the variables, the LLSR analysis was carried out to assess their correlation with the energy recovery potential of the sites. The Table 2 displays the results of the analysis. As it was mentioned in the subsection 2.3.2, two types of variables which were chosen to represent the terrain variability are: standard deviation of DEM buffers and slope at the locations of the sites (see Table 2). As in the case of the regression analysis with the population variables, the  $R^2$  for the initial dataset when all sites are included was insignificant (see Table 2, alternative 0). Unlike in the regression analysis with the population variables, the data filtering here did not bring any improvements of the  $R^2$ . Furthermore, almost all regression lines had negative slope, like in the Fig. 7, which is completely opposite from the expectations.

It should be pointed out that other nonlinear regression models were considered in the cases of both types of variables (population and terrain variability), but the datasets were too scattered and did not show any nonlinear trend. Also, our potential regression curves would have to have  $dPower/dPopulation > 0$  and  $dPower/dTerrain\ variability > 0$  in the whole range as it is expected for the power potential to increase with an increase in population and terrain variability.



**Table 2: Results of Linear Least-Squares Regression analysis between the energy recovery potential of the sites and terrain variability**

|                   | alternative | Filters applied         | Ireland |       |       |       | No. of sites | Wales |       |       |       | No. of sites |
|-------------------|-------------|-------------------------|---------|-------|-------|-------|--------------|-------|-------|-------|-------|--------------|
|                   |             |                         | 0.5km   | 1km   | 3km   | 5km   |              | 0.5km | 1km   | 3km   | 5km   |              |
| SD of DEM buffers | 0           | none                    | 0.011   | 0.002 | 0.007 | 0.001 | 51           | 0.026 | 0.040 | 0.045 | 0.037 | 186          |
|                   | 1           | type=PRV                | 0.057   | 0.006 | 0.045 | 0.042 | 28           | 0.004 | 0.004 | 0.006 | 0.014 | 173          |
|                   | 2           | type=PRV & Power<15kW   | 0.000   | 0.003 | 0.027 | 0.039 | 22           | 0.001 | 0.001 | 0.001 | 0.000 | 168          |
|                   | 3           | type=PRV & 2<Power<50kW | 0.005   | 0.060 | 0.000 | 0.000 | 14           | 0.002 | 0.000 | 0.001 | 0.013 | 81           |
|                   | 4           | Power<50                | 0.003   | 0.008 | 0.007 | 0.007 | 46           | 0.002 | 0.003 | 0.007 | 0.010 | 182          |
| Slope             | 0           | none                    | 0.069   |       |       |       | 51           | 0.044 |       |       |       | 186          |
|                   | 1           | PRV                     | 0.058   |       |       |       | 28           | 0.000 |       |       |       | 173          |
|                   | 2           | P<50                    | 0.044   |       |       |       | 46           | 0.000 |       |       |       | 182          |
|                   | 3           | PRV & 2<P<50            | 0.001   |       |       |       | 14           | 0.005 |       |       |       | 81           |

**Fig. 7. Regression analysis between the energy recovery potential and standard deviation of the 1km DEM buffer for the set of PRV sites in Ireland.**

#### 4. CONCLUSION

The spatial regression analysis was performed in this study to assess the correlation between the hydropower energy recovery potential of the sites in water and wastewater networks and the geographical data, in Ireland and Wales. The geographical data whose correlation with the potential was examined are the population and terrain variability. The regression analysis of both types of geographical data showed that there is no significant correlation between them and the energy recovery potential of the sites i.e. that they cannot explain the variations of the potential sufficiently. The only somewhat notable correlation of  $R^2=0.26$  was obtained for the set of Irish PRV sites when the potential of sites located in one population grid cell is summarised and correlated with the population of the grid cell. Because of the poor correlation with observed geographical data, it was not feasible to create a regression model which would enable us to extrapolate the potential to areas without the data. The overall conclusion of the study is that geographical variables such as population and terrain variability in the proximity to the sites (up to 5 km) do not explain the variations in the energy recovery potential of the sites well. Previous extrapolation of the MHP potential in the literature by population within countries or for the EU could therefore be erroneous.

Further research should focus on finding new independent variables which could be used for the extrapolation. This is particularly challenging owing to the fact that these variables have to be known in the whole area of interest and this limits the domain of potential variables significantly. Characteristics of a network which were previously used in the literature to explain the presence of excess pressure, such as difference in elevation between a water source and the rest of a network or those used by Tricarico et al. (2017) in equation 2 are considered confidential in majority of cases and water utilities are often not willing to share them. In some cases the data does not exist for the whole area of interest. The poor correlation results obtained in this study between the potential of individual sites and the geographical data in proximity to the sites indicate that maybe the scale on which the correlation is assessed has to be changed. In other words the potential of a site is too site-specific for variables such as the population to explain the variation in the potential. Instead the correlation may be assessed

between the sum of the potential of a cluster of sites and the geographical data of the whole area which is covered by the cluster.

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# Energy recovery using PAT

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## ABSTRACT

Pump working as turbines (PAT) can be seen as an interesting and promising energy converter to improve the system energy efficiency. This study focus on the use of the numerical models in conjunction with laboratory tests to explore the performance of a PAT. In the first stage, experiments were performed followed by numerical simulations to understand the main features of the PAT behavior under different operating conditions. Specifically, the behavior of the pressure variation and velocity streamlines distribution along the PAT were analyzed, evaluating the head losses and net head in different system components. The distribution of the velocity vectors inside the impeller was also studied. In a second stage, the numerical simulations were validated and compared with experimental data. A good approximation with experimental data was obtained. The performance of the PAT and the system was investigated using EPANET and CFD models.

*Keywords: PAT performance, numerical models, experimental tests, head losses, velocity profiles*

## 1. INTRODUCTION

In recent years, small hydropower systems have become attractive for generating electricity, despite the cost per kW of energy produced by these facilities that can be higher than the large hydroelectric power plants [1] [2]. [3] proposed the use of the pumps working as turbines (PATs) as an alternative solution to reduce the pressure in pipe systems, replacing or in conjunction with the pressure reduction valves. This renewable system, which presents feasibility indexes with payback periods lower than five years, can lead to the improvement of the future water systems sustainability [4] [5].

The knowledge of the operation points of these machines is a difficult task when their rotational speed is variable, because the head and the efficiency values are difficult to predict since the manufacture catalogue does not have these curves available [7]. This lack of knowledge to predict the best efficiency point of the pump operating in reverse mode, can be overcome using CFD techniques.

Pumps operating as turbines, besides presenting higher head and discharge in the same rotational speed. The flow field inside the volute is three-dimensional with an important vortex pair created by the curvature of the flow passage and by secondary flows, which are mainly generated by the flow through blades [6-8]. These flow structures create a very difficult problem for the theoretical modeling and the corresponding numerical solution, which needs to be validated by detailed experimental data [7-9].

Also, the PAT behavior is very complex and difficult to find a relation to cover all pumps operating in reverse mode, the use full computational fluid dynamics (CFD) to simulate the PAT

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performance can be a solution to overcome this problem allowing to make possible the knowledge of the PAT behavior and reducing economic costs of experimental developments [8].

## 2. MATERIAL AND METHODS

### 2.1 Experimental set-up

The PAT facility system was established at the Instituto Superior Técnico, Universidade de Lisboa and used for experimental verification of theoretical concepts and numerical results. To simulate the PAT performance, computational fluid dynamic (CFD) models were used together with EPANET model. Additionally, comparisons of CFD results and experiments were carried out to examine the overall performance of the PAT under different steady flow conditions.

The PAT model is Etnom 32-125 from KSB, with the best efficiency point (BEP) in 3.60 l/s and 4.43 m w.c. Fig. 1 shows the experimental set-up with the following components.

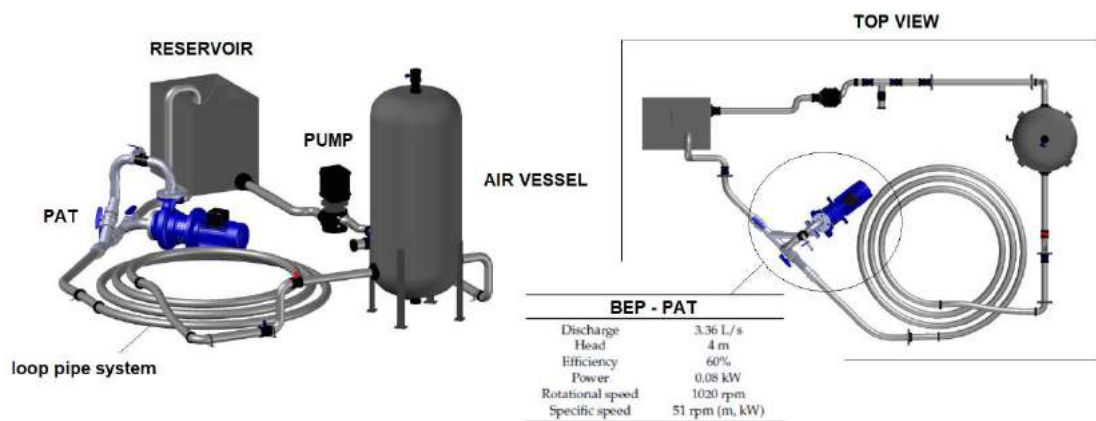


Fig. 1 – Experimental set-up.

The experiments were carried out for different rotational speeds i.e., 1050, 1275 and 1500 rpm and different flows (2.90 – 5.00 l/s) in steady state conditions. For each flow rate the rotational speed of the PAT was measured with a digital tachometer. The pressure was recorded in two pressure transducers located upstream and downstream of the PAT. Fig.2 shows the experimental values for three different rotational speeds.

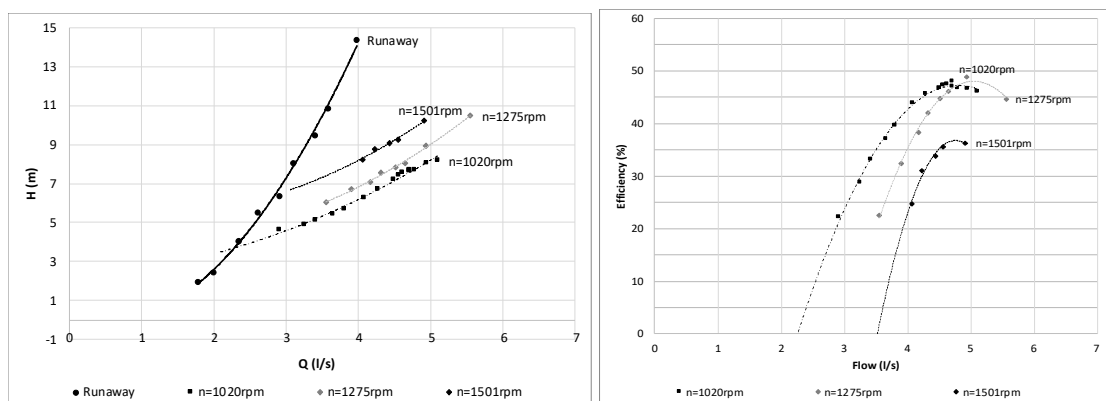


Fig. 2 – Characteristic curves of the PAT for different rotational speeds.

The below flow limit was established by the runaway curve, where the flow decreases when the speed increases for this type of impeller [10]. In Fig. 2, the maximum flow of the PAT was 5 l/s for N=1500 rpm. Fig. 2 also shows a considerable flow reduction for a constant head, which is a characteristic of radial impellers [4].

## 2.2 Numerical models

### 2.2.1 EPANET model

#### 2.2.1.1 Geometry

The EPANET model was prepared based on the experimental model considering the pipe lengths, diameters, minor head losses and pipe roughness as presented in Fig. 3. The pump curve was included in EPANET for the pump operation. For the PAT, a general purpose valve (GPV) was selected using the turbine curve as the operational curve of the valve. The system was considered as an open circuit since the Reservoir does not influence the upstream flow. The endpoint of the system was modelled using an emitter, in the EPANET, to simulate the discharge to the reservoir. The simulation was fulfilled by changing the discharge rate using a discharge coefficient. Increasing the discharge coefficient increases the flow rate. Afterwards, the initial head of the air vessel ( $H_0$ ) was changed from 10 to 40 m, in order to get the different operating conditions in the PAT i.e., (N and H) which depends on the head difference between points A and B (Fig.3).

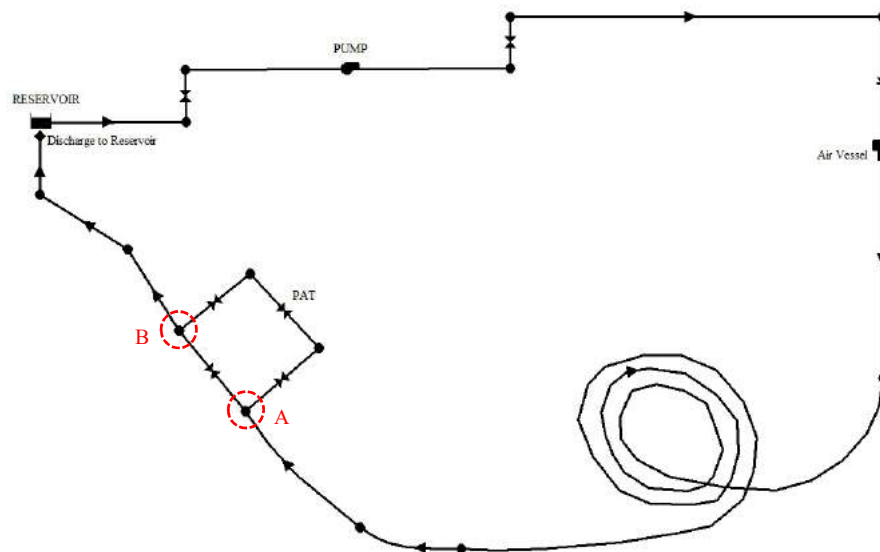


Fig. 3 – EPANET model for steady state simulation.

#### 2.2.1.2 Results

Head and flow rates in all the nodes and pipes were calculated using the EPANET software and compared with the experiments. The discharge coefficient was selected between 0.1, 0.5 and 1.0. For each discharge coefficient, the  $H_0$  was changed from 10 to 40 m. Results for the three simulations are presented in Figs.4, 5 and 6.

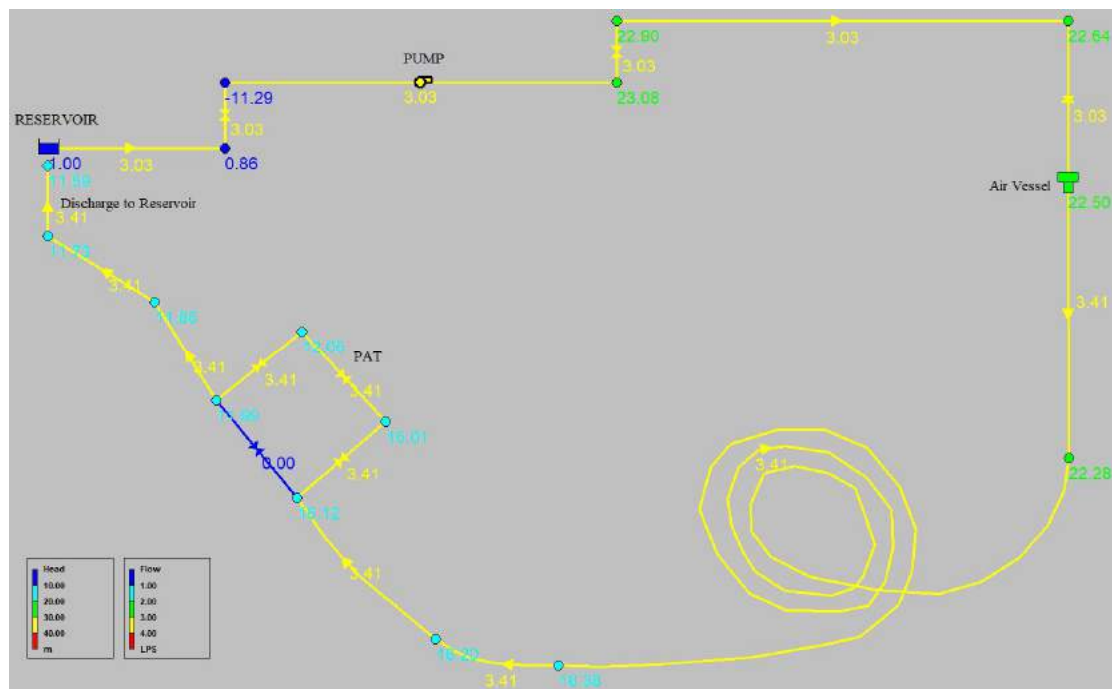


Fig. 4 – EPANET model results (head loss coefficient=1.0).

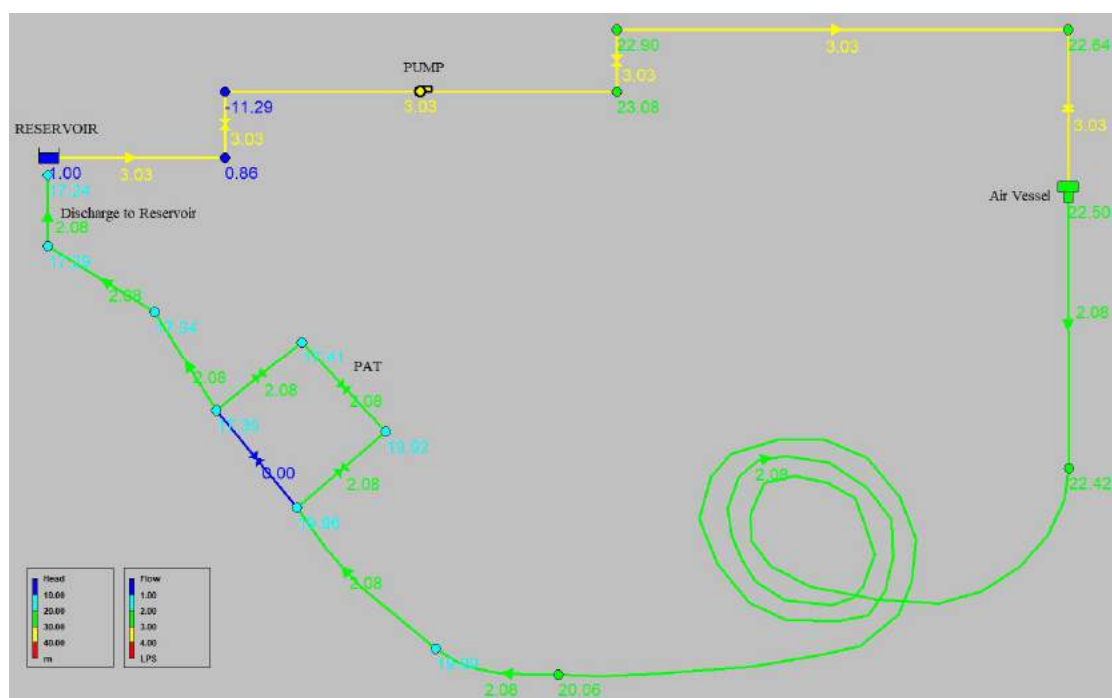


Fig. 5 – EPANET model results (head loss coefficient=0.5).

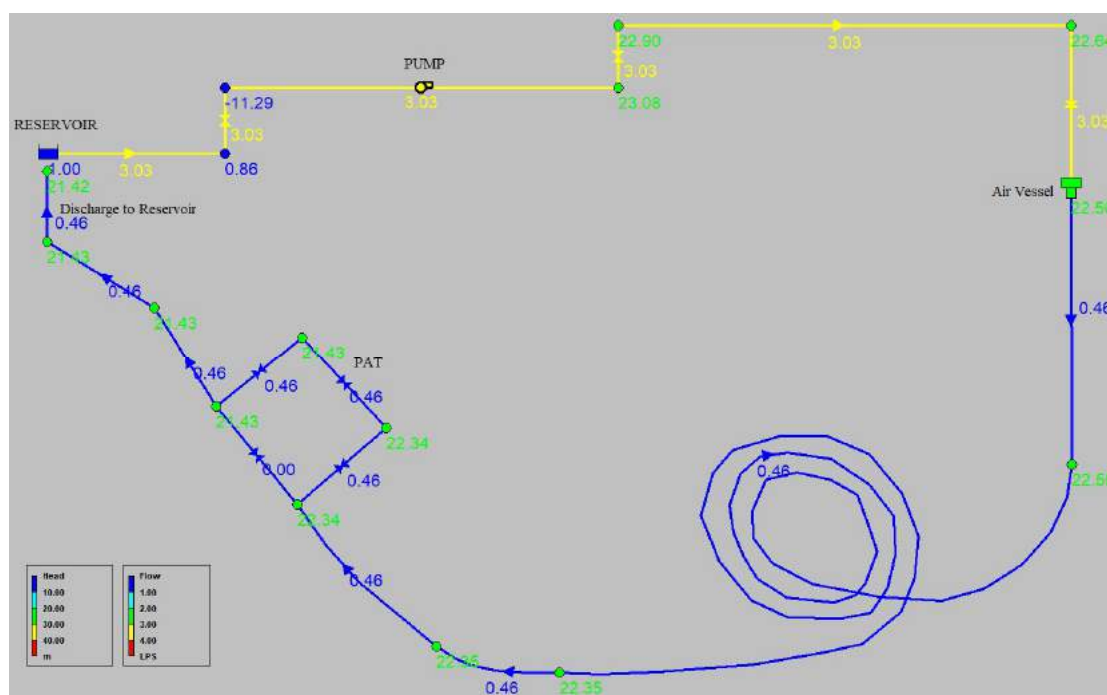


**Fig. 6 – EPANET model results (head loss coefficient=0.1).**

Based on the accomplished simulations, the PAT system curves for different discharge coefficients were obtained (Fig. 7).

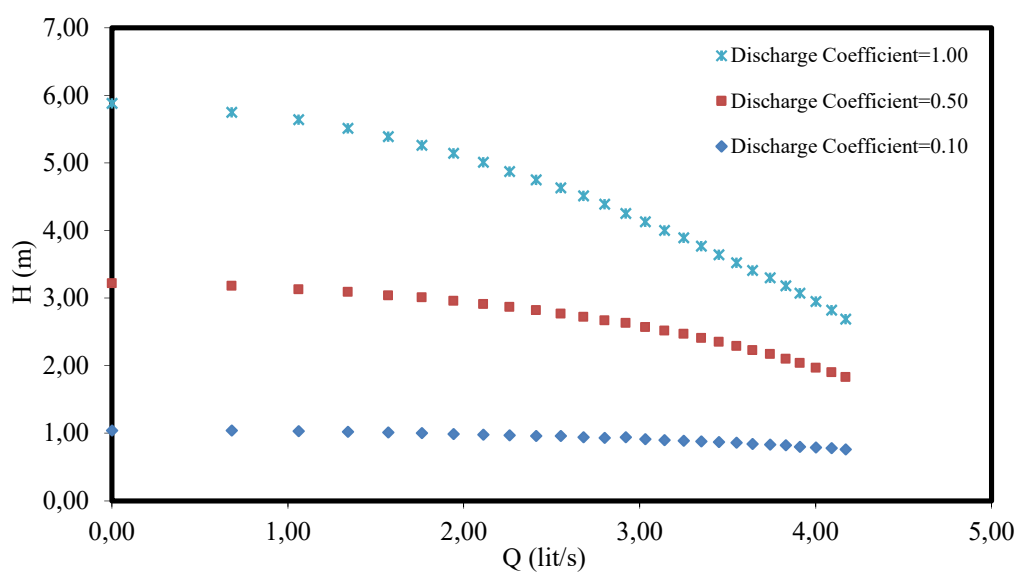


**Fig. 7 – PAT system curves.**

### **2.2.2 CFD model**

#### 2.2.2.1 Mesh and boundary conditions

To perform the computational simulation, the 3D geometric model of the PAT, represented in Fig. 1, was built, based on the real PAT characteristics. For that, the geometry was created in Solidworks and then imported to the CFD model (FloEFD). The computational modeling was performed only for the PAT system, i.e., between section 1 and section 2 as in Fig. 8.



**Fig. 8 – Characteristic curves of the PAT for different rotational speeds.**

The simulations were performed considering an incompressible flow, with constant properties and using the  $k-\varepsilon$  model as the turbulent model. After defining the geometric model, an automatic generation of the mesh was conducted, by specifying values for the parameters used to control the mesh resolution [12]. These parameters need to be adequate to the characteristics of the geometric models to obtain results with a satisfactory level of accuracy, without using significant computational resources.

With the complexity of the rotor geometry, an initial local mesh was defined in the local region of the computational domain relative to the rotor followed by a refinement procedure [13]. The mesh generation process begins with the definition of the rectangular computational domain. Three sets of orthogonal planes to the Cartesian coordinate system were defined inside of it. The intersection of these planes defines the set of rectangular cells that form the base mesh. In the next stage of the process, the program crosses the mesh cells sequentially and for each cell it parses the geometrical configuration inside the cell using a several refinement levels. The refinement level of the cell is the number of times it has been refined relative to the initial cell in the base mesh. In FloEFD the maximum number of refinement levels is limited to seven, so that the smallest cell size is 1/128 of the original cell in the base mesh (level 0) [14] [15].

The boundary conditions assigned to sections 1 and 2 (Fig. 8), were the inlet and outlet measured points of the PAT system, i.e., the volume of the flow rate, corresponding to each test, was allocated to the inlet condition, as for the outlet condition, the pressure recorded in the pressure transducer (located downstream of the PAT), was set. For the rotation of the impeller, the corresponding rotational speed obtained experimentally was also considered.

#### 2.2.2.2 CFD results

Fig. 9 shows the velocity streamlines for the three rotational speeds. The hydrodynamic of the flow is characterized by the presence of curves and elbows at upstream of the PAT. Fig. 9 (a) shows a reduction in the velocity magnitude, upstream and along the impeller, caused by the energy promoted by the flow to the impeller [10]. The vortex that forms at the exit of the rotor, more clearly in Fig. 9 (b), and that extends downstream thereof is associated with turbulence, and hydrodynamic instability, which effects result in pressure fluctuations and efficiency losses.

Reduced flow velocity values can be identified in the vortex core, located near the axis of the pipe). The rotational speed of the impeller and the shape of the blades mark the decrease of the velocity values (Fig.9 (a)). The centrifugal force effect arises with the increasing of the rotational speed (Fig. 9 (c)).

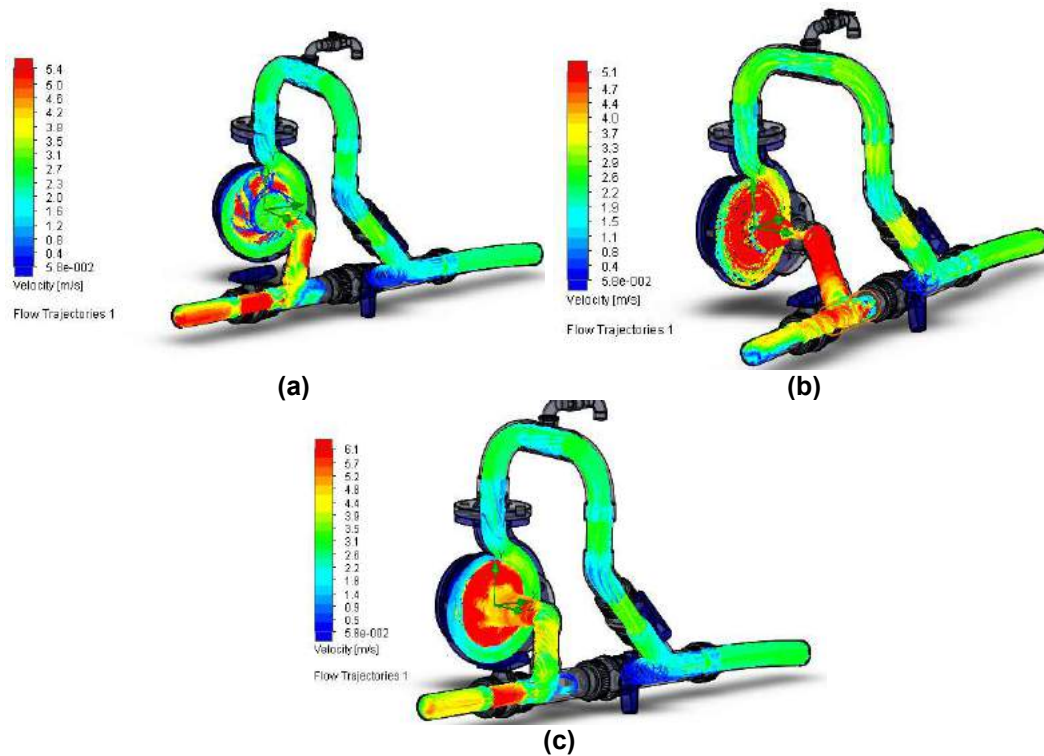


**Fig. 9 – Velocity streamlines for: (a) N=1020 rpm; (b) N=1275 rpm; (c) N=1500 rpm.**

The distribution of the velocity vectors as the flow enters and leaves the impeller is shown in Fig. 10. The velocity vectors can be decomposed into absolute velocity ( $V$ ), relative velocity ( $W$ ) and peripheral velocity [13-17]. The velocities fields of the flow inside the impeller at each particle position are visible in Fig. 10 (b).

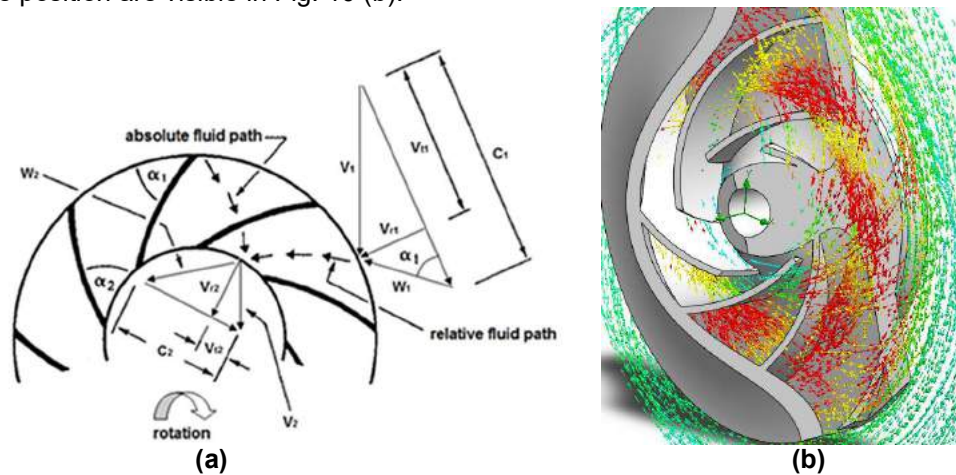


**Fig. 10 – Velocity triangles of the PAT impeller: (a) theoretical [10]; (b) CFD model.**

### 3. RESULTS AND DISCUSSION

Figure 11 shows the head losses achieved in EPANET and CFD models. The pressure distribution of the PAT for 1020 rpm in a cross-section plane of the impeller for  $Q = 3.00$  l/s is shown in Fig.11 (b). The pressure decreases from upstream to downstream as the fluid flows within the domain and along the impeller, from the inner to the outer region, as energy is transmitted to the shaft [11] [12]. As it can be seen, the head losses average given by EPANET from upstream to downstream of the PAT are about 4 m, against to 5.7 m from CFD model and 4.8m from experiments.



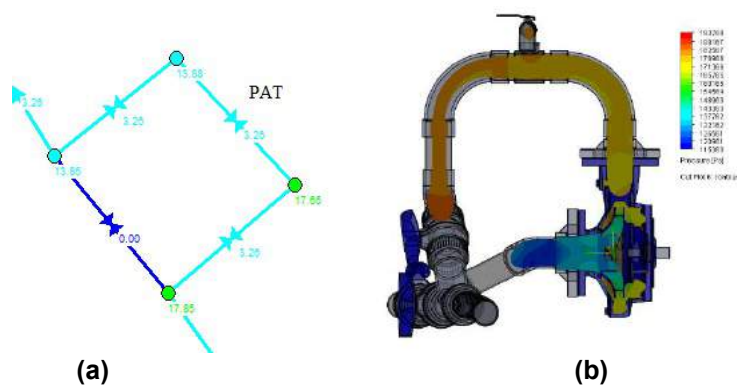


**Fig. 11 – Head losses for N=1020 rpm: (a) EPANET; (b) CFD model.**

For a rotational speed of 1275 rpm and 1500 rpm (Figs.12 and 13), the head losses obtained by each numerical model are similar.

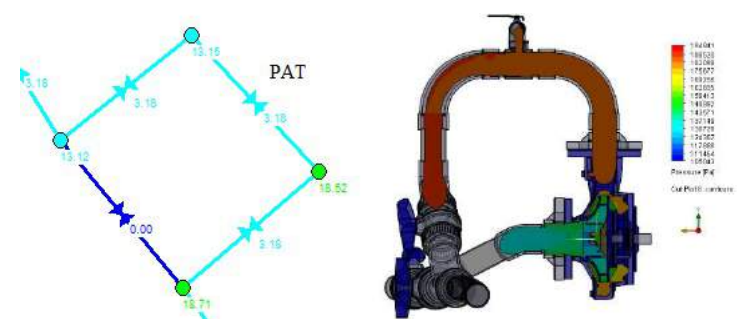


**Fig. 12 – Head losses for N=12750 rpm: (a) EPANET; (b) CFD model.**

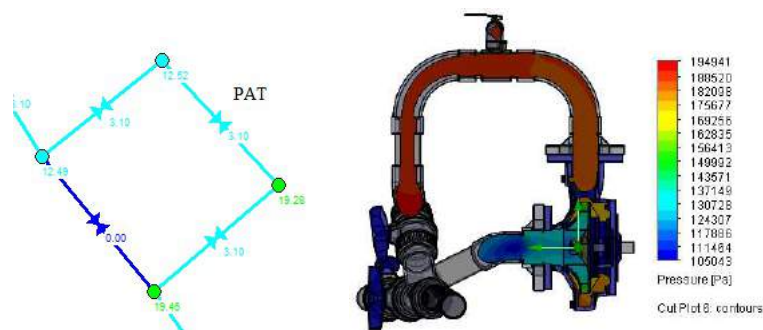


**Fig. 13 – Head losses for N=1500 rpm: (a) EPANET; (b) CFD model.**

## 4. CONCLUSION

This research studied a PAT system both experimentally and numerically to understand the behaviour of the major parameters of the system under different conditions. In this sense, the pressure and velocity values were studied using a 1D simulation in EPANET software and a 3D CFD simulation in FloEFD environment. The EPANET results show good accordance with experiments in terms of pressure in nodes and flow rates in pipes. The system curve calculated based on EPANET simulations demonstrate a reduction of the PAT's net head with the increasing flow rate in all the studied cases. Also, the simulation of the PAT system using a 3D CFD model was addressed in this study. The proposed 3D CFD model gives a complete information about the velocity change in different parts of the PAT including the impeller, and the inner and outer parts of the PAT. The provided velocity streamlines declare the velocity reduction in the upstream vicinity of the PAT and along the impellers. Evident vortices were

also formed in different parts of the PAT which is related to turbulence caused by pressure fluctuations.

The typology of the machine (i.e., specific speed) can influence the percentage of the head drop and the evaluation of local head losses in the simulation period. Nevertheless, this research allowed to identify the head drop in different parts of the PAT domain, for different rotational speeds as well as the velocity fields variation. Aside from geometry differences between CAD and the real PAT, the discrepancies of mechanical losses concerns the scale effect of frictions and bearings, the surface roughness of the tested model, the eventually entrapped air of micro bubbles in the pipe loop system and inside the PAT, responsible for additional turbulence and the swirl effects.

Finally, the PAT's flow and head provided by EPANET and 3D CFD models are quite similar to the experiments showing the ability of both model in analyse accurately.

## ACKNOWLEDGEMENTS

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# Evidence concerning the irrigation of urban green infrastructure using lightly loaded greywater

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## ABSTRACT

Regional, national and societal pressures are increasing with a view towards reducing the use of mains water for the irrigation of urban green infrastructure. The research aimed to separately evaluate the effects upon urban green infrastructure of irrigation using untreated or raw greywater (RGW), irrigation using a mains water comparison and importantly, irrigation using greywater treated using an industrial grade treatment system (TGW). The treatment system is in use in buildings in the City of London and elsewhere. Different mixes of soil and growing media were also included in the methodology.

Some authors have previously investigated, regarding food production and agriculture, the advantages and disadvantages of irrigation using raw greywater. Some results have included evidence showing that applying RGW to the irrigation of soils has led to a detrimental effect upon Soil Water Holding Capacity (SWHC). In the current research, the operational system providing up to 1m<sup>3</sup> of treated greywater per day made possible comparisons of effects upon SWHC produced by the three types of irrigation water. The effects of the three irrigation streams on different soil compositions (50:50, 80:20 and 20:80, as ratios of growing medium to compost) were measured.

The differences between the irrigation systems in their effects upon growing media and composts were found to be small; an adverse impact upon SWHC also arose from mains water irrigation. The results will assist in the forthcoming design of drainage and SUDS systems to support the wider use of lightly loaded greywater for the irrigation of urban green infrastructure.

*Keywords: recycling water for green infrastructure irrigation; greywater irrigation trials; water resource efficiency; irrigation and climate change.*

## 1. INTRODUCTION

Alternative irrigation water sources are needed due to predicted reductions and restrictions in mains water (MW) supplies and changes in rainfall patterns, due to overuse and climate change. Irrigation for green infrastructure systems is necessary for maintaining the maximum benefits from planted features and their irrigation supply technologies. Green infrastructure

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projects are being encouraged in the urban environment to harness their ability to attenuate storm water flowing into or along the urban drainage system, to provide natural aeration and treatment and to divert large volumes away from the main system into a holding basin, or to infiltrate to ground. In the literature, greywater irrigation has been associated with negative changes in soil water holding capacity (SWHC). If this effect were to be significantly observed in green infrastructure in the built environment, this could reduce the benefit of recycling and irrigating using greywater.

The aim was to evaluate the effects of greywater irrigation upon the soil and growing media, using green wall trials (green infrastructure) and laboratory based leachate column tests, including a biochar soil additive. The results would then be applied to the evaluation of the quality of raw greywater (RGW) and treated greywater (TGW) sources that could be used as alternatives to mains water for the irrigation of green wall and other green infrastructure. Chemical tests were also applied to the measurement of effects of greywater irrigation.

The methods for relevant testing were developed in order that the experiments would be repeatable, and to enable the comparison of results obtained with those in the literature. Experiments conducted using a Membrane Bioreactor (MBR) for treated greywater, green wall boxes and leachate columns enhanced the knowledge of; greywater processing and the consequences of greywater irrigation on soils, filtrate water quality and plants. The effects and consequences of the addition of biochar on soil and filtrate water quality were also evaluated.

In 2016, [1] suggested that the hydraulic capacity of soils irrigated with greywater is at risk of surface ponding and increased runoff. If the hydraulic capacity were to decline this gives an indication that the SWHC is also decreasing over time. Already in 2009, [2] had shown that compacted and loose soil irrigated with rain water also showed a progressive reduction in the SWHC. Then in 2010, [3] reported that the soil water retention of soils irrigated with greywater or surfactant rich water was only significantly affected in one-quarter of the soil samples collected. The literature has therefore offered some conflicting results suggesting different impacts of greywater irrigation on the SWHC.

In [4] in 2011, the addition of biochar to the soil matrix was identified for increasing SWHC. It has also been suggested by [5] in 2006, that the addition of biochar helps soil to retain higher concentrations of soil nutrients due to its large surface area and internal porosity. The presence of both polar and non-polar surface sites enable the biochar to absorb nutrients and organic molecules [6], (2010).

It is important to evaluate the soil's initial conditions since it is suggested in the literature that RGW can alter soil characteristics due to the elevated concentrations of various constituents including surfactants and salts [7], (2010). The problems include instability in the colloidal systems and pore space clogging [8] (2010). RGW irrigation has been previously reviewed by [9], (2012) with contrasting views whereby some suggest that there would be no detrimental effect of RGW irrigation and some indicating that the soil would be severely affected.

## **2. TEST CONFIGURATIONS, METHODS AND EXPERIMENTAL DETAILS**

### **2.1 General experimental approach**

In order to maintain comparability throughout the research, the RGW was prepared in the laboratory and was then treated using a manufacturer's full-scale greywater treatment plant (Membrane Bioreactor). The RGW recipe was based on the constituents in the standard BS8525:2;2011 [10]. The TGW produced as part of this treatment was used as an irrigation water type as part of the green wall irrigation trials.

On day 352 that the volume of shower gel soap in the synthetic RGW recipe was increased from 8.6 ml to 43 ml per 100 litres. The initial synthetic RGW quality was used for the first 60 days of experimentation and contained 8.6 ml of shower gel per 100 litres. During the last 120 days of the experiment, the synthetic RGW contained 43 ml of shower gel per 100 litres or 50% of the BS recommendation in BS8525:2-2011 [10]. This permitted comparison to be made between the first two months of the experiment and the last four months. The increase

in the proportion of shower gel applied was expected to show whether the shower gel has an immediate or long-term effect on the greywater filtrate quality. Over a longer time period, this would enable an evaluation about whether the increased concentration of shower gel contained in the synthetic RGW could be shown to be associated with any exacerbated detrimental effect on soil nutrient retention; or whether any impact on SWHC could be demonstrated.

An important factor to be considered was whether the irrigation water quality and type would affect soil quality over time. The two components that made up the soil for the green wall tests consisted of a growing medium (GM) and compost (COMP). The GM used was specifically designed for green walls and green roofs and contained a number of components including pumice, crushed brick, lightweight aggregate and expanded clay, with 10% being organic matter. A range of tests were conducted to determine the composition and nutrient concentrations of the GM and COMP.

## 2.2 Experimental Design Variables

### 2.2.1 Soil Water Holding Capacity (SWHC)

From each of the five planting layers in each box, two samples were used to obtain an average SWHC. The soil water holding capacity was used to calculate the water storage capacity of the green wall boxes throughout the experimental period.

Soil Water Holding Capacity (SWHC) was calculated using the following equation (1):

$$SWHC (\%) = \frac{\text{Mass of Drained Soil} - \text{Mass of Oven Dried Soil}}{\text{Mass of Oven Dried Soil}} \times 100$$

Soil samples taken during the tests were used to determine whether the SWHC of the green walls was reduced as a consequence of RGW irrigation and compared to soil taken from boxes irrigated with TGW and with MW.

### 2.2.2 Overview of experimental design variables, summarised in Table 1

The two components that made up the soil for the green wall tests consisted of a growing medium (GM) and compost (COMP). The GM used was specifically designed for green walls and green roofs, containing a number of components including pumice (2.5%), crushed brick (50%), lightweight aggregate (15%), expanded clay (22.5%), and organic matter (10%). The five green wall boxes were split into two groups. The first group of three boxes contained a soil mix of a 50:50 ratio of growing medium:compost based on weight and not volume. These boxes were placed outside, enabling environmental exposure to rainfall, solar radiation, and wind. Weather data were collected using a Reading University weather station.

**Table 1: Summary of green wall soil composition, irrigation and location variables.**

| Box Number | Location                                              | Soil Composition (Growing Medium: Compost) | Irrigation water type |
|------------|-------------------------------------------------------|--------------------------------------------|-----------------------|
| 1          | External location                                     | 50:50                                      | Mains water           |
| 2          | External location                                     | 50:50                                      | Greywater             |
| 3          | External location                                     | 50:50                                      | Treated Greywater     |
| 4          | Internal for 1.5 months; then external for 3.5 months | 80:20                                      | Greywater             |
| 5          | Internal for 1.5 months; then external for 3.5 months | 20:80                                      | Greywater             |

Boxes 1, 2 and 3 were separately irrigated; box 1 using RGW, box 2 using TGW and box 3 using MW. By keeping the soil filling composition the same through these boxes (50:50), the influence of irrigation, and the comparison of chemical, microbiological characteristics and quality of the filtrate water could be assessed. Subsequent soil analysis determined whether the different irrigation water types had influenced the soil chemical composition, nutrient availability and SWHC.

The second group of two green wall boxes, irrigated with synthetic RGW, contained respectively 80:20 and 20:80 ratios of the GM to COMP. These boxes were kept in the glasshouses at the start of the trials, providing relatively controlled environmental conditions. This enabled differences to be noted between the boxes;

- the 20:80 box, having a higher proportion of compost and a better availability of nutrients;
- the 80:20 box due to a higher proportion of growing medium, and relatively poorer availability of nutrients;
- standard industry practice evaluating the 50:50 ratio growing medium:compost ratio.

For the purpose to better represent an actual green wall environmental conditions boxes 4 and 5 was moved to the same location as boxes 1,2 and 3 after 1.5 months. This also allowed for better comparison between all 5 boxes.

No soil changes, top dressing or fertilisation was applied during the 6-month trial period in order to determine the effects of prolonged irrigation using three different water types, and allowing for comparison between them. At the start of the trials and subsequently every 2 months, soil samples were taken for the measurement of chemical parameters, so any change from baseline could be measured. This allowed for a full 180 days of irrigation whilst testing for and comparing any changes in the soils SWHC and nutrient content, and permitting comparison between the effects of different irrigation water composition.

### **2.2.3 Soil composition**

A range of analytical tests were conducted to determine the composition of the GM and COMP media; the nutrient concentrations of the 50:50, 80:20 and 20:80 ratio GM to COMP soils. On the basis of these tests, assumptions were proposed about how the soil composition could affect the leachate water quality following irrigation.

The results were compared to that of [11] who in 1988 presented a table showing an index of phosphorus and potassium concentrations in soils across England and Wales for crop mineral nutrition (**Error! Reference source not found.**). This index was used as a soil nutrition guide as such data is not available for green walls and green roofs. A lower number on the index represents soils that have a low nutritional value. The phosphorus and potassium concentration from the three soil compositions (50:50, 80:20 and 20:80) were placed into show a comparison between the different soil compositions as well as give the soil an index value.

Three 200g soil samples were taken from each of five planting layers from each green wall box. The samples were taken every 60 days during the experimental period. The sampling regime was chosen to determine variances between different box types, for instance the irrigation regime, synthetic RGW, TGW and MW and the difference in soil composition for 50:50, 80:20 and 20:80. In addition, the sampling assessed whether there were detectable differences in pH and plant nutrients between the planting layers (1-5).

## **2.3 Irrigation Water Quality Assessments**

### **2.3.1 Water tests for irrigation and filtrate**

Data were also gathered during the setup and commissioning phases in order to assess the treatment process efficiency for recycling treated greywater (TGW) from raw greywater (RGW). The parameters tested once every seven days included  $\text{PO}_4\text{-P}$ ,  $\text{NO}_3\text{-N}$ , and  $\text{NH}_4\text{-N}$  using an automated colorimetry with a Skalar SAN<sup>++</sup> continuous flow analyser.

Turbidity was tested daily. Weekly testing was conducted for Biochemical Oxygen Demand ( $BOD_5$ ), Chemical Oxygen Demand (COD) and Total Solids (Total Suspended Solids and Total Dissolved Solids).  $BOD_5$  was tested using the SCA Blue Book Method.

$BOD_5$  can be used as a gauge of water treatment effectiveness whether that be a basic treatment method such as a constructed wetland [12], (2001) or a number of more advanced treatment processes [13], (2010) such as physiochemical treatment.

### 2.3.2 Daily turbidity testing

Turbidity is a qualitative characteristic which is related to the concentration of particulate matter obstructing the transmittance of light through a water sample. A low turbidity is associated with clearer water which can be interpreted by the user as better quality. This means that a low turbidity of water samples can be associated with an increased chance of reuse. This view is expressed by [14], (2006) who suggests "The aesthetics of the water to be reused is probably as important because of the perception of the public".

## 2.4 Leachate Column Test Methods

The experimental design obtained data about the effects of firstly, soil additives upon a soil's ability to improve the filtrate water quality; and secondly, how irrigation with RGW may affect the physical properties of the soil.

### 2.4.1 Effects of soil additives upon a soil's ability to improve filtrate water quality

A 90-day irrigation trial using 28 leachate columns was conducted between 25/11/15 and 26/02/16. The experiment was designed to investigate how soil composition (with the addition of biochar) and irrigation water composition (synthetic RGW, MW and TGW) would affect the leachate water quality. The irrigation type, column number, and soil composition including the percentage biochar in the soil can be seen in Table 2. Due to the high profile and current interest in the use of biochar for soil improvement of nutrient retention, carbon sequestration and as an organic resource management tool [4] (2011; [15] 2017; & [16] 2014) biochar was chosen as the primary additive for the experiment.

**Table 2: Leachate Column Experimental Structure: soil make up and irrigation regime.**

| Leachate column | Irrigation regime<br>Irrigation volume 400ml/day | Soil make-up (600g).<br>Ratio of Growing<br>Medium: Compost | Biochar additive<br>(%) |
|-----------------|--------------------------------------------------|-------------------------------------------------------------|-------------------------|
| 1 and 2         | Greywater                                        | 50:50                                                       | 10%                     |
| 3 and 4         | Greywater                                        | 50:50                                                       | 20%                     |
| 5 and 6         | Greywater                                        | 50:50                                                       | 30%                     |
| 7 and 8         | Treated Greywater                                | 50:50                                                       | 10%                     |
| 9 and 10        | Treated Greywater                                | 50:50                                                       | 20%                     |
| 11 and 12       | Treated Greywater                                | 50:50                                                       | 30%                     |
| 13 and 14       | Mains Water                                      | 50:50                                                       | 10%                     |
| 15 and 16       | Mains Water                                      | 50:50                                                       | 20%                     |
| 17 and 18       | Mains Water                                      | 50:50                                                       | 30%                     |
| 19 and 20       | Greywater                                        | 50:50                                                       | 0%                      |
| 21 and 22       | Treated Greywater                                | 50:50                                                       | 0%                      |
| 23 and 24       | Mains Water                                      | 50:50                                                       | 0%                      |
| 25 and 26       | Greywater                                        | 80:20                                                       | 0%                      |
| 27 and 28       | Greywater                                        | 20:80                                                       | 0%                      |

The leachate columns were irrigated with 400ml of the respective waters daily. The irrigation was conducted over a 1 hour period. 400ml was used as an irrigation volume since this gave sufficient concentrations of leachate water for all required testing. All filtrate water was collected in jars beneath the columns before analysis. The water quality testing schedule and procedure for samples collected from the leachate columns was the same as those of the

MBR and the green wall boxes. For example, pH and dissolved oxygen testing was conducted once per day Monday to Friday and nutrient analysis of phosphorus and nitrate was conducted once per week on a Wednesday. Tests conducted daily from Monday to Friday, included pH, EC, dissolved oxygen and turbidity. Tests conducted once per week on a Wednesday consisted of nitrate, phosphate, ammonia, sodium, potassium and total solids. Microbiological analysis was undertaken on a Wednesday every two weeks. Bacteria tested included, E-coli enterococci total coliforms and *Pseudomonas aeruginosa*.

The soils in the leachate columns were tested on Day 1 and Day 90. The initial soil analysis determined nutrient concentrations and obtained a baseline prior to the programme of irrigation using different types of soil. Soils were tested for regular soil condition parameters including pH, sodium, potassium, nitrate, phosphate and ammonia. The SWHC was also tested to determine whether the soil additive (biochar) would affect the initial SWHC. SWHC was tested on day 1 and day 90 to establish if a particular water type had any effect on the SWHC during the experimental period.

The concentrations of 10%, 20% and 30% biochar were selected to determine the effects of the range from relatively low to relatively high biochar proportions in the soil, providing a range comparable with the literature. Results presented by [14], 2011, propose that the use of 7% biochar resulted in an increase of water holding capacity by 4.4% and numerous other soil nutrient benefits with a lower concentration of nutrients being detected in the leachate water samples.

### 3. RESULTS AND DISCUSSION

Each green wall box was irrigated between Monday to Friday with 100 litres of irrigation water per week. The supplier suggested that for the 1m<sup>2</sup> green wall boxes, 1 to 2.5 litres of water would be supplied per day dependent on the plants and soils in the system. This meant that the green walls were supplied with between 8 and 20 times the volume of water that a regular green roof installation would receive when irrigated with rainfall alone. One reason for applying a relatively large volume of greywater and mains water was that it introduced an additional stress factor reflective of in situ, aggregated volumes of irrigation water that could be experienced given prolonged periods of RGW irrigation.

#### 3.1 Characteristics of soils in the wall boxes

The soil analysis showed distinct differences between the 50:50, 80:20 and 20:80 soils, with regard to nutrient concentrations. As the proportions of compost in the soil were increased, higher concentrations of both phosphorus and potassium in the leachate were observed. This gave agricultural nutrient indices of 6, 7 and 8 respectively, for the 80:20, 50:50 and 20:80 (GM:COMP) soils.

#### 3.2 Comparison of irrigation of Boxes 1, 2 and 3 having a 50:50 soil ratio composition

Over the six-month experimental period (day 296 to 478), soil samples were collected every 8 weeks from all 5 planting layers in each green wall. The average soil pH of aggregated samples from each box showed changes from 5.69 in all boxes to 7.04 (1), 7.31(2) and 7.32 (3) respectively from day 296 to day 408. From day 408 to 478 the pH of boxes 1, 2 and 3 was more stable and only changed slightly to 7.23, 7.21 and 7.24 respectively.

##### 3.2.1 Soil pH variability

The results from soil collection between day 296 and day 352 showed that the irrigation water had increased the soil pH by almost 1pH in boxes 1, 2 and 3. Interestingly, this effect did not vary between the different irrigation waters applied, with all boxes having soil pH results within 0.1pH of each other between days 296 to 408. The pH of the soil in box 1 on day 408 deviated from the pH of the other boxes, with a pH 0.26 lower. The results show that after 6 months of irrigation with different water qualities that there was little difference in the soil pH, at pH 0.26. In all cases, the pH of the soil was changing from being slightly acidic to more neutral. Careful selection of the RGW source will be important in future to match the species grown with the source of the greywater.

The results provide evidence that synthetic RGW had an effect on the soil pH, and it was similar to that of both TGW and MW irrigated systems. Results presented by [17], (2010)

contrast with the results from our research. [17], (2010) found that using RGW for irrigation led to a significant increase in soil pH when compared to MW-irrigation. However, the RGW used in Pinto's study had an average pH of 10.5, which is not a pH that has been observed or reported within domestic greywaters in the UK.

When considering the use of RGW for irrigation, the source of the water should be considered before reuse, due to potential influences upon the pH of the reuse water.

### **3.2.2 Water holding capacity of the boxes**

The soil water-holding capacity of boxes 1, 2 and 3 was evaluated over the course of the experimental period (day 296 to 478); four sets of soil samples were collected. Since the soil composition was the same, all three boxes start at the same point on the graph, and decline over the experimental period. As soils settle and smaller particles filled some of the pore spaces, the holding capacity will naturally decrease. This is also a factor of compression [2], (2009). The results show that over the first two months (day 296 to 352) there was no difference between the synthetic RGW and MW irrigated boxes, indicating that there was little impact of synthetic RGW irrigation over this short term period. The TGW irrigated box (3); declined in SWHC the greatest over the first two months reducing to 96%. This may not be due to the irrigation water quality but small particles filling pore spaces or compression of the soil matrix. Over the 2-4 month period, there was a greater decline in the SWHC of the synthetic RGW irrigated box (2). This decline may be associated with the build-up of surfactants contained in the RGW. However, since all boxes declined in SWHC it was not possible to suggest that this decline was associated directly with the synthetic RGW, and it is notable that in all cases, mains water was the underlying carrier.

At the end of the experimental period, the SWHC of the three boxes was in the range of 77% and 81%, thus the lost percentage SWHC was 23.1%, 23.8% and 20.4% for boxes 1, 2 and 3 respectively. This result indicated that when the SWHC of RGW irrigated boxes was compared to MW and TGW irrigated boxes, there was no identifiable impact on the SWHC caused by the synthetic RGW during six-months. The TGW irrigated box 3 had the highest SWHC at the end of the experimental period, though the differences between the boxes was small.

### **3.2.3 Effects of biochar addition**

The addition of biochar to the soil in the leachate columns increased the pH but not substantially (pH 0.3 to 0.4). A combination of soil, biochar and irrigation water quality all appeared to affect the pH of filtrate water, but it was difficult to suggest to what degree as the pH differences between the columns were low. Soil pH increased over the experimental period. The columns that contained biochar increased slightly more than those containing no biochar (<1pH). The results have shown that the addition of biochar had little effect on the pH of the filtrate and soil. They also show that the RGW irrigation did not cause a greater effect when compared to TGW and MW irrigation. However, at the end of the experimental period it was seen that the columns that contained the highest amount biochar also had the largest percentage loss in SWHC.

### **3.2.4 Nitrogen concentrations**

Figure 5 depicts the soil nitrogen concentrations over the experimental period of boxes that were all irrigated with synthetic RGW, and that contained different soil compositions (box 2 50:50-soil, box 4 80:20-soil and box 5 20:80-soil). Initially, the results show that box 5, containing higher volumes of compost, resulted in higher nitrogen concentrations. Over the first 2 months (Day 296 to 352), the results suggest that box 4 containing higher volumes of the growing medium decreased in soil nitrogen concentrations by the lowest amount (5.7 mg/kg). The other two boxes have a sharper decline in the nitrogen concentration falling by 20.63 mg/kg (2) and 17.87 mg/kg (5). The third sampling on 23/12/15 shows that both boxes 2 and 5 have increased concentrations of nitrogen from 5.63 mg/kg and 15.36 mg/kg on day 352 to 33.11 mg/kg and 50.25 mg/kg respectively. However, box 4 continued to decrease by another 9.43 mg/kg. The soil nitrogen concentrations of all boxes 2, 4 and 5 end at around the same concentrations 4.65 mg/kg, 2.33 mg/kg and 5.21 mg/kg respectively. There were still small differences in the nitrogen concentrations between boxes which replicates what



happened on the first day of the experiment (02/09/15) whereby as the concentration of compost increased, nitrogen concentration also increased.

The results from boxes 1, 2, 3 and 5 showed that there was a peak in nitrogen concentrations in soil taken on day 408 not shown in box 4. One component of these boxes that differed from that of box 4 was that the compost concentrations were high at 50% and 80% of the soil mix. So the compost was affecting the nitrogen storage in the soil, explaining some of the variability, whereas the nitrogen concentrations in box 4 continued to decrease from the initial concentrations. This suggested that the storage mechanism was less evident when concentrations of compost in the soil mix were at 20%. [21] (1997) suggested that building a soil nitrogen reserve necessitates a focus on organic matter as it is a principle reserve of nitrogen. Since nutrients are lost through leaching, careful consideration should be given to fertiliser application for planted green infrastructure due to the downward trend in nitrogen concentration, which can be very low after the initial six-month period.

While greywater irrigation can cause minor detrimental effects upon soils, soils and planting media that are replaced on a regular cycle are unlikely to show adverse effects. Where soil replacement is not feasible, pragmatic decisions will be made regarding plant selection. The benefit of sustaining the green infrastructure planting for climate amelioration during periods of drought, in many locations, will be a predominant resource driver and benefit in future.

#### 4. CONCLUSIONS

Alternative irrigation water sources are needed due to predicted reductions and restrictions in mains water (MW) supplies and changes in rainfall patterns, overuse and climate change. Irrigation of green infrastructure systems is necessary for maintaining the maximum benefits that can be gained from planted areas in the urban environment, which will become increasingly dependent upon successful irrigation supply and recycling technologies.

The research evaluated the effects of greywater irrigation upon soil and growing media, in the context of green wall trials. Laboratory based leachate column tests that included a biochar soil additive, were also undertaken. The results showed that, following irrigation with treated and untreated greywater, and using drinking water irrigation as a control in all the tests, the difference in resultant soil constitution between using TGW and MW for irrigation was small. The effects recorded using RGW were only marginally less desirable in soil quality terms than using TGW and MW. The small changes in soil quality fell within statistical confidence levels; thus, evidencing that using lightly loaded greywater for irrigation of urban green infrastructure was confirmed to have relatively limited negative impacts, whilst harnessing the positive benefits at the same time. Future research will be required to show whether there may be any increasing effects using longer term irrigation, and irrigation systems themselves will continue to receive further development and innovation.

The methods for testing the greywater were developed in order that the experiments would be repeatable, and to enable the comparison of results with those in the literature. The effects and consequences of the addition of biochar on soil and filtrate water quality were also evaluated. In [4] in 2011, the addition of biochar to the soil matrix was identified for increasing SWHC, and in 2006, [5] reported that biochar helps soil to retain higher concentrations of soil nutrients due to its large surface area and internal porosity. However, those observations have not been replicated in this research. Where soil replacement is not easily accessible following long term irrigation by greywater, pragmatic decisions regarding plant selection will help to moderate replanting regimes. The benefit of sustaining the green infrastructure planting for climate amelioration during periods of drought, in many locations, will be a predominant resource driver and benefit in future.

Initially, the soils containing higher compost mass exhibited higher nutrient concentrations. Whilst this difference reduced slightly during the experimental period, as concentrations of nutrients became leached and absorbed by the vegetation, at the end of the experimental period, distinct differences in the soil nutrient concentrations were still visible between the green wall boxes. Thus, the box containing the highest compost concentrations at the start, continued to contain the largest concentration of nutrients.

While lightly-loaded greywater irrigation can cause minor detrimental effects upon soils, the benefits of using such water sources for irrigation is of increasing importance. Pragmatic decisions will be made in situ regarding plant selection and irrigation technologies. The benefit of sustaining green infrastructure planting using treated greywater during periods of drought in many locations, will be a predominant resource driver and benefit in future.

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# #5. Water governance and policy + Smart systems and cities

# Unfair water charging in the UK? ...or why Germany is ahead in SuDS

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## ABSTRACT

This paper reviews how in Germany changes to the charging methods for surface water drainage led to the introduction and rapid development of sustainable drainage features (SuDS) such as rainwater harvesting, green roofs and impermeable pavements.

The German success should be considered a call for reviewing the application of existing surface water drainage charges in the UK and strengthen the debate whether these charges are cost reflective, transparent and socially just.

In addition, the paper shows how a split and cost reflective charge (separation of surface water and wastewater charge) based on a more accurate surrogate for surface water discharged, i.e. the surface area of the connected site, would be a significant driver for SuDS features in the UK that are now being called for by politicians, councils and planning authorities.

As the German example shows, the introduction of a split and cost reflective charge must go hand in hand with the potential for proportional reductions meaning not only when a site is completely disconnected from the public sewer system. These proportional reductions of the surface water drainage charge would incentivise the uptake of SuDS measures in the UK.

*Keywords: surface water drainage, surface water charges, SuDS, split charges*

## 1. INTRODUCTION

The UK has been slow to take up sustainable drainage systems (SuDS), despite their acknowledged multiple environmental, social and economic benefits. Some new developments are starting to include SuDS feature as part of their planning consent, primarily to reduce their impact on existing wastewater networks and the water environment. However, there is little incentive on other major dischargers of surface water to change their practice or mitigate their impact.

Germany is significantly ahead of the UK in the development and use of SuDS features. This is down to a recent challenge to the historic basis of charging for surface water drainage by a green organisation. This challenge was accepted, and the Courts ruled the then basis of charging was against the principles of the German Constitution. This led to a nationwide change in charging for surface water drainage, based not on the metered supply of potable water to the property, but to a more cost reflective approach, based on site surface area.

This paper explores the rationale for the change in Germany, how it came about and lessons learned. Significantly it also highlights the beneficial impact the change had on reducing the impermeable areas connected to the wastewater network and the increased uptake of SuDS features in Germany.

As was the case in Germany, in the UK there are similar historic, but mixed, charging arrangements for surface water drainage, most of these not reflecting the actual costs incurred by discharge to the public wastewater network. The paper considers how a change to a more cost reflective, transparent and understandable charge basis in the UK, based on experience from Germany, would provide a positive incentive to reducing the impact of surface water on the public wastewater networks and a greater uptake of SuDS features.

## **2. THE BEGINNING FOR A SIGNIFICANT SUDS DRIVER IN GERMANY**

Surface water is considered to be part of the sewage. In Germany sewage is separated into three categories:

- 1) Waste water
- 2) Surface water from properties
- 3) Surface water from public roads and highways

The individual states in Germany are responsible for the disposal of sewage. This responsibility is passed on to the communities (§56 Abs. 1 des Wasserhaushaltsgesetzes i.V.m. den jeweiligen Landesgesetzen). For properties, the owner is responsible for the cost of sewage disposal. The communities are obliged to charge for the incurred cost according to the equality principle manifested in the German constitution.

In the past this was based on the “modified fresh water measurement” (modifizierter Frischwassermasstab). This means the mains potable water intake via the water meter is used to determine the cost allocation for the sewage and surface water disposal – as per most UK practice.

In early 2000 a green organisation called BUND (Federation for environment and nature conservation NRW Germany) supported individual court cases claiming unfair charging against communities/water companies and called for a split charge.

The BUND had done research on costs incurred by water companies for waste and surface water disposal. The research showed that surface water disposal was a significant element of the cost. This led to the conclusion that charging for surface water indirectly via the mains water supply meter did not reflect the costs generated by the real polluter.

The court ruling led to nationwide change in charging which created a driver/ financial incentive to invest in SuDS.

The following will explain the reasons for the need of a split charge. It will discuss the potential barriers and show the way the split charges were introduced as well as the results it produced.

## **3. RESULTS AND DISCUSSION**

### **3.1 Sewage charges based on mains water consumption**

In Germany there are currently two accepted methods of calculating the surface water charges:

- a) Charges according to ‘modified fresh water measurement’:

In this case the sewage and surface water disposal charges are determined by the usage of mains water recorded via the mains water meter and charged accordingly.

- b) Split sewage charge:

This method separates the sewage disposal charge from the surface water charge.

The sewage disposal charge is determined by the mains water meter and the surface water charge by the impermeable surface area connected to the surface water drain. Both methods using a probability measurement (indirect measurement) to determine the cost allocation. Real measurements i.e. actual measurements are not possible because in addition to the exact volume of sewage the level of pollution would have to be measured as well.

The “modified fresh water measurement” assumes a “homogenous settlement structure” meaning that the ratio between covered / impermeable surface of the disposal area (catchment area connected to the public sewer) and the mains water quantity of the same area is fairly constant. This is questionable due to today’s living habits which are characterised by significantly different lifestyles and practices in individual properties.

### 3.1.1 Case study

The BUND undertook a research for the city of Lemgo in Germany. At first 300 and later 530 households in a new housing development of the city of Lemgo were considered. Comparing the 530 households to the 300 showed that there was no significant difference and that the results were consistent and representative.

It showed that even with a homogenous settlement structure, there are significant differences in the mains water consumption between similar size properties. This leads to unjust sewage charges using the “modified fresh water measurement”.

The research used the actual charges invoiced by the city of Lemgo based on the split sewage charges and the total achieved revenue from this approach. The total revenue from the surface water charges (based on an assumed surface area of 145m<sup>2</sup> per property) and sewage water charges were used to compare charges that would be determined when using the “modified fresh water measurement”.

The result showed that low water users, up to 75m<sup>3</sup> per annum, pay much more for surface water drainage when using the split sewage charges compared to users above 150m<sup>3</sup>.

The assumption that ratio between covered / impermeable surface of the disposal area and the mains water quantity of the same area is constant could not be confirmed (see Table 1).

**Table 1: Household water consumption**

| Consumption in m3 |      | Households |      | Avg. Consumption   |
|-------------------|------|------------|------|--------------------|
| Level             | Avg. | Number     | %    | Household total m3 |
| 0-25              | 13   | 19         | 3.6  | 247                |
| 25-50             | 38   | 53         | 10   | 2,014              |
| 50-75             | 63   | 72         | 13.6 | 4,536              |
| 75-100            | 88   | 114        | 21.5 | 10,032             |
| 100-125           | 113  | 96         | 18.1 | 10,848             |
| 125-150           | 138  | 65         | 12.3 | 8,970              |
| 150-175           | 163  | 38         | 7.2  | 6,194              |
| 175-200           | 188  | 36         | 6.8  | 6,768              |
| 200-225           | 213  | 18         | 3.4  | 3,834              |
| 225-250           | 238  | 8          | 1.5  | 1,904              |
| 250-300           | 275  | 11         | 2.1  | 3,025              |
|                   |      | <b>530</b> |      | <b>58,372</b>      |

The figures in table 2 and 3 show that the living space per person declines with increasing number of persons in the household. The 1 and 2-person households with proportionally large

living space make up almost 70% of all households. Depending on rental or owned living, for one-person households, the living space is 91.4m<sup>2</sup> or 58.7m<sup>2</sup>. If this is compared to 5+ person households the proportionate value is 29.7m<sup>2</sup> or 19.7m<sup>2</sup>. Therefore, one-person households have more than three times the living space per person.

**Table 2: Owned properties (old states of Germany)**

| Number of persons | % of all households | m2 living area per household |       |       | m2 living space per person 1998 |
|-------------------|---------------------|------------------------------|-------|-------|---------------------------------|
|                   |                     | 1978                         | 1993  | 1998  |                                 |
| 1                 | 36.1                | 75                           | 87.4  | 91.4  | 91.4                            |
| 2                 | 33.4                | 92                           | 105.5 | 111.2 | 55.6                            |
| 3                 | 14.7                | 106                          | 119.2 | 124.7 | 41.6                            |
| 4                 | 11.5                | 117                          | 130.2 | 134.6 | 33.7                            |
| 5+                | 4.4                 | 132                          | 146.7 | 148.3 | 29.7                            |

**Table 3: Rental properties (old states of Germany)**

| Number of persons | % of all households | m2 living area per household |      |      | m2 living space per person 1998 |
|-------------------|---------------------|------------------------------|------|------|---------------------------------|
|                   |                     | 1978                         | 1993 | 1998 |                                 |
| 1                 | 36.1                | 52                           | 57.3 | 58.7 | 58.7                            |
| 2                 | 33.4                | 67                           | 72.8 | 75.4 | 37.7                            |
| 3                 | 14.7                | 76                           | 81.7 | 84.2 | 28.1                            |
| 4                 | 11.5                | 11.5                         | 89.3 | 91.4 | 22.9                            |
| 5+                | 4.4                 | 90                           | 96.5 | 98.5 | 19,7                            |

The BUND research concluded there is no relation between living space and covered/impermeable area. Therefore, a homogenous settlement or living space structure cannot be assumed.

### **3.1.2 Differences of rental and owned properties**

In Germany there are roughly 40% owned residential properties. This means that the rental properties have a significant share. These are often in multiple occupancy properties. Their covered/impermeable area with a connection to the sewer is probably much smaller in comparison with single family homes.

Using the “modified fresh water measurement”, lower income occupants living in multi residential buildings are paying relatively far higher for the cost of surface water disposal than the occupants of single family homes. Therefore the charging system is regressive.

This cannot be considered as equal and just according to equality principle of the German Constitution.

There are several other aspects that undermine the assumption of a homogenous settlement structure. The individual financial circumstances determine the style and size of a house and therefore impact on the covered/sealed area in much greater scale than the household size. The tendency to smaller, less expensive, houses and properties also undermines the homogenous settlement structure approach.

Example: Consider an individual decision to either live in a bungalow with 210m<sup>2</sup> covered/impermeable area or a three-storey terraced house with the same amount of living



space with 70m<sup>2</sup> of sealed surface. The size of the driveway or garage are dependent on the building owner and/or building regulations but not on the number of persons in the household. Any decision to fully or partly unseal impermeable surface areas also depends on the individuals in the household and at new build level, on legal/planning requirements to infiltrate rainwater locally.

Further research and data on mains water consumption has shown that the fluctuation is significant. In Switzerland research has shown fluctuation between 105l/p/d to 225l/p/d. In Dresden Germany research in multi-occupancy residential blocks showed a spread between 15.1l/p/d to 232.4l/p/d.

Therefore homogenous mains water consumption cannot be assumed.

Many more reasons can play a role. Differently equipped households with water efficiency devices will have significant impact on water consumption. In some rental apartment blocks there is only one water meter and the water consumption is allocated based on the square meter of each apartment or occupants per apartment. Research in the State of Hessen have shown that the installation of water meters has reduced water consumption by 20%.

In these cases, the charge for surface water disposal changes but the size of the connected surface area and hence the volume and intensity of surface water discharges to the sewer do not.

All these multiple reasons show that the assumption to use the water consumption as the measurement for the allocation of surface water disposal charges is not justified.

### **3.2 The split sewage charges – economic and ecological questions**

In this section the economic and ecological impact of the split sewage charge will be discussed.

Using the split sewage charges the total charge is separated into separate charges for sewage and surface water disposal and then allocated based on different principles. The charge for sewage disposal is calculated on the basis of mains water consumption and the charge for surface water disposal on the basis of the sealed/covered surface connected to the sewage system. This surface water charge can be reduced where green roofs, rainwater harvesting, rain gardens and permeable pavement etc. is used on the property being charged.

There are however three arguments against changing to the split charging model:

#### **3.2.1 Potential increase of charges for the household**

The BUND undertook a research based on figures from the association of tax payers of the state of North Rhine-Westphalia (Bund fuer Steuerzahler NRW) to understand the impact of the split sewage charge on household bill. Data was based on the years 2000 to 2002. The change to the sewage charges were determined for an average household with 200m<sup>3</sup> of mains water consumption and 130m<sup>2</sup> impermeable surface area pre- and post-switch to split charges. At the same time the change of an average household without impermeable surface connected to sewer (all water infiltrated on site) was calculated.

According to the association of tax payers the standard water charges had changed against the previous year in 2000 by 1.5%; 2001 by 1.8% and 2002 by 2.4%.

The result showed that in 23 cases of changed charges 6 model households showed an increase and 17 showed a decrease. The changes varied between +9.8% to -32.7%. Over the 3 years the study found an overall average decrease in charge to the properties in the study of 9.5% rather than the 'control' increases of 1.5%, 1.8% and 2.4% each year.

The reduction was more significant with model households that were infiltrating the rainwater (= no surface water charges). The changes were between 9.9% and 45.5%. The reason for the

decrease in surface water charges is explained by the fact that supermarkets now pay more due to the large surface area they have connected and other properties which have no water supply now pay surface water charges e.g. park houses and vehicle storage facilities.

Occupants of multi residential buildings approached the same reduction as the model household without surface water charges.

The result shows that large families, environmental conscious citizens who reduce surface water on site through infiltration, rainwater harvesting or permeable surfaces as well as occupants of multi residential buildings, when charged for surface water drainage using the mains water consumption model significantly subsidise companies and households with large surface areas.

### **3.2.1 Cost for the community to introduce and administer the charge**

People opposing the split charge argue that the administration would be prohibitive.

A survey of the BUND in North Rhine-Westphalia (NRW) showed that the cost of introducing the split charge in 32 communities totaling 2,256,300 people varied between 0.28€ to 9.59€ per person with the average being 1.95€. Due to this low cost, the argument was not sufficient in court cases to object to the change in charging.

### **3.2.2 Low surface water disposal cost does not support a change**

Another argument against introducing the charge was that the surface water disposal cost is so low that it does not need separate consideration.

The courts in Germany consider 12% to be the threshold. The German federal office for statistics estimated the proportion for surface water treatment of all public sewage treatment works to be 2.7 billion cubic meter or 29% in 1998. The cost for draining and treating surface water ranges between 20% to 75% of the combined cost for surface and wastewater according to Professor Pecher, sewage cost expert for many German communities.

The above indicated that surface water cost are a significant cost factor and cannot be ignored.

## **3.3 Implementing the new charges**

Due to the court judgements communities were forced to introduce the new charge. The challenge was to find a relatively simple method to collect the data to keep administrative cost to a minimum.

### **3.3.1 Methods of collecting the data and calculation the charge**

Firstly, the communities established surface area categories based on the amount of water the area would discharge in a rainfall event. This is dependent significantly on the type of surface.

The charges are the result of the multiplication between impermeable area and discharge factor of the category.

**Table 4: Example of surface category**

| Surface area category                              | Degree of impermeability |
|----------------------------------------------------|--------------------------|
| typical roof, asphalt, concrete, bitumen           | 90%                      |
| paving blocks, interlocking stones                 | 60%                      |
| lawn, areas with gravel, shingle, lawn grid stones | 30%                      |

Rainwater harvesting would also be accounted for by reducing the total connected area by e.g. 14m<sup>2</sup> when WC are supplied or 8m<sup>2</sup> for irrigation only use.

After the categories were established data of every property had to be collected regarding the amount and type of impermeable area connected to the sewer. Two main methods were used:

#### *3.3.1.1 Aerial pictures and land register*

In this case properties were photographed. The aerial pictures in combination with the land register are used to determine the impermeable area and its type. Based on the data and the surface categories the charge is determined. Once issued, the property owner can query the invoice showing proof that assessment is incorrect e.g. surface water is being infiltrated or rainwater harvesting is installed.

#### *3.3.1.2. Self-assessment*

Property owners are asked to fill in questionnaires to establish the amount of impermeable area and type of area connected to the sewer including the installation of infiltration or rainwater harvesting systems. The bill is issued accordingly. The community would allow for spot checks to verify the reported.

### **3.4 Results in Germany**

The introduction of the surface water charge has had a multitude of impacts. First, it allocates the cost of the surface water disposal according to the “polluter pays principle” and omits the social unfairness in the charging. It creates a financial incentive for unsealing of surfaces areas countering urban creep. It led to the increased uptake of rainwater harvesting, green roofs, rain gardens and other SuDS measures. The reduction in run-off allows the deferral of infrastructure updates or investments into new structures. At the same time combined sewer overflow potential is reduced.

In Munich 4.5M m<sup>2</sup> of impervious surfaces were disconnected from the stormwater system between 1997- 2015 (approximately 240,000 m<sup>2</sup> per year). Given the typical rainfall in Munich, this means that an estimated 3000 Ml of stormwater are now being re-introduced to groundwater, or evaporated to the atmosphere, instead of being transported to the local (combined wastewater and stormwater) treatment plant.

In the city of Dresden, imperviousness per person was reduced significantly from 37m<sup>2</sup> to 33.5m<sup>2</sup> – a 10% reduction. This was achieved despite a population growth of 12% during the same period, and a trend to more detached houses instead of apartments.

In Baden-Wuerttemberg, within 2 years of the introduction of the fee a qualitative survey found that 48% of townships observed some decreases in imperviousness, with 11% reporting a high decrease. The high future potential of the fee leading to further decreases in imperviousness was widely recognised. Initial changes in land holder behaviour have already be observed, particularly businesses changing approaches to paving of car parks and the introduction of green roofs to achieve savings in the imperviousness fee.

### **3.5 The UK Approach**

So how does the UK approach compare and contrast with Germany's?

For simplicity's sake we will only consider England and Scotland, where there are wholesale and retail markets operating for non-household customers. Household customers are supplied and billed directly by the wholesale water and sewerage companies (WaSCs).

The UK situation is in some ways similar to Germany's before the changes brought about by the BUND challenge, i.e. lacking transparency and cost reflectivity and arguably being unfair for some.

Most household customers pay a fixed charge for surface water drainage, irrespective of mains water consumption or size of their property. Where there is no connection from the property to the public sewer network for surface water drainage the WaSC will reduce the charge. Currently this varies between companies from around £20 to £65. One WaSC adopts a different basis with a flat rate charge for detached, semi-detached and 'other' properties. The detached charge is over twice the 'other' charge.

This rest of this paper will focus on the non-household arrangements.

### **3.5.1 Water and sewerage companies approach to surface water drainage for non-household customers**

Eight of the eleven WaSCs, charge for surface water drainage for non-households based on a standard charge, graduated charge or a combination of fixed and graduated or variable charges. Examples include 1) a charge based on rateable value of the property + variable charge depending on supply pipe diameter; 2) a fixed charge plus variable charges based on meter size. Clearly none of these variations are related to the actual or even likely surface water discharge.

Two of these eight WaSCs specifically refer to surface water drainage charges. The first 'does not consider it appropriate to reduce charges where some (but not all) surface water from eligible premises drains to a public sewer.' The second, more helpfully, 'recognises that alternative ways of dealing with surface run-off have an important role to play in encouraging sustainability and strengthening resilience. However, we have not yet put in place a system of applying partial reductions in standard charges as a number of important design and implementation issues are yet to be resolved. These include, but are not limited to, how a reduction in surface water drained to the public sewer can be reliably estimated.'

However, four of the WaSCs charge non-household customers, on the basis of the surface area of the site. Permeable areas, e.g. grassland and gravel areas are excluded from the measured area, provide they account for more than 10% of the total site area. All four companies base their charges on surface area bands, rather than using a unit charge per square metre. These bands vary in number and range. The charges also vary significantly between the four companies for the same site area. For example, for a typical UK supermarket of 25,000m<sup>2</sup> total site area, the charge can vary from one WaSC to a neighbouring WaSC by a factor of 11.

As in Germany, there should be an incentive for non-household customers in those four regions to take steps to a) reduce their surface area – probably not possible taking the supermarket case without losing valuable parking spaces or b) reducing their surface water discharge, either flow rate, total volume or timing of discharge to reduce their impact on the wastewater network.

The latter could be achieved by making use of SuDS features on site and controlling the release of captured surface water until after the storm (attenuation), potentially combined with rainwater harvesting and infiltration, thus reducing the overall volume discharged. However, assuming there is no adjacent watercourse to discharge to, there would still need to be a connection to the wastewater network.

The current issue for these large site-area customers is that 3 of the 4 WaSCs insist on full disconnection of the surface water drainage from the wastewater network before allowing any charge reduction. Ofwat, the economic regulator for the water companies in England and Wales has criticised this approach in the past suggesting it 'binary and inappropriate'. However, current charges schemes still adopt this principle.

Only one WaSC has suggested a more flexible 'partial surface water drainage allowance' where the volume of surface water has been significantly reduced and where this could be demonstrated to their Engineers. One other WaSC, though not one that uses the site-area based charging model has offered the option for non-household customers to be charged by volume of water discharged to the sewer through a wastewater meter.

### **3.5.2 Regulator's view**

Every 5 years Ofwat reviews the water companies' investment programmes, their proposed charges and planned service levels. As part of this Ofwat sets wholesale charging rules that water companies must comply with.

In August 2016 Ofwat set out a consultation on proposed changes to the charging rules. Under charging guidance it stated:

'We are also open to considering wholesale charging rules that will allow for the reduction of charges to recognise retailers taking steps for the purpose of reducing or managing water consumption or the discharge of matter from premises; or retailers taking steps for the purpose of reducing the volume of surface water entering public sewers or the rate at which it does so.'

Ofwat's latest statement on wholesale charging for wastewater for periods beginning April 2018 onwards states:

'Sewerage undertakers must provide for an appropriate reduction in the Wholesale Charges payable for the provision of sewerage services to any Eligible Premises where the sewerage undertaker knows, or should reasonably have known, that surface water does not drain to a public sewer from those premises.'

So, the regulator is not requiring or encouraging the WaSCs to make any consideration of reduced flows or other measures that could be taken by a non-household large site-area customer to mitigate their impact on the public sewer network. This means those customers have no ability, or incentive, to reduce their charges, except by a full disconnection from the public wastewater network, or a reduction in the impermeable area of their site.

The regulator has however required all WaSCs in England, from April 2020 to separate their wholesale charges for the sewerage service into individual charges for the reception, treatment and disposal of:

- Foul water
- Trade effluent
- Surface water draining from premises
- Surface water draining from highways

This may lead to more transparent and cost reflective charging for following years.

In the meantime there is little incentive for large site non-household customers to install new on-site SuDS measures or retrofit existing SuDS systems with the available new technologies that can control and monitor discharges to the wastewater network.

## **4. CONCLUSION**

The paper has shown how, in Germany, the challenge to charges for surface water drainage, by an environmental group, led to a move from a non-transparent, non- cost reflective approach, based on measured mains water consumption to one that reflected the consumer's impact on the sewer network, based on the impermeable surface area of their site. This has led to raised interest from property owners in reducing the discharge of surface water to the public network. This is supported by the increasing disconnection of impervious areas from the public wastewater networks and the increasing number of sustainable drainage systems, rainwater harvesting systems and green roofs being installed in recent years in Germany.

Conversely in the UK there is no support or incentive for those who create the most impact from surface water drainage, to minimise or mitigate that impact on the sewer network and the

environment. This is reflected in the very limited uptake of sustainable drainage systems in the UK.

Introducing a more cost reflective and transparent charging arrangement for surface water drainage by water and sewerage companies, based on site surface area and allowing charge reductions for reductions in discharge, not just complete disconnection, would be an important catalyst for increasing the uptake of sustainable drainage systems in the UK.

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# **Attitudes, Behaviour, and Engagement Toward Water Consumption and Conservation in a Higher Education Setting**

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## **ABSTRACT**

There is a need to develop more nuanced and playfully informed understandings of people's attitudes and behaviour toward water consumption and conservation in particular settings, particularly if we are to design initiatives designed to engage and then change behaviour. The Southeast of England, in the United Kingdom, is an example of a water stressed region where better understandings have a potentially key role to play in helping to tackle the issue of water scarcity through attempts to reduce the personal consumption of water. Therefore, this paper presents the findings of a small-scale research project that sought to playfully engage participants in an exploration of their attitudes and behaviour toward water use in a university setting. In particular, an interactive questionnaire was designed whereby participants were encouraged to give their answers by placing counters in buckets of differently coloured water. From an awareness perspective, the study found that whilst females appeared to be more aware of their water usage, participants in general appeared to be unaware of retro fit programmes design to improve water conservation. As a result of these findings, it is suggested that future education campaigns better reflect the needs of different groups, particularly in communities with highly transient populations, such as those in University towns. From an engagement perspective, the interactive nature of the data collection was noted as appearing to be successful in encouraging engagement over time. In conclusion, it is suggested that such playful approaches to data collection and awareness raising can be a useful in not only engaging but promoting a better understanding and awareness of water usage.

*Keywords: Higher Education, South East England, water attitudes, water behaviour, playful engagement.*

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## 1. INTRODUCTION

Traditionally, and from the perspective of the United Kingdom, water stress has tended to be viewed as being a problem not of ours but of others. However, it is notable that the UK, in particular, the South East of England, suffer from water stress (Environment Agency, 2011; Waterwise, 2009).

Water scarcity has traditionally been tackled by increasingly extracting and storing water for human needs (Butler & Memon, 2005). However, this approach is becoming increasingly unacceptable on sustainability grounds. Therefore, and in an attempt to make our usage of water resources more sustainable, attention is increasingly focusing on better understanding people's usage of and attitudes toward water use, so as to allow us to reduce our usage of water via behaviour change and in so doing make usage more sustainable (Defra, 2008 a and b; Jenkins and Oram, 2013; Jenkins and Pericli, 2014).

Attitudes and behaviour toward water usage can vary from person to person, from community to community, from business to business, and from one point in time to another (see Dietz *et al.*, 1998; Dunlap *et al.*, 2000; Honnold, 1981; Howell & Laska, 1992; Jenkins and Oram, 2013; Jenkins and Pericli, 2014). Therefore, it is imperative that research seeks to not only understand water usage and attitudes in a diverse range of settings, but that it also seeks to capture a changing attitudes overtime and as result of external events that may trigger a shift in understanding and thus resultant attitudes toward water usage.

A multitude of approaches exist to change peoples' usage, attitudes and behaviours toward water usage, with education and retro fit schemes being widely viewed as being key. (CCWater, 2013, Waterwise, 2013, 2016). In particular, education is viewed as being key to changing behaviour, particularly amongst younger age groups due to the belief that pro-environmental behaviours can be embedded more effectively in such groups (House of Lords, 2006; Wymer *et al.*, 2014;). Damerell *et al.* (2013) argue that environmental education is critical in implementing conservation into children at an early age, and by doing this they can change the behaviour of their parents encouraging greater water conservation in the home. While this is supposedly the case for children in primary education, Sammel and McMartin (2014) found that college students knew where their water came from. However, they had a limited idea with regards to water conservation, with many believing that taking shorter showers and turning taps off were not effective strategies to adopt to achieve increased water conservation. However, Bremner and Jordan (2012) found that while there are many educational programmes conducted in schools in the UK, there is very little evidence on whether these programmes are having any effect on children's attitude and behaviour towards water usage as the long-term impact cannot yet be recorded.

Progressing on from schools, Finlay and Massey (2012) suggest that universities are important transformation centres with regard to being drivers for social change. They can act as key places within which to address global issue and facilitate change (Moore, 2005; Clarke and Kouri, 2009). Therefore, and as result of this contention, this study contends that work done by and in universities can play an important role in fostering a positive shift in attitudes and behaviours towards water usage and it's conservation. However, research by Wymer *et al.* (2014), found that messages highlighting how much water is being used in each flat through meter readings, as well as public messages, played an insignificant role in motivating students in taking action to conserve water.

However, previous research by Jennet *et al.* (2016) highlights that approaches that seek to change attitudes and behaviours to promote pro-environmental behaviours, using methods such as leaflets, websites or social media to communicate information to the public and impact are ineffective because they don't promote engagement (see also Froehlich *et al.*, 2010; Owens & Drifill, 2008). Work done by Jannett *et al.* (2016) on 'promoting environmental awareness through playful interactions', using squeeze green balls to help encourage engagement with the issues of climate change, suggests that interactivity is key in encouraging more candidates to partake in a questionnaire and to actively think about their behaviour.

Therefore, it is notable that whilst this study set out to explore student understandings and attitudes towards water use it sought to do so in playful way that promoted increased engagement and discussion (see Section 2 for more information). Using interaction as an element to attract students and staff to answer questions may help in promoting water efficient behaviour and the adoption of pro-



environmental behaviours, with binding communication being argued to create more positive attitude towards conservation (Jannett *et al.*, 2016).

## 2. METHODOLOGY

From an overarching perspective, the research undertaken for this study adopted a qualitative approach that was designed to be interactive and focused on principally exploring the understanding and attitudes of students towards water use and its conservation at the University of Hertfordshire, United Kingdom. Data was collected via the development of an interactive questionnaire approach inspired by the work of Jannett *et al.* (2016), which focused on promoting environmental awareness through play interactions using squeezezy green ball. Therefore, the questionnaire was administered by setting up clear buckets with blue coloured water ranging from light blue to dark blue (see Figure 1). The buckets were used to answer the questions in a multiple-choice format. Different coloured counters were used to differentiate between the genders first (before they were given a fact) and second answers (after they were given a fact). In this instance, female participants were told to use red counters for their first answer and yellow counters for their second answer, whereas males were told to use a blue counter for their first answer and green counters for their second answer. One question per day was asked with a view to enhancing engagement with study to keep it as simple and as quick as possible to engage with.

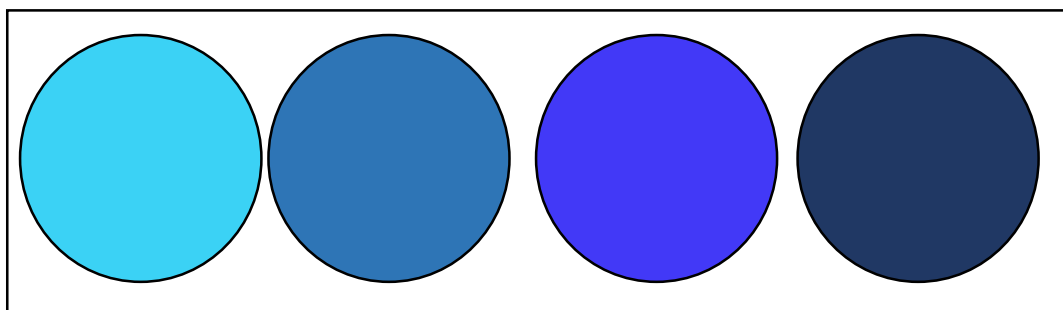


**Fig 1. An illustration of the buckets containing coloured water**

Figure 2 shows the actual set-up of buckets. Forum on day one and plate 2.2 shows the set up on all the other days. The buckets were also labelled in case some participants had visual difficulties and in so doing allow all to participate in the study.



**Fig 2. Photo showing how the buckets were set up on the first day of the questionnaire.**

The questionnaire consisted of asking a question, and then providing an attitude changing fact before asking the question again. The reason why the participant did or did not change their answer was also asked. This was done in order to see whether the attitude and behaviour of the participant had changed once given a fact. The participants were asked their gender (male or female), age, and occupation (staff or student) and then were asked a question about their water usage and behaviour. Table 2 shows the questions that were asked as part of the questionnaire on each day as well as the influencing fact.

**Table 2. Questions asked as part of the questionnaire and the influencing facts relating to them.**

| <b>Day</b> | <b>Question</b>                                                                                                                                                                                              | <b>Influencing fact</b>                                                                                                                                                                                                                                                                | <b>Image associated with the fact</b>                                                      |
|------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------|
| <b>1</b>   | How much water on average do you think a person uses in the UK per day?<br><b>a)10 litres b)50 litres c)100 litres</b><br>Follow up question - Does this encourage you to do more to save water? (Yes or No) | On average, every person in the UK uses 200 filled water bottles– like the one displayed (150 litres) of water per day and this number has been increasing annually by 1% since the 1930's and this number can be cut by a third if water saving devices were used. (Waterwise, 2016). | A pile of many used and disposed plastic bottles.                                          |
| <b>2</b>   | Do you think that the UK has a secured amount of water for the future and therefore can be used in abundance?<br><b>a) Yes b)Not sure c) No</b><br>Question is repeated after fact is given                  | The UK has less water available per person than most other European countries. London is drier than Istanbul. The water we use has a significant carbon footprint contributing to climate change (Waterwise, 2009).                                                                    | Image of Big Ben overlooking the River Thames and an image of the Blue Mosque in Istanbul. |
| <b>3</b>   | Do you consider it important to save water?<br><b>a)Yes b)Not sure c) No</b><br>Question is repeated after fact is given                                                                                     | With continuing population growth, household water demand has been increasing, and therefore there is a need to abstract more water in some areas which is not currently sustainable (Defra <sup>b</sup> , 2008).                                                                      | A crowded street with no space to walk.                                                    |
| <b>4</b>   | Would you consider cutting 1 minute from your shower per day?<br><b>a)Yes b)Not sure c) No</b><br>Question is repeated after fact is given                                                                   | Cutting your shower by a minute a day can save a family of 4 up to £52 per annum (Thames water, 2016).                                                                                                                                                                                 | A showerhead with water coming out.                                                        |
| <b>5</b>   | Did you know that Thames water and Affinity water provide free water saving devices?<br><b>a)Yes b) No</b>                                                                                                   |                                                                                                                                                                                                                                                                                        |                                                                                            |
|            | Would you consider putting water saving devices in your home?<br><b>a)Yes b)Not sure c) No</b><br>Question is repeated after fact is given                                                                   | Retrofitting devices can help save an average of £125 off your water bill per year. Retrofit shower heads can help save £91 per annum<br>Retrofit taps can help save £16 per annum<br>Toilet cisterns can help save £18 per annum (Thames water, 2016).                                | All the water saving devices which are available from Thames and Affinity water.           |

## 4. RESULTS AND DISCUSSION

A total of 414 responses were collected over the duration of a week. Overall, it was found that females were more aware of average water usage. However, it was found that many participants were unaware of retrofit programmes designed to conserve water but willing to consider them in their home after becoming aware of such programmes, suggesting that education and subsequent awareness are crucial to facilitating behavioural change. The interactive nature of study was observed to be beneficial in promoting engagement and thus potentially encouraging behaviour change. To aid discussion of the results, the following discussion has been split into three sub-sections. The first section focuses on water usage awareness and potential behaviour change, with this then being followed by a discussion of the impact the provision of facts and interactivity has on prompting behaviour change. The final section focuses on participants' awareness of retrofit schemes.

### 4.1 Water usage awareness and potential behaviour change

From the data collected and the subsequent analysis, it was found that more female students (17) were accurate about their water usage compared to male students (8), as more thought that the average water use in the UK was 150 litres of water per person per day. This may be due to females using more water than men, as suggested by Tong *et al.* (2017). However, when broken down into occupation. Upon learning about how much water is actually used on average, the majority of participants, 61 out of the 76, said they were encouraged to save water. However, there was a small number of male and female students that said 'no', with these responses being confined to the younger age groups i.e. 18-24 and 25-34-year-olds (see Figure 3.4). This finding is reflective of the work done by Roberts (1996), which suggests that older individuals tend to be more environmentally conscious. However, the results of this study show that both the younger and older individuals are equally environmentally conscious and therefore the work done by Roberts (1996) may be too outdated in comparison to studies done today. Tong *et al.* (2017) found that women were happier to adopt water conservation practices compared to men. However, the results of this study show that males and females are equally happy to adopt water conservation practices; this could be a result of being more aware of reasons to conserve water.

Reasons participants gave for why the fact they were given encouraged them to save water included:

*"water is important for our lives, we need to preserve it"*

and

*"it's a lot of water to use and waste"*

This suggests that the fact given to the participants had somewhat influenced their answer, hence supporting research done by Parant *et al.* (2016) which suggests that binding communication is key in facilitating positive attitude changes.

The reason participants gave for why the fact they were given did not encourage them to save water included:

*"I don't know how to save water"*

and

*"I don't think I use a lot of water"*

The responses highlight that people are aware of the issue with water but could potentially be limited by their poor knowledge of how water can be saved. Potentially, this finding serves to underscore the importance of education programme designed to better inform water users about their water usage and how they can change it.

### 4.2 Facts and interactivity

The study found that factual information, and efforts to enhance engagement, does have the potential to change a person's response and thus potentially their behaviour toward water usage and its conservation. This corresponds to the work done by Parant *et al.* (2016), which found that binding communication is significant in encouraging positive attitudes. It was hypothesised that there would be no statistically significant difference between the answer given by the participant before and after the fact was given. However, through the utilisation of  $\chi^2$  tests, it was found that for three out of the four

questions (see Table 2.1) that were tested found that there was a significant difference between the two responses given by the participants.

In particular, it was found that most participants thought that the UK does not have a secure amount of water that can be used in abundance. It was found that at first, students of both genders had split opinions, however, after being prompted with the fact that the UK had less water than most European countries was given, most participants answered 'no', reinforcing their previous opinion. The 18-24 age group mainly changed their answer after knowing the fact; all other age groups seemed to be more aware. The number of participants that said 'yes' the first time was halved after the fact was given. This suggests that the younger demographic are less aware of the issues surrounding water but are willing to change their attitudes after given, which is similar to the research findings of Roberts (1996). However, unlike his work, it was observed that many participants, mainly 18-24-year-olds would come back each day to learn a new fact about water suggesting that they are environmentally conscious but unaware of the water issue which other studies have not shown.

The reasons participants gave for why the fact changed their answer included:

*"We need to conserve for future generations"*  
and  
*"If population is increasing, we should be more careful"*

This suggests that the fact had a significant impact on the participant's attitude toward water usage the need for its conservation. The results also appear to indicate that binding communication, along with interactivity, is key in the promotion of pro-environmental behaviours as it engages an audience, as suggested by Jannett *et al.* (2016). Furthermore, whilst conducting this study, it was observed that students and staff would come back on consecutive days with colleagues to learn a new fact while remembering facts given on previous days. This suggests that interactivity is key in raising awareness as well as interactivity being a way of making facts given more memorable.

The reasons participants gave for why the fact did not change their answer included:

*"because there is a lot of water"*  
and  
*"I think the government is lying to us to make more money"*

This suggests that participants are aware that there is enough water in the world but they are unaware of its inaccessibility. A participant also thought that it was a way of government making money, suggesting a lack of institutional trust.

It was found that most participants (94%) considered it important to save water, this was then reinforced after the fact was given. It was subsequently found that most participants would consider cutting a minute from their shower per day. It was found more participants said 'yes' after the fact was given to them. It was found that all age groups were encouraged to cut a minute from their shower per day after the fact was given to them. However, some participants still answered 'no' after the fact was given to them. The reasons participants gave for why the fact did not change their answer included:

*"I like showering"*  
and  
*"I'll think about it when and if I ever get a water meter"*

This suggests that although there is a potential to save money, it is not substantial enough for to encourage some individuals to save money as water is seen as an inexpensive commodity.

### 4.3 Awareness of retrofit programmes

It was found that participants were unaware of the retrofit programmes provided by Thames and Affinity water (see Figure 3.12). This suggests that educational programmes provided by water companies have not encouraged the use of water saving devices. However, this could also suggest that not enough visits or programmes are being provided by water companies to make students more aware of water efficient technologies. However, it was found that many would consider adopting water retrofits in their

homes even before they were given the fact. After the fact was given it was found that more participants were more open to the idea of having water retrofits installed in their home. This finding signifies the importance of educating individuals about water efficiency in a setting which promotes higher levels of learning and could also make students identify water conservation as a sustainability initiative, which is something students failed to identify in a study by Cleverdon *et al.* (2017).

The reasons participants gave for why the fact they were given made them consider having water saving devices in their home included:

“To save money and water”  
and  
“it’s a precious resource, we need to save it”

The responses suggest that the fact given to the participants made them realise water is a scarce resource. It can also be noted that saving money is a big encouragement, especially to students when it comes to saving water. Therefore, being able to save money when saving water may lead to greater sustainable water usage by consumers.

## 5. CONCLUSIONS

Attitudes and behaviours are known to be alterable via technology, education and legislation. The Stern review (2007) emphasised the need to educate those currently in education to promote pro-environmental behaviours. It has been argued in this study, and by others, that universities are important transformation centres in regard to driving social change (see Finlay & Massey, 2012).

From the data collected it was found that interactivity combined with factual information had the potential to alter individual’s attitudes and behaviours, therefore, supporting the work done by Jannett *et al.* (2016). It was also found that those in higher education were unaware of retrofit programmes but were willing to consider putting them in their home after participants were given facts. It was also found that females were more aware of their water usage than males, which is supportive of research by Tong *et al.* (2017). The results from this project were significant as they found that attitudes and behaviours can be changed in a higher educational setting if the way of presenting facts and interacting with the consumers is made memorable.

With water becoming an increasingly scarce resource it is clear that being able to alter consumer attitudes and behaviours is important in educational contexts. Therefore, it can be concluded that binding communication and interactivity are essential in achieving pro-environmental behaviours and hence encouraging sustainable water usage in the home. As a result of the findings of this study, it is also suggested that future education campaigns better reflect the needs of different groups, particularly in communities with highly transient populations, such as those in University towns.

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# Resilience of Integrated Urban Water Systems

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## ABSTRACT

Strengthening the resilience of integrated urban water systems (UWS) comprised of water supply and sewer systems against floods and water shortages can be a challenging task. In this paper, a new set of resilience performance indicators is introduced for concurrent assessment of both failure conditions of water shortage and floods in the UWS. A number of potential intervention strategies such as rainwater harvesting (RWH) and greywater recycling (GWR) schemes for enhancement of UWS resilience are evaluated through a conceptual model of urban water metabolism assessment. Modelling of main UWS components is conducted using the WaterMet<sup>2</sup> to simulate the performance of intervention strategies in UWS through urban water metabolism. WaterMet<sup>2</sup> calculates key performance indicators of urban water metabolisms over a long-term planning horizon that can be used to calculate various resilience performance indicators. The demonstration of the suggested approach on a real-world case study reveals how different elements of resilience performance can be improved in the UWS by specific strategies against failure events such as flood and water shortage conditions.

*Keywords: Resilience indices, urban water systems, rainwater harvesting, WaterMet<sup>2</sup>*

## 1. INTRODUCTION

In general, resilience in a system is defined as the system ability to withstand (i.e. absorb and bounce back from) shocks and pressures, whether economic, climatic or demographic in nature. On the other hand, system resistance can be also defined as the ability to prevent system from structural or functional failures [1]. These two complementary concepts need to be considered when designing/retrofitting a system. In particular, resilience in water systems has been interpreted, defined and evaluated by various authors. Since Hashimoto et al. (1982), who initiated the first definition of resilience in water systems, many researchers and practitioners developed multiple definitions for resilience later on [2, 3]. The typical definition for resilience is that how quickly a system can be recovered from a failure/unsatisfactory to normal/satisfactory state [1, 4, 5]. Butler et al. (2017) define the resilience as to minimise the level of service failure magnitude and duration [5]. Regardless of different interpretations of resilience, all this is usually used as performance measure/indicator of sustainability criteria in water systems [4]. Due to different interpretations of resilience in water systems, it should be defined as a multi-component indicator in water systems [6]. Resilience may also be expressed with other indicators (e.g. reliability, robustness, sustainability and vulnerability) to represent the overall system performance. Although most of these performance indicators are seen as separate, they can be sometimes complementary, dependent or conflicting entities [5]. For example, reliability is necessary for resilience but not sufficient and vulnerability can be defined as contrary to resilience [7].

The abovementioned resilience indicators have been defined and applied separately for analysis of intervention strategies implemented in either water supply systems [2, 6, 8, 9] or wastewater/stormwater systems [11, 12, 13]. However, when analysing intervention strategies that may have impact on both water supply and sewer systems (e.g. water recycling schemes), performance assessment of resilience for all components are of paramount importance. In other words, for assessment of intervention strategies in integrated urban water systems (IUWS), resilience should be analysed concurrently for both water supply and sewer systems. For example, both water shortage and flood resilience need to be enhanced simultaneously for many IUWS. Despite a plethora of research works and technical reports related to resilience in water systems, none of them has considered the resilience improvement for IUWS. Drawing upon the various available definitions of resilience, this paper aims to develop new multi-component indicators for resilience that represent a comprehensive picture of resilience in IUWS and evaluate the performance assessment of water shortage and excess runoff (flood) resilience in IUWS for a number of water recycling schemes. The multi-component resilience indicators are estimated by using a conceptual urban water metabolism model called WaterMet<sup>2</sup> to simulate the performance of IUWS [14]. The demonstration of the suggested approach on a real-world case study reveals how the performance of flood and water shortage resilience of IUWS can be evaluated for different strategies which will help decision makers select appropriate strategies that can lead to the resilient IUWS of interest.

## 2. METHODOLOGY

This study uses various concepts of resilience performance assessment of water systems to develop multi-component resilience indicators for concurrent analysis of water recycling intervention strategies that can influence both water supply and sewer systems. This approach is used for performance assessment of water shortage and flood resilience in IUWS. In this study, water shortage resilience is analysed for water supply system under population growth while flood resilience is evaluated for sewer system under standard historic climate. The intervention options analysed here include a number of separate rainwater harvesting (RWH) and greywater recycling (GWR) schemes implemented in IUWS. All this is analysed through an integrated model that incorporates main components of IUWS including water supply and sewer systems. Performance assessment of these interventions in IUWS is undertaken by using the WaterMet<sup>2</sup> model for a long-term planning horizon. Further details of multi-component resilience indicators, the IUWS model, case study and associated assumptions are presented in the next sections.

### 2.1 Multi-component resilience indicators

Most of the references outlined above indicate that resilience concept in urban water systems (UWS) is related to the ability of these systems to recover/return from failure conditions such as excess runoff and water shortage to a normal state. However, interpretation of researchers and practitioners are subtly variant which has led to different indicators for quantifying resilience in the IUWS. For example, some researchers have expanded flood resilience in four capacities 'incorporating the above definition as: 1) to avoid damage; 2) to reduce damage if a flood exceeds a desired threshold; 3) to recover quickly to a normal state, and 4) to adapt to an uncertain future [3]. In other words, this implies that resilient cities are less vulnerable and more resistance against extreme flood events. The same definition can be extended for water shortage resilience.

Based on the definitions in the literature, a multi-component resilience is defined here in Table 1 through six indicators which can be applied to both water supply and sewer systems. These indicators can represent some specific perspectives and interpretations of resilience concept in UWS. The first two resilience indicators are to maximise recovery rate from failure to normal conditions (how quickly the system returns from unsatisfactory to satisfactory state) as indicated in Hashimoto et al. (1982) and Loucks et al. (2005) for water supply system [2, 4]. While the first indicator only focuses on the largest failure duration in a planning period, the second one takes average failure duration in the same period. These indicators partially coincide with the resilience definition of minimising service failure magnitude and duration [5]. Note that failure modes analysed here are functional failure [12] and it occurs when water demand is not fully



met in water supply system or runoff exceeds the sewer capacity in sewer system. It should also be noted that the indicators analysed in this study cannot be exhaustive measuring all aspects of resilience and other resilience indicators can be developed based on social, technical, and socio-technical frameworks of water systems [5,10].

**Table 1. Multi-component resilience indicators in UWS**

| No | Name                        | Water supply system                                                                                                                                                                         | Sewer system                                                                                                                                                                                | Ref.         |
|----|-----------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------|
| 1  | Min recovery rate           | $\frac{1}{\text{Max } T_F}$<br>where $\text{Max } T_F$ = the longest failure duration i.e. time period that water demand is not fully delivered                                             | $\frac{1}{\text{Max } T_F}$<br>where $\text{Max } T_F$ = the longest failure duration i.e. time period that runoff exceeds sewer capacity                                                   | [9,10]       |
| 2  | Average recovery rate       | $\frac{1}{\text{Ave}(T_F)}$<br>where $\text{Ave}(T_F)$ = average failure duration as above over the planning horizon                                                                        | $\frac{1}{\text{Ave}(T_F)}$<br>where $\text{Ave}(T_F)$ = average failure duration as above over the planning horizon                                                                        | [2,4,6,9,10] |
| 3  | Max Severity                | $\text{Max} \left( \frac{D_i - S_i}{D_i} \right) \times 100$<br>if $D_i > S_i$<br>where $S_i$ = water supply at time step $i$ and $D_i$ = water demand at time step $i$                     | $\text{Max} \left( \frac{R_i - C_i}{C_i} \right) \times 100$<br>if $R_i > C_i$<br>where $R_i$ = runoff generated at time step $i$ and $C_i$ = conveyance capacity at time step $i$          | [6,10]       |
| 4  | Average severity            | $\text{Ave} \left( \frac{D_i - S_i}{D_i} \right) \times 100$<br>if $D_i > S_i$<br>as above where average water deficit over the planning horizon is calculated.                             | $\text{Ave} \left( \frac{R_i - C_i}{C_i} \right) \times 100$<br>if $R_i > C_i$<br>as above where average excess runoff over the planning horizon is calculated.                             | [8,10]       |
| 5  | Max volumetric severity     | $\text{Max} \left( \frac{\sum (D_i - S_i)}{\sum D_i} \right) \times 100$<br>if $D_i > S_i$<br>as above where the largest consecutive water deficit is calculated.                           | $\text{Max} \left( \frac{\sum (R_i - C_i)}{\sum C_i} \right) \times 100$<br>if $R_i > C_i$<br>as above where the largest consecutive excess runoff is calculated.                           | [6]          |
| 6  | Average volumetric severity | $\text{Ave} \left( \frac{\sum (D_i - S_i)}{\sum D_i} \right) \times 100$<br>if $D_i > S_i$<br>as above where the average consecutive water deficit over the planning horizon is calculated. | $\text{Ave} \left( \frac{\sum (R_i - C_i)}{\sum C_i} \right) \times 100$<br>if $R_i > C_i$<br>as above where the average consecutive excess runoff over the planning horizon is calculated. | [6]          |

In addition to the first two indicators, the remaining four resilience indicators are introduced to address minimising the service failure magnitude represented as severity [6]. This can be represented in four states including 1) maximum severity in a time step over the planning horizon (#3 in Table 1); 2) average severity of failure throughout the planning horizon (#4); 3) maximum volumetric severity of consecutive failures in time steps (#5); 4) average volumetric severity of consecutive failures throughout the planning horizon (#6). More specifically, the magnitude of water deficit (severity) is considered for resilience metric in water supply system as either maximum single event/consecutive events or average ones over the planning horizon. However, magnitude of excess runoff is considered for resilience metric in sewer system and defined similar to those in water supply system.

All indicators in Table 1 can be calculated by using the time series of water flows in IUWS over its design life. For water supply, required flows include water demand and supply with some periods of water shortage to properly evaluate resilience as the system should be subject to exceptional conditions [5]. The water shortage can be due to either limiting water resources or population growth. For sewer system, the flows required for calculation of resilience indicators are 1) runoff generated in urban areas as a result of rainfall-runoff modelling; 2) conveyance capacity of sewer system. Time series of these basic flows are obtained here from simulation of urban water metabolism performance in IUWS. This is undertaken through WaterMet<sup>2</sup> model which is outlined below.

## 2.2 Urban water metabolism model

WaterMet<sup>2</sup> used here as the urban water metabolism model is a conceptual and mass-balanced-based model for simulation of the performance of IUWS with focus on sustainability-related issues over a long-term planning horizon [14]. The WaterMet<sup>2</sup> model with daily time step tracks down different flows and fluxes (e.g. water, energy, greenhouse gas emissions and materials) within IUWS. The integrated modelling implies the simulation of the key processes and components in urban water services as a complex and interrelated system. WaterMet<sup>2</sup> tracks down water flows both in water supply system from water resources up to water demand profiles and in sewer system from collecting stormwater/wastewater to discharging to receiving water bodies. WaterMet<sup>2</sup> adopts a simplified but distributed approach for conceptual modelling of the main physical UWS components in the main infrastructures of water supply and wastewater including separate/combined sewer networks. WaterMet<sup>2</sup> inherited the mass-balanced and distributed modelling approach from some tools such as UVQ [15] and combined it with industrial ecology based modelling approach. An UWS comprised of three major subsystems (i.e. water supply, stormwater and wastewater) is represented using four spatial scales in WaterMet<sup>2</sup> to simulate the principal flows and processes: (1) System area; (2) Subcatchment area; (3) Local area; (4) Indoor area. The Indoor scale provides the possibility of defining six types of appliances and fittings as (1) hand basin, (2) bath and shower, (3) dishwasher, (4) washing machine, (5) kitchen sink and (6) toilet. As the aim is to support strategic planning, WaterMet<sup>2</sup> adopts a daily simulation time step to track down all the modelled flows/fluxes. Hence, time series-based input data in WaterMet<sup>2</sup> (i.e. weather data and inflow to water resources) need to be provided on a daily basis for the time period being analysed.

All this enables WaterMet<sup>2</sup> to simulate water recycling interventions such as RWH and GWR in which collected rainwater (in RWH) and greywater (in GWR) can be used in water supply system for water demand profiles. WaterMet<sup>2</sup> tracks down daily time series of water demands delivered to customers and runoff generated and excess stormwater overflowed in sewer system over a long-term (e.g. 20-40 years) horizon. These time-series can be used as the basis for calculating different resilience indicators described above. Note that failure durations (e.g. periods that demand is less than supply) lower than the smallest time step of the WaterMet<sup>2</sup> simulation model (i.e. daily) cannot be captured in this study.

## 3 Case Study

### 3.1 Description

The suggested methodology is demonstrated here on a real-world IUWS of a northern European city with highest population growth over a 30 year planning horizon [11, 14]. The real-world IUWS including water supply, wastewater and stormwater collection (combined sewer) systems was modelled here by using the WaterMet<sup>2</sup> tool. The main input data for modelling runoff and water demands in IUWS model are given in Table 2. The key characteristics of the

IUWS and the model calibration procedure can be found in [14]. The performance of two individual intervention strategies including RWH and GWR schemes with different capacities are evaluated in this study and compared with business as usual (BAU) state in which no water recycling schemes are added to the IUWS over the planning horizon. Note that only water recycling interventions are analysed in this study due to their concurrent impact on both water supply and sewer systems compared to other interventions (e.g. additional water resources or treatment works) [11]. For the purpose of performance comparison with BAU, all water recycling interventions are assumed to be available in the analysed capacity from the first year of the planning horizon. The following assumptions are considered for water recycling intervention options.

**Table 2** Input data related to water demands and runoff modelling

| Parameter description                                | Value  | Parameter description            | Value            |
|------------------------------------------------------|--------|----------------------------------|------------------|
| Proportion of roof surface areas                     | 9%     | Number of households             | 160,000          |
| Proportion pavement and road surface areas           | 7%     | Total area of surfaces           | 8450 ha          |
| Proportion of permeable surface areas                | 84%    | Average occupancy per household  | 2.35             |
| Runoff coefficient of impermeable surface areas      | 95%    | Indoor water demand              | 180 L/day/capita |
| Infiltration coefficient for permeable surface areas | 30%    | Industrial water demand          | 27.4 ML/day      |
| Annual average rainfall depth                        | 803 mm | Household garden watering demand | 31.75 ML/day     |

Based on the recommendations for conventional design, the tank capacities of the household RWH schemes are set equal to 3m<sup>3</sup> [16]. The RWH scheme is assumed to collect runoff from roofs, roads and pavements and to supply water for toilet flushing, garden watering and industrial usages. Assuming adoption rate of the RWH scheme of 50% by the households, the IUWS is analysed for four design capacities of RWH. Each design capacity is considered as a percentage of conventional design capacity of RWH outlined above. They include: 1) 10% of full capacity, i.e. 0.048 million cubic metres (MCM) (i.e.  $0.1 \times 160,000 \times 3 \times 10^{-6}$ ); 2) 25% of full capacity, i.e. 0.12 MCM; 3) 50% of full capacity i.e. 0.24 MCM and 4) full (100%) capacity i.e. 0.48 MCM. The GWR scheme is assumed to collect greywater (i.e. from the hand basin, dishwasher, shower, washing machine and frost tapping) and treated greywater is used for the provision of toilet flushing, household garden watering and industrial uses. Similarly, a single representative GWR scheme assuming 50% of household adopting this scheme is analysed for the following capacities (similar to RWH as percentage to conventional design capacity): 1) 9,750 m<sup>3</sup>; 2) 19,500 m<sup>3</sup>; 3) 39,000 m<sup>3</sup> and 4) 78,000 m<sup>3</sup>.

### 3.2. Results and Discussion

The IUWS is first modelled by WaterMet<sup>2</sup> and calibrated by historic measurement data in water supply and sewer systems [14]. Then, it is simulated for the BAU state for a period of 30 years with daily time step and highest rate of population growth. Due to increasing water demand over the planning horizon and limited water resources, water supply system in the BAU encounters unmet water demand which is rather small in the first years but increases up to 27% water deficit towards the end of the planning horizon. Sewer system under historic rainfall data

also encounters excess runoff over the planning horizon. Following this, the two water recycling intervention strategies (RWH and GWR) with different capacities outlined above are simulated and all resilience indicators introduced here are calculated and compared in Figs. 1 and 2.

Fig. 1 presents the recovery rate resilience indicators for 9 strategies including (1) BAU, (2) RWH (with capacity of 0.048MCM), (3) RWH (0.12MCM), (4) RWH (0.24MCM), (5) RWH (0.48MCM), (6) GWR (0.00975MCM), (7) GWR (0.0195MCM), (8) GWR (0.039MCM), (9) GWR (0.078MCM) for water supply and sewer systems. The best minimum recovery rate for water supply system is GWR strategy with capacity of 0.078MCM which is able to reduce the largest failure duration from 4421 days in BAU to 336 days. It should be noted that this reduced failure duration (i.e. 336 days) cannot be acceptable in practice and hence other measures need to be added to this strategy. The next most resilient strategy with respect to this indicator is RWH strategies (0.24MCM and 0.48MCM) with 539 days of demand failure. However, when comparing the average recovery rate, RWH strategies (0.24MCM and 0.48MCM) with average 20 days of demand failure are the most resilient ones (compared with 71 days of the BAU) followed by strategies of GWR (0.078MCM) and RWH (0.12MCM) with 21 days of failure duration. This indicates most of RWH strategies with enough capacities generally outperform GWR strategies in water supply system. On the other hand, improvement of resilience performance of recovery rate in sewer system is modest in all analysed strategies relative to the BAU. This is observed in the reduction of maximum failure duration of excess runoff by 1 or 2 days only compared to 10 days of failure duration in the BAU (i.e. 0.1 recovery rate) and only less than 0.1 days in reduction of average failure duration. Such a trivial improvement can be linked to the fact that this maximum failure duration only happens in the late periods of the analysing period when the highest population reaches in UWS. This shows temporally appropriate and additional interventions should be taken for that period to substantially reduce such large resilience failures.

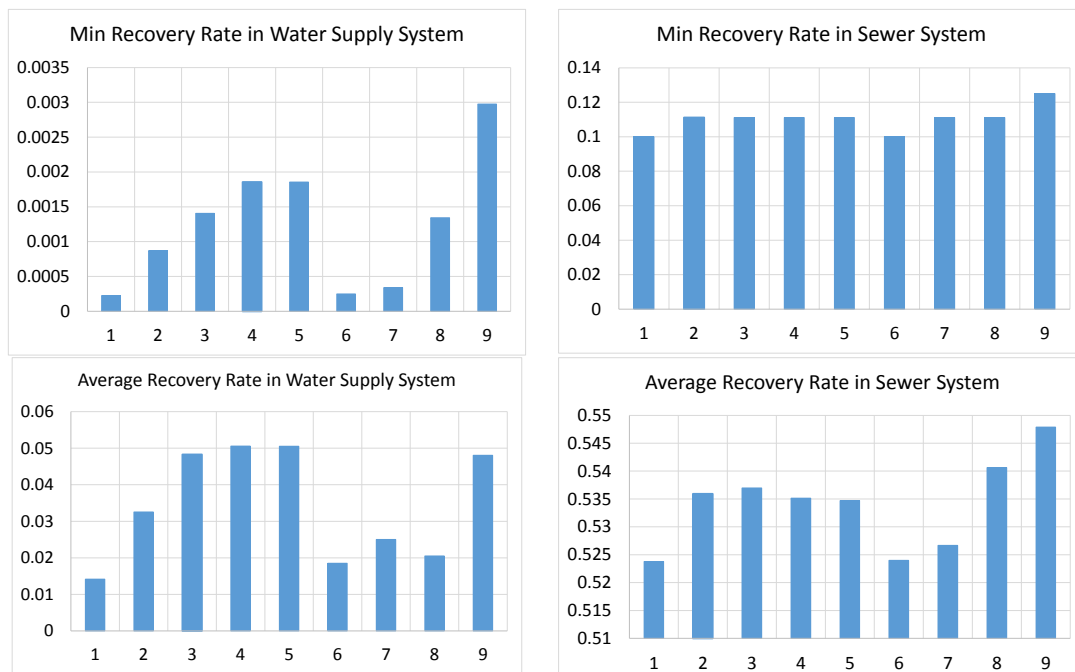


**Fig. 1. Recovery rate resilience indicators of different strategies: (1) BAU; (2) RWH(0.048MCM); (3) RWH(0.12MCM); (4) RWH(0.24MCM); (5) RWH(0.48MCM); (6) GWR(0.00975MCM); (7) GWR(0.0195MCM); (8) GWR(0.039MCM); (9) GWR(0.078MCM).**

Fig. 2 shows the performance of strategies for resilience indicators that minimise IUWS failure magnitude (severity). All water recycling strategies have a relatively small impact on improvement of max severity in water supply system (up to 21% reduction for GWR strategy with 0.078MCM) compared to more considerable impact on average severity (up to 43% for the same strategy, i.e. GWR with 0.078MCM). Whilst GWR strategy with 0.078 MCM (#9) is the most resilient one with respect to maximum and average severity in water supply system, the best resilience in sewer system based on the same indicators is RWH strategy with 0.48MCM (#5). The same trends are in place between strategies for resilience based on maximum and average volume severity. In other words, performance of RWH strategies in this study seems to outperform GWR ones for reduction in all aspects of failure magnitude (severity) in sewer system while GWR strategies have relatively better performance in water supply system. It should also be noted that these strategies per se are unable to achieve sustainable IWUS with respect to resilience indicators without having new interventions in appropriate times.

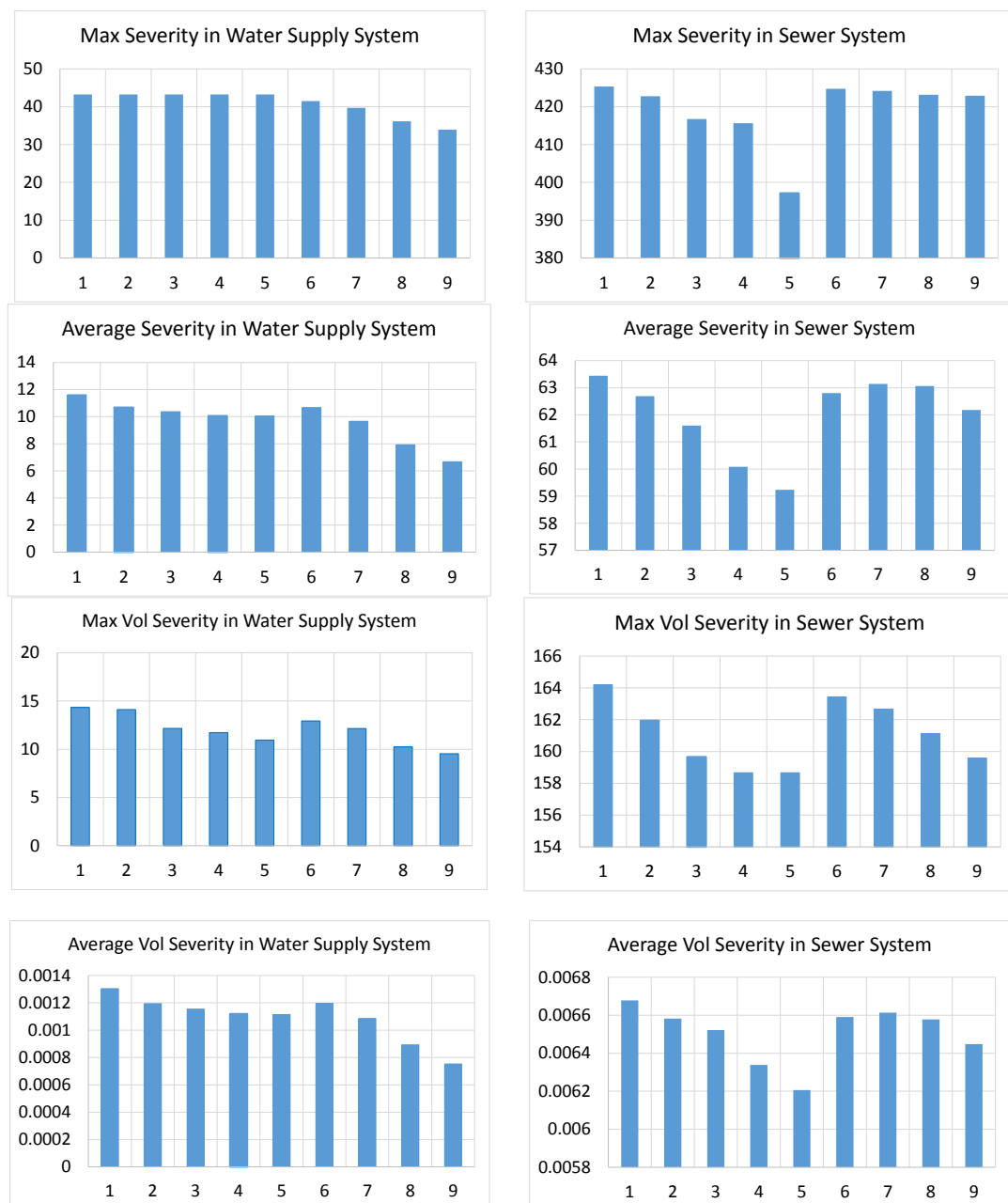


**Fig. 2. Severity-related resilience indicators (%) of different strategies: (1) BAU; (2) RWH(0.048MCM); (3) RWH(0.12MCM); (4) RWH(0.24MCM); (5) RWH(0.48MCM); (6) GWR(0.00975MCM); (7) GWR(0.0195MCM); (8) GWR(0.039MCM); (9) GWR(0.078MCM).**

Figs. 3 and 4 show the daily variations between runoff generated and capacity of sewer system over the first five years (Fig. 3) and between water demand and supply over the simulation period (Fig. 4) in three strategies including BAU, RWH with 0.48MCM and GWR with 0.078MCM. By comparing the runoff generated in water recycling strategies, it is evident that the RWH strategy can absorb more runoff due to its larger capacity relative to the GWR strategy that reduces sanitary sewage discharge into combined sewer system. This enables the RWH strategy to withstand some small excess runoff events that normally occur in the BAU. It should be noted that the conveyance capacity of sewer system is defined here as a function of available volume ( $V$ ) i.e.  $Q=a \times V^b$  [14] and hence conveyance capacity at each time step is variable depending on the water volume in sewer system at that time step. Generally, the daily conveyance capacity is reduced after a rainy day as it is part full. Other potential interventions to increase the resilience of sewer system can be suggested as adding on-line and off-line storage capacity to the sewer system. In addition, comparing water recycling strategies with the BAU for water demand/supply variations show that the GWR strategy is able to better resist small shocks of unmet demand in early years and reduce the failure magnitude during large shocks towards the end of the planning horizon. This can be due to the fact that periods of collected rainwater (i.e. rainy season) do not exactly match the periods of unmet demand (i.e. dry season) although the capacity of the RWH strategy is much larger than that in the GWR strategy.

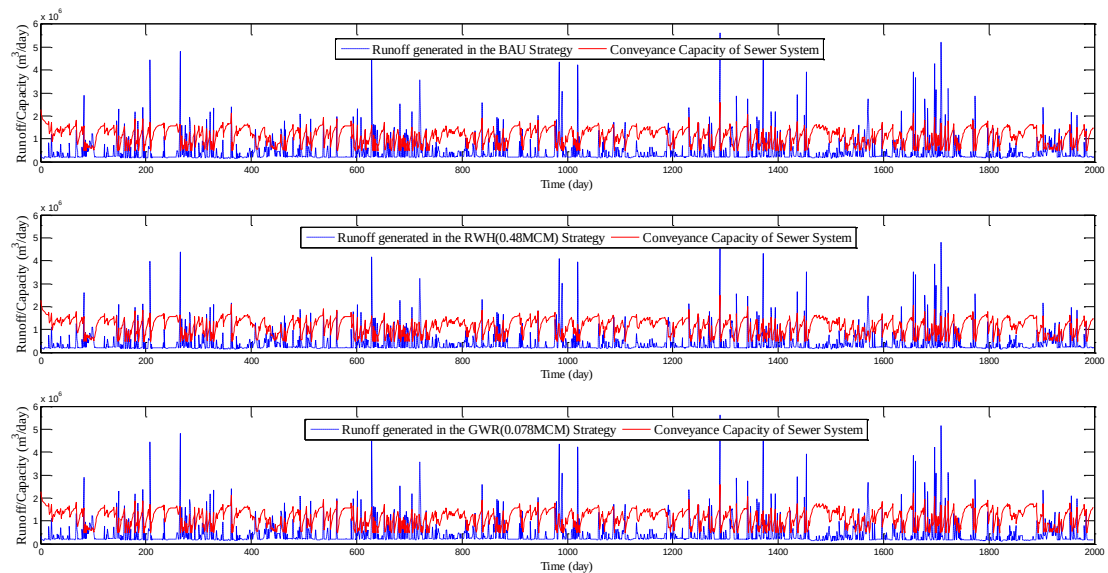


**Fig. 3. Variations of runoff generated and conveyance capacity of sewer system over the first five years in three strategies of BAU (upper graph), RWH with 0.48 MCM capacity (middle graph) and GWR with 0.078 MCM (lower graph)**

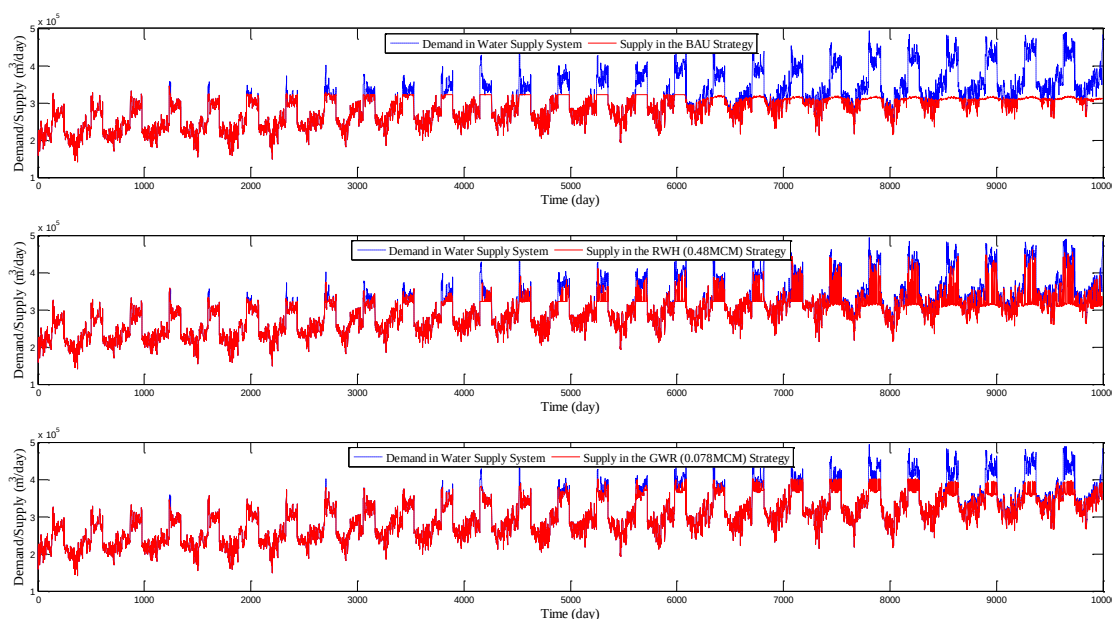


**Fig. 4. Variations of water demand and supply over the analysing period in three strategies of BAU (upper graph), RWH with 0.48 MCM capacity (middle graph) and GWR with 0.078 MCM (lower graph)**

When comparing these results and discussion in Figs. 1 and 2, it can be concluded that no unique water recycling strategy can be found as the best resilience performance for reduction in both duration and magnitude of failure in this case study. This has also been highlighted by Butler (2016) who noted that there is no single best approach for all situations of resilience [17]. As a result, for selection of a new strategy based on resilience-based performance criteria, all resilience definitions need to be addressed and estimated for concerning systems and improvement of resilience indicators of interest should be analysed based on the preferences of stakeholders and decision makers.

In addition to resilience performance, other aspects of the sustainability framework in water systems (e.g. economic and environmental) should be considered for decision making when analysing intervention strategies. For example, the above analyses show that GWR strategies outperform RWH strategies in water supply system with respect to failure magnitude, while GWR schemes per se use over three time more energy than RWH schemes [14] which can be less environmentally favourable solution due to increased greenhouse gas (GHG) emissions. This conclusion although needs a more comprehensive assessment (e.g. by using urban water metabolism framework) due to less energy used in other components (e.g. water supply or wastewater systems). Furthermore, one key aspect of decision making for a new strategy is the cost-effectiveness of the most resilient strategy. For example, in some of results discussed above, RWH strategy with 0.48MCM was the most resilient strategy with no or trivial difference for improvement of flood resilience when compared with RWH strategy with 0.24MCM. This little difference may play a prominent role when halving total capital investment for developing RWH schemes is important for stakeholders. The capacity of RWH schemes can also be reduced while maintaining the same performance of flood resilience by making RWH schemes smarter in which they can empty the storage tank well in-advance before following rainfalls [18].

## 4. CONCLUSION

Different aspects of IUWS resilience (i.e. system failure magnitude and duration [5]) were analysed here. Twelve resilience indicators were proposed for concurrent analysis of water supply and sewer systems to address both water excess (floods) and water shortage failure conditions. Urban water metabolism model was used to evaluate a number of water recycling intervention strategies (RWH and GWR) for resilience analysis. The results obtained on a case study of a Northern European city show that, there is no single best intervention solution that can reduce both failure duration and magnitude in water supply and sewer systems. For

example, failure magnitude of excess runoff can be minimised using the RWH based strategies but failure duration of excess runoff is minimised using the other, GWR based strategies. Also, performance of intervention strategies for different severity-based resilience indicators seems to be relatively similar. Finally, other assessment criteria (e.g. economic and environmental) should also be included when selecting the new intervention strategies. The findings presented here are limited to the case study analysed in this paper and their generalisation requires further application to other case studies.

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# Green roof design techniques to improve urban water management under Mediterranean conditions

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## ABSTRACT

Green roof typology can greatly vary depending on buildings structure, climate conditions, substrate and plants used. Climate is quite determinant in what concerns the plant selection, according mainly to temperature, rainfall and solar radiation. In regions with hot and dry summers, such as those with Mediterranean conditions, irrigation also plays an essential role, as during the year, the highest temperatures occur during a period without rainfall. In these climates irrigation can contribute to reduce the heat island effect, improving also the cooling of buildings during summer. However, water, the irrigation system, its maintenance and the energy to feed it present an additional cost to the green roof project that might outrun the benefits. Moreover, in situations where water is scarce or primarily channeled to other uses (domestic, agriculture or industry) during drought occurrence, it is advisable to implement green roof projects with the lowest use of water possible.

The main objective of the present work is to present and discuss several techniques, tested in our experiments that can be implemented to reduce water requirements in green roofs under Mediterranean conditions, such as those of Southern Europe countries. Some case-studies are addressed for the region of Southern Portugal, all addressing the use of native plant species, vascular and bryophytes, including the extreme type of a non-irrigated green roof (Biocrust roof) and innovative techniques for plant installation.

The emphasis is placed in the type of plant species selected concerning drought resistance, its aesthetic value in relation to water requirements and the rainfall water retention capacity according to species mixture.

*Keywords: irrigation, Southern Europe, native plant species, urban landscape, moss, seed mat*

## 1. INTRODUCTION

Green roofs firstly appeared in regions with temperate and cold climates, where they thrive without the need to irrigate [1]. However, for climates with hot and dry summers, as those of Mediterranean regions, the need to irrigate is unavoidable, as in these regions, plants on rooftops endure harsh conditions regarding temperature and insolation [2]. Therefore, the green roof project must include an irrigation system, enlarging the implementation costs, and later the system management costs include water and the energy to distribute it. One of the main benefits of green roofs often referred is the ability to thermally insulate buildings [3], as this might present an interesting economic return. During summer, in regions with Mediterranean conditions, this might decrease costs with air conditioning but if, in the other hand, it is necessary to irrigate, the costs might outrun the benefits [4]. In a larger scale, this is also true in

what concerns coping with the heat island effect in cities. Enlarging urban green roof areas can help mitigate the heat island effect [5-7], but if effective results are obtained only with large costly irrigation amounts, in economic terms, the results might again outrun the benefits. A different point of view is considering the moderation of the heat island as an ecosystem service, independently of the process cost in economic terms [8].

During the occurrence of extreme drought events, priority uses may be determined and this often implies mandatory watering restrictions in landscape irrigation [9], privileging human, agriculture and industry uses. The implementation of green roofs in zones prone to such events should prevent the situation and hence, low water demanding solutions should be used.

Thus, regions with hot and dry summers might benefit by the use of green roofs in what concerns thermic control of buildings and cities but a careful analysis of the costs is required. To help overcome this issue, innovative green roof design techniques that cope with water limited environments can provide adequate sustainable solutions.

We have studied several solutions aiming to create solutions to optimize water management for the implementation of green roofs in climates with hot dry summers: i) use of drought adapted species (native), ii) use of construction materials with water retention capacity, iii) deficit irrigation maintaining aesthetic value, iv) mixtures of vascular plants and bryophytes, v) moss-dominated biocrust roofs, vi) precultivated vegetation blankets for roofs and vii) wall plants transplanted to roofs.

## 2. MATERIAL AND METHODS

The work presented in this study has been developed in an experimental set installed at Instituto Superior de Agronomia (ISA, University of Lisbon, Portugal) in the rooftop of the Herbarium building (38° 42' 28" N, 9° 11' 0.4" W). The set was created in 2014, in the frame of the *NativeScapeGR* project ([www.isa.utl.pt/proj/NativeScapeGR/](http://www.isa.utl.pt/proj/NativeScapeGR/)) and consists of an array of metallic test beds (2.5 × 1 × 0.2 m<sup>3</sup>) that have been used to mimic different types of green roofs (Figures 1 and 2). The test beds are elevated 1 m above the roof surface and have a slope of 2.5%. They were constructed as commercial green roofs, with a non-woven blanket in the bottom layer, above a drainage layer composed by polyethylene plates with cavities, a filter system (non-woven blanket) and a substrate.

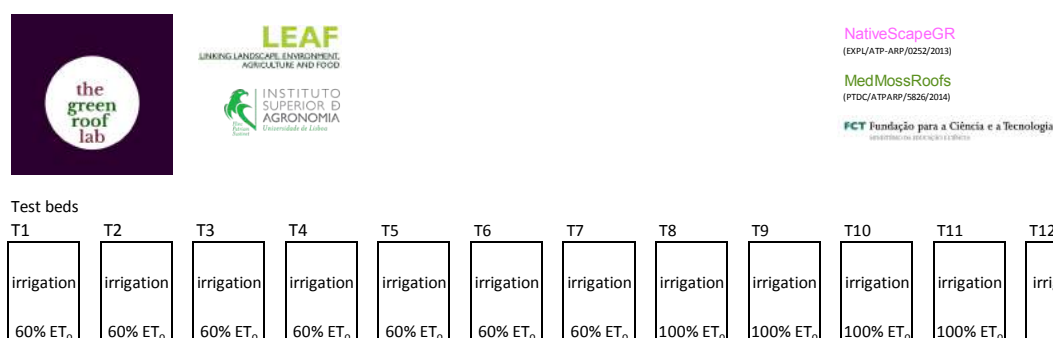


**Fig. 1. Scheme of the experimental set with test beds at the rooftop of the Herbarium building at Instituto Superior de Agronomia, University of Lisbon (T1 to T12 – test beds, ET<sub>0</sub> – reference evapotranspiration).**

In a first phase, between 2014 and 2017, the test beds were planted with different arrangements of drought adapted native plant species (Table 1), vascular and bryophytes (Fig. 3) (*Lavandula luisieri* subsp. *luisieri* (L.), *Rosmarinus officinalis* L., *Brachypodium phoenicoides* (L.) Roem. & Schult. and several species of bryophytes, mainly *Pleurochaete squarrosa*). The *MedMossRoofs* project, initiated in 2016, is currently studying different desiccation tolerant bryophyte species (<http://medmossroofs.campus.ciencias.ulisboa.pt/>), including *Didymodon* sp.,

*Tortella* sp. and *Pleurochaete squarrosa*, native to the Mediterranean and completely adapted to its dry hot climate, with the objective to increase their growth rate in controlled chambers and transplant them to the test beds.



**Fig. 2. General view of the test beds at the rooftop of the Herbarium building at Instituto Superior de Agronomia, University of Lisbon.**

In a second phase, from the beginning of 2018, some test beds (Table 2) were planted with species that thrive in walls of old buildings in the region, while maintaining the bryophyte species *Pleurochaete squarrosa* (APIwall – Another plant in the wall, [www.facebook.com/pg/thegreenrooflab/photos/?tab=album&album\\_id=952890424869636](https://www.facebook.com/pg/thegreenrooflab/photos/?tab=album&album_id=952890424869636)). A first adaptation test was performed with plants (*Centrathus ruber* (L.) DC., *Asphodelus fistulosus* L., *Antirrhinum linkianum* Boiss. & Reut, *Sedum* spp., *Galium aparine* L., *Reichardia picroides* (L.) Roth, *Medicago orbicularis* (L.) Bartal., *Andryala integrifolia* L., *Senecio vulgaris* L.) collected on March 2017 in old walls of the unfinished part of the National Palace of Ajuda (Lisbon), before the beginning of recent renovation works. The collected plants were transplanted for a nursery and kept there for 5 months, in order to evaluate survival. Plants of some of the species were later planted in the test beds (*Asphodelus fistulosus*, *Centrathus ruber*, *Antirrhinum linkianum*, *Sedum sediforme*), either coming from a nursery (Sigmetum) or transplanted from walls in the neighborhood.

Precultivated vegetation blankets (1 × 2.5 m) for later use in the test beds were prepared with plants well adapted to growth in walls and rocky environment, as well as other plant species, using an organic geotextile blanket, made with a coconut fiber matrix, reinforced with a fine photodegradable net for material strength improvement (Ecosalix®, EROMAT 6s). A small test was performed to experiment the seeds adhesion to geotextile without compromising seeds germination quality. Seven experiments took place, six with different concentrations of mixture and one control test. Mixtures concentrations made were 2:1 mixture of water and flour, 4:1 mixture of water and flour, 60 ml with half sheet of gelatin, 60 ml for one sheet of gelatin, 2:1 concentration of water and flour with one gelatin sheet, and 4:1 mixture of water and flour with half sheet gelatin, and control with just water.

The blankets were prepared using two different seed mixtures. First mixture of seed consisted in *Centrathus ruber* (10%), *Asphodelus fistulosus* (30%), *Sanguisorba verrucose* (30%), and *Papaver rhoeas* (20%), *Capsela bursa-pastoris* (10%); the second seed mixture consisted in *Trifolium angustifolium* (30%), *Brisa maxima* (30%), *Silene scabriflora* (10%), *Stachys germanica* (10%), *Teucrium scorodonia* (20%).

**Table 1. Description of test beds: species, irrigation (% of reference evapotranspiration) and substrates – NativeScapeGR and MedMossRoofs projects, (T1 to T12 – test beds, I – irrigation,  $ET_o$  – reference evapotranspiration, S - substrates).**

| test | vegetation         |                       |                        |            | I            | S*    |
|------|--------------------|-----------------------|------------------------|------------|--------------|-------|
| beds | <i>L. luisieri</i> | <i>R. officinalis</i> | <i>B. phoenicoides</i> | bryophytes |              |       |
| T1   | ✓                  | ✓                     | ✓                      | ✓          |              | S2    |
| T2   |                    |                       |                        | ✓          |              | S3    |
| T3   |                    |                       | ✓                      |            |              | S2    |
| T4   | ✓                  |                       |                        |            | 60% $ET_o$   | S1+S3 |
| T5   | ✓                  | ✓                     | ✓                      | ✓          |              | S1    |
| T6   |                    | ✓                     |                        |            |              | S1    |
| T7   |                    |                       | ✓                      |            |              | S1    |
| T8   |                    | ✓                     |                        |            |              | S1    |
| T9   |                    |                       | ✓                      |            | 100 % $ET_o$ | S1    |
| T10  | ✓                  |                       |                        |            |              | S3    |
| T11  |                    |                       |                        |            |              | S3    |
| T12  |                    |                       |                        | ✓          | No I         | S3    |

\*S2 and S3 – sandy texture, S1 – commercial green roof substrate, texture not classified due to high organic matter content



**Fig. 3. Test bed with vascular plants and mosses at the rooftop of the Herbarium building at Instituto Superior de Agronomia, University of Lisbon.**

**Table 2. Description of test beds: species, irrigation (% of reference evapotranspiration) and substrates - *APIwall* and *MedMossRoofs* projects, (T1 to T12 – test beds, I – irrigation,  $ET_o$  – reference evapotranspiration, S - substrates).**

| test | vegetation           |                 |                     |                     |                   | I      | S  |
|------|----------------------|-----------------|---------------------|---------------------|-------------------|--------|----|
| beds | <i>A. fistulosus</i> | <i>C. ruber</i> | <i>A. linkianum</i> | <i>S. sediforme</i> | <i>bryophytes</i> |        |    |
| T1   | 1                    | 2               | 4                   | 3                   | ✓                 |        | S4 |
| T2   | 1                    | 2               | 2                   | 2                   |                   |        | S4 |
| T3   | 1                    | 2               | 2                   | 2                   |                   | 60%    | S4 |
| T4   | 1                    | 2               | 2                   | 2                   |                   | $ET_o$ | S4 |
| T5   |                      | 1               | 5                   | 3                   | ✓                 |        | S4 |
| T6   |                      |                 |                     |                     |                   |        | S4 |
| T7   |                      |                 |                     |                     |                   |        | S4 |
| T8   | 1                    | 2               | 2                   | 2                   |                   | 100 %  | S4 |
| T9   | 1                    | 2               | 2                   | 2                   |                   | $ET_o$ | S4 |
| T10  | 1                    | 2               | 2                   | 2                   |                   |        | S4 |
| T11  |                      |                 |                     |                     | ✓                 |        | S4 |
| T12  |                      |                 |                     |                     | ✓                 | No I   | S4 |

\*S4 - commercial green roof substrate, texture not classified due to high organic matter content

### 3. RESULTS AND DISCUSSION

#### 3.1 Use of drought adapted native species

In regions with Mediterranean conditions, green roof plants have to endure difficult environmental conditions to survive and resistance to drought can be considered one of the essential selection traits [10]. Thus, the type of plants chosen is quite determinant of the success of the green roof. A logic approach is to use plants that are adapted to local natural conditions, especially native plants, plants that are indigenous to a certain area in geologic time. The plants studied during the NativeScapeGR project were all native plants and proved to be adequate to green roofs, evidencing adequate development and growth during the experiments.

#### 3.2 Use of structural materials with water retention capacity

At the rooftop of a building, plants are exposed to harsh conditions of temperature, radiation and wind, while thriving in shallow substrates, with limited capacity to hold water. Therefore, in dry hot climates, structural components of the green roof that can help to retain water can play an



important role. Commonly, green roof systems include the following layers from top to bottom: vegetation, lightweight substrate, filter, drainage layer, moisture retention layer and root-resistant waterproofing barrier. Water is mostly retained in the substrate, the drainage layer and the moisture retention layer. An example of the substrate effect on water retention at our experimental set is presented in Figure 4. Test bed 7 had a commercial substrate for green roofs (S1), with high organic matter content and test bed 3 had a mixture (S2) of the same substrate (50%) with sand (25%) and clay soil (25%). In T7 evapotranspiration was consistently higher, evidencing a larger quantity of water available for plants, since all the other factors (vegetation and irrigation level) were equal.

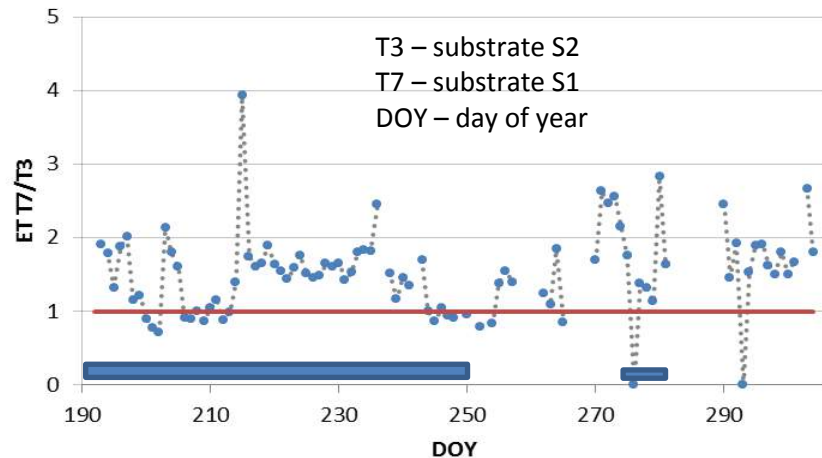


**Fig. 4. Relative evapotranspiration (ET) in test beds with *Brachypodium phoenicoides* submitted to the same irrigation level (60% of reference evapotranspiration,  $ET_o$ ) and different substrates; blue rectangles represent irrigation periods.**

Two of the construction elements, the drainage and the water retention layers, can act as interesting reservoirs for water. In our experimental set, both elements could retain up to 8 mm of water, which is approximately the double of the water evapotranspired in a typical summer day for deficit irrigation conditions, for example in a *Rosmarinus officinalis* test bed (Fig. 5).

### 3.3 Deficit irrigation vs. aesthetic value

Figure 2 presents the evapotranspiration of *Rosmarinus officinalis* under two different irrigation levels, showing that the lower level, corresponding to deficit irrigation, produced as expected lower rates. However, these differences were not significantly reflected in the aesthetic value that was in general maintained [11].

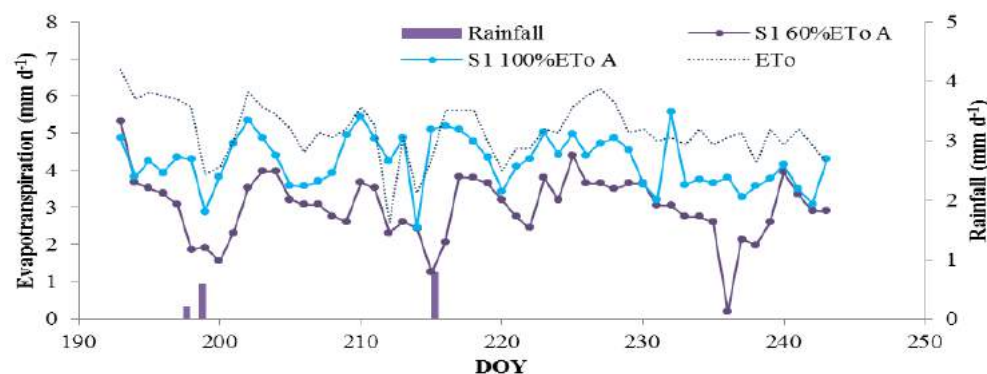


**Fig. 5. Actual evapotranspiration in test beds with *Rosmarinus officinalis* submitted to two irrigation levels (60% and 100% of reference evapotranspiration,  $ET_o$ ) and rainfall events (DOY=day of year).**

### 3.4 Mixtures of vascular plants and bryophytes

For test beds with mixtures of *Lavandula luisieri*, *Rosmarinus officinalis*, *Brachypodium phoenicoides* and *Pleurochaete squarrosa*, evapotranspiration was larger in comparison with test beds with only one species. Figure 6 shows the evapotranspiration of test bed 5 (T5, with a mixture of vascular plants and bryophytes) in relation to T6 (with *Rosmarinus officinalis* only). This relative evapotranspiration was higher than 1 most of the time (1.2 in average), during irrigation periods, indicating a higher water retention in T5, probably due to the presence of mosses, since irrigation levels and substrates were the same. This fact results from the high water retention of the mosses [12] that can benefit the soil moisture content around the vascular plants, increasing their water use efficiency. The same effect can be observed for *Brachypodium phoenicoides* (T7), even though not so pronounced (Fig. 7).

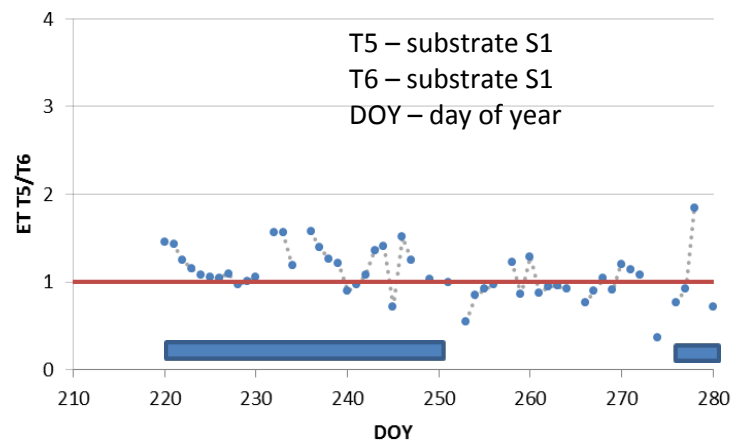


Fig. 6. Relative evapotranspiration of a test bed with all the vascular plants mixed with bryophytes (T5) and T6 (*Rosmarinus officinalis*) submitted to two irrigation levels (60% and 100% of reference evapotranspiration,  $ET_o$ ) and rainfall events.

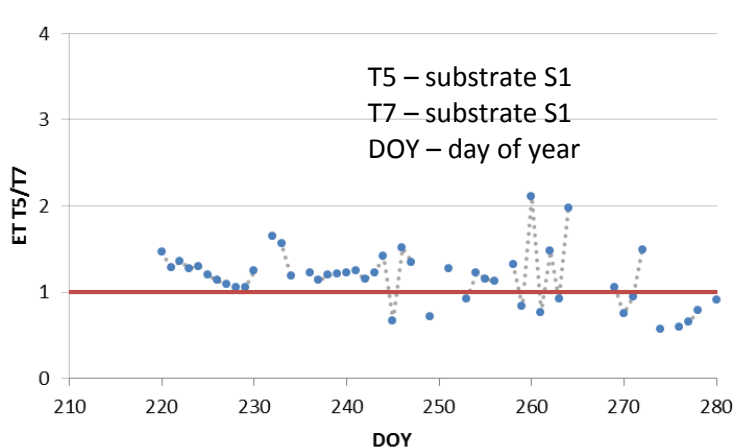


Fig. 7. Relative evapotranspiration of a test bed with all the vascular plants mixed with bryophytes (T5) and T6 (*Brachypodium phoenicoides*) submitted to two irrigation levels (60% and 100% of reference evapotranspiration,  $ET_o$ ) and rainfall events.

### 3.5 Use of bryophyte-dominated biocrust roofs

For the non-irrigated (rainfed conditions) test bed, the mosses acquired a dry and brown aspect during summer and after the first rains in September they restarted activity, showing it was possible to maintain the selected species without irrigation in such conditions. These bryophyte-

dominated biological soil crusts (biocrusts) are poikilohydric with desiccation tolerance, i.e., the ability to lose almost all water from inside the cells and upon rehydration regain normal function [13-16] and can be grown in two months under controlled climatic conditions [17, 18].

A Biocrust Roof of this type could be an interesting solution for low-cost green roofs in urban areas with dry, hot summers, since no irrigation is required and can increase water use efficiency of other vascular plants if irrigation is required. Furthermore, the floods in urban areas resulting from the increase of flash rain events (high water content in a small period of time) due to climate change can be attenuated by the ability of some mosses to retain water up to eight times their dry weight [12].

### 3.6 Precultivated vegetation blankets for roofs

The tests for seed adhesion to the geotextile blanket with the different combinations of water, flour and gelatine, showed that the most suitable combinations were the mixture 4:1 of water and flour or just plain water. These results are still preliminary and additional adhesion tests will be performed either in the lab or field conditions. Afterwards, the blankets will be seeded with the final best solution and the plants described in section 2.

Apart from the ordinary benefits of precultivation (increased plant survival, uniformity, readiness, etc.), the ability of blankets to act as mulches makes them interesting for green roofs in what concerns water conservation.

### 3.1 Wall plants transplanted to roofs

All the plants transplanted from walls to the nursery survived, evidencing also an appreciable growth (Fig. 8). This indicates that transplantation from the wall medium to a common substrate is viable, although in a less demanding environment (the nursery) than a roof, in what concerns temperature, radiation and wind conditions. Also, wall species planted in the test beds are so far well adapted and normally developing, though results are preliminary and the experimental work is underway.



**Fig. 8.** Test bed with *Antirrhinum linkianum*, a common plant in roofs and walls of old buildings, at the rooftop of Instituto Superior de Agronomia, University of Lisbon.



## 4. CONCLUSION

Several techniques for the design of green roofs in regions with Mediterranean conditions are described and analyzed, as a result from the practices developed in the frame of three research projects of the University of Lisbon. The techniques addressed are: i) use of drought adapted species (native), ii) use of construction materials with water retention capacity, iii) deficit irrigation maintaining aesthetic value, iv) mixtures of vascular plants and bryophytes, v) biocrust roofs, vi) precultivated vegetation blankets for roofs and vii) wall plants transplanted to roofs.

The main conclusions indicate that: the native plants so far studied were adequate to sustain deficit irrigation without significant loss of aesthetic value. Although aesthetics are important, other services provided by green roofs, such as particle retention, water retention against flash rain events and carbon sequestration, must be considered, possibly assuming a more important role in the urban environment; make a compromise between the two approaches seems a reasonable solution and bryophyte (biocrust) roofs can still be beautiful and perform more as a functional living roof. Water retaining materials and substrates can have an important role in such conditions; the most interesting solution for plant selection was the mixture of vascular plants and bryophytes, which is a nature-based solution, since it is a replication of what is observed in the natural environment. A relationship was established between mosses, which present a larger water retention capacity, and the vascular plants, that can use the retained water. Also, although mosses are drought-tolerant, being close to vascular plants allows them to maintain hydrated conditions during longer periods and therefore present a better performance, providing their services during an enlarged time frame. This new type of green roof can help adaptation to the effects of climate change, like increased temperature and light exposure as well as decreased precipitation.

Precultivated blankets showed to be a promising solution to help conserving water in green roofs and preliminary experiences with plants from walls and rocky environments indicate they are able to survive and develop in green roofs.

## ACKNOWLEDGEMENTS

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## COMPETING INTERESTS

We disclose any financial and personal relationships with other people or organizations that could inappropriately influence (bias) our work.

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# **Utilizing Blockchain in the Water Services Industry: prospects and possibilities**

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## **1. INTRODUCTION**

Blockchain algorithms were initially developed to trade digital currencies in the financial services sector, providing a secure, distributed trading network for various forms of transaction (Cognizant 2017). Recently however, Blockchain providers have branched out from cryptocurrencies and have begun to develop applications within non-financial spaces, such as the utilities sector (Global Water Intelligence 2018).

A blockchain is a distributed, secure and transparent network comprising of digital files that are shared across a digital ledger system. Data is combined into 'blocks' and stored in a distributed database with complex cryptographic layers to ensure a high level of cybersecurity. This makes the data immutable and enables peer-to-peer trading without the need for central authorities (Global Water Intelligence 2018).

Each node (device) in a blockchain network contains a complete replica of the blockchain data. The nodes are held by 'miners' who are responsible for authenticating and validating data transactions/alterations (De Perthuis, Scemama and Mallet 2018). Each 'block' contains data and is encrypted with a unique code – or 'hash' – that can be used to distinguish it from other blocks, adding an extra layer of security (Global Water Intelligence 2018). Each block also contains the hash of the block which preceded it, creating a chronological chain. If the data within an individual block is ever altered, its hash will also change, meaning the hash of the subsequent block will no longer match that of the altered block, making the rest of the chain invalid.

While this makes the blockchain fairly secure, the processing power of modern computers makes it easy for someone to alter the hashes of all the blocks in the chain fairly rapidly, validating blockchain once again and avoiding detection. In order to combat this, blockchains have a feature known as 'proof of work' which intentionally restricts the speed at which blocks can be altered and/or created, thus giving the blockchain miners more time to authenticate and validate transactions and alterations. With potentially thousands of miners working simultaneously to authenticate changes to the blockchain, making the likelihood of detection practically inevitable and ensuring that blockchains remain one of the most secure forms of data transfer (Cognizant 2017).

Anna Poberezhna, blockchain expert and founder of technology solutions developer Smart4tech, explained how blockchain compares to cloud technologies: "The cloud is controlled by a central party such as Amazon or Google. The control of data is done by a third party which immediately draws questions about trust, security and privacy of the data. On top of that, data is usually unencrypted. Blockchain doesn't require a central party to own or control data; once information is written in the database there's no way to delete it or change it."

The use of blockchain in the water utility industry remains sparse, with only a couple of technology investing in the technology's integration into their practices (Global Water Intelligence 2018). However, there are several applications and examples discussed at length in the literature – particularly regarding gas and electricity utilities – which could be applied to the water utility sector, and Bristol Water specifically.

Bristol Water's jurisdiction, SWMs are still absent from many homes, potentially rendering the proposed investment in blockchain for the purposes of smart contacting impractical at present. Also, as Blockchain is integrated more comprehensively into the data storage and transfer phases of water utility services, the amount of data being transferred will increase, potentially requiring increased computing power in the blockchain systems' nodes (Basden and Cottrell 2017). While the issue of increasing storage capacity is less of a problem in distributed networks such as blockchain than in centralised systems, it may pose challenges in the future that need to be considered if the technology is to be implemented into the water utility industry.

Questions over the true level of security provided by blockchain are now also being asked after the first documented cryptocurrency malware attack on the supervisory control and data acquisition server of a water utility in February 2018.

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## 2. APPLICATIONS

Blockchain offers not just a more efficient and secure method of transaction and data transfer, but also a more cost-effective approach to grid-management, contracting, demand resource management and asset tracking, compared with existing approaches (Utility Week 2017). Blockchains are the first systems to overcome the limitations of database synchronisation, allowing individuals and companies to store data and run applications greater level of reliability. The potential cost savings presented by a single global digitised ledger – or even an industry specific ledger, e.g. water utilities – are also significant (De Perthuis, Scemama and Mallet 2018). Blockchain's distributed ledger technology offers the opportunity for individuals and utilities to better manage their consumption data, which could allow them to devise more effective methods for addressing water scarcity and management (Medium 2017). Christine Easterfield, principal consultant at analyst firm Cambashi has commented that “distributed ledgers based on blockchain technology can support many applications, from wholesale energy trading to meter registration, and also reckon to provide greater security against cyber-attack, because every transaction is ‘witnessed’ by the entire user community” (Utility Week 2017).

Scenarios that would benefit most from the implementation of blockchain share these characteristics, according to Mooney, 2018; they are typically multi-party, require transparency and mutual control, and have little need for intermediate parties to process the transfer of data. The water utility sector possesses such characterises and thus, the integration of blockchain technologies could be beneficial. This integration would help to create an environment where data transfer – particularly with regards to financial transactions – is open and secure, resulting in a reduced risk of fraud, improved debt recovery, and increased transparency in the altering of prices and fees (De Perthuis, Scemama and Mallet 2018).

Blockchain could make it possible to carry out decentralised transactions between two or more users, where the terms of the contact are determined and accepted by the parties involved but the execution of the contract is then automated. These forms of transactional agreement have been termed ‘smart contracts’. In a smart contract, the terms are defined individually (e.g. quality, price, quantity) and thanks to blockchain technology, there is an autonomous matching between the parties, for instance, between distributed providers and prospective customers.

By encoding transactions within identical distributed ledgers held by both parties, the need for these documents disappears, as does the need for the accounting and checking processes to validate transactional documents. The secure and immutable nature of a blockchain ledger provides a means of easily and securely making monetary transactions where conventional bookkeeping and document exchange would be cumbersome (Utility Week 2017). One automated device can transact with another, with both devices agreeing the mutual balance of payment obligations at every step of the process (Utility Week 2017). Blockchain presents an opportunity for smart contracts within both the energy and water utility sectors (De Perthuis, Scemama and Mallet 2018).

Moreover, in any industry in which cyber-attack and digital fraud are very real concerns, the distributed nature of blockchain's ledgers add both security and resilience. As with the internet, there is no central point to attack – the system of record is the network itself, rather than a given node within it. This reduces the risk for water utilities in terms of cyber-attacks, as identity data would be decentralised and owned by its customers. This application is already well developed in the energy sector (Medium 2017).

## 3. EXAMPLES

As previously stated, it seems that energy providers have been the first to seize the opportunities presented by blockchain technologies. In the UK, energy start-up Electron is looking to streamline and speed up the utility switching process for consumers and businesses using blockchain technology. By establishing a blockchain for meter registration, Electron suggests existing gas and electricity switching services can be replaced

with a more efficient switching service with the potential to reduce switching time from around three weeks to a matter of minutes, in a move that the company believes will be welcomed by consumers (Gentrack 2017). It may be possible to utilise such technology within the water utility industry as well, making it much more efficient and convenient for customers to switch water providers. Meanwhile in Germany, the power company Innogy is running a pilot programme to investigate whether blockchain technology can authenticate and manage the billing process for autonomous electric-vehicle charging stations (Basden and Cottrell 2017). However, there are some cases of water utilities also harnessing the potential of Blockchain within their operations. While these projects are predominantly in their infancy, there may be room for development within areas that Bristol water may be interested in.

Several pioneering water industry players have begun incorporating blockchain technology into their portfolios. OriginClear, a US-based water treatment technology provider, announced that it was developing the plans for a blockchain protocol called WaterChain which aims to increase transparency and efficiency in the water industry by using smart contracts and cryptocurrency (Global Water Intelligence 2018). Similarly, commercial and waste water treatment utility, Genesis, is developing a smart sensor with the ability to track water quality and store the data on the Ethereum blockchain in the hopes that their customers will feel more secure about the quality of water they receive and the efficiency at which officials are notified if water quality deteriorates. If data such as this is monitored over time, potential problems could be addressed before people begin to suffer from the effects of reduced water quality. (Medium 2017). AQUAOSO Technologies are also looking to incorporate smart contracts into their existing platform by combining a blockchain system with “Internet of Things”-enabled sensors to monitor the movement of water, confirming delivery to buyers and automatically releasing payments to sellers (Medium 2017).

In Western Australia, the city of Freemantle will trial a blockchain project designed by Power Ledger for the purposes of integrating distributed water systems as a part of their efforts to transition into a leading smart city. Their goal is to compile data from SWMs and create a trading system to make water usage more efficient (Medium 2017). Civic Ledger, another civic-focused Australian blockchain company developed ‘Water Ledger,’ a blockchain trading platform that leverages smart contracts and a token management system to monitor water trading and automatically update state registries (Global Water Intelligence 2018). It is believed that blockchain enabled water trading will cut out the middlemen and streamline business processes, saving money and reducing fraud in the process. Civic Ledger – in partnership with the water utility South East Water – is also planning to explore the potential for a blockchain based micro-trading platform for the purpose of trading rainwater within a new residential development in Melbourne.

While the following case may not directly apply to Bristol Water, in terms of exemplifying blockchain’s utilization in a commercial sense, it does help to demonstrate the potential of blockchain integration into the water utility sector. In an effort to showcase blockchain’s humanitarian potential with regards to water provision, South African technology solutions provider Bankymoon launched a blockchain platform that enables donors to top-up African schools’ water meters from anywhere in the world. Similarly, blockchain technology could be incorporated into domestic smart meters in the future, enabling water consumers to pay utility bills using cryptocurrencies in a far more efficient manner than current practices (Medium 2017).

#### **4. CHALLENGES**

While the utilization of blockchain in the water utility sector seems to provide some benefits, there are also drawbacks to working in certain areas. For instance, cities or regions with water management infrastructure already implemented have much lower barriers to the incorporation of blockchain than areas with limited water meters and other quality measurement tools (Medium 2017). This is more of a problem in isolated rural areas, such as those in the American mid-west, than it is in the majority of the UK. It does however, raise the question about the uniformity of data gathering and whether this may affect the implementation of blockchain. While district water meters are installed across the majority of

**#6. Water in nature: hydrology, land use, low and high peak trends etc. + Water quality, reuse and recycling**

# Development of low-cost flow sensors using accelerometers

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## ABSTRACT

Sensors give an insight into the world around us and the Internet of Things approach presents an opportunity to find synergies that were previously unexplored. For water, smart metering is an area where this approach has shown promising applications, but the cost of the smart devices and the difficulties of installation have limited the adoption of flow logging, particularly at a resolution where disaggregation can be performed. Accelerometers provide a potential solution to the cost/installation issue; this study examines the performance of these sensors.

Keywords: Water sensors, demand modelling, disaggregation, accelerometers

## 1. INTRODUCTION

“Big data” and the “Internet of Things” (IoT) are concepts that have been widely discussed in the past decade, [1], [2], [3], [4], with the large amount of data available presenting opportunities for understanding synergies that were previously unexplained. The penetration of these devices has been limited so far, with a survey in 2017 [5], Figure 1, showing that only smart devices that are used for entertainment purposes have an adoption rate in the home that is higher than 7%.

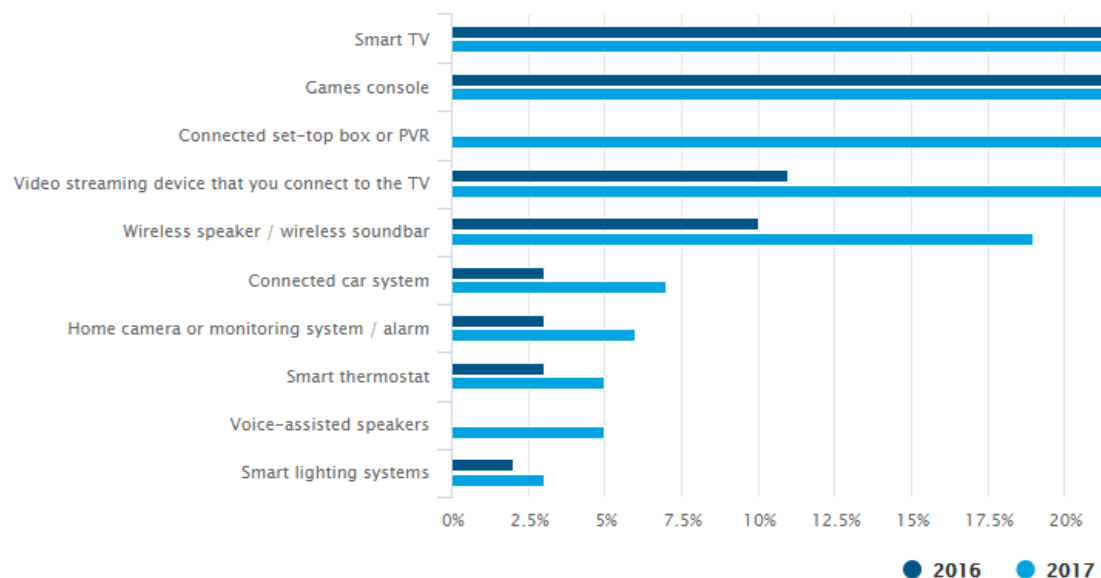


Fig. 1. Survey of IoT ownership/access, comparing 2016 and 2017 [5]

For a technology to be adopted, it must meet a specific need, be easy to use and be considered good value for money [6]. Therefore, increasing sensor penetration within the water industry will require devices that meet these criteria.

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## 1.1 IoT for Water

For water utilities, a common application of IoT and Big Data are through the use of smart water meters in domestic households. For smart water meters, the sampling rate and volumetric resolution limit the applicable uses and have a trade-off in cost. Less expensive meters that only sample hourly or every fifteen minutes can be useful for finding leakage using night flows or for modelling consumption, but would not be able to disaggregate the flow (i.e., break the flow into component parts, e.g., shower, toilet, tap, also known as micro-component analysis).

To determine the micro-components of water-use, the resolution and sampling rate needs to be sufficient to see when appliances start and finish and also how much water is used for an event. To collect this high resolution data normally involves using metering and logging equipment that is more expensive, especially due to the higher frequency sample rate which takes readings more often and therefore drains more battery, hence there is a higher cost associated with the devices used in disaggregation.

The range of options available for smart metering and their limitations are discussed in [6], including:

- Ultrasonic sensors – measuring the velocity of ultrasonic beams, with a sample rate of 0.5-2 Mhz and volumetric resolution of 0.0018 liters. These are very accurate and clamp outside of the pipe, so are easy to install but have a cost of £200+ per device.
- Pressure sensors – a steel device measures the pressure of the system which can be used to determine the flow rate via Poiseuille's law. The sample rate is up to 2kHz and a resolution of 0.001 psi. These require intrusive installation methods and are moderately expensive at £20+ per device.
- Flow Meters – Operating using Hall's law, by creating pulses per revolution of the internal mechanism. These have a sampling frequency of 0.1 to 10 Hz and a volumetric resolution of 0.01-1 liter. Complex to install since it requires placing in the pipe and ranging in cost from £10-200.
- Accelerometers – Measure vibrations in the pipe that are created due to turbulence in the flow. The sampling rate is in the 100 Hz range and the resolution is 0.015 liters. These are easy to install since they are mounted outside of the pipe and very low cost at £5+, however they may require calibration as discussed in the following accelerometer section.

For a technology to be well-adopted, two factors are important: a low cost solution allows more units to be purchased within a set budget; A solution that is easy to install would be attractive for purchasers, since more devices are able to be fitted in the same time span. Accelerometers fulfil both of these criteria, but the limitation of calibration will need to be overcome. However, it is reasonable to expect that increased usage and research on the sensors would make future calibration far easier.

## 1.2 Accelerometers

The use of accelerometers to measure flow required significant calibration in earlier research [7], [8], but more recent research [9], [10], demonstrates that technological improvements have reduced the amount of calibration required. The detailed study in [8] demonstrates a low error range (0-10%), Figure 2, even for low flow situations.

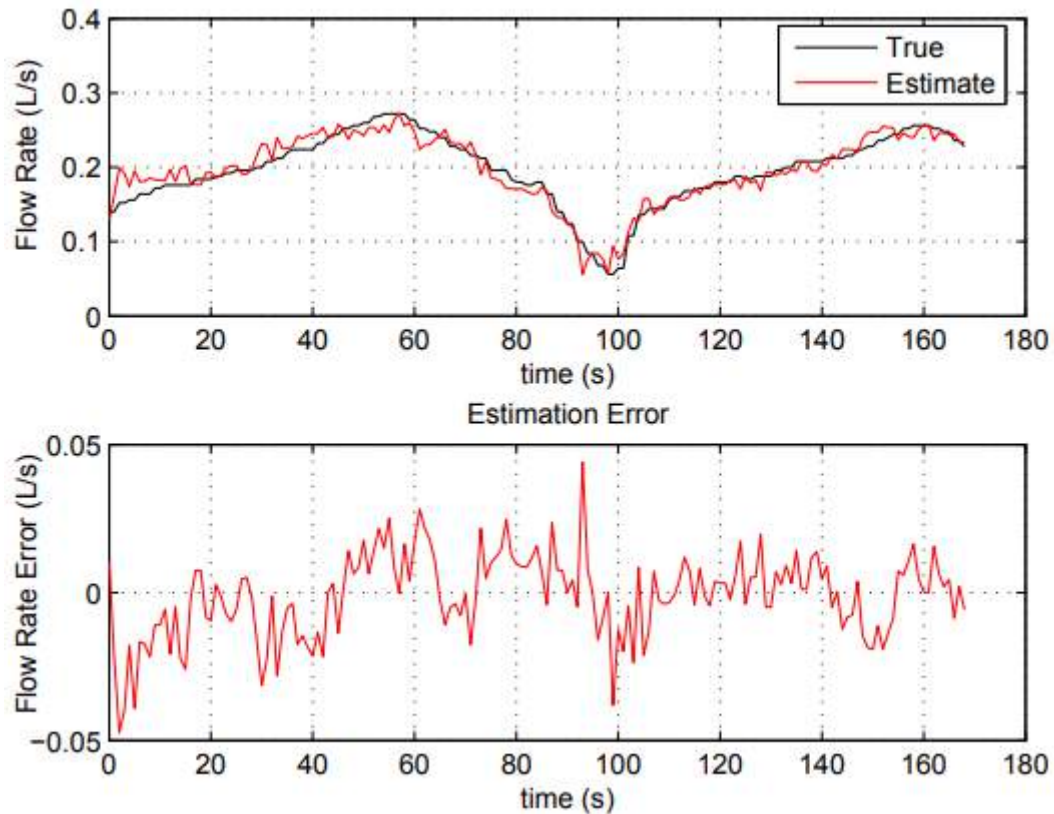


**Fig. 2. Accelerometer flow measurement against ground truth and the absolute error [8]**

Many Inertial Measurement Units (IMUs) also contain a temperature sensor, which could potentially act as another means for calibrating the accelerometer. The temperature sensor alone may correlate to the flow rate and investigation may prove fruitful, even as a measure for cross-checking.

## 2. METHODOLOGY

Initially, it is necessary to verify the results of the previous studies by performing tests in the laboratory, in particular looking at how the device should be mounted. Methods of contact shall also be compared, e.g., bindings, adhesives and wax, to determine if this can affect the accuracy of the result.

It is proposed to use a Wi-Fi enabled board in conjunction with an IMU module, which will require configuration to function. Since battery life will also be an issue, the frequency of transmission, sampling rate and properties of the board will be examined in order to save power. As accelerometer data is typically noisy, an appropriate filter will need to be selected, e.g., high-pass, low-pass or Kalman. This may vary depending upon the sampling rate that is chosen.

### 2.1 Field testing

Once the device is functioning in the lab, it will be used in initial field tests for 20 households. The aim will be to use the devices on the pipes connecting to each appliance/fixture in the home, i.e., showers, hot and cold taps, washing machines, dishwashers, toilets and external taps. The flow meters inside the house will be compared to an external aggregated flow logger, so that the accuracy of the readings can be determined and the error calculated.

### 3. RESULTS AND DISCUSSION

Once both datasets are obtained, it will be possible to compare the correlation of flow measurements and calculate the deviation of the flow logger result from the accelerometer result. Results may differ based on pipe material, pipe diameter and flow rate, therefore, comparing how these factors affect the flow measurements will be important for future reference.

A comparison will also be made of how the temperature change correlates with the accelerometer and flow logger readings, to determine the future suitability for exploitation.

### 4. CONCLUSION

Previous research has shown the potential of accelerometers to be used as flow measurement sensors. The low cost nature of the solution combined with the simplicity of the installation provides a platform for widespread adoption of this flow sensor. This gives an ability to perform water network monitoring and flow disaggregation on a large scale, giving an IoT and big data solution in the water industry.

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# Renaturalising the water courses: dynamic interactions between communities and nature.

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## ABSTRACT

In ecology, an ecosystem is defined as a system of interconnected elements formed by the interaction of a community of organisms with their environment. In all ecosystems, communities of organisms include people as main actors, either as designers of its infrastructure or as participants in its upgrading. Combined with urban design, landscape architecture has the power to stimulate human experiences by alluding to dynamic patterns of still or rushing water. We love landscapes as physical spaces and we also respond to landscape beauty with immense appreciation; our urban cultural ecosystems blend harmoniously with water. By being transformed into polluted artificial waterways or fiercely running rainwater discharges, sometimes our meandering water courses can endanger people as well as the environment.

How can we re-establish a balance between our ecosystems and the anthropocentric remodelling of our cities? The authors discuss the trends of renaturalisation/renaturation of water courses in some European countries, where previously water management has implied working against nature to ensure progress for mankind. Instead of only containing rivers, the new paradigm shift makes nature an ally to stabilise water levels, prevent floods in densely urbanised areas, and safeguard water uses. Water managers and city planners pursue water systems with water rules and policies backing their claim: 'living with water' and 'building with nature'. Recent projects could be easily compared with Leonardo's hydrology ideas in Renaissance. In his Treatise on Water, Leonardo focuses on moving waters and trained rivers in relation to their water cycles and the tectonics of the earth's surface with the aim of benefitting cities and people.

*Keywords: Ecosystems, green and blue infrastructure, hydrology, renaturalisation of waterways, anthropocentric city models, living with water.*

## 1. INTRODUCTION

Water courses are either important part of naturally formed historical landscapes; they are also considered as a vital part of developing ecosystems and are reinforced by design and controlled landscape management. Today infrastructure proposed and designed for urban spaces and our immediate surroundings depends on how we - as humans - value the landscapes around us. Influences to humans by ecosystems, such as water courses, are getting stronger and stronger. New management and design solutions have also emerged in many contemporary cities in which 'we build with nature' in order to accept 'living with water'. Designers and planners argue that green infrastructure which includes dynamic natural elements, such as water and native flora and fauna should be incorporated in any contemporary anthropocentric city model.

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Although green infrastructure developments may vary between locations, some authors think that: *“there is a positive association between the discussions of its value and its development within policy and practice”* [1]. This means that there is a growing understanding of what green infrastructure is and what social, ecological and economic value it can deliver in cities today; designers and policy makers are able to set its role for our sustainable and resilient cities of the future.

Although green infrastructure is a simple approach to landscape planning, it is also a complex approach, because of the large range of its principles; it has been anticipated that green infrastructure preserving and promoting ecosystems can promote landscape multi-functionality. Consequently, several authors describe green infrastructure as supporting ecological functions, social needs and economic developments [1, 2, 3]. Some authors affirm that green infrastructure planning may be not the same in all countries. For example, it is thought that UK green infrastructure planning takes a more holistic approach to the integration of socio-economic and environmental influences. Thus, it differs to other countries' predominantly water-centric approaches, such as USA, some European countries, etc. [4].

The Landscape Institute presented a number of key characteristics, which are central to our understanding of green infrastructure: *“Green infrastructure includes the network of green spaces and other natural elements such as rivers and lakes that are interspersed between and connect villages, towns and cities. Individually these elements are green infrastructure assets and the roles that these assets play are green infrastructure functions”* [5]. Hence, several authors reflecting upon this aforementioned assertion suggest that, in fact, green infrastructure is the life support system of all landscapes; it should be considered as planned interactions between socio-economic and environmental factors [3]. According to the Landscape Institute, rivers and canals, including their banks, are considered as important assets within natural England green infrastructure typology. Thus, they are included in the section of resources, which are classified as 'green corridors'. Wetlands and open and running water are also considered as important resources and are included in 'natural and semi-natural urban green spaces' [1].

We also find that, with the increasing impacts of climate change, landscape planners and urban designers working together are now looking at alternative solutions to establish more effective and sustainable landscape practice. Now there is a flexibility to green infrastructure planning that enables its users to address a range of development scenarios en bloc [1, 6]. For example, water management, biodiversity conservation, as well as climate change, are some areas where a green infrastructure approach has been successfully applied [1]. Another advantage is that green infrastructure planning can be applied at a number of scales, therefore, offers a flexible approach to private and public investment. For example, by relying on some international policies, such as the Water Framework Directive, green infrastructure practitioners have managed to make use of spatial characteristics to scope management at a regional and landscape scale. Green infrastructure investments can be often presented as an approach to landscape resource management that promotes the use of landscape networks/ecosystems (as an integrated approach to investment) [7].

Nowadays, the renaturalisation of the water courses is included as a dynamic part of several contemporary projects, which propose innovation in green infrastructure, and therefore, offers new opportunities for investment at a variety of scales, as we see further in our discussion of specific case studies selected and investigated by the authors of this paper. However, the notion of renaturalisation has appeared, when life styles had to be improved to accommodate healthy living via mobility by walking or by using a bicycle. So, we often find out that recently many projects refer to 'riverside (re-)developments', which extend to recreating natural environments in conjunction with artificial interventions; the intention is to revitalize heavily polluted and/or neglected areas around water courses, which have been abandoned for many years. Now these areas are developed to provide modern cities with both built environment growth and integrated green infrastructure. We are now dealing with 'water-sensitive' design and 'blue infrastructure' management.

Nevertheless, in history, water has been always considered as a powerful element which either divided or brought together people from different backgrounds and also disciplines, such a

scientists, artists, architects philosophers and political leaders. Leonardo Da Vinci in his *Art of Water* suggests that “*the body of the earth is of the nature of a fish ... because it draws water as its breath instead of air*” [8]. Leonardo spent as much time observing and drawing rivers and waterways as he did by observing dissected bodies in Santa Maria Nuova Hospital morgue. In fact, he compared the human body’s vascular system – veins and arteries with the flow of rivers and their feeding streams, thus, he perfectly understood the importance of healthy systems and patterns of arteries preserving healthy lifecycles.



**Fig. 1.** Leonardo’s deviation of the Arno River; bypassing a stretch of the river with an artificial canal (never put into practice). (Source: Royal Collection Trust at <https://www.royalcollection.org.uk/collection/912279/a-scheme-for-a-canal-to-bypass-the-arno>).

## 2. INVESTIGATION ON RELEVANT LITERATURE - CASE STUDIES

### 2.1 Leonardo Da Vinci and his fascination with hydrology

Leonardo is known to many scholars across a variety of disciplines for “his fascination with water and rivers, which pervaded his art and science” [9]. His interest in hydrology can be seen in his paintings and maps; he was fascinated especially by the power of water, when the rivers become furious and flood the plains; no artefact or human being can oppose enraged rivers. However Leonardo followed the seasons to observe dangerous rivers, such as the River Arno, and proposed solutions, some of them attempted or abandoned; he is an exceptional artist in his combination of the arts, science and engineering.

His background makes him often eager to search for a funding generous patron, and he passed to a range of them. He was hired for a variety of works by powerful people, such as Ludovico Sforza (Duke of Milan), Cesare Borgia (Pope Alexander VI son), Charles d’Amboise, French governor in Milan, and many others until his death in 1519 at the court of Francis I, King of France. Thus, his deeds were often related to or combined with defense projects or masterminded political trickery, such as “*Niccolò Machiavelli’s dream to change the course of Florentine history*” by diverting the Arno River as part of the war effort against the nearby seaside city of Pisa [10]. This project failed as the Arno River destroyed the weir and related canals after a heavy rainfall and flood.

Leonardo’s passion to depict landscapes in his paintings including impressive views of rocks emerging through vegetation and falling waters as well as his hydrological maps and projects has been main focus in several publications by Martin Kemp, art historian, since some decades now. Kemp’s *Leonardo da Vinci: The Marvellous Works of Nature and Man* was published three



times; in 1981 he won Mitchell Prize. This book was reprinted with minor revisions, 1989 and a revised edition came out in 2006 [11, 12].

Leonardo's fascination with hydrology and evolution of natural environment is also present in one of his most famous paintings: Mona Lisa or La Gioconda; he had included one of the most important natural developments in the history of the plain between Florence, Prato and Pistoia. This plain was occupied by a huge lake for several millions of years until Roman times. Because of erosion caused by water, a crevice was created and a river (the Ombrone River) went through it to flow in the Arno River.

The lake waters which were pressing the massive rock of Gonfolina disappeared and the entire landscape was transformed; hills are visible, as we can see in Zocchi's far fetching view, including the Lastra a Signa Bridge on the right (where nowadays we find Carmignano train station). Gonfolina is shown in Giuseppe Zocchi's print in 1744, some centuries after Leonardo's walks to this place, probably when visiting his mother and grandmother's native home at Carmignano (Toia's house and inn – still existing at Bacchereto village in Carmignano). The rock on the left and the entire bridge (in part demolished in Zocchi's time) appear behind Mona Lisa's shoulders; you can see Gonfolina and the Ombrone River by her right shoulder and the Lastra a Signa Bridge in its entirety over her left one. Leonardo's hydrological drawings and attempts demonstrate that nature finds always its own way to shape natural landscapes whatever artificial interventions the humankind may attempt, such as the case studies discussed in this paper further [13].



**Fig. 2. Zocchi's View from a village (Lastra a Signa) to the Arno River through "Golfolina" (or Gonfolina rocks).** (Source: [Public domain], via Wikimedia Commons) at [https://commons.wikimedia.org/wiki/File:Zocchi,\\_ville\\_18\\_gonfolina.jpg](https://commons.wikimedia.org/wiki/File:Zocchi,_ville_18_gonfolina.jpg)

## 2.2 Modern hydrology: greenways and first blue infrastructure

One of the most influential approaches that shaped green infrastructure was the development of parkways and greenways. Greenways are linear features, which have been primarily constructed of environmental features, such as trails imprinted by regular flows of people; these trails originally aimed to facilitate movement from urban areas into the wider landscapes and countryside. Greenways appeared from the late 1800s onwards, and firstly developed in the USA to be utilized later worldwide.

Greenways performed as a cost-effective method to landscape management, as urban dwellers were seeking increased accessibility to nature; they also managed to strengthen a widening participation of the people and/or interactivity with the surrounding landscape which is now claimed as leisure time. Access to public transport also helped, as distances became less time-consuming. As a result, people were able to explore the countryside effortlessly, especially where nature was located in close proximity to urban centres (i.e. along and across green parks

and along river banks); access to nature was enabled by the implementation of organised trails [15].

After the 1800s we see green infrastructure along the boulevards and parkways, and in spacious commons. During a second era of development of the cities, we see the establishment of trail oriented recreational greenways. The current greenways uses have been extended with intend to develop multi-functional networks, which are able to promote a range of leisure, economic and environmental benefits.

The most famous greenway development included in available literature was constructed in Boston by Frederick Law Olmsted; it aimed to help the city's adaptation to its specific climate. Boston's Emerald Necklace covers an area of more than 1,100 acres; it was designed to manage the ice or snow melt of the Charles River, which led to annual flooding [3]. It is stated that:

The success of this investment helped the city of Boston to limit some of the negative impacts of urbanization through the development of a constructed wetland system. The investment also brought extensive socio-economic benefits to the city, with Boston Common acting as a hub for community activities, which is still the case today. [1]

Following Boston's success in investment, several North American cities, such as Indianapolis, Toronto and Montreal, benefitted from greenway-led regeneration. However, each city had a different approach to the development and management of greenways, which are often linked to waterfronts and/or water courses. According to Little, these greenway interventions fall into five distinct categories of investment: *“urban-riparian corridors, recreational greenways, ecological corridors, scenic and historic routes and comprehensive networks”* [14].

Although Little prescribes how greenways were historically developed, we see that contemporary investments utilize more than one type. Nowadays a 'features-led' understanding of greenways is promoted; this is because authors wish to indicate a greater relevance to green infrastructure planning [1]. In contemporary greenways literature, authors affirm that greenways are *“linear features that are spatially applied at different scales, which promote connectivity between people and place, and support a wide range of socio-economic and ecological benefits”* [1, 15]. Hence, most greenways key elements, such as, for example, connectivity are also integrated into green infrastructure planning. And the most relevant element is that, most of the times greenways are strictly linked to water courses' uses, as it happens in present-day renaturalisation of the rivers.

### 2.3 Recent hydrology: renaturation (renaturalisation) of the Aire River

The authors have come across an interesting and professional network, Landezine, which owns a web site started in June 2009. Since then, this network has been showcasing landscape architecture projects created by architects/landscape architects from around the globe [16]. Today Landezine claims that this is an internationally renowned landscape architecture network with more than 5,000 visitors from all over the world visiting its site every day. In 2016, Landezine expanded its network and empowered its voice in the global community by opening their “Landscape Issues” section and launching Landezine International Landscape (LILA) Award.

The renaturation of the Aire River project has been promoted by Landezine since 2016. This project is a finalist for Rosa Barba Prize by Atelier Descombes & Rampini, Superpositions group, and it was presented at the International Biennial of Landscape Architecture in Barcelona on 29 September 2016. Hargreaves Associates' Queen Elizabeth Olympic Park in London won the Rosa Barba International Landscape Prize at the International Biennial of Landscape Architecture in Barcelona on the 30th of September 2016. The project was selected from a shortlist of ten finalists.

Nevertheless, the Public Opinion Prize was voted by the attendees of the Biennial; it was awarded to Atelier Descombes & Rampini Architects for their project Renaturation of the Aire River in Geneva. Their client is the République et Canton de Genève (State of Geneva). The



architects have collaborated with B+C Ingénieurs (Engineers), ZS Ingénieurs civils, Biotec SA (Biology). Chronology of the construction period: Phase 1 (2002 – 2006), Phase 2 (2009 – 2011), Phase 3 (2012 – 2015), Phase 4 Ongoing. The length of the project is 5 km and the surface 50 Ha [17].

The group has considered the fact that the Aire River flows through valleys historically devoted to farming. Nevertheless, since the late 19th century, it was progressively canalised, and as canal it was used in many ways during the industrial revolution era. In 2001, the State of Geneva proclaimed a competition with the idea of restoring the river to its original shape by demolishing the canal. Superpositions instead proposed to combine the canal with a vast discharge area for overflowing river waters, quite similar to Leonardo's idea for the Arno River back in the 15th century in Florence.

As the group states: *"in the process the canal becomes the pointer for the transformations, a reference line giving the possibility to understand the before and after"* [17]. This new flowing development overlaps with previous geometries shown as a rigid diamond grid in its previous construction phase. However, nature has managed to overcome any rigid previous artificial restrictions by creating free-flow lines of water. Along and across this project, several greenways blend with the river flowing free to fill designed discharge areas according to seasons.



**Fig. 3. Renaturation of the Aire River – construction of a channel/landscape architecture – Aerial view showing evolution between June 2014 and May 2015. Courtesy © Superpositions.**

The official interpretation for the competition programme was based on natural balance. The legitimate necessities for environmental improvements suppressed any other considerations and entailed antagonism between nature and culture. The group affirms that their project attempts to propose an alternative process, in which the urgent ecological shifts are amalgamated into a larger cultural change.

The complex organisation of the design links the new river space and a linear series of gardens inside the former canal. In reality the whole design becomes a linear garden. The original morphology of the mountains and the traces of human interventions embrace and contain the whole water course; this long river garden organises the locations, views, confrontations, presences, aiming at introducing questions, worries, hopes into this fragile and precious territory. The essential calm and interiority yields organized sequences of differentiated places and paths, allowing a reasonable distribution of people and movements. The footprint of the canal is a key device for building the necessary calm and interiority; without it, there is no real garden. It is a

permanent trace which introduces a complex temporality, both past and future, memory and desire [17].



**Fig. 4. Naturalisation of the River Aire – River waters' discharge area and ex-canal used as integrated greenways. Courtesy © Superpositions.**

Superpositions group also explains that:

For the drawing of the river itself – conscious of the impractical effort to design a fixed river bed and aware that a river usually loves to design itself freely – we instead proposed an initial pattern, the form of which addresses the play between the river flow and the prepared terrain. This diamond-shape pattern opens a complex series of undetermined channels for the flows. These channels were excavated along the entire new river by removing layers of mud accumulations and maintaining a precise control of the longitudinal profile of the river. The dimensions of these lozenge-shaped islands were configured to be able to 'accept' the general sizes of the former meanders. The result is spectacular and suggests devices created by land artists, who clearly disturb nature by artificial interventions. Thereafter, the artificial is left to the mercy of natural forces. One year after the opening of the new river space, the results are beyond our expectations; the river flows by displacing diverse materials, pebbles, sand, and the geometrical matrix of lozenges has been significantly modified. We must accept this paradox: the more defined the grid given to the river, the more the river will be free to design itself [17].



**Fig. 5. Renaturation of the River Aire – Discharge area of the river still showing signs of an artificially shaped flow via a diamond-shape pattern. Courtesy © Superpositions.**

### 3. OUTCOMES FROM THE STUDY - DISCUSSION

Renaturation or renaturalisation projects with reference to water courses take place in diverse conditions; not only this depends from varied microclimate worldwide, but also is due to the variability of understanding between academics, policy-makers and practitioners in relation to the restoration of water courses. Therefore, it is obvious that there has been no unified consensus yet on how we should plan for reinstating and re-designing landscape resources. Often green infrastructure materialises as both a sum of its parts (by using and/or promoting certain ecosystems), and as an intrinsically context-specific approach [18]. In some countries, such as the UK and USA, we find out that there are several barriers to green infrastructure developments, such as policy formation, application and political support, support of other sectors (i.e. transport, sanitation or housing), and, most importantly, public responses to development (political/financial) [1]. Although these barriers and differences suggest that: *“there is a level of consistency to green infrastructure discussions in different locations, there are nuanced understandings or applications of the concepts and principles in different locales”* [1].

With reference to the aforementioned renaturation of the Aire River, we may see more flexibility in policy-makers by accepting a project which restores a long portion of a river that was artificially damaged for many years by being transformed in a canal. Perhaps persisting problems with frequent overflow and floods, and pollution, may have had a real impact on their decisions. Another important point raised by the team who has designed and is still delivering this project is their attempt to create spaces which will improve healthy conditions and human wellbeing. For citizens of urban spaces today, this is what is very much needed.

Greenways in some countries, such as North America, Switzerland (as above), etc. can be considered as a key precursor to green infrastructure planning, whereas in the UK planners have drawn more often on the principles of the garden cities' movement in order to include these debates. The relationship between garden cities and green infrastructure has been comprehensively explored by the UK Town & Country Planning Association. The promoter of the garden cities movement has been Ebenezer Howard; his proposed principles support the civic need to address a vast range of issues in the late 1800s and 1900s (socio-economic, health and wellbeing) [19].

Howard attempted to place social equity at the centre of urban development; his vision for garden cities aimed to reinstall the critical link between health, wellbeing and human-environment interactivity that is also evident in the Aire River project, too [19]. Howard's vision echoed the design principles of Olmsted in Boston and New York, where Olmsted had wanted a ground where people could go after work; we can say that: *“Howard aimed to incorporate the functional elements of urban and rural landscapes into his designs to achieve greater livability and multi-functionality”* [1]. In the Aire River project, urban and rural landscapes blend within the focused restoration of the water course to achieve livability of spaces which were previously abandoned and maybe out of control for several decades.

Several authors believe that for a number of years during the initial conceptualisation of the green infrastructure, water was to be underrepresented [3]. However this may vary spatially in some countries, such as the USA, for example, heavily emphasising the role of water source management mainly in the discussions of green infrastructure, and thus, introducing blue infrastructure management related to stormwater issues in urban areas and functional values of water by instigating terrestrial resources' debates. In the USA, the engineered management of water is of national importance [2, 6]. Although the USA dominates the discussions of water-focused green infrastructure research, there has been a growing exploration of similar issues in Europe, as we have seen above [17]. *“Many cities in the former industrial heartland of central and northern Europe in the Netherlands, Belgium, Germany, etc. have been at the forefront of this, examining ways to re-establish value in polluted and derelict water bodies”* [1]

#### 4. CONCLUSION

The authors have found that, although water managers and city planners pursue water systems with water rules and policies backing their claim 'living with water' and 'building with nature', some projects in progress need more time to be fully accomplished. This happens not because of lack of policies and/or financial support, but, because nature has to come back and respond to artificial manipulations. Nature has the final word of regenerating itself and renaturalising water courses.

Projects, such as the Aire River renaturation/renaturalisation in Geneva could be easily compared with Leonardo's hydrology ideas in Renaissance for the areas surrounding Florence. We find Leonardo's ideas in his Treatise on Water, in which he focuses on moving waters and trained rivers in relation to their water cycles and the tectonics of the earth's surface. All his studies and efforts managed to reduce problems in Florence and adjacent plane areas. Nevertheless, today danger of floods and damages is still a threat for central urban areas in proximity of the Arno River. More needs to be done along the extension of this river, and mostly in discharge areas. Perhaps examples as the Aire River renaturation could help many more cities to get meaningful green and blue infrastructure with a view to current and future needs and necessities of their citizens who are currently demanding healthy living conditions persistently.

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## A D(r)ying River: the Upper Paiva

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### ABSTRACT

Riverine population consistently report that the upper section of the Paiva River, a tributary of the Douro River, in Portugal, began to completely dry up by the end of the dry season in the late 1990s / early 2000s. The consequences of this phenomenon to the fluvial ecosystem and the nearby communities' use of the river were tremendous. Fish population decreased and survived the dry period in reservoirs remaining from deactivated water mills and the population has to travel further downstream to find usable river beaches. The present study focuses on the possibility of climate changes to be a contributing factor in the described Paiva River changes using a statistical approach. It was found that there are statistically significant results in terms of the decreasing trend, jump in mean and difference in mean/median on the yearly and monthly rainfall, and on the number of consecutive days without rain. The results support the observed drying up of the river by the end of the summer months.

*Keywords: climate change, rainfall, hydrology, hydrological analysis, Paiva River.*

### 1. INTRODUCTION

Based on several macro-scale hydrological modelling studies at continental (Arnell 1999a; Lehner et al. 2006) and global scales (Arnell 1999b; Döll and Zhang 2010; Sperna et al. 2012; van Vliet et al. 2013; Vörösmarty et al. 2000), climate change is expected to impact the hydrological regime of rivers and lakes. Along with studies focusing on Mainland Portugal, these general models estimate either an increase in seasonality, with higher winter flows compensating lower summer flows (Corte-Real et al. 1998, 1999; Trigo and Palutikof 2001), or even an annual flow decrease (APA 2010; Kilsby et al. 2007; Santos et al. 2002). Despite the sometimes contradicting results, at a regional/local scales, the consequences of the forecasted climate changes are becoming evident in several points of the globe (e.g., Asia – Bastakoti et al. 2014; Xiao et al. 2016; Africa – Hamandawana and Chanda 2013; Degefu and Bewket 2014, Natkhin et al. 2015; Australia – Risbey 2011; Europe – de Luis et al. 2014; Middle East – Ziv et al. 2014).

The Paiva River is regarded as one of the most scenic rivers in Portugal and enjoys the reputation of being mostly in its pristine condition. Based on the river classification system developed for the implementation of the EU Water Framework in Portugal (INAG 2008), the few small northern mountain rivers (type M) and most of the small northern rivers (type N1;  $\leq 100$ ) of all Douro river basin are located in the Paiva river basin. The Douro Hydrographic Region Management Plan (APA/ARH Norte 2012) classifies the Paiva River and its main tributaries as being little artificialized and good or higher quality water bodies. The climate is Mediterranean with influence from the Atlantic Ocean, being classified as Csb on the Köppen-Geiger scale.

The Paiva river basin extends for an area of 790 km<sup>2</sup>, covering 12 municipalities: Arouca, Castelo de Paiva, Castro Daire, Cinfães, Lamego, Moimenta da Beira, São Pedro do Sul, Sátão, Tarouca, Vila Nova de Paiva and Viseu. In 2008, there were 31 637 inhabitants in the Paiva river basin, but this number has been decreasing steadily over the last decades, in line with the overall population decrease in Portugal and the migration to the coastal regions. In

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addition, the main sectors of economic activity changed from primary (agriculture and livestock) to some industry and mostly services (tourism). The upper Paiva River is the reach with roughly 20 km between the headwaters and Vila Nova de Paiva, with a basin of nearly 100 km<sup>2</sup>. As most of the Paiva River, this reach is in its pristine condition. The few exceptions are some leisure areas and abandoned small traditional weirs that were used in the past to divert water for irrigation and milling purposes.

Based on the collective memory of the population in the communities along the upper Paiva River section, there has been a dramatic change in the hydraulic regime that became visible over the last two decades. According to interviews carried out during the study of EGSP (2015), there was a consistent report that the complete dry out of the river by the end of the summer months (end of August and beginning of September) began during late 1990s/early 2000s and has been regular ever since. Climate changes were considered a possible explanation considering that (EGSP 2015): i) the population has been decreasing since the early 2000s; ii) there was a shift from agriculture to other, in principle, less water intensive economic activities; and iii) in addition to the decline of agriculture, the only major land covering changes have been due to numerous wildfires that occur every summer. Historical water withdrawal data is not available, since the water for irrigation was not metered, but empirical evidence from the questionnaires does not support Human consumption as the main cause for the river drying (EGSP 2015).

Since climate changes are not abrupt but rather smooth transitions over a long period of time, their impacts may become evident before the perception of climate change. The research presented herein starts from the observation of an alteration that took place on the hydraulic regime of the upper Paiva River and explores if climate changes may be amongst the underlying causes.

## 2. DATA AND METHODS

There are 10 hydrometric stations in the Paiva River basin, 3 of them in tributaries and the remaining in the Paiva River. None of the stations are within the upper Paiva section and the closest are located near Castro Daire, 24 km downstream of Vila Nova de Paiva. The 2 hydrometric stations near Castro Daire are 180 m apart and measure the discharge from a basin with 288 km<sup>2</sup>. The station 08J/01H, maintained by EDP – Energias de Portugal (Energies of Portugal), is equipped with a limnigraph and there are records of water level and discharge between 01/10/1945 and 30/09/2004. The station 08J/02H, maintained by INAG – Instituto da Água (Water Institute), is equipped with a water level sensor and provides data on water level from 02/02/2002 to 12/02/2008. Considering the location of the hydrometric stations and the basin limits, 20 udometric stations were selected, covering points within and limiting the basin contributing to the stations section. The stations are listed in Table 1, along with some rainfall statistics and the length of the record series. The rainfall records were limited to 1945/1946 to be coincident with the runoff records. Both the hydrometric and udometric stations data is available through the National Water Resources Information System (Sistema Nacional de Informação de Recursos Hídricos – SNIRH) managed by the Portuguese Environment Agency (Agência Portuguesa do Ambiente – APA) available at <http://snirh.apambiente.pt/>.

The methods used were statistical tests and involved: i) analysis of the runoff data; and ii) analysis of the rainfall data. The analyses were carried out at a yearly and a monthly time scales using basic statistics (average, maximum, minimum, standard deviation) and a set of statistical test to identify: i) trends (Mann-Kendall, Spearman's R, Linear Regression); ii) jump in mean (Distribution free CUSUM, Cumulative Deviation, Worsley Likelihood Ratio); and iii) difference in mean/median (Wilcoxon Rank Sum, Student's t).

The tests used were selected because the WMO (2000) defined them to be official tools in analyzing hydrologic data and several studies demonstrate their efficiency in analyzing hydrologic and other variables, especially in the context of the ongoing climate change (e.g., Degefu and Bewket 2014; Hisdal et al. 2001; Lespinas et al. 2010; Razavi et al. 2016; Yue et al. 2002; Westmacott and Burn 1997). The non-parametric Mann-Kendall is independent of whether its shape is linear or non-linear (Kendall 1975; Mann 1945). The Spearman's rho is a

rank-based test for correlation between two variables and can be used to test for a correlation between time and the data series (Siegel and Castellan, 1988). The linear regression tests the significance of the regression gradient coefficient, assuming that the data is normally distributed. The distribution-free CUSUM is non-parametric rank-based test in which successive observations are compared with the median of the series (Chiew and McMahon 1993; McGilchrist and Woodyer 1975). The Cumulative Deviation test (Buishand 1982) is based on the rescaled cumulative sum of the deviations from the mean. The basic version of the test assuming normality was used herein. The Worsley likelihood ratio test (Worsley 1979) is similar to Student's t-test, since it also assumes normality, but is suitable when the change-point time is unknown. The tests for the difference in mean/median are classified along with the tests for the jump mean as tests for step change by the WMO (2000), but require the previous knowledge of the change-point time. The Student's t-test is a standard parametric test for testing whether two samples have different means and the Wilcoxon Rank Sum (Wilcoxon-Mann-Whitney test / Mann-Whitney test / Mann test / Rank-sum test) is a rank based test that looks for differences between two independent sample groups (Helsel and Hirsch 1992; Siegel and Castellan 1988; WMO 1988). Randomness was also tested using Median Crossing, Turning Points, Rank Difference and Autocorrelation. The first three are non-parametric tests (Grayson et al. 1996) while the last is parametric, assuming normality (Box and Jenkins 1976).

**Table 1. Udomedric stations in the area of interest**

| Station                          | Annual rainfall [mm] |               |                |                | Number of years with records since 1945/1946 |
|----------------------------------|----------------------|---------------|----------------|----------------|----------------------------------------------|
|                                  | Maximum              | Minimum       | Average        | Std. Deviation |                                              |
| <i>Ariz</i>                      | 2418.60              | 761.00        | 1352.81        | 425.36         | 40                                           |
| <i>Brufe (Barreiros)</i>         | 1501.70              | 607.00        | 1072.51        | 249.95         | 17                                           |
| <i>Calde</i>                     | 1541.80              | 522.80        | 1021.80        | 275.44         | 20                                           |
| <i>Carregal</i>                  | 1759.50              | 135.00        | 873.36         | 386.97         | 38                                           |
| <i>Castro Daire</i>              | 3336.10              | 870.90        | 1651.73        | 495.54         | 56                                           |
| <i>Castro Daire (Lamelas)</i>    | 1292.90              | 1213.80       | 1263.60        | 43.35          | 3                                            |
| <i>Forninhos</i>                 | 1472.10              | 445.50        | 870.88         | 252.04         | 21                                           |
| <i>Lapa</i>                      | 1906.80              | 491.20        | 1115.69        | 345.80         | 19                                           |
| <i>Leomil</i>                    | 2049.90              | 525.90        | 1044.09        | 358.60         | 54                                           |
| <i>Mezio (Paiva)</i>             | 3530.30              | 821.50        | 1956.51        | 661.64         | 58                                           |
| <i>Paradinha</i>                 | 1027.80              | 350.90        | 676.59         | 191.70         | 17                                           |
| <i>Pendilhe</i>                  | 3968.30              | 881.40        | 1822.11        | 674.08         | 53                                           |
| <i>Pindelo dos Milagres</i>      | 1817.20              | 745.90        | 1247.77        | 305.75         | 17                                           |
| <b><i>Queiriga</i></b>           | <b>1740.00</b>       | <b>617.90</b> | <b>1119.87</b> | <b>276.29</b>  | <b>21</b>                                    |
| <i>Quinta da Fumadinha</i>       | 1490.00              | 693.10        | 983.75         | 221.10         | 21                                           |
| <i>Sarzedo</i>                   | 1150.80              | 624.30        | 884.42         | 180.37         | 13                                           |
| <b><i>Sátão</i></b>              | <b>2081.90</b>       | <b>411.50</b> | <b>1162.63</b> | <b>375.77</b>  | <b>41</b>                                    |
| <b><i>Tarouca</i></b>            | <b>2810.80</b>       | <b>551.50</b> | <b>1109.82</b> | <b>430.74</b>  | <b>50</b>                                    |
| <b><i>Touro</i></b>              | <b>2763.50</b>       | <b>270.50</b> | <b>1448.35</b> | <b>563.83</b>  | <b>57</b>                                    |
| <b><i>Vila nova de Paiva</i></b> | <b>2378.00</b>       | <b>608.50</b> | <b>1379.77</b> | <b>396.11</b>  | <b>50</b>                                    |

Bold stations are located in the border between the basin of the upper Paiva River downstream section and the hydrometric stations section

Italic stations are located in the limit or within the upper Paiva river basin

Remaining stations are located in the limit or within the basin between upper Paiva River downstream section and the hydrometric stations section

### 3. RESULTS AND DISCUSSION

#### 3.2 Runoff

Analyzing the data in the period of time with records from both hydrometric stations, the correlation coefficient using a power law discharge curve was 0.55. In addition, several of the udometric stations only have records until 2000-2002 due to the changes in the monitoring network that were implemented in that period. Therefore, the runoff analysis was limited to the data from station 08J/01H.



The runoff presents a strong inter-annual variability (Fig. 1) and, despite the small apparent increasing trend, the statistical tests performed didn't return any significant result with a 5% significance level. In addition to the linear regression, a 5 year moving average dashed curve is presented. Even comparing to a 5 year moving average the runoff varies more than 200%.

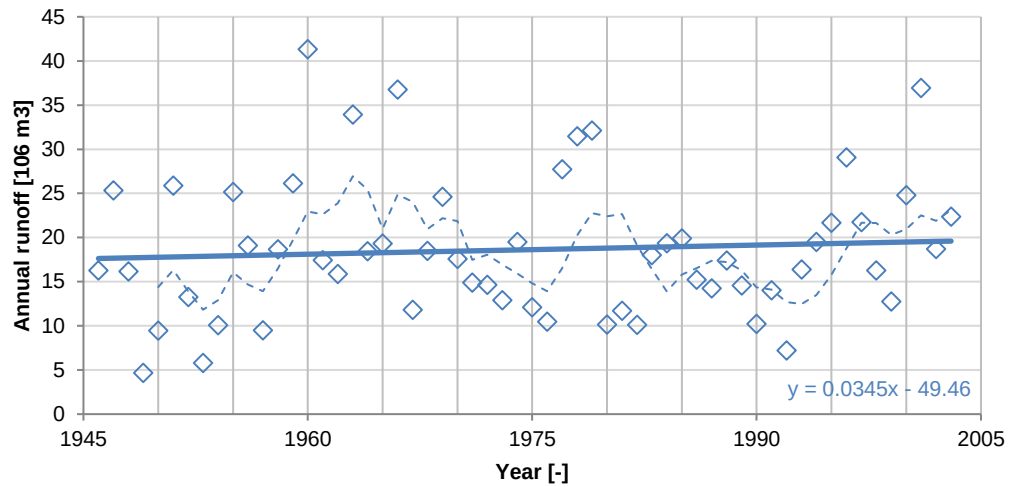
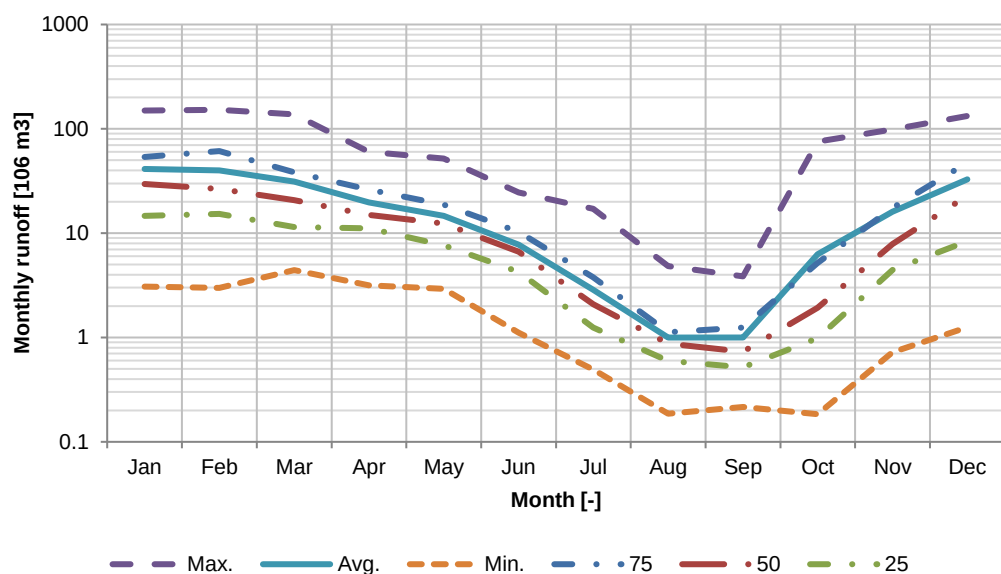


**Fig. 1. Annual runoff evolution**

At a monthly scale, the runoff during the wet and dry seasons are clearly marked. If the annual runoff variability was already significant, at a monthly scale it is even bigger. January was the month with the highest increasing trend and March the month with the highest decreasing trend in runoff (Fig. 2). Still, there were no statistically significant results from the tests to the runoff of each month.

The discharge analysis didn't provide any explanation for the observed drying of the upper Paiva River. In fact, the indication is for a slight increase of the total annual runoff but with changes in the monthly distribution. However, the hydrometric stations are located in a section with a basin almost three times the size of the upper Paiva River. Furthermore, immediately downstream of Vila Nova de Paiva there is a very abrupt fall (over 20 m in elevation in less than 200 m length) and the river starts to become steeper, particularly near Castro Daire, so the results may not be valid for the upper Paiva River.



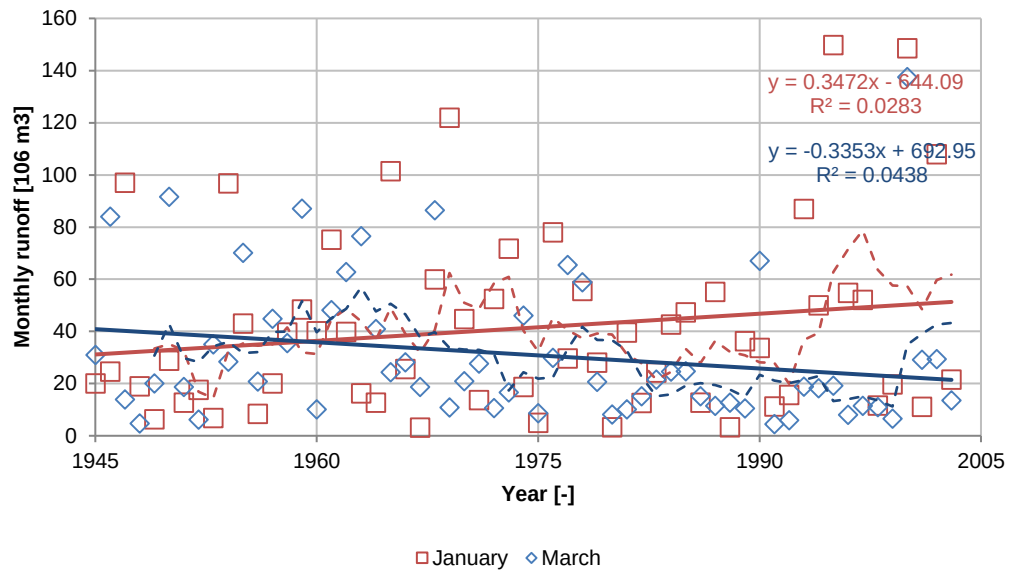


**Fig. 2. Monthly runoff annually (top) in January and March (bottom)**

### 3.2 Rainfall

The average annual rainfall of the udometric stations listed in Table 1 is presented in Fig. 3, showing a clear decreasing trend. No data treatment or station weighting was performed before averaging the rainfall since the goal is not to produce a hydrological model but rather capture an indication of overall changes.

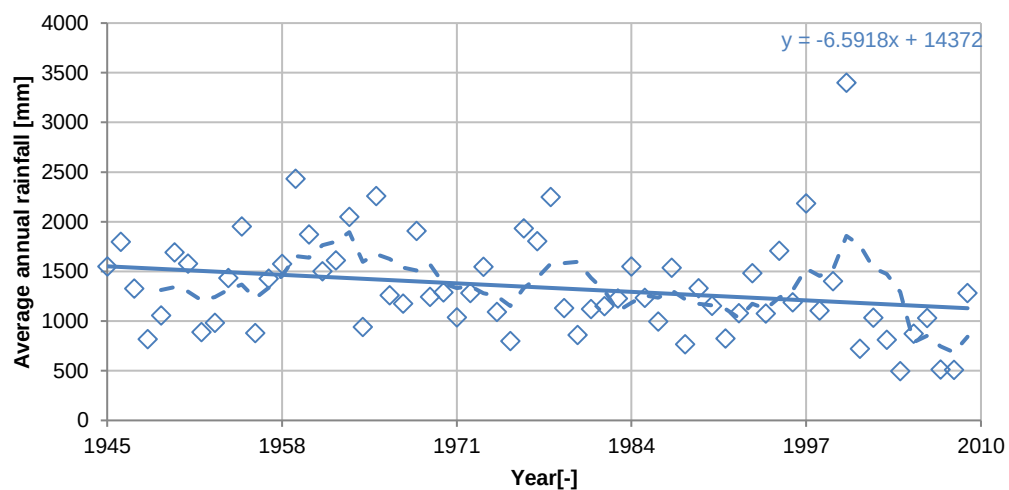


**Fig. 3. Average annual rainfall**

The tests indicate that there are some statistically significant results, namely in terms of trend and jump in mean (Table 2). However, these results vary when applied to each udometric station depending on several factors, namely the length and the period covered by the data series.

Presenting data for all 20 stations would be cumbersome, so Fig. 4 presents the annual rainfall of the four udometric stations with the longest data series since the year when data on runoff is available (1945/1946). The tests indicate statistically significant decreasing trends, jump in mean and difference in median/mean for the Mezio, Touro and Leomil stations, but not for Castro Daire. However, the Castro Daire station is neither in the border nor within the upper Paiva River basin and is the most distant from it.

Analyzing the monthly rainfall records of the seven stations with more than three years of records after the year 2000, the biggest differences are during winter and spring months (Fig. 5).

**Table 2. Statistical test on the average annual rainfall**

| Test                      | Statistics | Critical values ( $\alpha$ ) |       |       | Turning year |
|---------------------------|------------|------------------------------|-------|-------|--------------|
|                           |            | 0.01                         | 0.05  | 0.10  |              |
| Trend                     |            |                              |       |       |              |
| Mann-Kendall              | 3.070      | 2.576                        | 1.960 | 1.645 | -            |
| Spearman's R              | 3.002      | 2.576                        | 1.960 | 1.645 | -            |
| Linear Regression         | -2.211     | 2.690                        | 2.010 | 1.680 | -            |
| Jump in Mean              |            |                              |       |       |              |
| Distribution free CUSUM   | 9.000      | 11.526                       | 9.617 | 8.627 | 1978         |
| Cumulative Deviations     | 1.223      | 1.520                        | 1.270 | 1.140 | 2000         |
| Worsley Likelihood Ratio  | 3.492      | 3.790                        | 3.160 | 2.870 | 2000         |
| Difference in Mean/Median |            |                              |       |       |              |
| Wilcoxon Rank Sum         | 2.168      | 2.576                        | 1.960 | 1.645 | -            |
| Student t                 | 1.294      | 2.690                        | 2.010 | 1.680 | -            |
| Randomness                |            |                              |       |       |              |
| Median Crossing           | 0.143      | 2.576                        | 1.960 | 1.645 | -            |
| Turning Points            | 0.342      | 2.576                        | 1.960 | 1.645 | -            |
| Rank Difference           | 1.077      | 2.576                        | 1.960 | 1.645 | -            |
| Autocorrelation           | 0.476      | 2.576                        | 1.960 | 1.645 | -            |

*Italic value indicates statistically significant results*

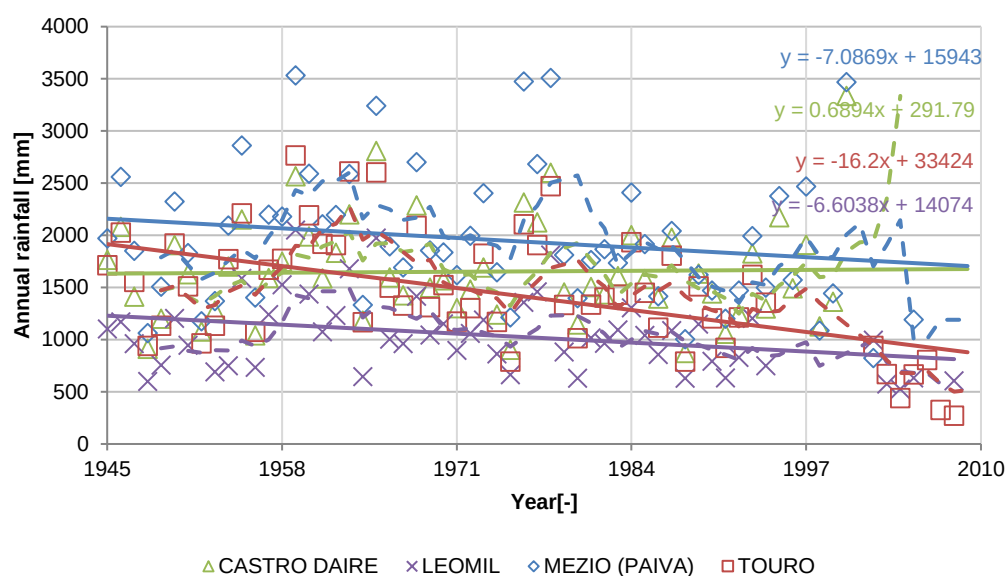


**Fig. 4. Annual rainfall in the stations with longest records**

The months with statistically significant difference in the mean monthly rainfall before and after the year 2000 are the following for each station: i) Forninhos - Feb, Apr, May; ii) Leomil - Feb, Mar, May, Dec; iii) Paradinha - May; iv) Queiriga - May; v) Quinta da Fumadinha - May; vi) Sátão - Feb, May; and vi) Touro: Jan, Feb, Mar, May, Sep, Nov, Dec. May was the only month with statistically differences for all stations (Fig. 6). Only Leomil station didn't reveal any statistically significant trend, jump in mean or difference in mean/median.

Despite the statistical significance of some of the results for the rainfall data, it should be noticed that: i) the apparent rainfall decrease in the early 2000s concurred with the reorganization of the monitoring network and the transition to automated systems in many stations; and ii) the number of years with annual rainfall records after the year 2000 is limited (maximum of 7 for Touro station), because with the reorganization of the monitoring network some were deactivated. Also, since 2008, the financial crisis imposed resources limitations restricting even further the number of stations in operation.

According to Daveau (1987-1991), the hydrogeology of the Paiva river basin is capable of retaining the groundwater for up to two months. Selecting the station with the overall longest daily rainfall data series (Castro Daire has daily precipitation records from 1916 to 2001), a statistically significant increase in the maximum number of consecutive days without rain was found (Table 3). The Casto Daire station was also selected because it did not present any statistically significant trend, jump in mean or difference in mean/median regarding the rainfall.

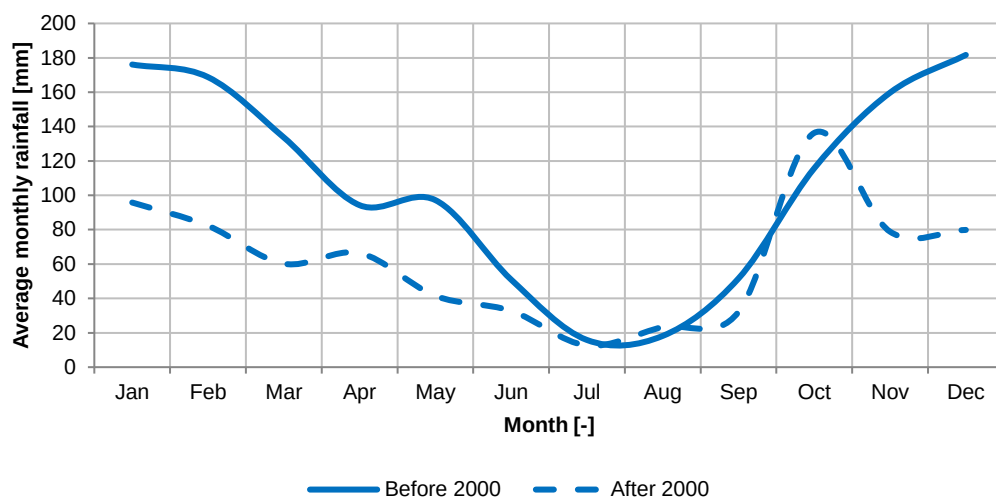


**Fig. 5. Aggregated average monthly rainfall before and after the year 2000 in selected stations**

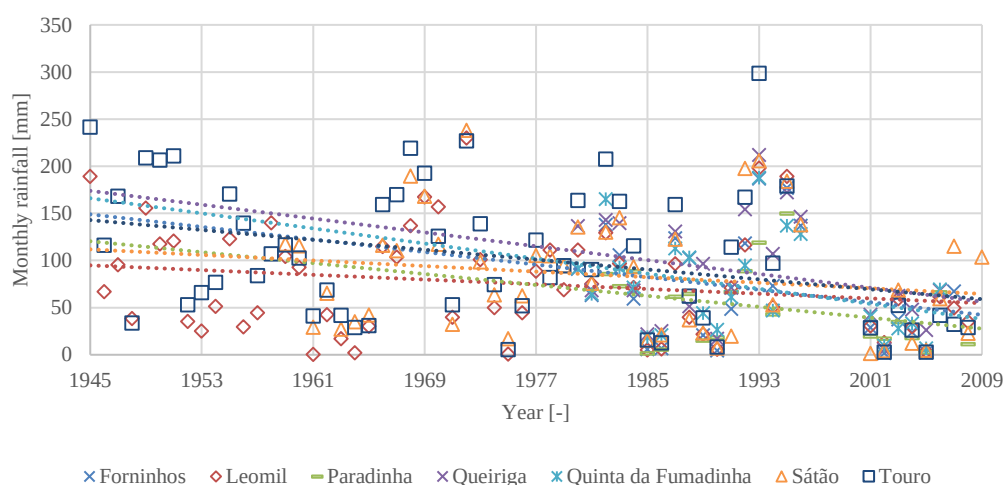


**Fig. 6. Monthly rainfall in the month of May in selected stations**

**Table 3. Statistical test on the maximum number of consecutive days without rain**

| Test                      | Statistics | Critical values ( $\alpha$ ) |       |       | Turning year |
|---------------------------|------------|------------------------------|-------|-------|--------------|
|                           |            | 0.01                         | 0.05  | 0.10  |              |
| Trend                     |            |                              |       |       |              |
| Mann-Kendall              | 2.710      | 2.576                        | 1.960 | 1.645 | -            |
| Spearman's R              | 2.708      | 2.576                        | 1.960 | 1.645 | -            |
| Linear Regression         | 2.809      | 2.690                        | 2.010 | 1.680 | -            |
| Jump in Mean              |            |                              |       |       |              |
| Distribution free CUSUM   | 10.000     | 11.526                       | 9.617 | 8.627 | 1975         |
| Cumulative Deviations     | 1.745      | 1.520                        | 1.270 | 1.140 | 1975         |
| Worsley Likelihood Ratio  | 3.969      | 3.790                        | 3.160 | 2.870 | 1975         |
| Difference in Mean/Median |            |                              |       |       |              |

| Test              | Statistics | Critical values ( $\alpha$ ) |       |       | Turning year |
|-------------------|------------|------------------------------|-------|-------|--------------|
|                   |            | 0.01                         | 0.05  | 0.10  |              |
| Wilcoxon Rank Sum | 2.624      | 2.576                        | 1.960 | 1.645 | -            |
| Student t         | 2.468      | 2.690                        | 2.010 | 1.680 | -            |
| Randomness        |            |                              |       |       |              |
| Median Crossing   | 0.714      | 2.576                        | 1.960 | 1.645 | -            |
| Turning Points    | 1.025      | 2.576                        | 1.960 | 1.645 | -            |
| Rank Difference   | 1.077      | 2.576                        | 1.960 | 1.645 | -            |
| Autocorrelation   | 1.707      | 2.576                        | 1.960 | 1.645 | -            |

#### 4. CONCLUSION

A statistically significant change in the rainfall amount and the number of consecutive days without precipitation was found within the Paiva River basin for the analyzed period. The available data does not allow concluding if the rainfall amount explains the drying of the upper Paiva River, but the number of consecutive days without rain is consistent with the time to deplete the upper Paiva river groundwater supply.

The results obtained are consistent with previous studies reporting statistically significant rainfall decline during spring (Corte-Real et al. 1998; de Lima et al. 2007, 2010; Mendes and Coelho 1993; Miranda et al. 2002; Paredes et al. 2006; Santo et al. 2014; Trigo and DaCamara 2000). Herein, the maximum increase in rainfall was during January. However, the increase in the number of consecutive days without rain contradicts other studies (e.g. Santo et al. 2014). However, Santo et al. (2014) performed a seasonal study and the decrease number of consecutive days without rain were observed during the Summer and Autumn.

This is not a conclusive result that the observed drying of the upper Paiva River is due to climate changes alone as, most probably, other causes may also be contributing to it. Nevertheless, there is a strong statistical evidence that climate change is one of the potential contributing factors not due to the change in precipitation and/or total runoff, but due to a change in the time distribution of the precipitation over the year. This explains why the smaller river basin already reveals changes in the hydraulic regime, while the sections further downstream do not. Understanding the phenomena underlying this change is of outmost importance for the design of and any mitigation measures.

#### ACKNOWLEDGMENT

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# Technical solutions for water reuse in a social and cultural center

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## ABSTRACT

This study evaluated the potential of water reuse in a social and cultural center, proposing solutions for the reduction of potable water consumption and testing the technical feasibility of four water reuse solutions. One of the solutions only suggests the replacement and/or the modification of the equipment, whilst the remaining solutions point out for the use of rainwater for supplying the cleaning water cisterns with variation of the volume.

Any of the solutions can be implemented and would lead to a considerable reduction of the water consumption and the water service cost. However, the use of rainwater to supply flushing cisterns entails very high investment costs compared to the savings achieved, making it unviable for regions of the country with lower water prices.

In a short time period, the solution with the fastest return investment is also the one with the lowest investment costs. However, in a long time period the greatest savings are achieved by combining rainwater harvesting with the installation of more efficient equipment for water consumption.

Therefore, in areas with lower water billing prices, the most viable investment it seems to be the adoption of high water efficiency equipment's. In areas where the billing reaches higher values, it is economically feasible to invest in a rainwater supply system, preferably in conjunction with the use of equipment with good water efficiency.

*Keywords: Water reuse, Building water systems, Reduction of water consumption, Technical and economic feasibility*

## 1. INTRODUCTION

Water is the most valuable natural resource on the planet, and its conservation is one of the most important pillars of sustainable development. In regions where the water scarcity is a natural reality, and where population growth and/or climate change are a source of scarcity, sustainable management of water resources implies conservation of these resources, which should include water reuse procedures [1].

The Portuguese National Program for the Efficient Use of Water (PNUEA) [2], which under implementation in the period 2012-2020, establishes measures for the urban, agricultural and industrial sectors that promote the efficient use of water, valuing water resources, not only environmental preservation, but also for its value for economic and social progress. Specific objectives for the urban sector include, for example, the minimization of the use of drinking water in activities that may have the same performance with alternative water quality such as the use of rainwater and the reuse of treated wastewater and the promotion of the use of

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standardized and certified equipment's for the water efficient use, encouraging their production and marketing [2].

In isolated or decentralized zones, the use of rainwater presents great possibilities of use, once these waters are captured in the place where they will be consumed. Rainwater harvesting is done using pre-existing structures, and can be stored in reservoirs or cisterns and used with little or no treatment [3].

Being the shortages of drinking water a increasingly reality on most continents, with high consumption patterns associated with the progressive growth of the world's population, it is of most importance the implementation of alternative sources of water such as a Rainwater Harvesting System (RHS).

According to [4], a RHS consists of six basic components with very specific functions, namely: catchment or collection surface, transport system, filtration, storage, distribution and treatment. In Portugal, the installation and certification of a RHS, must comply with the conditions established in two technical specifications developed by the National Association for Quality for Building Installations (ANQIP). The Technical Specification ANQIP 0701 (ETA 0701) [5] establishes the technical criteria for the performance of a RHS in buildings, for purposes other than human consumption, and the Technical Specification ANQIP 0702 (ETA 0702) [6] establishes the conditions for Certification of a RHS, performed accordingly [5]. As this type of systems is not yet widely applied in Portugal, these specifications are an important support to the development of RHS.

Due to the high billing of drinking water consumption in the Social and Cultural Center of Santo Aleixo (SCCSA), located in the village of Unhais da Serra (Covilhã, Portugal), the main objective of this study was to find possible solutions to reduce water consumption in the building. The technical and economic feasibility of four solutions and a comparison of these solutions in other areas of the country were also analysed.

## 2. METHODOLOGY

### 2.1 Description of the building and characterization of the sanitary equipment's

The SCCSA is a Private Institution of Social Solidarity, formed by a residential building (Fig. 1-a)) and a building of new valences (Fig. 1-b)). The residential building consists of a ground floor and a first floor, having in the surrounding area a garden with about 600 m<sup>2</sup>. It has 27 residents, 27 workers and 4 children in pre-school, having 24 sanitary facilities that aim to accommodate the needs of all of them. There are 24 flushing cisterns (with 10 L reservoir), but only 2 have a dual flushing mechanism and 32 conventional single-lever mixer taps (9 L min<sup>-1</sup>).



**Fig. 1. Social and Cultural Center of Santo Aleixo: a) residential building; b) building of new valences**

### 2.2 Solutions to reduce drinking water consumption in the building

Two options were studied to reduce the consumption of drinking water in the building. The first option involved a solution for replacing and modifying of some of the equipment (namely

flushing cisterns and taps), and the second option involved the study of three solutions for the reuse of rainwater [7]. An analysis was made for the technical and economic feasibility of the four solutions. A comparison of the same solutions in two other areas of the country (Chaves and Faro counties) was also setup [7].

### **2.2.1 Option 1 - Replacement and modification of some equipment**

In this option, a solution was proposed for reducing water consumption by replacing the existing flushing cisterns by dual flushing cisterns with 6 L/3 L, the 19 conventional taps by timed taps and also by installing flow reducers in other 13 taps.

From an environmental perspective, this measure has as main benefits the reduction of drinking water consumption and the consequent reduction of the volume of associated wastewater discharges.

### **2.2.2 Option 2 - Rainwater harvesting**

In this option, it was proposed to supply the flushing cisterns with rainwater, involving the three following solutions:

- Solution 2-a: direct supplying of the flushing cisterns with rainwater, without making any change in the equipment;
- Solution 2-b: supplying of the flushing cisterns with rainwater and replacing the existing flushing cisterns by dual mechanism flushing cisterns with a capacity of 6 L/3 L.
- Solution 2-c: supplying of the flushing cisterns with rainwater and replacing the existing flushing cisterns by dual mechanism flushing cisterns with a capacity of 6 L/3 L, as well as replacing/modifying the existing taps by a more efficient taps.

## **2.3 Sizing of the reservoirs for rainwater building supply**

For computing the volume of the reservoir for rainwater storing, there were only considered the water needs for flushing all the toilets. The water volume computing it was considered the number of uses per inhabitant per day for 30 days and not the number of flushing toilets.

Taking in account the number of people at the SCCSA (i.e. 27 residents, 27 workers and 4 children) and that they have different residence times at the building, it was considered the following residents-equivalents: the 27 workers are in the SCCSA in 3 work shifts of 8 hours each, which is equivalent to have 9 residents; the 4 children are in the building for 8 hours and have the same water consumption as an adult for 24 hours; the visiting people have a water consumption equivalent to two adults. In total, the building has 40 residents-equivalents [7].

In the solution 2-a, the supply would be made for flushing cisterns with a capacity of 10 L. It was considered 5 uses per day per inhabitant, for 40 residents-equivalents per 30 days, which gives 60 m<sup>3</sup> per month. Thus, a reservoir with 70 m<sup>3</sup> it would be adequate for flushing the toilets during one month [7].

For the solutions 2-b and 2-c, the calculation was made taking into consideration the dual mechanism cisterns with capacity of 6 L/3 L. It was considered one use of 6 L and four uses of 3 L per day per inhabitant, which gives a volume of 21.6 m<sup>3</sup> per month. Thus, a reservoir with a capacity of 30 m<sup>3</sup> it would be adequate for flushing the toilets during one month [7].

## **2.4 Sizing of the rainwater drainage network and the water supply network with recovered rainwater**

The resizing of the building networks was done in accordance with the Portuguese General Regulation of Public and Building Systems of Water Distribution and Wastewater Drainage Systems (Regulatory Decree no. 23/95, of August 23 [8]) and the procedures suggested by [9]. The recovery rainwater for building supply (i.e. for the flushing toilets) will be stored in a reservoir located in a green area in front of the main building. The water will be pumped into the flushing cisterns through a water supply building network.

In the Fig. 2 is presented the building plant with the two building networks.

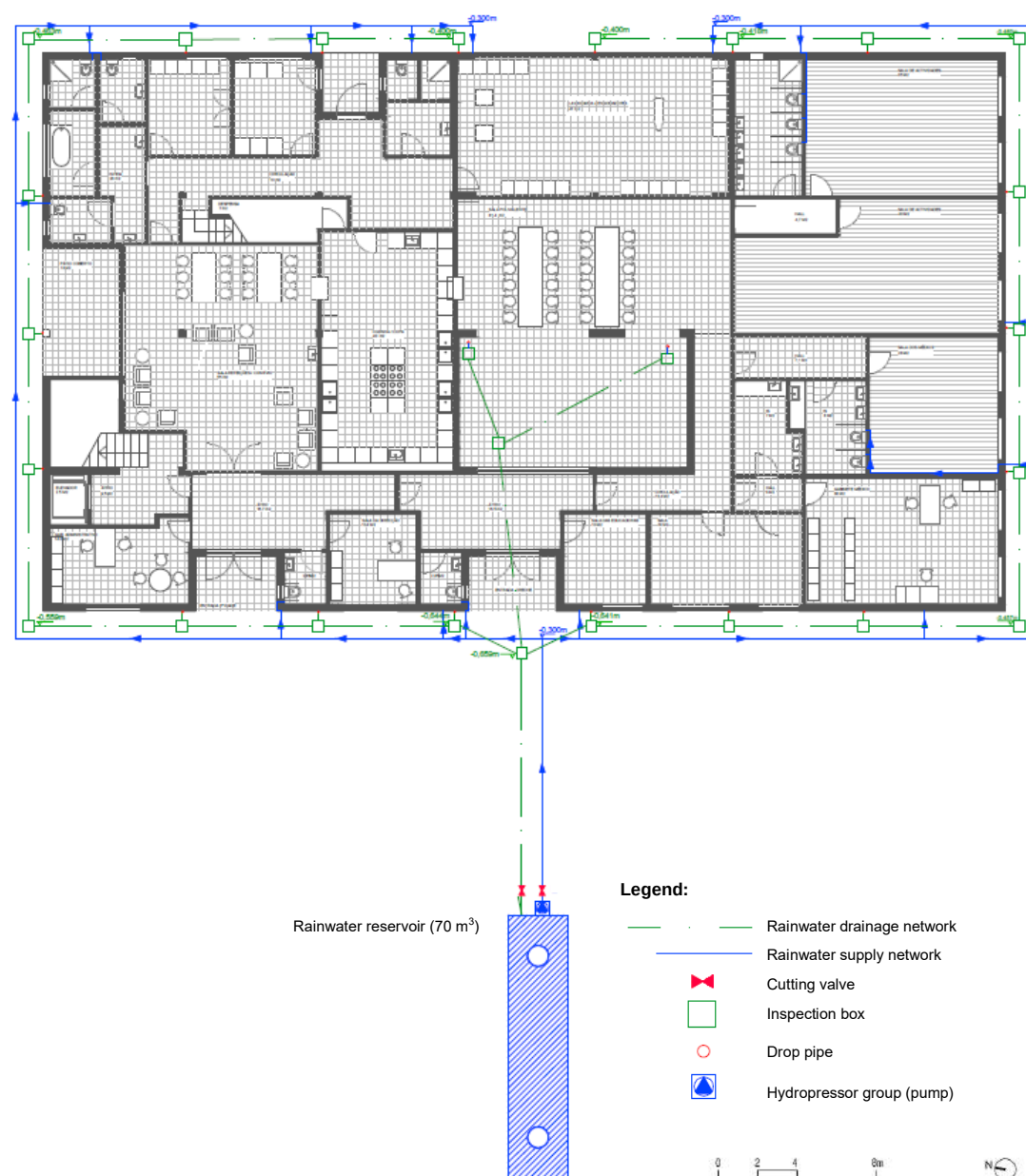


Fig. 2. Rainwater drainage network and rainwater supply network (1st floor) [7]

### 3. RESULTS AND DISCUSSION

#### 3.1 Technical feasibility

Both options considered for reducing the drinking water consumption in SCCSA can be implemented, from a constructive and hydraulic-sanitary perspective [7].

Regarding the rainwater drainage network, the values of the flow velocities are within the stipulated limits, and the shear stress values are higher and could allow good self-cleaning conditions [7,8].

In the rainwater supply network, the flow rates are within the range indicated by regulation [8], from 0.5 m s<sup>-1</sup> to 2 m s<sup>-1</sup>. An hydropressor group (Fig. 2) will guarantee the minimum pressure necessary for the correct operation of the equipment. Therefore, the rainwater supply network is considered technically feasible.

## 3.2 Economic feasibility

This study was based on the volumes of water saved, on investment, operation, maintenance and inspection costs, energy costs and the time for returning the investment. The most favourable solution was considered the one that presented the greater water savings, associated with a lower investment, lower maintenance and a quick return of the financial investment.

### 3.2.1 Reduction of the consumed potable water volumes

The calculation of the volumes for water flushing cisterns followed the same criteria used for the volume calculation in the Section 2.3 [7].

For the water consumption in taps, there were considered the duration and average uses for the taps (10 uses per inhabitant per day, for 10 s and 9 L min<sup>-1</sup>). In the calculation of the water savings were assumed the same criteria, however, it was a reduction of 5.5 L min<sup>-1</sup> due to the installation of flow reducers.

In bot calculation it was considered an increase of 20% in the consumptions of water for the summer months.

Table 1 presents the average annual water volumes consumed, as well as the potential savings associated to each option.

**Table 1. Average annual volumes of potable water consumed and potential savings**

|                   | Average annual volumes of potable water consumed (m <sup>3</sup> ) |          |              |              |              |
|-------------------|--------------------------------------------------------------------|----------|--------------|--------------|--------------|
|                   | Current consumption                                                | Option 1 | Option 2     |              |              |
|                   |                                                                    |          | Solution 2-a | Solution 2-b | Solution 2-c |
| Flushing cisterns | 792                                                                | 285.12   | 228.7        | 39.9         | 39.9         |
| Taps              | 285.12                                                             | 174.24   | 285.12       | 285.12       | 174.24       |
| Total             | 1077.12                                                            | 459.36   | 513.8        | 325.0        | 214.1        |
| Savings (%)       | 0                                                                  | 57.4     | 52.3         | 69.8         | <b>80.1</b>  |

According to Table 1, regarding savings of water resources, the solution 2-a is the one with the higher water consumption, achieving savings of 52.3%. The solution which would lead to greater savings of potable water is she solution 2-c, with 80.1% of water saving.

### 3.2.2 Investment Costs

The investment costs, presented in Table 2, include the costs associated with the installation of the rainwater supply network, the installation of building sewers, accessories and manholes, the earth excavation and installation/construction of the reservoir, network elements, equipment, hydropressor group and accessories, and the manpower.

**Table 2. Costs associated with the installed equipment and the modification of the building networks**

|                                                                                     | Option 1         | Option 2                   |                            |                            |
|-------------------------------------------------------------------------------------|------------------|----------------------------|----------------------------|----------------------------|
|                                                                                     |                  | Solution 2-a <sup>1)</sup> | Solution 2-b <sup>2)</sup> | Solution 2-c <sup>2)</sup> |
| Replacement and modification of sanitary equipment                                  | 5 520,00€        | 0,00€                      | 3 797,04€                  | 5 520,00€                  |
| Rainwater drainage network (including equipment, elements and accessories)          | 0,00€            | 7 720,36€                  | 7 720,36€                  | 7 720,36€                  |
| Rainwater supply network                                                            | 0,00€            | 2 085,12€                  | 2 085,12€                  | 2 085,12€                  |
| Equipment and its installation (e.g. reservoir, hydropressor group and accessories) | 0,00€            | 21 169,60€                 | 10 569,60€                 | 10 569,60€                 |
| <b>Totals</b>                                                                       | <b>5 520,00€</b> | <b>30 975,08€</b>          | <b>24 172,12€</b>          | <b>25 895,08€</b>          |

<sup>1)</sup> Considering a reservoir with 70 m<sup>3</sup>.

<sup>2)</sup> Considering a reservoir with 30 m<sup>3</sup>.

Analysing Table 2, it can be observed that the equipment's for the collection, storage and distribution of rainwater are the expensive ones, namely the cost of the reservoir [7].

### **3.2.3 Costs and operating requirements**

In a rainwater harvesting and supply building network it is necessary to replace the elements of the network, equipment and accessories throughout the operating time. It's considered appropriate the replacement of the hydropressor group and valves every 10 years [7]. The costs associated with the maintenance of equipment and replacement of the elements for each of the options are presented in Table 3.

**Table 3. Costs associated with the replacement of elements and equipment maintenance every 10 years**

|                                                   | Option 1 | Option 2     |              |              |
|---------------------------------------------------|----------|--------------|--------------|--------------|
|                                                   |          | Solution 2-a | Solution 2-b | Solution 2-c |
| Equipment maintenance and replacement of elements | 0,00€    | 2 256,00€    | 2 256,00€    | 2 256,00€    |

### **3.2.4 Reduction of the monthly and annual water billing**

In the calculation of the water billing reduction, it was necessary to consult the tariffs in force for the supply of drinking water and the drainage of wastewater at the district of Covilhã, which also considers the tariffs associated with the collection and treatment of solid waste. The water service are provided by the local Council, whilst the management of solid wastes is carried out by the municipal company Águas da Covilhã (ADC) [10].

A similar calculation was computed for other two districts in Portugal (Chaves, in the North, and Faro, in the South), with different costs for services of water, wastewater and solid wastes, in order to compare savings in different areas of the country.

Applying the current tariffs of 2017 in Covilhã (for Unhais da Serra place) [10], Chaves [11] and Faro [12], there were computed the average monthly savings and the annual average savings regarding the water supply, wastewater sanitation and solid waste management for the two options [7]. The municipality of Covilhã is the one which has the highest water billing. The values are shown in Fig. 3-a) and Fig. 3-b), respectively.

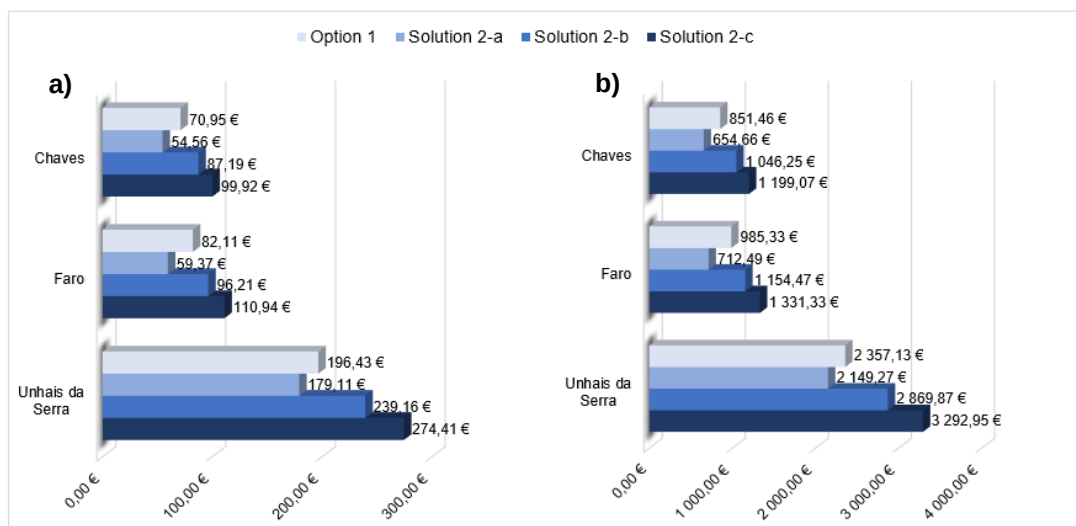


**Fig. 3. a) Monthly water savings and b) annual water savings, for Unhais da Serra (Covilhã), Chaves and Faro**

Analysing Fig. 3-a) and 3-b), it is possible to observe that any of the options presented is a good solution for reducing water consumption and the associated billing.

These values were calculated considering the volume of water saved and also the monthly average availability of rainfall from January 2001 to August 2017. The rainfall data were collected at the National Water Resources Information System (SNIRH) [13] in the meteorological stations of Covilhã (for Unhais da Serra), São Brás de Alportel (for Faro) and Travancas (for Chaves).

### 3.2.5 Return of the investments

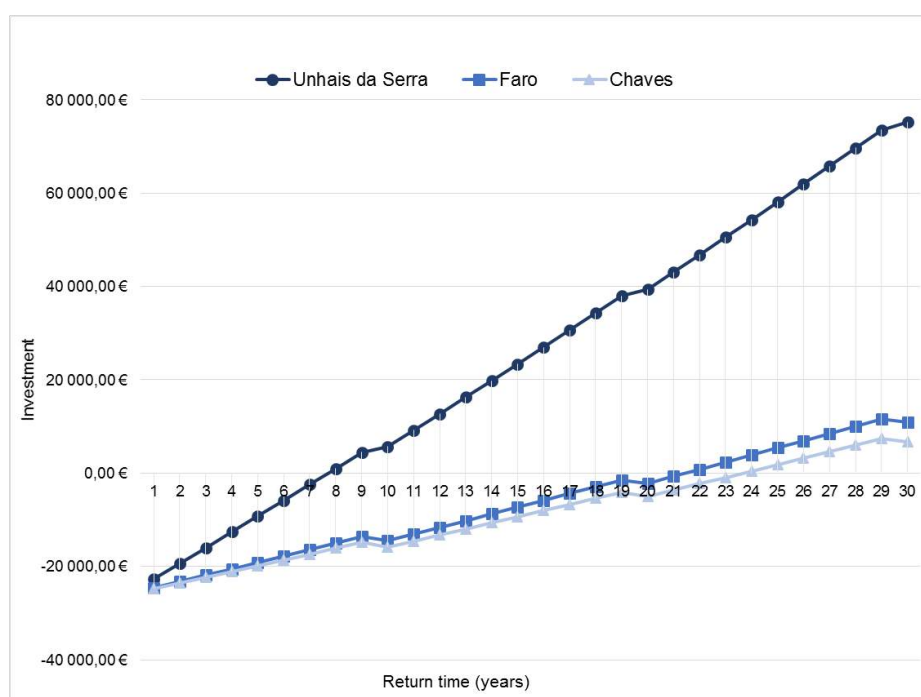
From an economic point of view, the time for returning the investment is another criterion to consider when choosing the best solution for a reuse system. The time needed to recover the investment it was determined taking into account the total of the investment, the maintenance costs for every 10 years and the savings in the water billings [7].

After analysing all the data, it was verified that the solution most favourable to the saving of water resources, as well as for reducing the billing costs is the solution 2-c [7], whose values for the return of investments is presented in Table 4. The Fig. 4 presents the return time for the three places.

Thus, analysing Table 4 and Fig. 4 it is possible to verify that Unhais da Serra presents the higher values for water savings and also the quickly return on investments (8 years), when compared to Faro (22 years) and Chaves (24 years). For a period of 30 years, the SCCSA can save around 75 000,00 €.

**Table 4. Calculation of the return of the investments for the option 2: solution 2-c**

| Option 2: Solution 2-c |             |             |             |     |            |                  |
|------------------------|-------------|-------------|-------------|-----|------------|------------------|
| Unhais da Serra        |             |             |             |     |            |                  |
| Years                  | 1           | 2           | 3           | ... | 7          | 8                |
| Investment value       | 25 895,08€  | 0,00€       | 0,00€       | ... | 0,00€      | <b>0,00€</b>     |
| Annual return amount   | 3 292,95€   | 3 312,70€   | 3 332,58€   | ... | 3 413,28€  | <b>3 433,76€</b> |
| Balance                | -22 602,13€ | -19 289,43€ | -15 956,85€ | ... | -2 425,38€ | <b>1 008,38€</b> |
| Faro                   |             |             |             |     |            |                  |
| Years                  | 1           | 2           | 3           | ... | 21         | 22               |
| Investment value       | 25 895,08€  | 0,00€       | 0,00€       | ... | 2 256,00€  | <b>0,00€</b>     |
| Annual return amount   | 1 331,33€   | 1 339,32€   | 1 347,35€   | ... | 1 500,53€  | <b>1 509,53€</b> |
| Balance                | -24 563,75€ | -23 224,43€ | -21 877,08€ | ... | -706,21€   | <b>803,33€</b>   |
| Chaves                 |             |             |             |     |            |                  |
| Years                  | 1           | 2           | 3           | ... | 23         | 24               |
| Investment value       | 25 895,08€  | 0,00€       | 0,00€       | ... | 0,00€      | <b>0,00€</b>     |
| Annual return amount   | 1 199,07€   | 1 206,27€   | 1 213,51€   | ... | 1 367,73€  | <b>1 375,94€</b> |
| Balance                | -24 696,01€ | -23 489,74€ | -22 276,23€ | ... | -929,37€   | <b>446,58€</b>   |

**Fig. 4. Returning time for the investment for Unhais da Serra (Covilhã), Faro and Chaves (option 2: solution 2-c)**

#### 4. CONCLUSIONS

This study allow concluding that the implementation of rainwater reuse in a collective social center can lead to water savings of 57.4%, only changing equipment's and accessories (option 1).

If there is no storage structure, it is necessary to acquire a reservoir for rainwater storage, which involves a high initial investment (option 2). Rainwater harvesting is not feasible if it is not combined with the introduction of highly water efficient equipment, except when the costs associated with water billing are quite high.

Replacing the existing sanitary equipment, in order to make them more efficient (option 2: solution 2-c), it can lead to water reductions around 80.1%, with the investment being recovered in 8 years. For a period of 30 years the savings can reach around 75 000,00€.

Therefore, in areas where water billing reaches high values, it is economically feasible to invest in a Rainwater Harvesting System, preferably associated to the use of hydraulically efficient equipment's. However, in cases where the water billing prices are lower, the most viable investment could be the adoption of high water efficiency equipment.

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**#7. Water efficiency in all sectors; domestic, industry, agriculture etc.**

# POTENTIAL OF RAINWATER HARVESTING IN A BRAZILIAN NEIGHBOURHOOD

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## ABSTRACT

The use of rainwater has been highlighted in recent years with regard to actions aimed at a more sustainable city. From the building's point of view, it can reduce its consumption of drinking water. In the urban aspect, the use of several systems can cause a considerable reduction of the volume drained in the stormwater infrastructure. Therefore, it is proposed the study of a neighborhood in the city Goiânia, determining the impact that the total or partial implantation of a standard rainwater harvesting system could cause in the volume drained. For this, high quality images from Google Earth were used to determine the collection areas as well as the irrigation area and size of the issue, using the Netuno Software to determine the usable volume of rainwater, as well as the drained volume. It was considered a typical RWS to be used in 10%, 25%, 50%, 75 or 100% of the buildings in a chosen neighborhood. The results pointed to the indication of guidelines that may promote the adoption of public actions to encourage the use of this input.

*Keywords: RWH, Rainwater Harvesting, Overflow, Urban drainage, GIS*

## 1. INTRODUCTION

Rainwater harvesting system (RWHS) has been used as a way to promote water conservation in buildings and it can be noticed an increasing interest in this technology in the last years.

In the literature, few papers focus on the RWHS role in urban storm water management. MARSALEK and SCHREIER (2009) described a number of combined practices, what includes RWHS and green roofs, in three different level (household, urban and basin) to verify the reduction of urban flooding. WHEATER and EVANS (2009) also place RWHS as a mitigating factor of flood control in the household's level

WALSH, POMEROY and BURIAN (2014) evaluated this impact of the RWHS in the flood control in the city of San Diego, United States. The authors confirmed that the total implementation of a given RWHS could reduce the runoff flow by up to 14%.

In Brazil, some studies also verified the impact of RWHS in the urban drainage (DORNELES, 2012; TESTON, 2015). DORNELES (2012) observed that, in Porto Alegre, there was a partial retention of the initial runoff flow but, by analyzing the reduction of the rainfall peak, RWHS were inefficient. TESTON (2015) verified a runoff peak flow can be reduced by 6% in Curitiba. The author pointed that the superficial flow reduction suffers influence of the demand, the rainfall frequency and the contribution percentage of the roof in surface runoff.

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In this context, more studies about the use of RWHS as a way to reduce the amount of stormwater in public drainage galleries are necessary. It has different influences and it can serve in promoting public policies.

It is worth mentioning that the rainwater's quality must be investigated. Minimum quality standards must be met, depending on where the system will be installed. In Brazil, the Brazilian standard NBR 15527/2007 (ABNT, 2007) establishes minimum requirements as well as the frequencies these parameters must be verified. In Portugal, the technical specifications of ANQIP establishes the appropriate treatment for each use destined to this water source. (ANQIP, 2015).

Then, this study objective is to measure the impact on urban drainage when residential rainwater harvesting systems (RWHS) will be installed in a neighborhood scale in the city of Goiânia. For this purpose, several resources were used and a research protocol was developed.

## 2. METHODOLOGY

### 2.1 Neighborhood Selection

The choice of the studied neighborhood was guided by three criteria: the neighborhood should be basically composed of single-family buildings; it has already been built and that the buildings must be similar to each other, so that the lots and buildings characteristics could be replicated.

In this way, it was chosen a housing project conceived in the 80's and located in the southeast region of the city of Goiânia named Parque Atheneu. This neighborhood has 1,86 km<sup>2</sup> of surface and an estimated population of 14.068 habitants. The average income is among 683 USD and 890 USD in this region (SEPLAM, 2010; IBGE, 2018). Figure 1 illustrates, in pink, the chosen neighborhood position in Goiânia (in black).

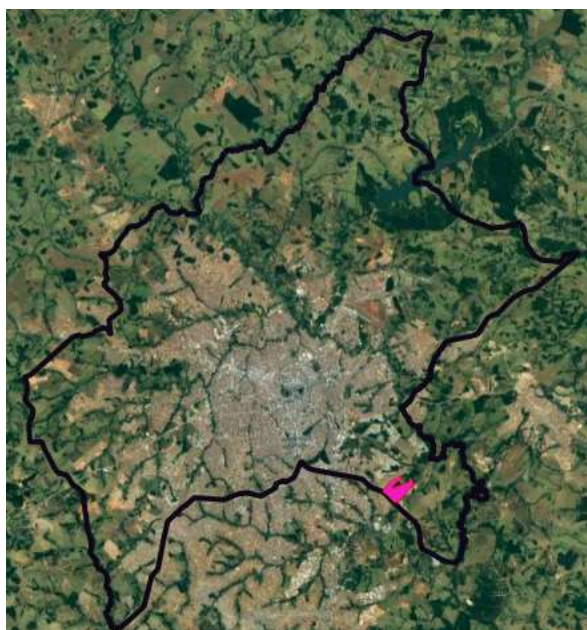


**Fig. 1 Parque Atheneu's position in Goiânia**

### 2.2 Materials

Some geographic information system (GIS) tools were used to obtain data used in this paper: from the Goiânia's Geographic Information System (SIGGO), it was obtained the limits and characteristics of neighborhoods, blocks and lots. It was also used images and tools available

in the computer programs Google Earth Pro and QuantumGIS 2.18.17 to obtain the use of the lots.

This research also used daily rainfall data from 2000 to 2017 recorded by the meteorological station TRMM 2731 and obtained from the Agrometeorological Monitoring System (AGRITEMPO, 2018).

## 2.3 Sizing of the rainwater tank

The amount of water used and discarded over time is closely related to the volume of the rainwater tank used in the RWHS, to the consumption and the rainfall patterns. Therefore, it was fundamental to size properly the reservoir, in order to perform the analysis proposed by this work.

To size the reservoir, it was used the Neptune software. This program calculates the potential for potable water savings of tanks with sizes between 0.5 m<sup>3</sup> and 100 m<sup>3</sup> performed every 0.5m<sup>3</sup>. And the best volume is determined by choosing a minimum difference of this potential of two consecutives storage volume must have. To this paper, it was chosen 1%/ m<sup>3</sup>. Details about this software can be found in Ghisi et al., 2009.

To implement these simulations some input data were necessary: rainfall pattern, water demand and the catchment area.

### 2.3.1 Water supply

The rainwater supply is limited by the rainfall patterns of the city. The daily precipitation data from 2000 to 2017 obtained from AGRITEMPO (2018) were used in this research. These data compose a 17 years historical series that was arranged in an electronic spreadsheet.

Two main seasons are observed in Goiânia: a rainy season from October to April and a dry season from May to September (Figure 2).

Goiânia has an annual rainfall average of 1491,91mm. December and July are the months with highest and lowest rainfall, respectively with 249,7mm and 3,2mm. From April to November the average monthly rainfall is less than 200mm.

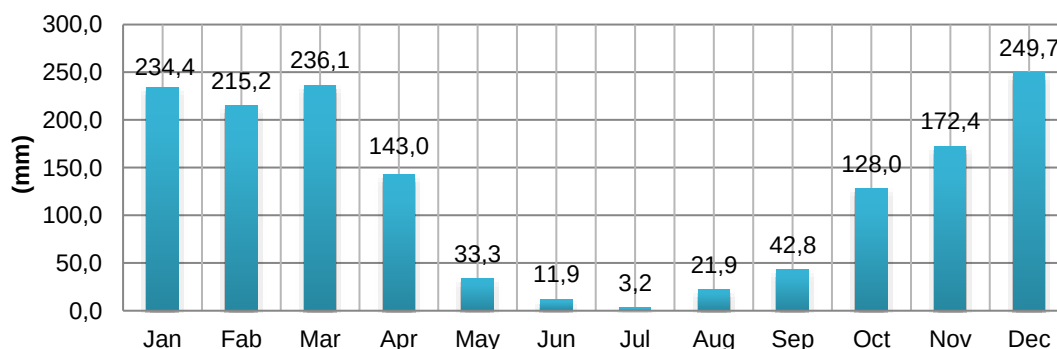


Fig. 2 Average Monthly Rainfall of Goiânia

### 2.3.3 Demand for rainwater

It was considered that the RWHS will supply the following activities: toilets flushing, external floor cleaning and water gardening. The demand was calculated having as reference the work of PACHECO and CAMPOS (2016) and the regulation NBR 15527 (ABNT, 2007).

It was defined that each household uses a toilet flushing (6,8 l/flush) around 6 times/day. The water gardening spent 2,4liters/m<sup>2</sup> and it will happen three times a week (Mondays, Wednesdays and Fridays). The external floor cleaning, in turn, will happen every day but on Sundays. On weekdays, it will use a cloth and a bucket to cleaning, what results in a 0,5 liters/m<sup>2</sup> consumption. On Saturdays, the cleaning is with a broom, squeegee and bucket and it will spend 1,0 liter/m<sup>2</sup>.

The water demand also varies according to the rainfall patterns. External floor cleaning and water gardening happen just in months that the average monthly rainfall is less than 200mm.

## 2.4 MODEL LOT CHARACTERIZATION

It was necessary to characterize a standard lot for the studied neighborhood in order to determinate the catchment area and the water demand. The characterization process occurred considering the following information:

- Satellite images of Google Maps and vector files, obtained from the Goiânia's Geographic Information System (SIGGO) were superimposed on the QuantumGIS computer program. These files have neighborhood, blocks and lots boundaries information (Figure 3a);
- Parcels indicated as public areas were removed from the Attributes Table;
- Parcels that did not had any edification were removed, They were visually identify in Google Earth Pro program;
- Parcels where were recognized no single-family housing using were removed. Street View tool from Google Earth Pro was used for this task. Thus, just the pertinent lots were left behind (Figure 3b);
- The pertinent lots characteristics such as: average, median, frequency distribution and standard deviation were described in an Excel spreadsheet. This analysis served to define a standard area for the Model Lot of the study;
- Polygons were built in QuantumGIS to represent the dimensions of roof areas and pervious areas in lots from a block. These lots had sizes close to that of the Model Lot (Figure 3c);
- External impervious areas were obtained by the difference between the total lot area and the roof and permeable areas som;
- Roof, pervious and impervious average areas were calculated. The percentage contribution of each one was calculated to the total area. Then, the permeable, impermeable and catchment areas on the Model Lot were calculated with the percentage contribution values.



**Fig. 3 Model Lot characterization process**

## 2.4 Result analysis

To analyze the results, it was used Neptune Software. This program calculates the quantities of daily water saved and daily overflow in a residence for one year. These quantities were measured for three volumes: the one sized by the software,  $1\text{m}^3$  and  $5\text{m}^3$ .

Six distinct scales of urban implantation were also evaluated. In the first one, it was considered that no system was in place and in the others it was allowed to install the systems in 10%, 25%, 50%, 75% and 100% of the residences.

Therefore, the possible impacts of the RWH systems implantation in the runoff volume was verified in 18 scenarios resulting from the combination of the six implantation scales and the three storage volumes.

## 3. RESULTS AND DISCUSSION

### 3.1 Model Lot characterization

The neighborhood has 4159 parcels, which 3601 are single-family buildings. In the distribution graphic ( Figure 4) is possible to appreciate the areas of these 3601 parcels. The largest and the smallest lot has  $1440,67\text{m}^2$  and  $159,56\text{m}^2$ , respectively. However, almost 75% of the lots have areas between  $159,56\text{m}^2$  and  $250\text{m}^2$ . These can be confirmed by the  $213,65\text{m}^2$  median area. Finally, the Standard Lot area is  $242,02\text{m}^2$ , this value were designate using the average area between the 3601 single-family buildings.

The block selected to trace the polygons was the Square 72 . This Square has 24 lots with areas between  $187,91\text{m}^2$  and  $228,90\text{m}^2$ . On average, lot's built area, lot's pervious area and lot's impervious area correspond, respectively, to 71,49%, 2,33% and 26,19% of the lot's total area. In Model Lot, it implies in a  $173,01\text{m}^2$  roof area, a  $5,64\text{m}^2$  yard area and a  $63,38\text{m}^2$  impervious area. And the sum of oof areas match with 47% of the neighborhood area.

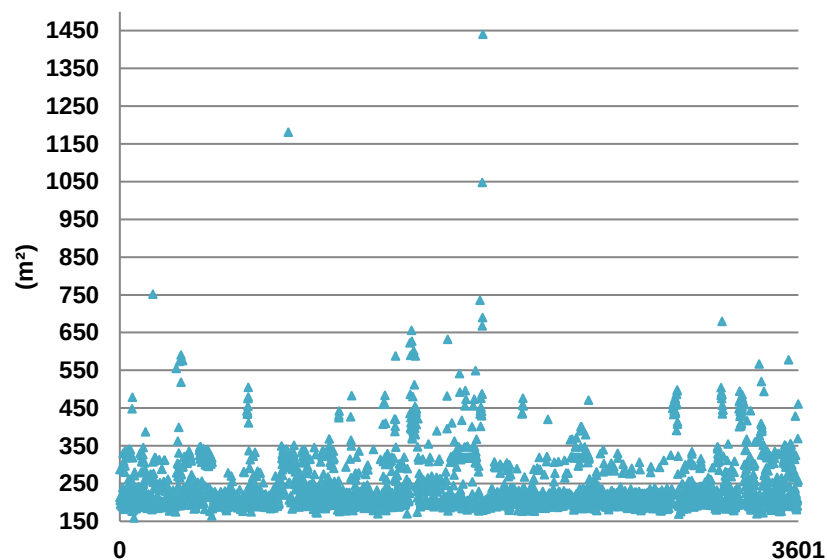


Fig. 4 Lots Areas Distribution Graphic

### 3.3 Rainwater supply

The demand for rainwater, shown in Table 1, was calculated based in 2010 estimate population for this neighborhood, which was 14.068 people. It was considered 5 people living in each domestic building.

**Table 1. Demand for Rainwater**

| Months                           | weekday   | Estimated Rainwater Daily Demand (Liters/person) |                         |                 |       |
|----------------------------------|-----------|--------------------------------------------------|-------------------------|-----------------|-------|
|                                  |           | Toilet Flushing                                  | External Floor Cleaning | Water Gardening | Total |
| December to March (rainy season) | Sunday    | 40,80                                            | 0,00                    | 0,00            | 40,80 |
|                                  | Monday    | 40,80                                            | 0,00                    | 0,00            | 40,80 |
|                                  | Tuesday   | 40,80                                            | 0,00                    | 0,00            | 40,80 |
|                                  | Wednesday | 40,80                                            | 0,00                    | 0,00            | 40,80 |
|                                  | Thursday  | 40,80                                            | 0,00                    | 0,00            | 40,80 |
|                                  | Friday    | 40,80                                            | 0,00                    | 0,00            | 40,80 |
|                                  | Saturday  | 40,80                                            | 0,00                    | 0,00            | 40,80 |
| April to November                | Sunday    | 40,80                                            | 0,00                    | 0,00            | 40,80 |
|                                  | Monday    | 40,80                                            | 6,34                    | 2,71            | 49,84 |
|                                  | Tuesday   | 40,80                                            | 6,34                    | 0,00            | 47,14 |
|                                  | Wednesday | 40,80                                            | 6,34                    | 2,71            | 49,84 |
|                                  | Thursday  | 40,80                                            | 6,34                    | 0,00            | 47,14 |
|                                  | Friday    | 40,80                                            | 6,34                    | 2,71            | 49,84 |
|                                  | Saturday  | 40,80                                            | 12,68                   | 0,00            | 53,48 |

### 3.4 Rainwater tank size

The ideal storage volume founded was 23,5m<sup>3</sup>. This volume provides a mean save potential of 90,3%, This average potential is 40,9% and 25,6% higher than the 1 m<sup>3</sup> and the 5 m<sup>3</sup> reservoirs potentials, respectively. The 5 m<sup>3</sup> reservoir save potential is 20,5% higher than the 1m<sup>3</sup> reservoir potential. The daily save potential given by month is showed in the Table 2.

**Table 2. Daily Save Potential by Month**

| Month   | Saving Potential (%) |                 |                    |
|---------|----------------------|-----------------|--------------------|
|         | 1m <sup>3</sup>      | 5m <sup>3</sup> | 23,5m <sup>3</sup> |
| Jan     | 92,7%                | 100,0%          | 100,0%             |
| Feb     | 93,5%                | 100,0%          | 100,0%             |
| Mar     | 92,5%                | 100,0%          | 100,0%             |
| Apr     | 62,4%                | 96,5%           | 100,0%             |
| May     | 25,8%                | 60,1%           | 100,0%             |
| Jun     | 9,2%                 | 27,3%           | 100,0%             |
| Jul     | 4,1%                 | 4,4%            | 90,4%              |
| Aug     | 8,3%                 | 12,5%           | 57,8%              |
| Sep     | 31,3%                | 41,9%           | 51,9%              |
| Oct     | 62,7%                | 86,4%           | 90,1%              |
| Nov     | 89,2%                | 100,0%          | 100,0%             |
| Dec     | 97,0%                | 100,0%          | 100,0%             |
| Average | 53,4%                | 67,2%           | 90,3%              |

### 3.5 Overflow and urban drainage



It was determined the percentage of the runoff volume over the total rainfall volume. The results are shown on Table 3. Table 4 illustrates the annual runoff volume decrease rate

**Table 3. annual runoff volume compared with total rainfall volume**

| Tank volume (L) | Rate of domestic buildings with RWHS system |       |       |       |       |       |
|-----------------|---------------------------------------------|-------|-------|-------|-------|-------|
|                 | 0%                                          | 10%   | 25%   | 50%   | 75%   | 100%  |
| <b>1000</b>     | 26,1%                                       | 25,7% | 25,2% | 24,3% | 23,4% | 22,6% |
| <b>5000</b>     | 26,1%                                       | 25,6% | 25,0% | 23,9% | 22,9% | 21,8% |
| <b>23500</b>    | 26,1%                                       | 25,3% | 24,2% | 22,4% | 20,6% | 18,8% |

**Table 4. Annual runoff volume contribution decrease rate**

| Tank volume (L) | Rate of domestic buildings with RWHS system |       |       |        |        |        |
|-----------------|---------------------------------------------|-------|-------|--------|--------|--------|
|                 | 0%                                          | 10%   | 25%   | 50%    | 75%    | 100%   |
| <b>1000</b>     | 0,00%                                       | 1,34% | 3,35% | 6,70%  | 10,05% | 13,40% |
| <b>5000</b>     | 0,00%                                       | 1,64% | 4,10% | 8,20%  | 12,30% | 16,40% |
| <b>23500</b>    | 0,00%                                       | 2,78% | 6,95% | 13,89% | 20,84% | 27,79% |

The runoff volume represents a reduction around 26,06% of the annual stormwater in this neighborhood. This contribution tends to be lower when part of the water is harvested to be used as shown in the Table 3. In the scenario that 100% of domestic buildings have installed the 23,5 m<sup>3</sup> tank, the runoff volume would decrease in 27,79%. However, when commercial volumes are used, this reduction is higher when it increases the percentage of the implementation of RWHS increases (Table 4).

Figure 5 and 6 represents the daily runoff volume when 100% of domestic buildings have RWHS installed, the same tendency is observed in different deployment scales.

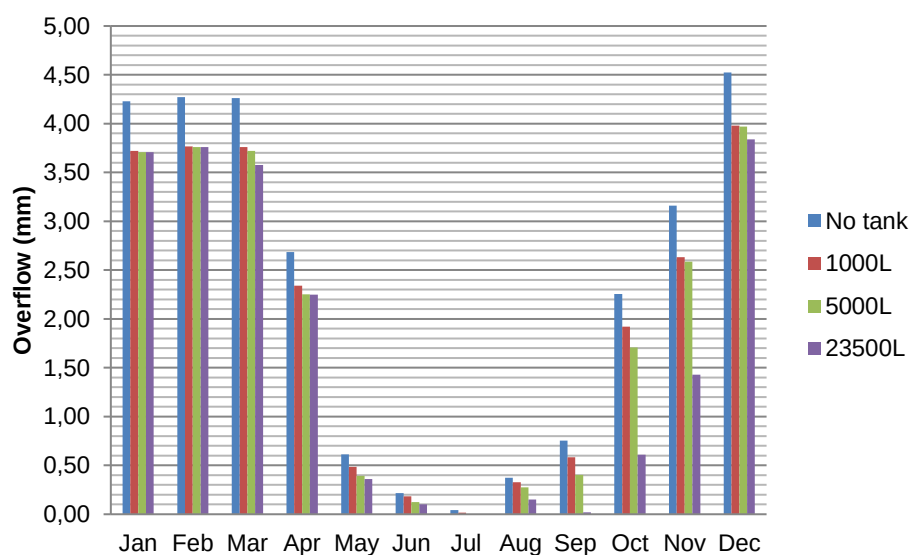
Runoff volume is higher in rainy season (Figure 5). The daily runoff volume is similar among different tank sizes in rainy season. Although, the 23,5m<sup>3</sup> tank shows a lower runoff volume the others volumes in September, October and November. This could be explained by the fact that those months are just next to the dry season and have more irregular rains, and then, the tank has a bigger hold volume to be filled than the others.

Runoff volume contribution in daily stormwater is almost constant in the rainy season. Hold volume in different tanks keep the same, as a result of constant rain. However, bigger tanks result in lower roof overflow contribution in dry season and the beginning of wet season. Again, the hold volume filling process explains this (Figure 6).

Daily runoff volume has a contribution decrease rate higher in dry season. The higher value is in July, the driest month, when the decrease rate achieves 100% (Table 5).

**Table 5. daily runoff volume contribution decrease rate**

| Month | Tank size |         |         |
|-------|-----------|---------|---------|
|       | 1000L     | 5000L   | 23500L  |
| Jan   | 12,02%    | 12,33%  | 12,33%  |
| Feb   | 11,78%    | 11,99%  | 11,99%  |
| Mar   | 11,81%    | 12,74%  | 16,09%  |
| Apr   | 12,75%    | 16,05%  | 16,18%  |
| May   | 20,61%    | 35,47%  | 40,95%  |
| Jun   | 14,52%    | 41,81%  | 52,78%  |
| Jul   | 63,12%    | 100,00% | 100,00% |
| Aug   | 12,21%    | 26,53%  | 59,71%  |
| Sep   | 22,47%    | 46,42%  | 97,33%  |
| Oct   | 14,87%    | 24,23%  | 72,94%  |
| Nov   | 16,75%    | 18,18%  | 54,78%  |
| Dec   | 12,06%    | 12,29%  | 15,17%  |
| Mean  | 13,39%    | 16,37%  | 27,68%  |

**Fig. 5 daily runoff volume (100% of residential buildings with RWHS)**

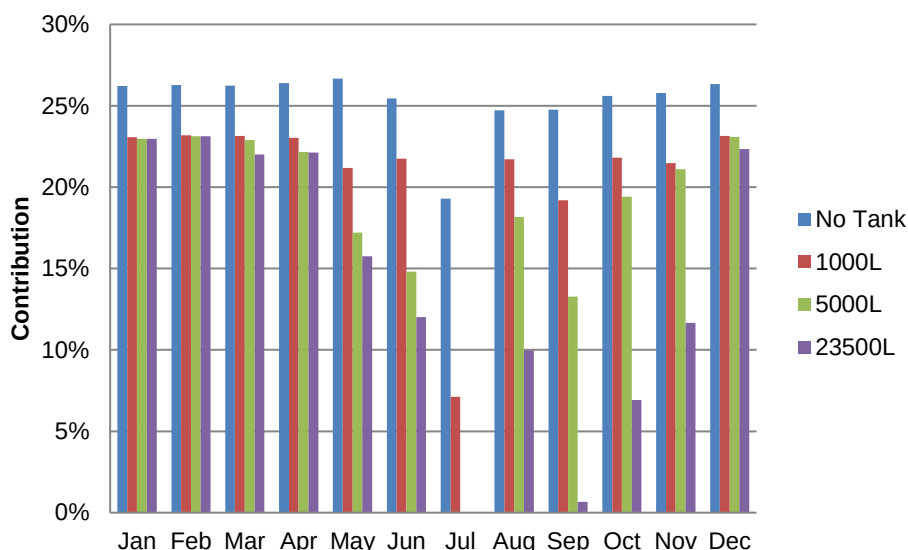


**Fig. 6 Roof overflow contribution in daily rainfall volume (100% of households with RWH system)**

#### 4. CONCLUSION

This paper's main objective was measure the impact on urban drainage when residential RWHS is installed in a neighborhood scale. It was made a case study in single-family residential neighborhood in Goiânia, city from Brazilian Midwest.

The total roof area of the residential buildings cover 47% of the neighborhood area. It leads us to believe that the RWHS' implantation can play an important role in urban drainage. However, as the RWHS's objective is provide water to residential consumption, the system tends to keep all tank volume filled, and then there is no hold volume to retain rainwater in rainy season. The contribution is mostly verified in dry season and when a higher tank volume is installed.

It is observed that there is an incompatibility of the volumes used for storage and to aid in the urban drainage. It is necessary to deepen those studies in order to allow the indication of the ideal volume that satisfactorily contemplates both purposes.

Although at an early stage, it can be observed that the results obtained can encourage the adoption of public policies that promote the mass implementation of RWHS, thus allowing a more efficient management of rainwater in the cities.

#### ACKNOWLEDGEMENTS

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# Challenges of researching showering routines – from the individual to the socio-material

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## ABSTRACT

Water supplies are under threat from climate change, population growth and modern lifestyles. Excessive demand wastes money, energy and carbon. Evidence indicates that young adults are particularly high water-users. This population segment is at a transitional life-stage, leaving home to become independent adults. It is a time when new life-long habits can be shaped, but also when there is pressure to conform to high standards of cleanliness and body-image required to fit with new social groups and form intimate relationships with peers. Showering is the largest and growing component of domestic water consumption. This paper sets out the study design, presents early findings and reflects on the challenges faced by a doctoral researcher in working with different types and scales of data to explore how theories of behavioural and social change can help to inform a real-world programmes of water efficiency measures underpinned by rigorous research. It focuses on the showering patterns of first year students living in campus accommodation at the University of the West of England, Bristol. The Scottish Government Individual-Social-Material model, underpinned by cross-disciplinary behaviour and social change theories, was applied to evaluate typical showering demand reduction measures and co-design alternative or novel ideas. A mixed-methods approach explored the inherent variability of personal showering routines and the relationship with conventional household metrics of water consumption by combining household meter, logged water-fixture micro-component, personal-use survey, user diary and stakeholder focus group data.

*Keywords: behaviour change, Individual-Social-Technical toolkit, mixed-methods, showering, water efficiency, young adults*

## 1. INTRODUCTION

The privatised water supply companies in England and Wales have had a *duty to promote the efficient use of water* since the 1990s [1] and in 2010 Ofwat introduced new statutory water saving targets [2]. Water policy-makers deal in the language of average per capita consumption (PCC) measured in litres per person per day, as a key metric for domestic water use. The estimated average PCC in England is about 150 l/p/d [3], although the latest reports, following seven years of targets indicate that this figure is now reducing (141 l/p/d [4]).

The measure presents several challenges for water companies in understanding the dynamics of daily water-using routines [5]. PCC is only an estimate [6] and can be calculated based on the measured water volume supplied to domestic properties divided by the estimated population served, or based on a panel study of metered households, for which water companies hold more reliable occupancy data [7]. In contrast, calculating the PCC for students living within the university is more reliable than calculations for the wider population, as information on lettings and corresponding occupancy is more readily available. However, assumptions still need to be made on actual occupancy levels, as a let flat may not be fully occupied, with tenants opting to spend much of their time living elsewhere with friends or, for UK-based students, returning home at weekends and holidays. Conversely, rooms may be over-occupied with house guests staying occasionally, regularly or on a semi-continual basis.

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One flaw in relying on PCC is that it represents an underestimate of total personal consumption. Water is not consumed by individuals solely within the household meaning that PCC excludes personal water-use in places of work, education and leisure, through sanitation and hygiene (WC flushing and hand washing) or process water from the provision of drinks and meals consumed away from home (cooking and dishwashing). For example, day-time office use is reported to add a further 16–28 l/p/d to personal consumption [8], with more associated with leisure-time pursuits.

Another challenge is that the process of aggregating and averaging individual water use hides the variations in everyday personal water use patterns. There is growing interest in understanding how water is consumed in the course of everyday life so that behavioural-based interventions may be designed to reduce consumption [9], Micro-component studies indicate that there is a great variety in individual household patterns of consumption [10, 11], made all the more difficult to measure when almost two thirds of consumption takes place in the privacy of a locked bathroom.

Working with averages also hides the differences between different demographic groups (age, gender or nationality). Research by Waterwise [12] indicates that younger people shower for about two-minutes longer than older population segments. Whilst education is seen to be important to creating more sustainable behaviours by both children directly and with other members of the household by 'pester-power' [13], there is little evidence of any effect on water use from the many environmental educational programmes delivered in UK schools [14], despite self-reporting of pro-environmental attitudes. Evidence suggests that older generations are more environmentally conscious [15]. There are likely to be stronger social pressures working in the opposite direction of rising environmental awareness among this age-group, partly as a result of life-course stage and the need to conform to higher standards of body-image. Young adults are at the transition point between maturing from dependent children into independent autonomous individuals, and universities can play an important role in facilitating social change to address important issues [16, 17, 18].

The variations in showering routines amongst a group of mostly first year under-graduate students living in on-campus university accommodation were observed using a range of metrics including water consumed at both household and shower component level, and self-reported data collected from surveys and diaries. These insights were combined with outputs from a series of focus groups, to evaluate a range of conventional technological and behavioural water-saving measures, to collectively design alternative programmes of measures. The focus group discussions and outputs were structured using the Scottish Government Individual-Social-Material toolkit to move discussions beyond traditional individual behaviour change ideas to encompass wider social and material determinants. The ISM model is based on theory and developed out of [19] an international review of successful behaviour change initiatives. It has been refined through research and the evaluation of environmental behaviour change interventions.

A mixed-method approach was adopted, in which both quantitative and qualitative data were collected. Data processing and analysis is on-going. This paper reports on some initial findings and the challenges faced when undertaking real-world research and the process of triangulating between different epistemological and methodological approaches.

## **2. METHODOLOGY**

### **2.1 Participants and setting**

Fieldwork was conducted during the first quarter of 2018 and set out to explore the showering routines and associated water consumption by student residents. The study site concentrated

on ten townhouses comprising 88 beds, within a larger 404-bed development, built in 2014 at the University of the West of England (UWE) main Frenchay campus, Bristol. The water consumption for all 37 houses in the development are sub-metered at 30-minute intervals, as part of the Building Management System. Two thirds of the houses in the development comprise 12 single study bedrooms. However, this study focused on ten of the smaller eight and ten-bed houses (total design occupancy of 88 beds), clustered together around a courtyard (labelled A-J in this paper to preserve anonymity). In each house, the ground floor has a communal kitchen/diner with two mixer-tap sinks (high flow, no regulators) and a single dual-flush WC with wash-hand basin (with flow regulating tap aerators). Some leaking kitchen taps were identified and reported to the Facilities department for fixing by the Researcher during the study.

Six of the ten townhouses (A, B, C, F, G, J) comprise eight single bed study rooms with four shared shower/WCs across two floors (four bedrooms and two shower room/WCs per floor). Four slightly larger corner-aspect townhouses (D, E, H, I) have the capacity for ten occupants, with one twin/shared bedroom, three single occupancy bedrooms and two shared shower/WCs on each of the upper two floors. The shared shower rooms include a shower enclosure with water efficient showerhead (c.8 litres per minute), wash-basin (tap-aerators, flow regulated to c.4-5 l/m) and a dual-flush (pneumatic) WC. Laundry facilities are provided centrally for residents in a separate facility and are outside the scope of this study. There is no outside water use. Demographic data from the university Accommodation Services reveal that within the study site, there are two void bed (house E), 53 females and 33 males; 72 (84%) are aged 18-22 years; 35 (41%) have UWE gym membership; and there are 52 (61%) UK nationals, 9 (11%) from the EU and 25 (29%) are non-EU international students.

## 2.2 Water fixtures audit

In Aug 2017, during the summer void period, the Researcher undertook an audit of the water fixtures within the un-occupied development to familiarise herself with the plumbing installations. Flow-rate data were collected for five townhouses across the wider 37-house development including two within the study site (houses B and G) and are indicative of the relatively standardised fixtures for each house across the estate.

## 2.3 Water consumption monitoring

Each townhouse within the development is sub-metered at 30-minute intervals as part of the university's Business Management System (BMS). To supplement the BMS data, the ten townhouses in the study were fitted with Siloette loggers (supplied by Artesia Consulting, see Fig.1.), which record a pulse for every 500 ml of water through the meter. The finer resolution allows for detailed analysis of flow, duration and frequency profiles and identification of water-using events by individual types of fittings within a household, such as showers, WCs and taps. These micro-components help to bridge the gap between measurement of household consumption

by metering and individual water-using routines.



**Fig.1. Siloette logger attached to water meter**

Following an 18-day test using one logger from 15 Nov 2017, to check for metering system compatibility, Siloette loggers were installed with splitter cables from each sub-meter (to allow

for the BMS to continue to record 30-minute water consumption and the loggers to record 500 ml water use) on 18 and 19 Dec 2017, and removed on 28 Mar 2018.

## 2.4 Water-saving interventions

Conventional water-saving measures of the sort deployed by current water company water-efficiency programmes were tested during the study in pairs of households. These are summarised in Table 2.

**Table 2. Summary of water-saving measures tested**

| House | Measure                                                                                                          | Location                                                                                                                                                                             |
|-------|------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| A & B | Nil – control group                                                                                              |                                                                                                                                                                                      |
| C & D | Posters<br>( <i>installed 14-Feb, removed 07-Mar</i> )                                                           | Generic water-saving messages in communal area notice board/downstairs WC (back of door) 'Share a shower' (house C) and 'Pee in the shower' (house D) in shower rooms (back of door) |
| E & F | 4-minute shower timers<br>( <i>left with diary participants on 21-Feb</i> )                                      | One per resident                                                                                                                                                                     |
| G & H | Amphiro a1 smart shower meter<br>( <i>installed by Estates on 14-Feb, diary participants briefed on 21-Feb</i> ) | Installed in each shower room                                                                                                                                                        |
| I & J | Face-to-face engagement<br>( <i>28-Feb, 2.30pm in house J</i> )                                                  | Communal area – all residents invited, refreshments provided                                                                                                                         |

## 2.5 Qualitative data collection

To complement the quantitative data at both household and shower fixture scale, qualitative data from individuals was also collected to help understand the shower routines of student residents. Participants were principally recruited by door-knocking and leafleting the target houses, with recruited participants subsequently asking their housemates to join in.

Initially, residents were asked to keep a simple shower diary for two weeks (21 Feb to 07 Mar 2018). The Researcher aimed to recruit two or three diary participants per house (20-30 in total, representing between a quarter and a third of the population). Active consent was obtained from all volunteers, as per ethics approval requirements. Participation was incentivised by compensating students for their time and commitment with a £20 shopping voucher of their choice on return of completed diaries.

A series of five focus groups were conducted for each pair of houses/intervention type. The focus group workshop for houses I and J was conducted at the mid-way point of the diary fortnight, on 28-Feb. This focus group had a dual purpose as it formed both the water-saving measure of itself (in the form of face-to-face education and engagement) and served to co-design future water-saving measures. The four subsequent focus groups followed a similar structure to evaluate interventions, and these were run on Wednesday afternoons on 07-Mar (houses G and H); 14-Mar (2 focus groups, houses C and D, followed by houses E and F); and 21-Mar (houses A and B). The final focus group was used as a 'wash-up' session and any diarists that had been unable to attend their own focus group were invited.

Diary participants were actively invited to take part, and they were encouraged to ask their housemates to join-in. The Researcher also advertised the focus groups by delivering leaflets a few days before the planned sessions with the promise of refreshments, and entry into a prize draw for a £20 shopping voucher for all participants of the focus groups. Each focus group was run within the downstairs communal dining/sitting area of one of the pairs of houses (with prior



agreement from the residents, pragmatically selected based on the higher number of engaged participants to ensure maximum attendance), and lasted for about 1.5 hours (active consent was obtained from all participants, in-line with research ethics protocols). Once the consent forms were completed over refreshments, an audio-recording of the discussion was made on the Researcher's mobile phone for later transcription.

The discussion started by setting ground rules; discussing why there is a need for water efficiency; how water is used in the home (with showering accounting for 25% of demand and growing); and a description of conventional water-saving measures. The rest of the focus group used the Individual-Social-Material toolkit [20] to structure discussion to both evaluate existing measures and co-design future interventions to tackle a specific showering determinant (selected by the focus group, such as flow rate, duration, frequency or in-shower activities). The 18 factors from the three ISM contexts (see Table 3) were introduced with definitions on a set of prepared flashcards. Each factor was discussed in turn, and colour-coded notes were made by the group on an A3 sheet (green for Individual, blue for Social and black for Material contexts).

**Table 3. Individual-Social-Material toolkit**

| Context    | Factors                                                                                            |
|------------|----------------------------------------------------------------------------------------------------|
| Individual | Values, Beliefs & Attitudes; Costs & Benefits; Emotions; Agency; Skills; Habit                     |
| Social     | Opinion Leaders; Institutions; Norms; Roles & Identity; Tastes; Meanings; Networks & Relationships |
| Material   | Rules & Regulations; Technologies; Infrastructure; Objects; Time & Schedules                       |

At the end of the diary fortnight, an online survey was launched (07 to 21 Mar) and all research participants (directly by email) and the residents (via leaflets and word of mouth) in houses A-J were invited to take part. The survey collected information on environmental awareness, showering habits and other water-using routines, water fixtures at home and demographic information. The questions were very similar to a wider survey targeted at all UWE students Oct 2017. Participation was incentivised with entry into a prize draw for a £20 shopping voucher.

### 3. RESULTS AND DISCUSSION

#### 3.1 Quantitative data analysis

Despite the same standard of fittings broadly installed across the estate, the water audit found some variability in flow rates. Most of the 26 showerheads tested were water efficient, ranging between 7 and 9 l/m, and manufactured by Ideal Standard. However, one showerhead delivered a flow of more than 14 l/m (regulating the flow from 21 l/m without the showerhead). In contrast, one showerhead only delivered 4.2 l/m (with a flow of just 4.4 l/m without the showerhead). Showerheads (and tap aerators) are changed (removed, cleaned and replaced) every few months as part of the Estates department routine *legionella* control management programme, and are not necessarily replaced with identical fittings, but with whatever is available at the time.

In analysing the metered water consumption data from the BMS, it became apparent that the meters sometimes stick. There were several periods before, during and after the trial in which the consumption value for a 30-minute period was repeated in the next and subsequent time steps, and this pattern could be detected across multiple sub-meters for the same time steps. This discovery puts a question mark over the reliability and accuracy of the BMS sub-meter water consumption data.

During the focus group and survey phase, the estate experienced a major water mains-burst event which resulted in a large proportion (40%) of the campus estate, including the trial site,

having no water for a period of more than 30 hours (from 02:30 hrs 14 Mar to 12:00 hrs 15 Mar). When the water was turned back on following the repair, debris was pulled through into the pipework and resulted in several sub-meters including one of the trial houses (house A) being damaged (and flat-lining). In addition, for the duration of the trial, there is no BMS data for house G, due to the splitter cables for the Siloette loggers not working as expected.

Artesia Consulting downloaded the Siloette logger data. Unfortunately, only one logger (house G) recorded any pulses for the duration of the main trial. Subsequent investigation has shown that the splitter cables did not operate as expected, and in most cases failed to send pulses to the loggers. For house G, the pulses were recorded at the expense of main sub-meter data recorded by the BMS. A solution to this problem will be worked on prior to a repeated trial in the autumn 2018.

To-date only the limited test dataset (house A) has been analysed for shower micro-components. A total of 160 shower events (and 4000 WC flushes and tap uses) were identified from the 18-day test logger (15 Nov to 4 Dec, house A), although there was a 4-day mid-week period (21-24 Nov) in which no pulses were recorded. It is not clear why this happened and it warrants further exploration.

The limited results available to-date are summarised in Table 4. They should be viewed with caution due to limited dataset and skewed demographics of house A (all eight female, mostly non-EU international, and slightly older students). There is little difference in the median per household consumption (PHC) for weekends and weekdays (equivalent to a PCC of 211 l/p/d), but the spread on weekends is larger, revealing greater variability in routines at weekends. Average shower duration and frequency are notably higher than reported UK norms (of 7-8 minutes duration daily showers [12]). However, average shower volumes of about 62 litres are not excessive, indicating that the shower fixtures help to curtail consumption despite the longer durations.

**Table 4. Summary of PHC and shower micro-components (test period, house A)**

| Variable        | Median PHC (l/h/d) | Mean PHC (l/h/d) | Mean shower volume (litres) | Mean shower frequency (per day) | Average shower PHC (l/h/d) | Mean duration (mins) |
|-----------------|--------------------|------------------|-----------------------------|---------------------------------|----------------------------|----------------------|
| Weekday         | 1,689.5            | 1,439.2          | 56.2                        | 8.92                            | 501.12                     | 12.5                 |
| Weekend         | 1,690.3            | 1,608.5          | 64.8                        | 8.83                            | 572.40                     | 11.6                 |
| <i>All days</i> | <i>1,689.5</i>     | <i>1,495.6</i>   | <i>62</i>                   | <i>8.89</i>                     | <i>551.18</i>              | <i>12.2</i>          |

Figure 2 shows the correlation in the proportion of daily PHC (ranked from high to low)) with that associated showering component (in red), and confirms that showering represents about a third of daily consumption. Weekend showers are taken later during weekend mornings (not before 10:30am) whilst weekday showers start between 6-8am.

### 3.2 Qualitative data analysis

There were 34 unique participants across the qualitative data collection methods, representing a 34% participation rate (adjusted for five participants recruited from outside the main study site). Participation (split by gender) is summarised in Table 5. There were nine participants (six females and three males) that contributed to all three methods (diaries, focus groups and survey), representing 10% of the study population.

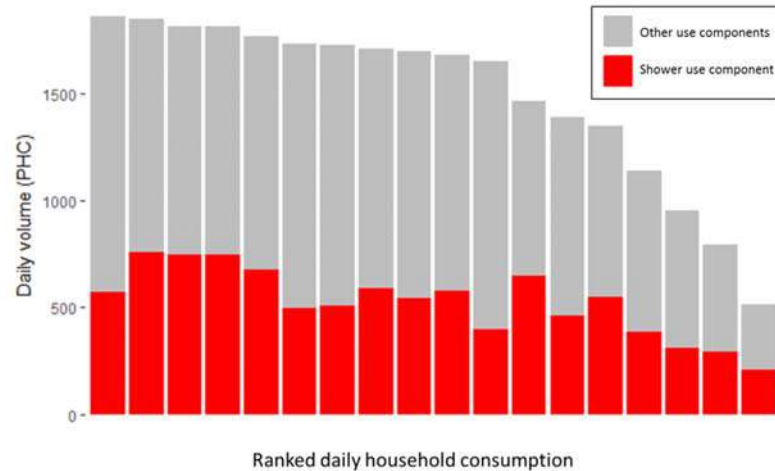


**Fig.2. Daily Per Household Consumption assigned to showers and other uses (test period, house A)**

**Table 5. Summary of participants (split by gender)**

| Houses/intervention   | Diaries                    | Focus groups          | Survey responses          |
|-----------------------|----------------------------|-----------------------|---------------------------|
| A, B & Q - Control    | 1♀, 1♀ 1♂, 3♀ <sup>1</sup> | 0, 1♀ 1♂, 0           | 0, 1♀, 1♀ 1♂ <sup>3</sup> |
| C & D - Posters       | 1♀, 2♀                     | 0, 2♀ 3♂ <sup>2</sup> | 2♀, 1♀ 1♂                 |
| E & F - Shower timers | 2♀, 3♀                     | 0, 3♀                 | 2♀, 4♀                    |
| G & H - Amphiro       | 2♀, 2♀ 3♂                  | 0, 1♀ 5♂              | 1♀, 2♀ 1♂                 |
| I & J - Face-to-face  | 2♀, 2♂                     | 2♀, 1♀ 3♂             | 0, 1♀, 1♂                 |
| Total                 | 19♀, 7♂                    | 10♀, 12♂              | 15♀, 4♂                   |

♀ = female, ♂ = male

<sup>1</sup> diaries = 3 females from site Q outside study site, within 37-house development

<sup>2</sup> focus groups – 2 males from site Q, outside study site

<sup>3</sup> surveys = 1 male from site Q, outside study site (also house C/D focus group)

The diary method had the highest participation (19 female including three from outside the study site, and 7 male). This high recruitment may be because the Researcher set out to recruit participants to keep diaries first; they were guaranteed a £20 shopping voucher on completion; and it was earlier in the semester, before end-of-term assessments loomed. Even removing the three female participants from site Q, the sample was skewed towards female participation (69% sample, v 62% population). This may be due to recruitment bias on the part of the female Researcher or it may be evidence that females are more willing to be engaged in the topic. Data analysis is ongoing, but deciphering handwriting is proving a challenge!

However, the pendulum swung in the opposite direction for the focus groups with more male participants (including two new recruits, from site Q). The immediacy of the activity being situated within the student house and the opportunity for free food (pizza) and juice may have influenced this change in gender participation; or because attendance at the focus group was less of a time commitment. Alternatively, females may be more reluctant to discuss private showering habits within the collective context of a focus group.

Only in the first focus group on 28 Feb, hosted by house J, did participants from the other paired house participate, despite multiple invitations via email, leaflet and door-knocking. This workshop was also the only gender-balanced group. It doubled up as the intervention and therefore it was important that the diarists participated. The scheduling also meant that it was early into the participation process and perhaps didn't get jeopardised by course assignment deadlines. Diary and survey participants who had been unable to attend the previous sessions

were invited to attend the final focus group on 21 Mar (or to participate in one-to-one semi-structures interviews instead, if they were more comfortable discussing their showering routines with the Researcher in private). However, this focus group comprised just two participants and one of those (male) was via Skype, meaning that there was a lot of leftover pizza! No students volunteered to be interviewed.

Focus groups for houses C/D and E/F took place on 14 Mar during the 'no water' event. This made the reality of water shortages very tangible and resulted in interesting discussions. The 'no water' event presented challenges to the Researcher too. The Student's Union was unable to supply pre-ordered pizza due to the supply interruption, so an off-site alternative was ordered. The Researcher assumed that they would be delivered directly to the houses hosting the focus groups at the booked times. Instead, they had to be collected from a designated collection point on the opposite side of the campus, a good 5-minute walk. The mobile phone signal within the study site was poor making it difficult to liaise with the delivery operative. Delivery for the second focus group was attempted before the late-running first session was complete. The Researcher gave instructions for the focus group to complete the discussion on the ISM factors, left her mobile to record the discussion, and went to collect the delivery for the next workshop. On return, she discovered that not only had she missed the discussion, her audio recording had stopped due to the delivery phone call interruption!

Focus group transcription and analysis is on-going. The discussion will be categorised using the ISM factors and their linkages between contexts or levels, to present an evaluation of the conventional water-saving measures tested and to develop a programme of alternative interventions. The ISM structure guides the discussion to consider wider social and material structures and their interactions beyond more tactical and intuitive individualised behavioural factors. This results in a more strategic view of the multiple factors and scales that shape the way things (in this case showering) are done. A further focus group with supply-side stakeholders including university estates, facilities, accommodation and sustainability representatives is planned to complement the demand-side student-focused research summarised in this paper.

The survey had the lowest uptake, with 19 participants (15 female). This lower participation was disappointing as it provides rich background information on the student's water-using routines along with socio-demographic information to supplement Accommodation Services lettings and demographic data. However, the Researcher also has the results of a similar survey from Oct 2017 targeted at all UWE students, in which 158 responses were received (66% female, 33% male).

#### **4. CONCLUSION**

This research aims to use a combination of different metrics, including sub-meter PHC data alongside shower micro-components to quantify the showering routines of young adults. Quantitative data has been complemented with the collection of qualitative insights into the reality of how showering is practiced, and how it changes during the transition from home to adult independence. This has been facilitated using the ISM model to bring rigour to evaluation and design of real-world water-saving measures.

Despite apparent standardisation of water fixtures across the estate, there remains some inherent variability within the shower flow rates, compounded by the routine swapping of showerheads during Legionella risk management processes. Further investigation is needed to understand why the BMS consumption data is not completely reliable and accurate, and a solution will be developed to the household meters to operate in parallel with the micro-component loggers.

Recruitment of student participants via door-knocking proved to be successful, although the Researcher will reflect upon how to improve the demographic representativeness of the different research approaches and will consider adding semi-structured interviews into the mix. Finally, the timing of future fieldwork will be mindful of schedules of the potential participants to avoid busy assessment periods and holidays.

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The Researcher is grateful to the 34 committed student residents who kept diaries, completed the evaluation survey, and/or hosted and participated in focus groups. Finally, thanks go to Rosie for helping prepare 18 ISM factor flashcards for use in the focus group sessions.

## COMPETING INTERESTS

None

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# Development of a noise-sensing device for water end-uses monitoring

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## ABSTRACT

Different approaches have already been applied to learn, in the best possible way, how water is consumed through the different end-uses at home. Some of them were based on direct surveys and water diaries that customers must answer and fulfil periodically. Other studies explored the installation of water meters in the main water appliances, inside each participant household. Finally, the best results have been provided by performing an accurate monitoring of household water consumption with one single high-resolution data-logged water meter. In any case, rather than mutually exclusive, all the mentioned approaches can be mutually complementary, and in fact, they keep being extensively employed today.

From different perspective, authors are working on another approach - a noise-sensing device that can be installed in the visible parts of the indoor piping system. It is non pipe-intrusive, silent, small and discrete, and will store and retrieve the appliances water use by recording the noise produced.

The paper presents the development process to produce the current fully-operative prototypes and the main features of the device: data provided, operation procedures, battery duration, etc., as well as the kind of noise information, RMS and frequency spectra, it provides on water end uses.

*Keywords: noise sensing, monitoring, water end-uses*

## 1. INTRODUCTION

Learning about how water is consumed at homes, through different end-uses, is essential to improve water demand management policies. Therefore, for several years now, different technologies and techniques have been applied to that aim.

Basic approaches are invasive methods, directly based on “getting” somehow into the households to learn about how people use water there. The intrusion degree varies depending on the method employed. The smoothest one could be filling a water diary [1]. It consists in writing down, one by one, an accurate record of all single water uses in the household during a given period. Maybe the most practical way is laying a diary, generally in a table format, at the side of each main water appliance. This way, every time an occupant uses that appliance, he or she takes note of the main features of the use made – date, time, duration, etc.

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A mid-intrusion degree is generally caused by surveys [1]. They can be performed either on the phone or through personal interviews, and consist in asking the occupants, or the occupants' representative, a number of questions about their water consumption habits.

The strongest intrusion degree has been reached in studies that consisted in installing independent water meters in each main water appliance for a given period [2]. One particular case, related with metering single end-uses is a user-friendly meter for showers with no battery requirement [3].

Each of these basic methods collects a different type of information, so in the end, they are complementary each other, rather than exclusive. Diaries and surveys are, by far, the most frequently employed. Though valuable, easy and cheap (in comparison), they imply many uncertainties – occupants may forget to write some uses down, or may fail in answering accurately the survey questionnaire, or the interview fails to be long or specific enough. On the contrary, the meter-per-appliance method is extremely costly in both materials and staff.

Other kind of approaches could be considered like advanced approaches, since they focus on monitoring end-uses consumption by means of a high accuracy meters and data-loggers [4]. On the one hand, these approaches are non-intrusive at all since the meter replacement and logger installation take place out of the household, and only a simple authorization agreement is needed from the occupants. On the other hand, these techniques are also costly not only in terms of material and staff, but also in terms of mathematical analysis [5]. Some other devices in the market [5], monitor water end-uses consumption by measuring pressure variations at the household water inlet.

In parallel, some researchers have studied how water is used in indoor water appliances by other different ways, for other different aims. The methods they have developed are based on direct noise sensing.

In [7], several noise sensors were installed in a household in both the supply pipes (hot and cold) and the drainage pipes (drain and stack). They developed a complete procedure to identify each end-use of water through the sequence of noises recorded by all the sensors installed, suggesting the possibility of using it as a non-intrusive system of elderly surveillance.

In [8] a sensing device, attachable to a tap or shower, was produced. This device could detect each appliance opening, and could record the water-running time during each use. The device compared each use duration to a previously saved pattern for the average use, and then inform the current user by a color light or a digital display. They used those devices to inform users, in real time, about the use of water they were doing, and hence rise their awareness to avoid water wasting. At the same time, they gathered all the information on water consumption and produced sharp statistics on it.

In [9] some of the results published in [10] were applied for a different purpose. They were interested in monitoring the usual bathroom activities, focused on identifying “abnormal” behaviors that could highlight problems in clinical care or dementia patients. The tool prepared for so was an ambient microphone connected to a door sensor. The noise samples thus obtained were subsequently analyzed in both the time and the frequency domains.

From these background references, the authors began in 2017 a pilot project to produce a noise sensor that could be used as a cheap and accurate tool to identify indoor water appliances in use. In turn, the information thus obtained could complement that one gathered through other ways explained above.

To that aim, a research team was formed by members from the Hydraulic Engineering Dpt. and the Electronic Engineering Dpt. at the Universitat Politècnica de Valencia in Spain. The original idea was implemented as an end-of-course project to be developed by a student of the Industrial Electronic Engineering Degree, under a grant funded by the Spanish Ministry of Education, Culture and Sports.



## 2. MATERIALS AND METHODS

The project was structured in five successive stages that started in July 2017, and it was planned to last for a single year. Table 1 shows the denomination and time for each stage.

**Table 1. Stages for the prototype development**

| # | Stage                             | Time       |
|---|-----------------------------------|------------|
| 1 | Requirements and basic design     | July 2017  |
| 2 | Performance simulation            | Sept. 2017 |
| 3 | First prototype construction      | Oct. 2017  |
| 4 | Preliminary tests                 | Nov. 2017  |
| 5 | Definitive prototype construction | Jan. 2018  |
| 6 | Full performance tests            | Feb. 2018  |
| 7 | Future developments               | June 2018  |

In the first stage, the requirements for the device were set. According to the use requirements, the device should:

- Be easily attachable to the inlet water hose to any water appliance, such as basins, sinks, toilets, etc. Alternatively, in case of appliances with no accessible inlet hose, such as showers, the device should be attachable to the appliance itself. Additionally, it could also be applied to other components of the indoor piping facility like shut-off valves.
- Register the noise made by water as it circulates through the pipes during any water consumption.
- Filter any other environmental noises, or noises made by other near-by sources different from the water consumption.
- Storage the basic information of the water noise as it is registered. That information should be available for further off-site analysis.

Upon these requirements, the design was made as simplest as possible. The general scheme of the device is shown in Figure 1.

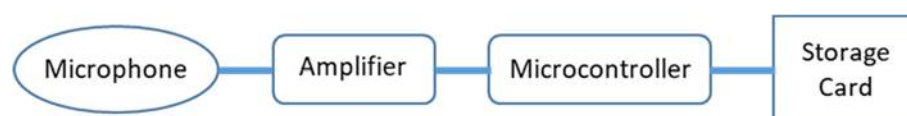


**Figure 1. Basic scheme of the noise sensing device**

Before going into the electronic lab, the design was tested through the Proteus (v8) software package for electronic performance simulation. In this stage, the design performance was tested and, also, the electronic board was devised. Proteus proved to be rather effective in checking the main processes but not all of them. In particular, it did not show some noise interferences that were to appear later in the operational amplifier during the first prototype testing.

Once the design was theoretically ready, a first prototype was assembled in the lab, and preliminary tests on real practice could be done. Three basic tests had been planned:

- Different types of sensors - the main decision was between selecting a microphone (as in [7]) or a piezometer (as in [8]). As a result, the piezometer option was discarded because the sensitivity it achieved was not as good as the microphone option. Then,

several microphones were also tested. The final selection was a unidirectional noise-reduction microphone model.

- Different types of attachments to the hose – in the end, any of the microphones tested had not been originally designed to be attached to a water hose in a cumbersome way. At the same time, the mechanical contact between the microphone and the hose is key to assure an acceptable quality during the noise recording. Therefore, a particular attention had to be set in the practical way by which the microphone was to be attached to the hose. After trying several techniques, the one chosen was a clothespin-like device (Figure 2).
- Different device firmwares - the microcontroller operation must be optimized, to extend the battery life as much as possible. In general, the battery life problem was only one part of a larger dilemma: the compromise between the battery life, the tasks performed by the microcontroller, and the amount of data to be stored. At the moment this paper is being written, both the sampling process and the battery life have been prioritized, so that as much (raw) noise information as possible is being stored; and all further processing is performed off-site.

Apart from the planned tests, other works had to be done because of unexpected problems. The most relevant one was related to some noise interferences produced in the amplification stage. Not surprisingly, there was no sign of such problems in the electronic simulation of the device, but once practical noise recordings began, an additional noise level appear to be added to the real one, especially during silent (no-flow) periods.

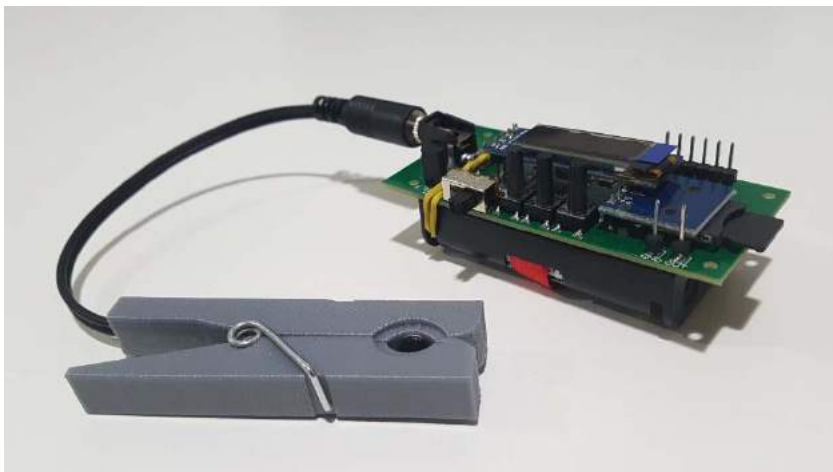


**Figure 2. Definitive prototype**

As the second-round problems were fixed, three definitive prototypes, like the one shown in Figure 2, were assembled for a more extensive field testing. In summary, the device's main features at the moment are the following:

- Bandwidth: 30 kHz, which is, obviously, an excessive value, according to the characteristics of the water noise in hoses.
- Sampling rate: 60 kHz.
- All the raw information for each sample is individually stored in an embedded memory card.
- A noise threshold (RMS) can be calibrated by the device itself (according to the general environment noise), or can be manually set, before the recording.
- Expected battery life in continuous operation is estimated from 2 to 3 months.

New performance tests were carried out in different households, and at the University facilities (Figure 3).

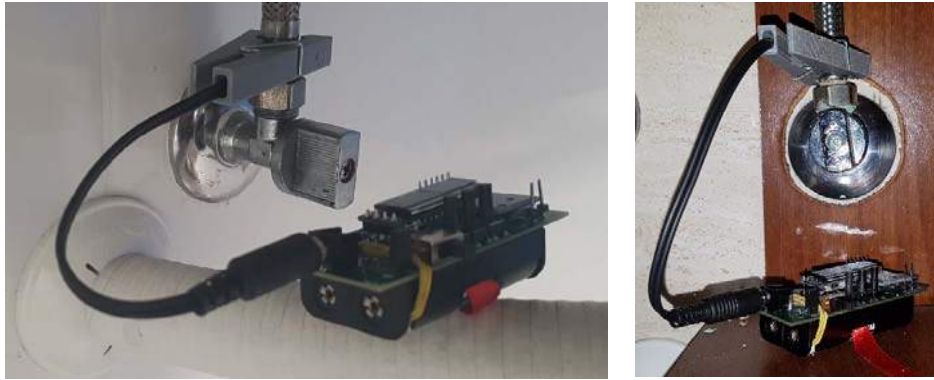


**Figure 3. Sensing device installed in two test locations**

### 3. RESULTS AND DISCUSSION

All the tests performed were aimed to two goals. The main one is assuring the accuracy in catching the time and duration of each use in the monitored water appliance. The second one consists in knowing as much as possible about the uses of other water appliances that are located near to the one being monitored.

In order to identify different uses of water appliances, two aspects or the noise registered are analysed:

- The noise level – represented by the particular value of RMS. As expected, the closer to the device, the higher the registered RMS is. The maximum range of water noise detection the device can reach depends on the magnitude the flowrates, the layout and material of water pipes, the spot (hose, screw, tap) onto which the device is attached and the base level of the environmental noise.
- The noise characteristics – represented by the frequency spectrum. Depending on the facility (water velocity, flow rates, ease of water flow, valves opening) the noises produced by water can be lower or higher. While the RMS level is intended to be the main tool to locate the noise (water use), a secondary analysis of each noise spectrum is planned to look for additional valuable information.

Results obtained so far effectively confirm that water noise, as considered in this work, can be a good tracer to identify the appliance in use. Figure 4 and Figure 5 show the test series registered at a restroom in the University and a bathroom in a private household, respectively.

In both cases, the device was installed on the cold water hose of the tap, and in both cases the sequence of appliance uses was the same: #1 is the fully open cold water tap (in which the sensor is installed); #2 is the mid-open cold water tap (in which the sensor is installed); #3 is the fully open tap, which is next to the one in which the sensor is installed; #4 is the mid-open tap, which is next to the one in which the sensor is installed; #5 is a toilet tank flush; #6 is a toilet tank filling; #7 is the urinals flush; #8 is the fully open bidet tap; #9 is the fully open shower.

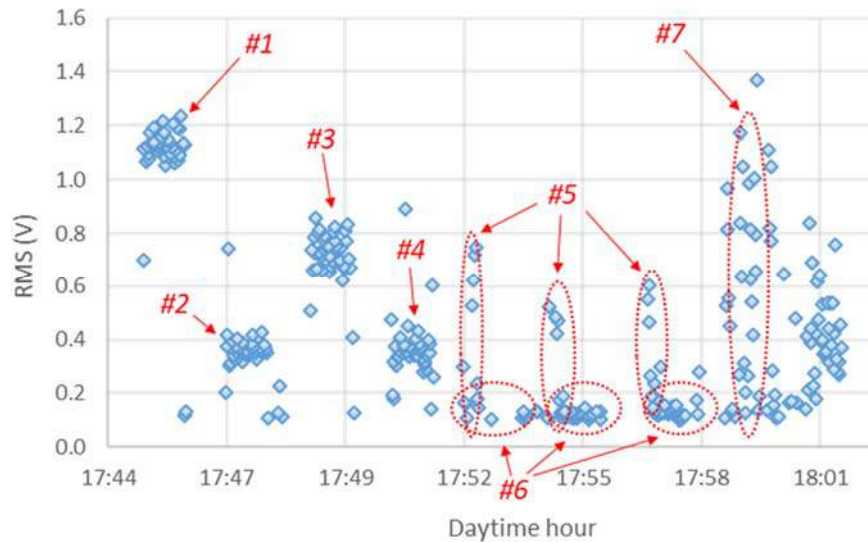


**Figure 4. Test - RMS vs time in a University restroom**

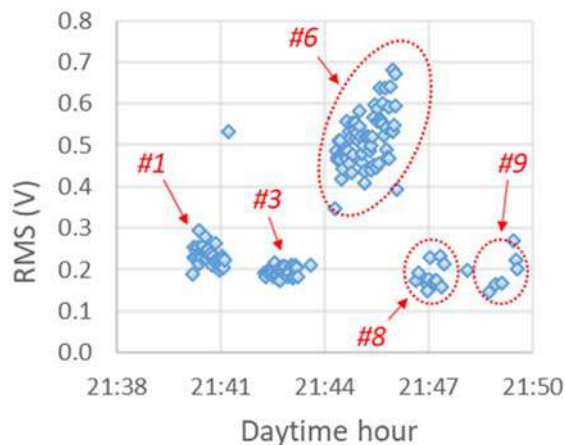


**Figure 5. Test – RMS vs time in a private household bathroom**

As a first finding, the noise levels at the restroom are, in general, higher than they are in the bathroom. Regarding water noise in taps, it is confirmed and quantified that the noise level is greater the closer the consumption to the sensor (from 0.1 to 0.2 V more), and the higher the flowrate (from 0.4 to 0.6 V more). It can be surprising the different RMS values for #1 between the restroom and the bathroom. Though further research is needed, that difference could be due to the fact that the tap in the bathroom is a low-flow one (about 6 L/min), whereas the tap in the restroom is not (about 9 L/min). Regarding water noise originated in toilet tanks, the recordings at the restroom show the difference between the tank flush, which is noisier (RMS  $\approx$  0.6 V) and shorter (about 10 s duration) and the tank filling (RMS  $\approx$  0.15 V and 1.5 minutes duration). The case of the toilet in the bathroom differs significantly because the fitting of the filling valve (which is fairly closed) makes it rather noisy. Therefore, the filling noise covers the flush noise and lasts for more than 1.5 minutes. Additionally, Figure 5 shows how (still because of the filling valve) the filling noise gets louder as the valve is just about to close.

The other registered noises are not so relevant. The urinals flush is really loud in the whole restroom and, according to the timestamp, that is what is shown in Figure 4. However, some other unmanaged noises seem to have interfered in the recording after the urinals flush. Finally, the noises caused by water use at the bidet and at the shower, in the bathroom, have been still caught.

Charts in Figure 6 show two particular frequency spectra that correspond to two different tap noise records. The one on the left, has been recorded at the same tap in which the device is installed, whereas the one on the right was registered in the tap next to the one in which the device is installed. After a first sight, main features of both spectra (apart from amplitudes) look quite similar, further ideas can be extracted for future developments, like the probably excessive bandwidth used at the moment, or the relation structure-amplitude to compare the spectra registered at different appliances of the same (or also different) type.

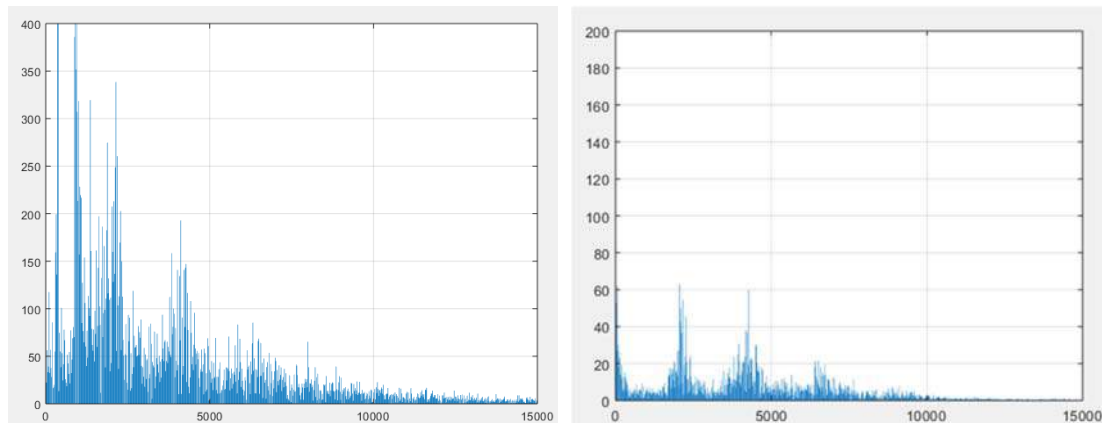


**Figure 6. Frequency spectra of two noises at the monitored tap (left) and at the next tap different from the monitored one (right), when fully open.**

#### 4. CONCLUSION

After the whole development process and these, and others, tests undercarried, the sensing device has shown to be operative and to fulfill the specifications for which it was designed. Water noises at each appliance can be registered and characterized.

Results also show that further work is needed to devise the best calibration procedure before a monitoring campaign is set on. After such calibration, the noise level can be a convenient indicator to point out which is the appliance in use in a wet room. In any case, this technique is intended to be implemented as a complement for some of the others already presented in the Introduction section. This way, information provided by the sensor will back and clarify the one obtained through those either intrusive or non-intrusive end-uses identification methods.

There is one final issue that, yet collateral, should not be neglected – the privacy in a bathroom. This sensor is not at all and by any means a threat for such privacy. In first place, the sampling procedure and feature extraction (and, in the future, bandwidth) is focused on the characteristics of water noise in pipes, and not in aerial sounds. In second place, the microphone has been selected not to be influenced by any noise source different from that at which it is aimed to. Thus, the only external noise that has eventually succeeded in producing some sort of minor interference is a hair dryer at full power.

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# LEGIONELLA RISK IN DOMESTIC WATER SERVICES

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## ABSTRACT

Evolving building functional requirements introduces challenges in estimating hot and cold water supply demands to ensure that designs can satisfy the operational needs of a building in a cost efficient design whilst addressing key public health considerations e.g. Legionella risk, water quality etc.

An efficiently designed domestic water supply system (which also takes account of periods of low usage) is dependent on a well-engineered circulation system and storage or re-heat arrangement. The design of such domestic water systems typically rely on a fixture unit or demand unit method to establish the design peak flow rate and pipe sizes, whilst storage volumes are calculated using the same design guides typically based on litres stored per person. However, the final storage capacity is often amended due to engineering experience and discretion in response to knowledge regarding recharge time. Contributory factors such as the building water usage and turnover (water profile), occupancy times, and sanitary specification (low water use appliances) should also be considered.

This paper presents an examination into domestic water systems with consideration to bacteria growth, the importance of sizing the systems and water storage appropriately and the effect design standards have on expected operational performance. Furthermore, a brief summary of services issues is presented along with potential methods to mitigate excessive capital cost, running costs and aforementioned public health issues.

*Keywords: Demand, Legionella, Recovery time.*

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## 1. INTRODUCTION

Generally when we consider bacterial growth we think of Legionnaires' disease, *Legionella* is an aquatic bacteria comprising of many species that can infect the human lungs [1]. *Legionella* is widespread in nature, in rivers, lakes, etc. However, it is rarely contracted from these sources. In building services we typically associate *Legionella* with air conditioning, wet cooling towers and cold water systems. The domestic hot water quality that our mechanical appliances produce is equally important, this is because effectively it is part of the same Hot and Cold water system, distributed by a separate pipe network but with potential to mix/ cross contaminate within the water system, either by blended water at an outlet or the annular in the calorifier or buffer vessel, water network. There are many variations of water systems supplying hot and cold water services within buildings, with the types chosen varying based on the size and complexity of the building. *Legionella* can be contracted by inhalation or aspiration.

It is a common misconception that a water spray is an aerosol and that *Legionellae* have to be contained within a wet droplet. A mist of water droplets might constitute an aerosol if the droplets are small enough. Water evaporates from small droplets very rapidly. Water that is contaminated can become a risk of infection if it can become an aerosol and airborne. Small particles can remain suspended in air for prolonged periods of time and travel over considerable distances [2]. These particles are dry and contain no free moisture. Only bound water is present which represents a small percentage of the total mass. When contaminated air is inhaled into the lungs, 5 micrometre or less (5  $\mu\text{m}$ ), will be retained in the lungs, as these sizes are difficult to expel [2]. Further, the risk increases with duration of exposure, respiratory rate and number of *Legionellae* in the air [2].

*Legionellae* are only able to grow in water in the presence of other micro-organisms. In addition, *Legionellae* have been shown to be associated with biofilm on surfaces in water systems where they can grow in the protozoa, grazing the biofilm [1]. Growth within protozoa, particularly with the potential for incorporation within protozoal cysts, can protect *Legionellae* from biocides, heat and drying. The association with biofilms, as with other aquatic bacteria, offers *Legionellae* a nutritional advantage and also provides them with some protection against adverse environmental conditions, particularly biocides that would otherwise kill them if they were simply suspended within the water column. Thus control of biofilm formation within water systems is of paramount importance for the control of *Legionellae*.

With the availability of advanced technologies, opportunities exist for engineers to identify and design for anticipated building demands for current and future use. The challenge for the engineer is to not only ensure the design performance for current usage but also for the future anticipated use of the building. The effectiveness therefore is influenced by design guidance, manufacturer's literature and Client briefing.

Water flow temperatures also have an influence on the water volume being used, particularly in relation to hot water services. However, hot water temperatures need to be sufficiently low enough to mitigate against scalding risk but in doing so this also introduces a concern in relation to bacterial growth, and the presence of *Legionella* bacteria, *Stenotrophomonas* and *Pseudomonads* including other waterborne opportunistic pathogens. The optimum *Legionella* bacteria multiplication temperature is between 32°C and 42°C [3]. However, it has been demonstrated by Sharaby *et al*, 2017 [4] that different environmental *L. pneumophila* genotypes can have different temperature related growth preferences.

HSE L8 [5] requires there is a need to maintain temperatures above 50°C - 60°C for domestic hot water systems. Interestingly there is no minimum time limit for 60°C in the calorifier. HSE L8 also mentions to ensure stored hot water is generally not less than 60°C with a recommended distribution temperature of not less than 50°C and 55°C in healthcare premises, within one minute of running an outlet [2]. Temperatures in excess of approximately 44°C [6] may result in burns to the skin therefore there is a conflict between storing hot water at 60°C and the risk of scalding. Hot water temperatures therefore need to be controlled either via thermostatic control devices such as thermostatic mixer valves (TMVs) or suitable warning signs adjacent to hot water outlets. Or better still a thermostatic mixing tap (TMT) directly on the WHB minimising pipe lengths from lowered blended temperatures from a TMV to the outlets.



This paper summarises the current design methodologies for sizing distribution systems, water storage tanks and associated codes of practice, followed by a review of relevant standards and regulatory requirements with respect to water temperatures and the risk factors that impact water quality within the domestic water systems. Finally, the paper provides some potential areas of exploration for further research.

## 2. BACKGROUND

The fundamental principles of domestic water systems are not a new concept, but developments in sanitary-ware specification and building design standards have evolved. However, the UK British Standards (BS) [7] and Institute of Plumbers (IoP) [8] guidance currently adopt sizing methods that are based on consumption data dating back to the 1970's & 1980's for storage tanks and 1940's for pipe sizing. Due to the modern advances in technology, combined with the drive to conserve water (e.g. low flush toilets, low flow devices) it is clear there is a need to obtain current and reliable data on building water consumption to allow building water demand to be more accurately assessed. Without considering the implications of current practices which reduce or limit building water consumption, demand and water tank turnover rates can lead to stagnation of water in domestic installations and result in public health issues, i.e. bacteria growth.

If *Legionellae* are stressed via starvation, chemical disinfection, UV light or heated they can opt for a VBNC state rather than die [9]. Whilst bacteria may be in a state of Viable but Non culturable (VBNC) at low temperatures, they are capable of amplification in warmer water temperatures [9]. A biofilm is any group of microorganisms in which cells stick to each other and often also to a surface. Further, this means *Legionella* may be protected from normal water treatment methods [2]. However, it is still possible for biofilm to form that will support bacterial growth if water is circulated within a system. Water flowing/ pumped in a water distribution system only causes shearing of biofilm; it does not remove the biofilm once it is established. Surfaces of pipework are not smooth so biofilms will adhere to the surface. Therefore, regular draw off and water movement through the system supported through automated flushing systems or via manual intervention by janitorial or Facilities Management (FM) staff are important to help minimise the risk. Therefore, consideration in the sizing of all aspects of domestic water systems should include an accurate estimation of the water consumption anticipated by the end users.

For *Legionella* bacteria to amplify several factors need to be correct including ambient temperature, relative humidity (RH), and wind [3]. For the bacteria to proliferate there are several potential areas in domestic water systems where bacteria may grow under the correct environment. These include storage tanks, calorifiers, pipework and plant, filters and particular types of fittings and materials [3]. All bacteria need a substrate (food source). With the common causes of contamination from hot water or cold water systems being showers, taps, spray heads and spa baths. Other risk systems include humidifiers and air washers, car wash- lances, horticultural misting systems etc [2]. Other obvious locations for potential *Legionella* growth in domestic water system include, potentially the base of hot water cylinders, cold water storage tanks and pipework deadlegs or blind ends not limited too. Thermostatic mixing valves (TMV) are also considered to be a source for bacterial contamination, as this is where the cold and hot water mix with the resulting blended temperature ideal for opportunistic bacteria/ *Legionella* growth.

For *Legionella* to proliferate there are a number of conditions required which include [5]:

1. Water temperature in the system between 20°C – 45°C,
2. Potential for water aerosols to be formed and become airborne,
3. Water being stored and/or re-circulated,
4. Presence of deposits in the system, such as sludge, organic matter, rust, scale and nutrient,
5. Amoebae are also known to cause retro grade contamination of *Legionella* bacteria.

Beattie and Kane 2015 [10] suggested there is a need for design guides to re-evaluate pipe sizing methods and in 2016 [11] suggested cold water storage tank sizing should also be readdressed as site based evidence indicates many building storage tanks are being drained down and decommissioned due to oversizing. This has posed the question, should current guidelines be seen as the upper limit? And therefore as a result these standards should not be exceeded? Subsequently, if the methods used for sizing the domestic water systems were to be re-examined system

components may reduce in size, resulting in potential savings in capital and (where applicable) running costs in addition to the possibility of reducing bacterial growth.

### 3. BASIC ENGINEERING DESIGN METHODOLOGY

#### 3.1 PIPE SIZING

In the UK the Institute of Plumbing (IoP) – Plumbing Engineering Services Design Guide [8], BS EN 806 [7] and CIBSE Guide G [12] are the recognised methods for designing and sizing domestic water system pipework. The industry practice of using loading units to size pipework is based on the 1940s methodology created by Hunter of the USA. These loading units are based upon; probability theory, time between uses of an appliance, duration of use and flow rates when in use. Dr Hunter knew most appliances are intermittently used, from this he theorized the loading of a single appliance did not just depend on the rate of flow to the appliance but also the frequency of use and duration of use [13]. Konen [14] reviewed part of the Hunter method based on the probability theory and also established that the frequency of use is the most critical parameter for water turnover rather than flow rate. However with the use of water conservation measures, the flow rate may become just as important. Also in academia, Goncalves *et al* [21] presented a paper which summarised mathematical models for the design of water systems. This included, Courtney (1976) a probabilistic model to determine flow rate, Konen (1980) and Holmberg (1981) a dimensioning formula, and Webster (1972) a generalised binomial distribution function. There are further studies such as by Mui and Wong 2011 [15] and Agudelo-Vera *et al* 2013 [16] and the LUNA (Loading Unit Normalisation Assessment) project by the UK's Chartered Institute of Building Services Engineers [24]. This list is not exhaustive as many more researchers are each addressing the sizing and or design methodology.

#### 3.2 COLD WATER STORAGE TANKS

Cold water storage tanks are relatively straightforward appliances, however with ever increasing water efficient low flow devices and building thermal insulation and improved air tightness can result in frequent overheating in cold water systems. The cold water storage tank (and pipework system) needs to be assessed accurately from all aspects prior to its design.

The following notes the formula used in determining the cold water storage capacity.

$$\text{Storage volume} = \left( \frac{\text{number of}}{\text{persons}} \right) \times \left( \frac{\text{litres per}}{\text{person}} \right) \times \left( \frac{\text{number of}}{\text{days' storage}} \right) \left( \text{or \% of 1 days supply} \right)$$

If the building occupancy is not known, the Health and Safety at Work etc Act 1974 [17] gives an allowance of 10m<sup>2</sup> per person of working floor area may be used. The sole objective of the period of storage is to cover any interruption of the mains water supply.

The UK Water Regulations Scheme (WRAS) [18] offers guidance on the application of appropriate backflow protection and tests the standards of the water appliances being supplied and installed.

#### 3.3 DOMESTIC HOT WATER CYLINDERS

Basically the operation of a hot water cylinder works by a surface area of the heat exchanger, if this is increased its heat transfer capacity is increased and the rate of heat transfer in the cylinder is increased. Therefore boiler modulation is potentially decreased and heat-up times are reduced [18]. Howarth 1983 also listed the following as factors affecting system efficiency, thus performance:

1. Appliance thermal capacity;
2. Cylinder heat exchanger surface area;
3. Primary water flow rate, and
4. Draw off water frequency.

Also, the amount of heat or power required to heat a cylinder is:

$$\text{kW} = \frac{\text{Cylinder capacity (l)} \times 4.187 \text{ KJ/KgoC} \times (\text{t hot} - \text{t cold})}{\text{hrs heat up} \times \text{efficiency of heat exchange} \times 3600}$$

Further, as the hot water storage vessel requires energy to generate domestic hot water, the following gives a simplified efficiency calculation as:

$$\frac{\text{The energy of drawn off water above supplied cold water temperature}}{\text{energy consumed in generating hot water}}$$

#### 4. WATER QUALITY STANDARDS AND REGULATIONS

The most widely known bacteria is the *Legionella Pneumophila* which is a member of the family 'Legionellaceae', that was first discovered in July 1976, when an outbreak occurred at an American Legionnaires' convention in Philadelphia in the Belle Vue Stratford Hotel [3]. Legionnaires' disease is an illness recognisable by high fever, or chills, headache and muscle pain. There are several standards and regulations that are applicable to water hygiene management supply temperature in the UK, these are:

- UK Health and Safety Executives L8: 2013, Fourth Edition Approved Code of Practice and Guidance, '*The control of Legionella Bacteria in Water Systems*' [5].  
This requires that temperatures between 20°C and 45°C are to be avoided.  
Cold water systems should be, where possible below 20°C.  
Hot water stored at least 60°C and distributed at 50°C within one minute.
- UK Water Regulations (WRAS) [18].  
This requires temperatures to be kept below 25°C.
- BS 8580:2010 '*Water Quality – Risk Assessments for Legionella Control*' [19].  
This requires the temperature of a cold water outlet to be below 20°C after the outlet has been opened for 120 seconds and a hot water outlet reaches 50°C within one minute.
- CIBSE TM13:2013, '*Minimising the Risk of Legionnaire's disease*' [2].  
This requires the temperature of a cold water outlet to be below 20°C after the outlet has been opened for 120 seconds and a hot water outlet minimum of 50°C within one minute.

The Chartered Institute of Building Services Engineers Technical Memorandum TM13 '*The Control of Legionella*' [2] identifies the following as temperatures for *Legionella* growth:

- Dormant; 0°C to 20°C;(VBNC)
- Will multiply; 20°C to 45°C;
- Will not multiply and will die in time; 50°C to 70°C;
- Not active; 70°C to 100°C.

Further, Dennis *et al*, (1984) [20] tested and found the following results with *Legionella* kill time,

- 50°C 111 minutes;
- 54°C 27 minutes;
- 58°C 6 minute.

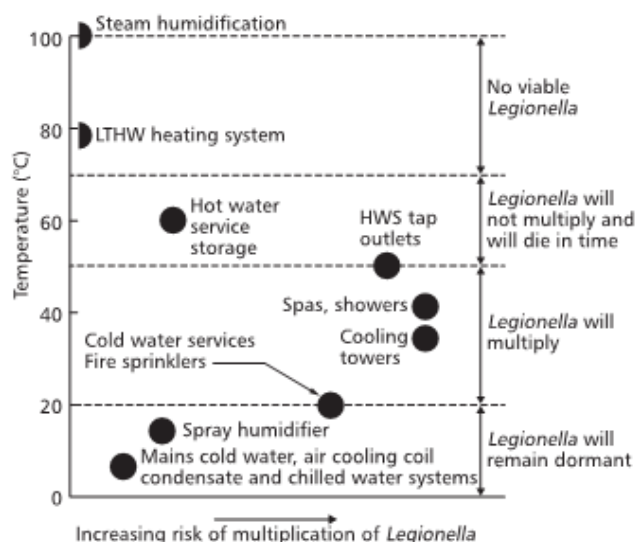


**Figure 1:** Water system temperatures with multiplication of Legionella [2].

The ideal temperature, based on empirical data suggests that the perfect microbial growth and proliferation is 37°C. Below 37°C the rate of multiplication declines, were it can be considered marginal below 20°C [2], refer to figure 1. Also, certain groups of people are known to be more susceptible, for example; over 45 year olds, smokers, alcoholics, diabetics, immune compromised and those with cancer, respiratory or kidney disease. The HSG 274 states, that all pipe branches to individual outlets should be capable of delivering cold water at a temperature that is as close to the incoming water temperature within two minutes of running.

The volume of stored cold water should also be minimised and should not normally exceed that required for one day's water use although in healthcare premises, a nominal 12 hours total onsite storage capacity is recommended.

BS 8580:2010 provides detailed guidance on how to conduct a Legionella risk assessment; the risk assessor should however have an in depth understanding of water systems [19].

## 5. IDENTIFYING RISK OF INFECTION

The management of Legionella risks are described within the Approved Code of Practice (ACOP) Guidance document 'L8' Legionnaires' disease: The control of Legionella bacteria in water systems [5] and HSG Part 2 [6]: The control of Legionella bacteria in hot and cold water systems.

The key actions are:

1. Appointment of a 'responsible person' to be managerially responsible;
2. Identification and assessment of sources of risk including the preparation a risk minimisation scheme for preventing and controlling the risk;
3. Implementation and management of the risk minimisation scheme;
4. Record keeping and checking the actions taken are effective in preventing or controlling the risk.

Risk assessments are about compliance and vulnerability. Therefore, risk assessments involve assessing compliance status using checklists, the response to which are either 'yes' – indicating compliance or 'no' – meaning non-compliance. A 'Risk' increases when the non-compliant aspects accumulate. Fundamentally this means the more non-compliant conditions, there is an increased likelihood that something shall transpire. When the risk has been assessed it is then necessary to minimise and control it. The risk assessment must be reviewed regularly as stated in Paragraph 47 L8.

The record of the assessment is a living document that must be reviewed to ensure it remains up-to-date. Arrangements must be made to review the assessment regularly and specifically whenever

there is reason to suspect it is no longer valid. An indication of when to review the assessment and what to consider should be recorded [2 & 6], this may result from, e.g.:

1. changes to the water system or its use;
2. changes to the use of the building in which the water system is installed;
3. the availability of new information about risks or control measures;
4. the results of checks indicating that control measures are no longer effective;
5. changes to key personnel;
6. a case of Legionnaires' disease/Legionellosis associated with the system.

The design of domestic water systems should always be in accordance with local Water Bylaws guidance, current design guides and industry good practice. The bacteria are most commonly found in hot water services, particularly in calorifiers and evaporative cooling systems for air conditioning. Also systems that are corroded or that contain debris or organic fouling, water stagnation and correct temperatures are most likely to harbour Legionella bacteria [3]. However, a risk of infection from a water source is dependent on several factors. Liu *et al*, 1996 [23] expressed these as six important elements in estimating Legionella disease risk:

$$LD = \text{Bacteria} + \text{Sufficient concentration} + \text{Aerosol} + \text{Inhalation} + \text{Susceptibility} + \text{Other factors}.$$

It is worth exploring the above factors in more detail, as these help provide some guidance in preventing and controlling the risk of infection.

The following list contains some of the factors which should be considered [5]:

1. Source of system supply water;
2. Possible sources of contamination of the water within the premises before it reaches cold water storage, hot water storage, cooling tower or any other system using water that may present a risk;
3. Plant operating characteristics;
4. Unusual but foreseeable operating conditions;
5. Means of disinfection;
6. Review of current control measures;
7. Local environment.

When the assessment indicates there is a reasonably foreseeable risk from a water system, exposure has to be avoided so far as is reasonably practicable. Where this is not reasonably practicable a Written Scheme for controlling the risk from exposure should be implemented and properly managed. The scheme should specify measures to be taken to ensure it remains effective.

## 6. CONSIDERATION TO DOMESTIC WATER SYSTEMS

The following lists several important aspects which can help prevent Legionella proliferating within domestic water systems [2 & 10, this list has been extended from the references]:

Cold water system:

1. The cold water outlets, mains or stored achieves <20°C
2. Suspected low use outlets are disconnected or run full flow until temperature stabilises weekly, also to achieve a temperature <20°C;
3. Dead legs are removed and piped through; if possible, if not then they should be managed as per L8 paragraph 80 and identified in the Legionella risk assessment;
4. The cold water storage tank shall be an appropriate size for the demand;
5. Through flow of water from inlet to outlet of the tank, for good tangential flow;
6. A lid is required and insect screens on overflows, warning pipes and lid air vents;
7. The inlet flow is fitted with the appropriate backflow protection;
8. And the temperature achieves <20°C – with the tank insulated where possible to prevent heat gain.

Hot water system:

1. Storage temperature 60°C;
2. Check for temperature variations regularly;
3. Check volume, usage and recovery rates;
4. All hot water outlets achieve >50°C within 1 minute; unless fitted with a TMT or TMV;

5. Remove any dead legs; if possible;
6. Install or extend secondary pipework. If required in the design;
7. Consider using a venturi daisy chain pipework system design.

The above aspects may not be exhaustive, but may contribute to minimising legionella growth in domestic hot and cold water installations.

## 7. LEGIONELLA RISK SCORING SYSTEMS

*Legionella* risk assessments may contain a “risk scoring system” or “risk algorithm” as an aid to understanding the relative risk of the systems assessed. However, any scoring system used by the risk assessor should be explained to the intended reader and cover the following.

### *Contamination:*

An evaluation of the risk at source, including assessment of the quality, temperature and integrity of the water supply.

### *Amplification:*

Determination of the cultivation conditions: assessment of the likelihood that *Legionella* will proliferate, including an assessment of conditions such as the temperature, water change rate, areas of static or slow water movement and how conducive the conditions are to microbial growth.

### *Transmission:*

An assessment of whether droplets or aerosols are likely to form and spread.

### *Exposure:*

Determination of the risk that droplets or aerosols will be inhaled or contaminated water aspirated.

### *Host susceptibility:*

An evaluation of the nature of the exposed population, taking account of their vulnerability when exposed to *legionellae*.

For the implementation of a risk scoring system to be of value, the repeatability of the system should be assured by clear guidance on the application of such a system to all risk assessors undertaking such evaluations.

## 8. SUMMARY

From a building services industry perspective it is important to highlight that many of the design guides for domestic pipe sizing have not been updated to reflect current domestic water services approaches particularly with regards to water conservation measures and building design standards and strategies. It is becoming ever increasingly difficult to size cold water and hot water systems as more low flow devices and mixing valves are being incorporated.

This paper has discussed the hot and cold water storage tanks and pipework with the issue of potential bacterial growth, to reduce energy costs and improve water quality. The paper outlined the history of existing methodologies and presents supporting guidance and legislation associated with maintaining safe hygienic water systems.

Even though Legionnaires' disease outbreaks are infrequent they are potentially life threatening, which may be avoidable through engineering design and operational side maintenance and management. The successful control of *Legionella* bacteria is a combination of good technical engineering design and client side control management. One of the engineering key considerations for this examination of domestic water systems should be to review the sizing guides/methodologies to account for modern practices; this will also require more research data analysis and promotion of knowledge sharing of raw, live consumption data from actual buildings.

## 9. COMPETING INTERESTS

The issues raised in this paper have accumulated through several resources and in no way reflect any one specific project of AECOM or ARUP design. The issues and mitigation measures have been compiled through the experience of multiple engineers from many consultancies over several years.

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# Environmental benefits from water efficient taps

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## ABSTRACT

Water is a key resource at risk, not only because it is already scarce in various parts of the globe, but also since climate changes scenarios point towards an aggravation of water scarcity in the near future. However, water use by modern communities implies the consumption of other natural resources and results in environmental impacts. The present communication attempts to present a more holistic assessment of the environmental benefits from water efficiency, including the related energy consumption and the carbon emissions from the energy generation. The case study is the Department of Civil Engineering of the University of Aveiro; a public building with high occupancy and, as such, with greater potential for water saving. This research quantifies the energy and carbon emission reductions from using water efficient tap aerators, considering the impact on the entire urban water cycle. The water consumption pattern of the studied building was captured through in situ campaigns, including the assessment of the effective water consumption reduction for four different types of aerators, based on user's behaviour, and the energy consumption was based on the activities of the utility that operates the water supply and the wastewater treatment systems in the city of Aveiro. A comparison between annual and monthly analysis shows that an annual approach can return results with significant errors on the released carbon emissions when in presence of seasonal consumption variation.

*Keywords: Water-efficient devices, Energy consumption, Carbon emissions, University building, Urban water cycle*

## 1. INTRODUCTION

As the effects of Human activity become more global, a deeper understanding of the interlinks between the activities is more relevant for understanding the causes, sources and underlying mechanisms and identify, assess and implement the best solutions to tackle nowadays and future challenges [1-2]. Since the water and the energy sectors are inextricable intertwined, their interdependence has received attention at various levels (e.g., individual researchers, organizations, governments) under the designation of "water-energy nexus".

The efforts exploring the natural and extensive interlink between water and energy have addressed topics such as: i) water use for energy production and supply in electricity generation [3-6], oil and gas operations [7], and total energy productions [4, 8]; and ii) energy consumption for water production/water abstraction, treatment, end use, reclamation and disposal [9-11]. The scale of these studies also varied, from worldwide [12], nationwide [13-14], region wide [15], citywide [16], building wide [17] to a specific end use or technological solution [18]. These studies demonstrated the strength of the relationship between water and energy and the cascade influence throughout the communities, since they are two key basic resources used virtually in any Human endeavour, revealing the context specificity of the topic despite being a global issue.

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Within the context of climate change, several researchers have also explored the additional connection with greenhouse emissions. The greenhouse emissions have been analysed in different components/stages of the water-energy nexus both from the energy production [19-20] and water [21] perspectives. This brought another layer of complexity to the problem, since the greenhouse emissions will vary significantly depending on the sources of energy in the energy mix, making this global problem even more context specific.

In addition to the studies on establishing the present water-energy-greenhouse emissions scenarios in various contexts and scopes, there have been also some authors exploring the potential benefits from either water or energy efficient or cleaner solutions [22-24]. These research efforts tend to be not only context specific but also scope limited due to the growing degree of complexity that hinders analysing all aspects and dimensions of the water-energy-greenhouse emissions problem.

In Portugal, the urban water consumption accounts for only 8% of the total volume of water consumed per year (agriculture accounts for 87%) but represents 48% of the total annual water cost due to the infrastructure needed and resources spent on water treatment and supply [25]. The importance of the water-energy nexus is strongly acknowledged in [25], since a significant driver of the water costs is due to the energy used in the urban water cycle. It should be noted that in [25] the energy used for pumping or heating water at a building level is not accounted for, neither the costs with the greenhouse emissions.

The present communication presents a contribution to address the water-energy nexus at an end-use level, accounting for greenhouse emissions. A case study approach is used to assess the water-energy-greenhouse emissions benefits from the installation of water efficient washbasin taps in a university building in Aveiro, Portugal, and two different approaches are considered to tackle the problem. Despite the level of specificity of the case study, which is aligned with the context specific nature of the water-energy nexus and the scope limited approach for efficiency analysis, the methodology can be generalized to other contexts.

## 2. CASE STUDY

The case study is the Department of Civil Engineering of the University of Aveiro (DECivil), Aveiro, Portugal. There are about 300 individuals in the DECivil community, mostly students, but also researchers, professors and administrative and lab workers. The building has several water consumption points, namely the laboratory and the toilets.

Four different types of tap aerators (Figure 1) were installed in the washbasins of the existing toilets and the impact of the user preferences and behaviour changes on the water efficient performance of the aerators was evaluated by Meireles et al. [26].



**Fig. 1. Characteristics of the different aerators: a Aerator A (aerated flow;  $Q = 4.7$  l/min); b Aerator B (spray flow;  $Q = 3.9$  l/min); c Aerator C (aerated flow;  $Q = 3.4$  l/min); d Aerator D (spray flow;  $Q = 2.0$  l/min).**

The baseline situation consisted on the existing laminar flow push taps with an average discharge rate and shut off time of 6.7 l/min and 6.1 seconds, respectively, corresponding to an average water discharge of 0.82 l per use. An effective water consumption reduction (aerator A – 15%, aerator B – 17%, aerator C – 27% and aerator D – 49%) smaller than the discharge reduction (30%, 42%, 49% and 70%, respectively) was observed, confirming that user factors

affect the potential water savings. On average, the water consumption reduction was 46% smaller than the discharge reduction achievable with the tap aerator alone.

### 3. METHODOLOGY

The methodology adopted seeks to link the observed water reductions due to the installation of the aerators with the corresponding energy and carbon emissions savings considering the specificities of the context. The methodology can be split into the following stages: i) estimate the specific greenhouse emissions in terms of CO<sub>2</sub> (CO<sub>2</sub>/kWh) in the energy production; ii) estimate the specific energy consumption (kWh/m<sup>3</sup>) in the urban water cycle; iii) quantify the total water (m<sup>3</sup>) consumption and water-end use pattern (%); and iv) quantify the water savings (%).

The information on the energy sources and the corresponding carbon emissions from electricity production between 2008 and 2017 were provided by EDP – Energias de Portugal, which has the biggest market share in Portugal. It should be noticed that, since the share between energy providers to the Aveiro Water Utility (AdRA – Águas da Região de Aveiro) is unknown, a scenario of 100% of energy provided by EDP was considered. This may entail some bias due to the difference on the energy mix from the various retailers operating in Portugal. However, the energy mixes are not so distinct and, considering the monthly uncertainty in the energy sources, it is possible to assume that the effect of such bias is negligible.

The energy required for the urban water cycle was estimated based on the published annual values of AdRA. Data from 2011 to 2016 are publicly available and include all different stages in the urban water cycle, namely the abstraction, treatment and distribution of potable water (the supply system), and the drainage, treatment and rejection of treated wastewater (the drainage system). The energy required per unit volume was calculated based on the weighted sum of these two components and referenced to the unit volume of potable water supplied. This implies that the energy consumption reported herein includes the losses in the water system and the infiltration/inflows in the wastewater system.

For the present study, the total water consumption in the DECivil building was retrieved from the telemetry records between 2011 and 2016. The data is available at an hourly basis, but it was reduced to a monthly basis since none of the previous information was available with higher time resolution. The water end-use in the DECivil was obtained from Meireles et al. [27], providing a quantification of the water consumption in the washbasin taps with reference to the total water consumption in the building [28].

The effective water consumption reduction due to the installation of aerators in the toilet's washbasin taps was studied previously by Meireles et al. [27] during two subsequent academic years. The study encompassed in situ campaigns based on questionnaires and direct observation to evaluate the number of tap pushes for the different aerators and in the base situation.

The present study was conducted both on monthly and annual bases, in order to evaluate the influence of the time scale resolution in the results. It expands the study performed by Pombo et al. [29] specifically for the aerator D taking into account an annual time scale.

## 4. RESULTS AND DISCUSSION

### 4.1 Energy grid mix

EDP generates electricity through different technologies and primary energy sources that can be renewable or non-renewable (also called traditional sources). Electricity from traditional sources is produced by burning fossil fuels (coal and natural gas) in nuclear reactors (imported) and through cogeneration. Water, wind and sun are the more common renewable generation sources.

Figure 2 presents the evolution of the relative weight of the clean (blue scale) and non-clean (yellow scale) energy sources in the energy produced by EDP. Clean energies are understood as CO<sub>2</sub>, SO<sub>2</sub>, NO<sub>x</sub> and radioactive waste free. The annual distribution of energy shows a clear trend towards an increase in clean energy sources, reflecting the commitment to the Sustainable Development Agenda. The largest change occurred between 2008 and 2011, with an increase in clean energy sources from 26% to 60%. For that reason, and since the energy sources classification defined by the regulator (ERSE – Entidade Reguladora do Sector de Energia) also changed in 2011, the monthly energy source distribution includes only the years from 2011 to 2017 to avoid the bias due to the energy sources distribution in the previous years.

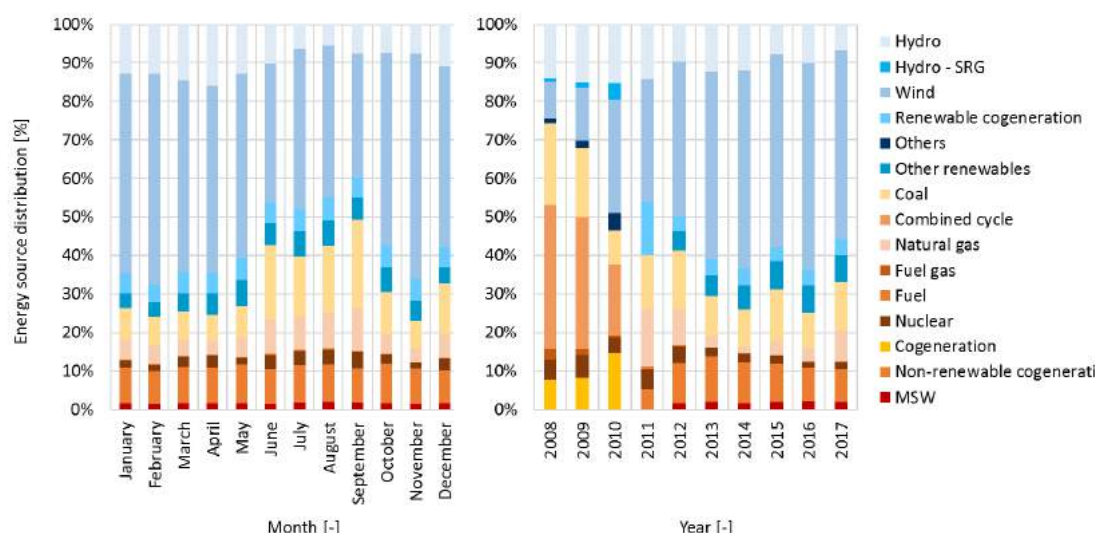


**Fig. 2. Distribution of EDP energy sources at a monthly (left) and annual (right) time scales.**

The year of 2009-2010 represented an important mark in the energy sector in Portugal. On one hand, the wind energy capacity growth stabilized after increasing from little over 500 MW in 2004 up to almost 4000 MW in 2010. In 2016 the installed capacity was 5300 MW, implying that it is still growing but at a lower rate. On the other hand, the start of the natural gas turbines in the Lares (2009) and Pego (2010) and the closure of the Barreiro (2010) power plants represented the “virtual” closure of the fuel-oil power plants and reduced the relative weight of the coal power plants in the energy mix. These investments result from a national strategy for the energy sector that is driven by internal and external factors of various natures (e.g., political, economic, environmental) and their modelling falls outside the scope of the present research.

Between 2011 and 2017, the clean energy sources weight varied between 60% and 75%. Part of this variation is due to investments in other clean energy sources in addition to wind power. In the fourth quarter of 2011 EDP kicked-off operations at Picote II and Bemposta II, two power increase investments totalling 437 MW. In December 2012 EDP started up operations at Alqueva II (a 256 MW power plant with pumping). In 2015, EDP started operating the dam of Ribeiradio/Ermita (82 MW) and, in 2016, the dams of Salamonde II (223 MW) and Baixo Sabor (151 MW). In 2017, Venda Nova III (780 MW) and Foz-Tua (263 MW) new power plants started operating. These new power plants were built in existing dams to increase the installed power and used reversible groups to pump water using the excess of wind energy. Therefore, their contribution to the energy mix is more related to the performance of the wind energy generation, which power was mostly installed in 2011. Therefore, for the scope of the present study, it was assumed that the variations in the energy sources distribution between 2011 and 2017 was mainly due to weather and consumption conditions.

Further investments are expected, such as the construction of the Daivões dam in the Tâmega river (118 MW) scheduled to be concluded in 2020. In 2017 EDP also completed the process of decommissioning the Energy cogeneration plant and continued the deactivation of three other thermal generation facilities, namely Carregado, Setúbal and Tunes, respecting the plan

submitted to the Portuguese Environmental Agency. The continuous investments are changing the energy mix and affect the results obtained in the present research. Still, the methodology can be replicated to account for new contexts.

## 4.2 CO<sub>2</sub> emissions per kWh of electricity produced

The data on the amount of CO<sub>2</sub> emissions per kWh of electrical energy produced (Figure 3) was also obtained from EDP and corresponds to the previously analysed circumstances of electricity generation.

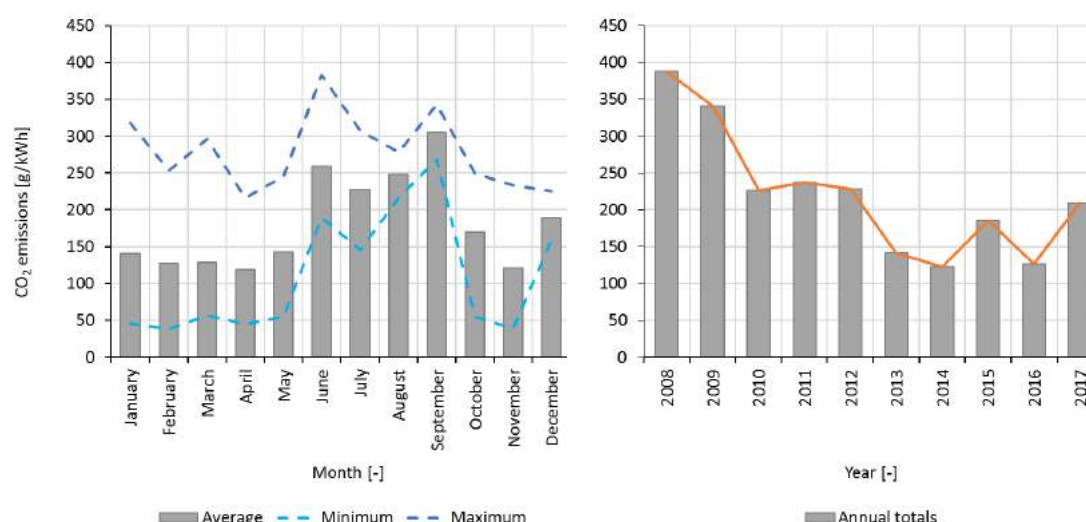


**Fig. 3. Specific CO<sub>2</sub> emissions due to electricity production at EDP at a monthly (left) and annual (right) time scales.**

The monthly and annual charts of CO<sub>2</sub> specific emissions are very similar to the ones presented in Figure 2, since these emissions are a direct consequence of the energy mix.

## 4.3 Energy required per m<sup>3</sup> of supplied water

The energy consumption in the urban water cycle managed by AdRA was obtained from ERSAR (Entidade Reguladora dos Serviços de Águas e Resíduos), entity that regulates and supervises the public water supply and urban wastewater sanitation sectors in Portugal.

The data on the annual volumes of supplied water (which includes billed and unbilled water), are characterized in Figure 4. It should be noted that unbilled water includes illegal abstractions, losses and leakages. The presented energy consumption is linked to the activities in the entire urban water cycle, comprising the processes of abstraction, treatment and distribution of water for public consumption (directly related to the water supply system) and the drainage, treatment and rejection of urban wastewater (that are processes involved in the wastewater sanitation system). In this case, the availability of information has restricted the analysis to a 6-year period, from 2011 to 2016, and the lack of monthly information imposed the consideration of the same energy ratio for the whole year.

The energy-for-water ratio considers all the aforementioned energy-consuming stages that are directly or indirectly required to supply 1 m<sup>3</sup> of water at the studied building. This ratio corresponds to the sum of two amounts related to the water supply and drainage systems, considering for each case the total volumes of water and effluent transported and the respective quantities of energy needed for those two phases. This factor represents the volume of affluence into the wastewater network (billed effluent) when calculated as a function of the consumed water (billed water).

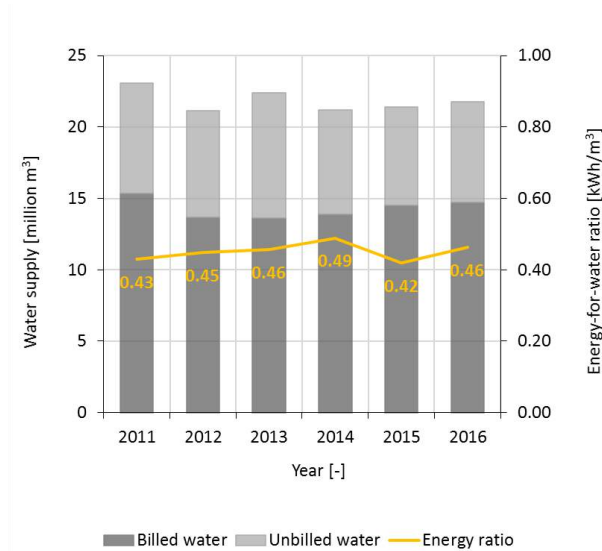


**Fig. 4. Annual water supply and energy consumption ratio at AdRA.**

The fluctuation on the volume of water supplied and on the energy-for-water ratio is due to the interconnected dependence on several variables that are unpredictably changing over time, namely: i) consumers habits that change over time and that are often a reflection of the economic situation; ii) the existence of network leakages and the repair and maintenance actions that are being taken to resolve them; iii) the affluence of undue flows in the periods of intensive precipitation; or iv) the need to resort to underground abstraction in dry years.

#### 4.4 Water consumption in the DECivil building

The six main toilets of the DECivil building (three for female users and three for male users) are responsible for roughly 70% of the building's water consumption. These have 14 washbasins, equally divided between the female and male toilets, that contribute for 12% of the total water consumption of the building (Figure 5), according to previous studies [27, 29].

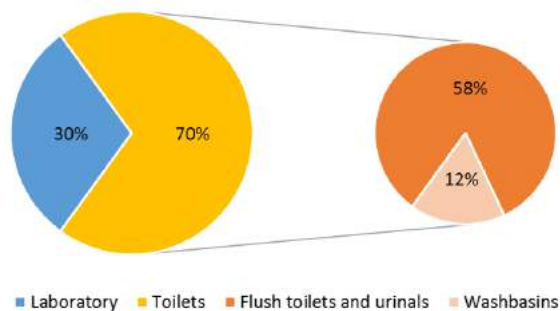


**Fig. 5. Distribution of water consumption points in the DECivil building.**

Since the middle of 2010, the water consumption measured in the DECivil building through a totalizer water meter has been recorded at an hourly rate by telemetry. These records were used to evaluate the water consumption pattern at a monthly timescale, that is the highest time resolution available for the remaining data used in the present research.

Figure 6 shows the monthly distribution of the average water consumption, along with the maximum and minimum values per month, and the total annual volumes, between 2011 and 2016. The annual water consumption has oscillated, showing a decrease of 13% between the first and the last year represented, reflecting the reduction on the number of students enrolled



in the Civil Engineering degree from 2012 and not structural changes or equipment adjustments in the building.

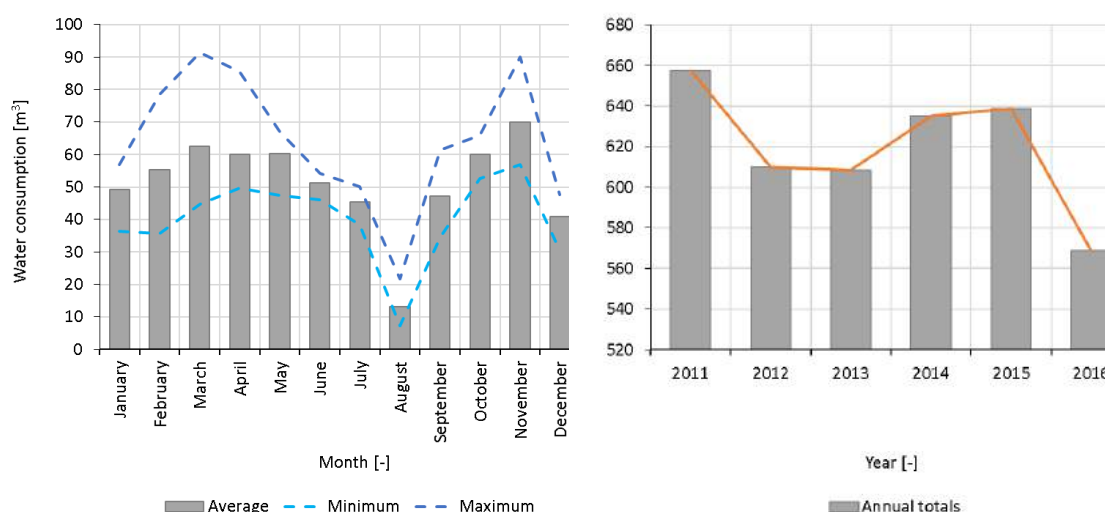


**Fig. 6. Water consumption in the DECivil building at monthly (left) and annual (right) time scales.**

In order to transform the hourly water consumption data into a monthly basis, certain assumptions had to be taken into account when in presence of missing records: i) when a gap on the water records of more than 7 days existed in the beginning or the end of a month, the corresponding month was excluded from the analysis; and ii) for all the other situations an expert analysis was performed to distribute the recorded volumes of water through the corresponding periods of time. The records of the years of 2013, 2014 and 2016 allowed to take into account all the months. In contrast, 2011, 2015 and 2012 presented 10, 9 and 3 months of reliable data.

The monthly consumption pattern accompanies the academic calendar and the expected affluence of users. August, which corresponds to the Summer Holydays, is observed to have the minimum water consumption records, with the lowest record of 7.33 m<sup>3</sup> in 2013. The two maximum values registered took place in March 2014 (91.49 m<sup>3</sup>) and in November 2016 (89.98 m<sup>3</sup>) which correspond to periods in the middle of the Winter and Summer semesters, respectively, where classes take place. In addition to that, there may also have been more intense laboratory activities as well as sporadic events organized in the department that lead to this occurrence.

#### 4.5. Water, energy and CO<sub>2</sub> emissions savings

With the installation of the four water-efficient devices under consideration, were observed savings on water and energy consumption and on carbon emissions, as summarized in Figure 7. From the monthly analysis, the installation of tap aerators D (the most efficient) in the DECivil building represents annual savings of 35 m<sup>3</sup> of water, 16 kWh of energy and 2.7 kg of CO<sub>2</sub>.

Performing the analysis at either monthly or annual time scales returns equal water and energy savings. On the opposite, differences are observed in the CO<sub>2</sub> emissions, since the energy mix varies from month to month, resulting in a variation on the CO<sub>2</sub> emissions throughout the year. In the present situation both approaches return similar annual CO<sub>2</sub> emissions, with a difference of only 5%

Analysing the results month-by-month (right side of Figure 7), the relative differences of CO<sub>2</sub> emissions estimates in each month ((Month CO<sub>2</sub> emissions estimate with yearly approach – Month CO<sub>2</sub> emissions estimate with the monthly approach) / Month CO<sub>2</sub> emissions estimate with the monthly approach) of up to 174% are observed. This disparity is particularly visible in buildings affected by seasonal consumption variation, like school and touristic buildings, since

carbon emissions are also season related. If in a school building, where the consumption drastically drops in the Summer months and the annual approach overestimates the carbon emissions, in an hotel, where the occupancy reaches its maximum in Summer, the annual approach would underestimate the CO<sub>2</sub> emissions, considering the Portuguese context.

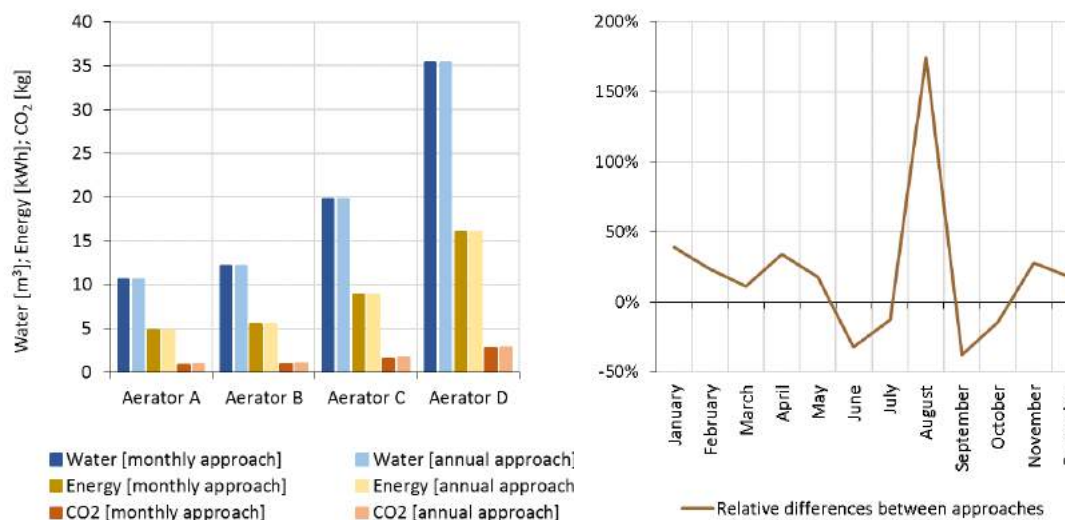


**Fig. 7. Potential savings for the four different types of tap aerators at monthly and annual time scales (left) and the relative differences of CO<sub>2</sub> emissions between the annual and monthly approaches (right).**

## 5. CONCLUSIONS

Water use appliances retrofit can be a way to achieve sustainable water use efficiency. In addition, since water consumption is intrinsically related to energy consumption and CO<sub>2</sub> emissions, when saving water, environmental benefits also arise from a diminution on energy consumption and carbon emissions release. However, studies only focused on technical approaches (e.g., water efficient technologies) do not reflect the dependency of the effective reduction on water consumption with users' habits and perception of comfort.

This study reflects the savings on water, energy, and carbon emissions through the installation of water efficient devices (tap aerators) taking into account the habits of the users. In the DECivil building, savings of around 50% on water, energy and carbon emissions can be achieved with the most efficient aerator studied, corresponding to annual savings of 35 m<sup>3</sup> of water, 16 kWh of energy and 2.8 kg of CO<sub>2</sub>, using an annual analysis, or 2.7 kg of CO<sub>2</sub>, using a monthly analysis.

It was also observed that the results are time scale dependent, showing that an annual analysis can conduct to either over- or underestimated results of the carbon emissions, particularly for buildings affected by seasonal water consumption variation (case of schools and hotels). In the present case study, an overestimation on the carbon emissions of 174% was observed for the month of August, when performing the analysis on an annual basis. This is due to the fact that Summer is the period of the year when larger emissions occur, since the lower average rain and wind records are more adverse to the generation of renewable energy (hidropower and wind energy), and the annual approach considers constant carbon emissions through the year.

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# Use of Remote Sensing and Geographic Information Systems in Irrigation Performance: A Case Study of Atabey Irrigation Scheme

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## ABSTRACT

In this study, the irrigation performance of Atabey Irrigation Scheme was assessed by making use of Remote Sensing (RS) and the Geographic Information System (GIS). For this purpose, the crop pattern maps of the scheme were generated by the help of the supervised classification method with the RapidEye satellite data of 2012. The monthly water supply ratios – one of the performance indicators – were computed. A total of 24 crop classes, 10 of which were in the irrigated area corresponding to about one-third of the total area but the remaining 14 of which were in the non-irrigated area corresponding to about two-thirds of the scheme area, were determined as a result of the crop pattern classification. The water supply ratio in the months concerned ranged from 28.16 to 2.39 and the average water supply ratio in 2012 was calculated as 3.25.

*Keywords: Remote Sensing Geographic Information Systems, Irrigation Performance, Water Supply Ratio*

## 1. INTRODUCTION

The rapidly increasing world population makes the optimum utilization of natural resources inevitable. The requirement for water at every moment, and in every sphere, of life envisages an efficient distribution of water among different spheres of use to ensure the maximum utilization of water resources (1). It is quite important to decide how water – which has become a rapidly decreasing resource – will be used more efficiently, equally, and sustainably. Therefore, it has in a sense become inevitable to convey the irrigation water to be used in crop cultivation to the irrigation areas. These operations, which are required for the efficient use of water, should be carried out and the data to be obtained from the irrigation scheme should be obtained and processed quickly and reliably and turned into a form that the decision-makers can use. About 70% of the water annually used in Turkey, as in the world, is used in agricultural irrigation. Thus, the efficient use of the water allocated for agriculture and the opening of new areas for irrigation with the saved water or its use in other sectors are gradually gaining importance. The technologies which will provide the efficient use of water resources such as remote sensing and geographic information systems should be adapted to the irrigation schemes which cover large areas and therefore use considerable water. In this study, a database of Atabey irrigation scheme was generated by employing the technologies of remote sensing and geographic information systems. The performance evaluation of the Atabey irrigation network was done with this database.

## 2. MATERIAL AND METHODS

Located 15 km to the north of Isparta province at the District of Lakes, the study area lies between the altitudes of 850 and 1,000 m. Selected as the study area, Atabey irrigation scheme covers some gross agricultural land of 16,471 ha and some net agricultural land of 14,000 ha.

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The study area, which is in the position of being a transitional zone between the Central Anatolia Region and the Mediterranean Region, reflects the characteristics of both climates.

The methodology applied in the study includes the stages of (1) generating the digital data layers; (2) fieldwork; (3) generating the crop pattern maps; (4) calculating evapotranspiration; and (5) performance assessment. ARCGIS 9.1 geographic information systems (GIS) software and ERDAS IMAGINE 9.1 remote sensing software were used to generate the digital database. CROPWAT 8.0 computer software was used to calculate the evapotranspiration. Water supply ratio was used in the performance assessment of the study area. Water supply ratio were calculated by means of the following equations. WSR (Water Supply Ratio) = Amount of water delivered to the scheme / Water requirement of the scheme.

### 3. RESULTS AND DISCUSSION

#### 3.1 Classification of the Crop Pattern

The crop classes obtained with the supervised classification performed by using the RapidEye satellite data about Atabey Irrigation Scheme – the study area – in the study are provided in Figure 1. A total of 24 different crop classes were determined as a result of the classification. Of these plants, 10 are the crop classes in the area where irrigated agriculture is performed, but 14 represent the crop classes in the areas where rainfed agriculture is carried out within Atabey irrigation scheme (Figure 2). The crop classes in the irrigated areas are presented in Table 1. As seen in the table, 10 classes, namely vineyard (1.89%), vegetable (0.92%), poplar (2.48%), maize (3.12%), fruit (48.91%), nursery (11.42%), forage crop 1 (1.36%), forage crop 3 (5.30%), flower garden (11.85%), and sugar beet (12.75%), were determined in the irrigated area. A map of the crop pattern in the non-irrigated areas within the scheme is presented in Figure 3. At the end of the supervised classification, a total of 14 crop classes were determined in the non-irrigated areas. At the end of the land supervisions, for these classes, it was established that there were 5 different crop patterns in the non-irrigated area (Table 2).

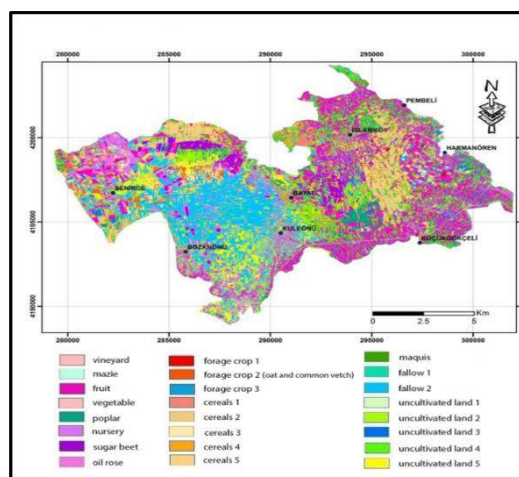
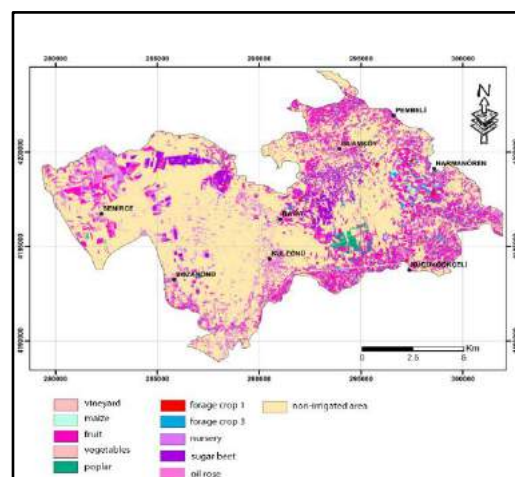
Since most of such field crops as barley and wheat in the non-irrigated area were harvested in July, when the image was taken, and as the soil properties underground differed, the number of classes in the satellite image turned out to be greater in the non-irrigated areas. Therefore, the 14 classes determined with supervised classification also by obtaining the location data, the fieldwork results, and the views of the field owners were categorized into 5 main groups, namely maquis, fallow, grain, uncultivated land, and forage crop 2. In the figures in Table 2, 28.81% of the non-irrigated areas within the scheme area are comprised of fallowing land; 32.31% of them are comprised of uncultivated land; and 33.73% of them are composed of grain land. The rates of these classes in the total areas of the scheme are 19.09%, 21.42%, and 22.35%, respectively.

**Table 1. The crop pattern in the area where irrigated agriculture was performed within the scheme**

| Crop Classes | Area (ha)       | Total Areas (%) | Irrigated Area (%) |
|--------------|-----------------|-----------------|--------------------|
| Vineyard     | 99.01           | 0.64            | 1.89               |
| Vegetable    | 48.26           | 0.31            | 0.92               |
| Poplar       | 129.73          | 0.83            | 2.48               |
| Maize        | 163.30          | 1.05            | 3.12               |
| Fruit        | 2,562.97        | 16.49           | 48.91              |
| Nursery      | 598.39          | 3.85            | 11.42              |
| Forage Crop1 | 71.39           | 0.46            | 1.36               |
| Forage Crop3 | 277.64          | 1.79            | 5.30               |
| Oil rose     | 620.90          | 4.00            | 11.85              |
| Sugar Beet   | 668.17          | 4.30            | 12.75              |
| <b>Total</b> | <b>5,239.75</b> | <b>33.72</b>    | <b>100.00</b>      |

**Table 2. The crop pattern in the area where rainfed agriculture was performed within the scheme**

| Crop Classes        | Area (ha)        | Total Areas (%) | Non-irrigated Area (%) |
|---------------------|------------------|-----------------|------------------------|
| Maquis              | 269.72           | 1.74            | 2.62                   |
| Fallow 1            | 146.59           | 0.94            | 1.42                   |
| Fallow 2            | 2,820.60         | 18.15           | 27.39                  |
| Cereals 1           | 212.52           | 1.37            | 2.06                   |
| Cereals 2           | 524.23           | 3.37            | 5.09                   |
| Cereals 3           | 745.60           | 4.80            | 7.24                   |
| Cereals 4           | 895.85           | 5.76            | 8.70                   |
| Cereals 5           | 1,095.43         | 7.05            | 10.64                  |
| Uncultivated Land 1 | 3.97             | 0.03            | 0.04                   |
| Uncultivated Land 2 | 426.86           | 2.75            | 4.14                   |
| Uncultivated Land 3 | 636.90           | 4.10            | 6.18                   |
| Uncultivated Land 4 | 1,130.36         | 7.27            | 10.97                  |
| Uncultivated Land 5 | 1,130.66         | 7.28            | 10.98                  |
| Forage Crop 2       | 260.44           | 1.68            | 2.53                   |
| <b>Total</b>        | <b>10,299.74</b> | <b>66.28</b>    | <b>100.00</b>          |

**Figure 1. A map of the crop pattern obtained with supervised classification****Figure 2. The crop pattern in the area where irrigated agriculture was performed within the scheme**

### 3.2. Irrigation Performance

#### 3.2.1 Water supply ratio

One of the most used indicators in the evaluations made with respect to the water use by irrigation schemes is the water supply ratio. When the water supply ratios on a monthly basis at Atabey irrigation scheme in 2012 are examined in light of these evaluations, it is discovered that the scheme was not provided with water by the operator despite the presence of such crops as poplar, flower garden, sugar beet, and forage crop in April as well as such crops as vineyard, forage crop, sugar beet, and poplar in October within the irrigation area and in spite of the requirement of these crops for 57,489 m<sup>3</sup> and 112,730 m<sup>3</sup> of irrigation water in April and October, respectively. The water supply ratio ranged from 28.16 to 2.39 in May and September. The mean water supply ratio was 3.25 in 2012 (Table 3). . It is seen that the water supply ratios calculated for 2012 in the study area were in agreement with Beyribey et al. (2), Çakmak (3) and Uçar (4) the other studies carried out in Turkey.

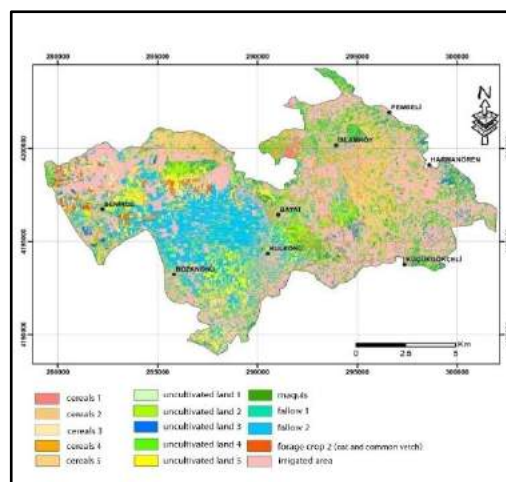


**Figure 3.** The crop pattern in the area where rainfed agriculture was performed within the scheme

**Table 3.** Water supply ratios by month at Atabey irrigation scheme in 2012

|      | April  | May        | June       | July       | August     | September  | October | Annual     |
|------|--------|------------|------------|------------|------------|------------|---------|------------|
| TIWR | 57,489 | 42,618     | 3,402,215  | 5,647,246  | 3,989,069  | 2,515,009  | 112,730 | 15,766,375 |
| IWS  | 0      | 1,200,000  | 12,000,000 | 15,000,000 | 17,000,000 | 6,000,000  | 0       | 51,200,000 |
| TCC  | -      | 16,257,888 | 15,733,440 | 16,257,888 | 16,257,888 | 15,733,440 | -       | 80,240,544 |
| WSR  | 0.00   | 28.16      | 3.53       | 2.66       | 4.26       | 2.39       | 0.00    | 3.25       |

TIWR: Total irrigation water requirement according to the existing irrigation ratio (33.72%), m<sup>3</sup>; IWS: Irrigation water amount supplied to the scheme, m<sup>3</sup>; TCC: Total canal capacity, m<sup>3</sup>; and WSR: Water supply ratio.

#### 4. CONCLUSION

A database of Atabey irrigation scheme was generated and the irrigation performance of the scheme was determined by the help of it in this study, which investigated the possibilities of using the databases generated through the combination of GIS and RS techniques in the performance assessment at irrigation schemes. WSR was varied between 28.16 and 2.39 in May and September and the average WSR was calculated as 3.25. It was established that the WSR in May was substantially great as compared with those in the other months. It was concluded that this was because the rainfall in May 2012 was more than twofold the average of long years but that the irrigation water was distributed in a way similar to that of the previous years in the operating without considering this situation. At the end of the study, it was concluded that RS and GIS could be used in the performance assessment of irrigation schemes.

#### ACKNOWLEDGEMENTS

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# #8. Water-energy, water-energy-food nexus

*Water Efficiency Conference 2018*

## **WATERS: A system architecture for acquire dwellings water & energy consumptions**

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### **ABSTRACT**

The study of nexus water and energy has become a focus of researchers that are working to make more sustainable villages, cities, regions and countries, in order to bring in the long-term well-being of families and make it a reality. Instrumentation of water and associated energy consumption in dwellings is very intrusive and implies expensive equipment and installations. This fact led to short time studies with small number of dwellings instrumented and only the use of surveys and manual readings.

In this paper the WATERS, a system architecture and implementation solution, is presented. The system has been thought to be low cost, acquire water and related energy data with high detail and for long periods. The system is installed in 9 dwellings. In order to illustrate the applicability of the system the number of files acquired in 9 months from one of the dwellings are presented. The implementation issues and the solutions found are also identified.

*Keywords: Water, Energy, nexus, consumptions, acquisition, system.*

### **1. INTRODUCTION**

Water and energy are important issues in modern societies since they are fundamental pillars for the wellbeing of individual persons, for the family where they are inserted as well to the population in general, ranging from a village, to a city or to a region. Water utilities use energy to extract, pump, convey, treat and deliver freshwater. They collect also the wastewater and treat it before its disposal [1]. The increasing demand for good quality water causes the increase of these water utilities which in turn demands more energy usage and the associated greenhouse gas emissions (GHG) [2]. Seven percent of worldwide electricity is consumed for the production and distribution of drinking water, as for the treatment of wastewater [3]. Taking into account that energy may be used from the point of water collection to the point where the water returns to the environment, passing by the user [4], an integrated approach of energy and water is crucial to optimize the inter-relationship between energy and water, in order to reduce GHG and CO<sub>2</sub> emissions and to minimize consumptions.

Several studies, that use acquiring data systems, were carried out on water and energy consumptions separately, and some on water and associated energy consumption in dwellings, but due, not only, to the high cost involved in the implemented systems, results in acquired data with low level of detail and precision and for small periods of time [5, 6, 7, 8].

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Less expensive solutions, easy to deploy, are required to enable the implementation of larger data sets, in terms of the number of dwellings but at the same time in larger time periods and in number of dwellings' elements instrumented. In this way, the acquisition system should be robust, easy to maintain and involve as small as possible changes in the infrastructure of the dwellings and in the household day life routine. It should also provide realistic estimations in cases where it is not possible to obtain readouts.

This work is part of the project ENERWAT [9] that is developing a system entitled WATERS: WATER and Energy Reading System, to measure *in situ* the water/energy consumption related with water supply end use in rural and urban dwellings in order to validate the data collected by a survey.

In this paper the WATERS system architecture and implementation solution is presented. The main contributes are: being a low cost system, capable of acquire water and related energy with high detail and for long periods. The system is installed in 9 dwellings. The number of files acquired in 9 months from one of the dwellings are presented and highlighted the faults and the solution found.

In section 2 a brief stat-of-the-art of similar approaches is presented. In section 3 the proposed overall architecture is introduced follow by the specific practical implementation issues/solutions found, both at the physical and algorithm level. Section 4 presents some early results from a prototype implementation in a single dwelling, while section 5 presents some conclusions, from this initial approach, and future work.

## 2. STATE-OF-THE-ART APROCHES

Studies on water and associated energy consumption in dwellings were initially, obtained separately, using surveys, manual readouts and extrapolation from water and energy bills. Only recently did automatic systems emerge that recorded water and energy data, and also the nexus water energy became an issue.

Willet Kempton [5,10] carried out *in situ* measurements of the hot water consumption in seven dwellings, within a period ranging from 7 to 18 months. The volume of water, the water temperature at the entrance and exit of the water heater was measured. It was also measured the quantity of gas and/or electricity used by the water heater and the hot water temperature at the outlet of each faucet, using a programmable microprocessor-controlled field instrument and also surveys. The instrumentation used allowed recording of the data only when water was used (when temperature roses on the tap and flow rate reaches at least 0.1 liter per minute) with a time resolution of 1 minute.

For the behavioral analysis of hot water consumption, Willet Kempton did not consider a unit of measure, but a "water event". It defined the "water event" as a continuous stream of hot water limited for at least 1 minute without hot water uses before or after the event. To understand the hot water consumption, he found that it was critical to examine the water usage events, the needs that they serve, and the system's efficiency to meet those needs. The author experienced several difficulties, some of them due to the costs and the intrusion levels of the instrumentation. Those difficulties prevented large samples and a random selection of samples. Another problem was that it was not possible to determine the volume of water used in each faucet, due to installation difficulties and expenses that prevented the purchase of volume meters. Willet Kempton concluded that the energy associated with water consumption was determined primarily by consumer behaviour. This consumption varies greatly from one dwelling to another dwelling, both in total usage and in the amount consumed for different uses within the dwelling. In addition, it was found that small uses of hot water are very frequent, essentially in the kitchen. The fact was due to that the device is far away, in this case from the water tank, making the system inefficient. According to the measurements made, more than 40% of the hot water was consumed in baths, in addition, it was observed that the residence with the largest number of inhabitants is not the one with the higher consumption.

Sanghyun Kim et al.[11] analyzed water consumption and the relationship with the social, cultural and economic status of consumers, using statistical methods of trend analysis (Mann-

Kendall test and Spearman's Rho test) and through surveys. Water consumption data was obtained from an intensive monitoring program developed for 145 houses randomly distributed throughout the Republic of Korea, within a public water management company, between December 2002 and February 2006. The water consumption was monitored by electric flow meters installed at the end of all the household water taps, using the principle of the fluid oscillator. The acquisition of data was done using a wireless network with a server attached to it. The author has occasionally encountered errors associated with equipment failures, system communication errors and unexpected noise. To ensure the reliability of the results, a filter was applied to the acquired data. The washing machines data was investigated by means of a questionnaire and taking into account the specs described in the machines' manual. The authors conclude that the factors contributing to the increase in water consumption were the presence of infants, the number of washing machines in the dwelling and the number of family generations living in the same dwelling. The economic factors that cause an increase in consumption were a greater number of meals taken, the larger area of residence and a higher income or double income. Sanghyun Kim et al.[11] also analyzed the factors that lead to a decrease in consumption, such as the absence of babies, consuming bottled water, a low level of education, a smaller area of residence and fewer meals consumed in the dwelling.

Amanda N. Binks et al [6] consider that the use of energy for residential water heating in Australia was 5 to 11 times greater than the energy required to provide urban water by the services. As such the main objective of this study was to quantify the energy consumption associated with the water consumption in dwellings and to identify characteristics of the dwelling that could contribute significantly to the variation in consumption. Data was acquired through home audits, interviews, high-resolution water flow meters that recorded frequency, duration and volume of individual water end uses, with detailed flow data (15 second interval, 0.01l resolution), and detailed shower use data monitoring in 5 dwellings in Melbourne and 2 in Brisbane. The data allowed to characterize 139 parameters of influence that permitted to describe the characteristics of occupation, behaviors, technologies and structural and environmental aspects, used in a mathematical model. The authors concluded that energy consumption associated with dwelling water consumption was between 13% and 24% of total energy consumption in Melbourne, and between 76% and 79% in Brisbane. In Melbourne shower usage meant between 11% and 61% of energy consumption. Losses due to inefficiency of the system resulted in 8% to 31% of energy consumption, and the use of washing machines accounted for 4 to 17%. They consider that it was necessary to better analyze the use of showers, since it lead to greater consumption at domestic level.

Matos et al [7] monitored 197 baths in a dwelling in a total of 60 days (during the months of October, November, December and January). However, the measurements were performed manually, proving to be a time consuming but an objective process. The authors recorded the measurements from the counters before and after each bath. The energy consumption was register at the heat accumulator, recording values before and after each bath using an energy intensity meter. Four different scenarios were studied: C1RT60 (with flow rate reducer and temperature, 60°C), C2RT75 (with flow rate reducer and temperature, 75°C), C3T75 (without flow reducer and temperature, 75°C) and C4T60 (without flow rate reducer and temperature, 60°C). Afterwards, using a statistical analysis program (ANOVA), a correlation was obtained between the following variables: bath duration and water consumption; bath duration and energy consumption; water consumption and energy consumption. They concluded that the C1RT60 Scenario was the one that had the best results, proving to be the most efficient, and Scenario C2RT75 was the one that proved to be less effective.

### **3. THE WATERS ARCHITECTURE**

The development of the WATERS system is presented in three phases: requirements planning, system architecture and implementation.

### 3.1 Requirements planning

In this phase the researchers of ENERWAT project, based on state-of-the-art studies approaches and on the project goals, established that the main requirements for the system should be the following:

- Consumptions read of water and related energy in dwellings should be done with high resolution (water/ gas: 0.5 liter, electricity 0.5 Watt, at least at 1Hz) and separated by each use (see usage model, Fig. 1).
- System should be robust, easy to maintain, have a simple solution for installation and posterior removal, involve as small as possible changes in the infrastructure of the dwelling and minimal impact in households daily life;
- Use low cost devices;
- Scalable solution (up to 20 installations);
- Permits long periods of acquisition (at least 6 month);
- All acquired data should be centralized in a main system for posterior validation and usage in a consumption simulator. Data validation and simulation are currently under development but are out of the scope of this paper.

The Fig. 1 present a diagram that models the different uses of water and energy in a dwelling (defined by the ENERWAT project).

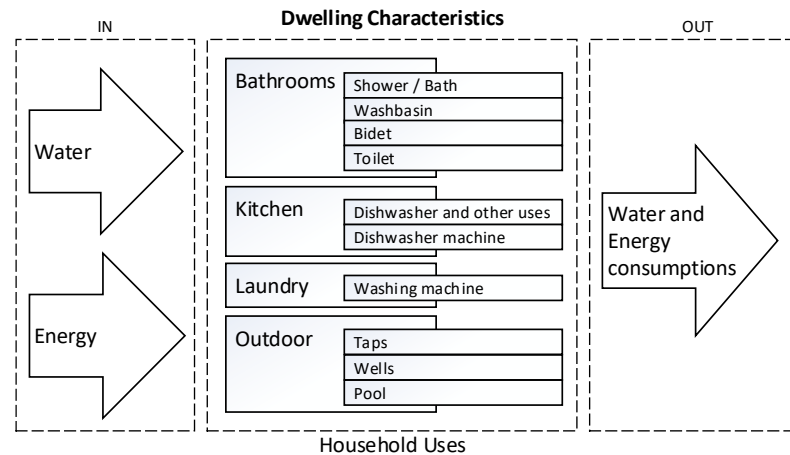


**Fig. 1 Model of water and energy uses in a dwelling.**

Each dwelling is seen as an isolated unit that has as input water and energy (different energies) and output water and related energy (energies) consumptions. Inside each dwelling should be applied a demand-driven approach for water consumption, organizing the uses in 5 sectors: 1) bathrooms - shower / bath, washbasin, bidet and toilet; 2) kitchen - dishwasher and other uses and dishwasher; 3) laundry - washing machine; 4) outdoors - taps, well and pool.

### 3.2 System Architecture

In order to minimize costs and develop an easy to install and maintain system it was decided to use a simple and robust approach. The WATERS architecture is composed by three main components: central nodes, sensors and cables, and central server. The overall architecture is represented in Fig. 2.

Nodes are small board computers (SBC) placed at each dwelling strategic sectors (e.g. kitchen, WC), according to the specified model of uses (Fig. 1). They are responsible for acquire data from sensors, store it locally and periodically transmit it to the central server through a secure channel (VPN).

Sensors are responsible for convert physical events into electrical signals. It was decided to use only two types of sensors: On/off sensors placed in all relevant usage points to signed

water usage, e.g. taps, showers, washing machines; and webcams for reading water and energy consumptions from the dwellings meters. Cables are used to connect sensors to nodes.

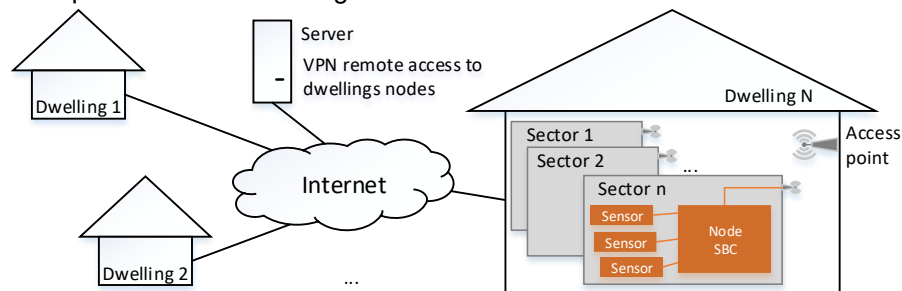


**Fig. 2. System architecture.**

The central server monitors the links to each node and generates alerts to a human operator, when maintenance operations are needed (for example in case of link failure). The received data is stored in a database and made available for posterior validation. In cases where the dwelling does not have Internet available, data is transferred with a local wireless link to the operator computer (or smartphone) and later transmitted to the central server.

### 3.3 Implementation

In the WATERS implementation the main challenge was the development of a method for dwelling instrumentation that fulfill the requirements: robust system, easy to maintain, have a simple solution for installation and posterior removal, involve as small as possible changes in the infrastructure of the dwelling and had minimal impact in the households daily life.

#### 3.3.1 Nodes

As a solution it was chosen a low-cost SBC that has standard USB interfaces for connecting webcams, and has wireless connectivity. For each of the SBC has been assembled tailored interfaces for ease connection of on/off sensors and for monitor their states, see Fig. 3.

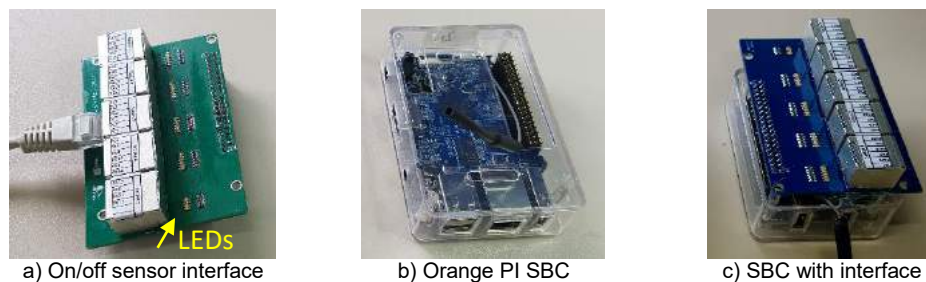


**Fig. 3. Node implementation.**

The on/off sensor board interface can be seen at Fig. 3 a). It has 5 RJ45 sockets that permits connect 5 cables with on/off sensors to the 28 digital I/O available in the SBC. RJ45 are very low cost, easy to connect and produce cables mount and establish a good electrical contact. The light emitting diodes (LDEs) permit the operator to direct verify the stats of the on/off sensor. They were a great solution for the ease of installation and maintenance. The interface plugs to SBC easily. Two interfaces were produced since two Orange PI SBC models where needed: a version with 4 USB ports Fig. 3 b) for nodes that require three webcams and a cheaper one with 2 USB ports in the other cases Fig. 3 c).

The SBC are Raspberry Pi compatible with 4 cores ARM processor and run the Armbian operating system (OS), a derivate of Debian Linux. This choice simplified the node implementation since it is a widely known OS with a lot of available solutions for instrumentation and use of resources such as I/O interface, image acquisition, WIFI connection, and VPN setup.

Software developed for node acquisition was kept as simple as possible. It was created a service that, at reboot, connects to internet access through available WIFI connection, updates local time, establishes VPN connection to the central server, and run a python script for sensors data acquisition.

For on/off reads, a simple routine cycle through sensors and daily registers to a text log file the change of their states.

The file has a code name “<nodename>\_<year>\_<month>\_<day>.log” (e.g: “CASA00\_COZ1\_2017-03-17.log”) and the messages added have three fields: time stamp (UNIX time stamp - seconds since 1st January 1970), port ID and port state (e.g: “1488491820.83, port.PA14, ON”). Sporadic events, such as local time update are registered with format: time stamp, event name, event data.

1488491820.83, port.PA14, ON

For energy meters reads, two approaches were devised based on webcam images:

- 1) Meters with odometer display: The implemented routine captures every 200 ms grayscale images with 30x20px of each of the 2 less significant digits of the odometer, (dozens and units) and save them to the SD card with the timestamp in the name. In order to get a global reference and recover from malfunctions, every hour it save the 4 less significant digits (thousands, hundreds, dozens and units). Image files are aggregated daily in a TAR file. Later at central server these images are automatic recognized with a machine learn approach, already detailed in [12].
- 2) Meters with digital display: The implemented routine captures, every 200 ms, images of the digital meters, identifies the digits and register them in a log file, similar to the previous presented (messages with timestamp and the digits read).  
The automatic read is strait forward and the routine is implemented and working as it can be seen at Fig. 4, a) shows a digital electricity meter display, b) shows the grayscale image with corrected perspective, the window digits identified and the automatic read digits at upper right, and c) shows an example of the digit “U” with the segments lighted. Detailed approach is out of the scope of this paper, and will be the subject of a later publication. However, you can find some insights and code at Adrian Rosebrock website [13].

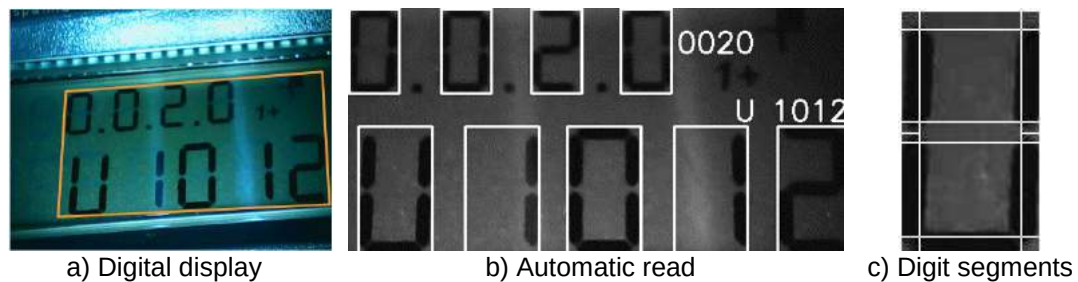


**Fig. 4. Digital meter read.**

The unitary cost of the hardware used to build node is presented in Table 1 (transportation and customs costs are included).

### **3.3.2 Sensors**

Two type of low cost sensors were used: webcams for reading displays and on/off sensors used to register states of devices, e.g. as faucets, cistern flusher or electric machines. It follows a brief description with details of their how they were installed.

#### **Sensors description**

The used webcams are standard ones with focus regulation and self-illumination. These two requisites were mandatory because meters are placed in small spaces requiring webcams to

be positioned at short distances of the displays (e.g. 10 cm) and because they are most the time in the dark. The webcams were used with no alteration.

In the case of the on/off sensors it was chosen the Hall sensor A3144, because it is very small and work without contact that makes it suitable for uses in humid environments. When a tiny magnet is near, they close the electric circuit, otherwise the circuit stays open. In Fig. 5 a) it is presented the used electric scheme. It turns on and off a LED and provide a standard 5 V digital output that is direct read by the SBC.

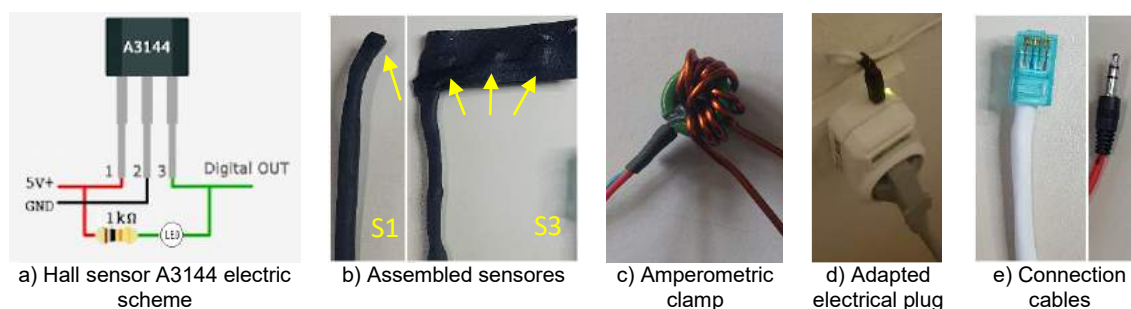


**Fig. 5. Details about on/off sensor built based on Hall sensor A3144.**

The UTP network cable is used to connect the sensors to the nodes, and once they have 8 conductors permits the connection up to 6 on/off sensors. Fig. 5 b) shows at left an example of a cable with one sensor mounted (S1) and at right an example of a cable with three sensors mounted (S3). For water insulation it was decided to use black rubber tape that provide a very good electric insulation - it is usually used to insulate contacts in submersible water pumps. In the S1 sensor, after wrapping the tip of the cable with the sensor, the cable is fully closed using thermally shrink sleeve. In the S3 case, the sleeve ends with horizontal rubber tape. In these sensors, LEDs are not mounted.

In order to sense electric machines (such as water pumps or laundry machines), it was implemented an amperometric clamp using a toroid core with insulated copper wired as shown in Fig. 5 c). The clamp was mounted in a 220 V standard plug with a LED to sign machine activation. In Fig. 5 d) it can be seen a working prototype detecting an active machine.

Finally at Fig. 5 e), it can be seen the cables with RJ45 plug used to connect all the sensors to the nodes and a stereo jack 3.5 mm used to connect the instrumented 220 V plug to the node.

### Sensors installation

The installation of sensors was a very labor task. In order to guaranty easy install and removal, the sensor and cables were fixed using thermal glue and insulation tape. The webcams were applied in front of the meters, avoiding reflex in display glasses and assuring a focused image. They were fixed with off the shell solution made with thermal glue. The sensor S1 and S3 were meant to sense water devices such as open and closing faucet or cistern flushes. In Fig. 6 a) it can be seen the sketch for the instrumentation of a mix faucet with S3 sensor and in b) an image of their application. A magnet is fixed with tape to the lever center and the S3 is fixed in the base of the faucet (see the three blue sensors in the Fig. 6 a) ). When the user moves the faucet lever up, the magnet gets near S3 internal sensors. Depending on the angle, one or two sensors will have their circuits closed providing 5 different faucet position: 1) Left Sensor, 2) Left and Center sensors, 3) Center sensor, Center and Right sensors, and Right sensor. When connecting the cable to the SBC, the installer can verify the proper functioning of the sensor.

Using S1 can be used for several proposes, for example:

- To instrument a simple faucet: in this case the magnet should be placed at the faucet handle and the sensor fixed in the base guarantying that the sensor has its circuit closed. When the user opens/closes the faucet, the sensor will have their circuit opened/closed accordingly.
- To instrument a cistern flush, as can be seen in Fig. 6 c) and d). The magnet should be placed in the floater and the sensor fixed in a way that keep its circuit closed when the



cistern is full. When a user flushes the cistern the water level drops forcing the floater and the magnet to move away from the sensor, opening its circuit. When the cistern gets full, the sensor will close the circuit.

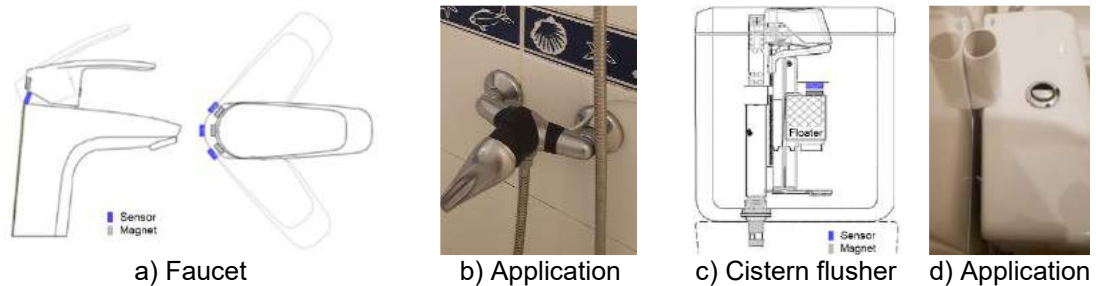


**Fig. 6. On/off sensor installation scheme and application for mixer faucet and for cistern flush.**

### 3.4 Costs

The costs of the hardware used to build the acquisition system in the dwelling presented in the next point, casa00 is shown in Table 1 (transportation and customs costs are included).

**Table 1. Hardware used in the acquisition system in casa00.**

| Devices                                                       | Cost (€)   |
|---------------------------------------------------------------|------------|
| 4 Orange PI SBC (with case, memory card and sensor interface) | 263        |
| Sensors                                                       | 15         |
| Cables, chargers, sockets, plugs                              | 47         |
| 3 Webcams                                                     | 36         |
| Other material (tape, glue, magnets)                          | 10         |
| <b>Total</b>                                                  | <b>371</b> |

The hardware cost is very low compared to other systems used in the literature. Labor costs and travel costs for an operator to configure and maintain the system are not included but are an important parcel of the costs, however we believe that these will be the same or lower than other systems used.

## 5. RESULTS AND DISCUSSION

Installation of WATERS system in dwellings was initiated in April 2017 on one dwelling and since then more dwellings have been added. At the time of this publication the system is installed in 9 dwellings acquiring data. In order to illustrate their functioning, a dwelling was selected, casa00.

The dwelling was instrumented with 4 nodes: 1) Hall, that receives 3 tar files with images for electricity, gas and water meters; 2) Kitchen, that acquires 1 log file that register the state of laundry machine, washing machine, gas dwelling heating and kitchen sink; 3) WC1 and 4) WC2 each of it acquiring a file that register the state of the cistern flush and faucets (shower, washbasin and bidet). The files acquired until 11 December are represented in the table Fig. 7.

The files are organized by months. Each month has up to 7 different files, namely: Electricity meter (analogic meter); Electricity D meter (digital meter installed in the middle of May); Gas meter, Kitchen, Water meter, WC1 and WC2. At the left side of the figure, the list of the registered files is presented, each of it is represented with a different color and the respective percentage of registration in that month. At right, each file is represented in line by day of month, with small rectangles: light gray rectangles indicate that no file was received and colored rectangles indicate the file was received. At the left bottom side, the average of files in the in the whole period is presented.

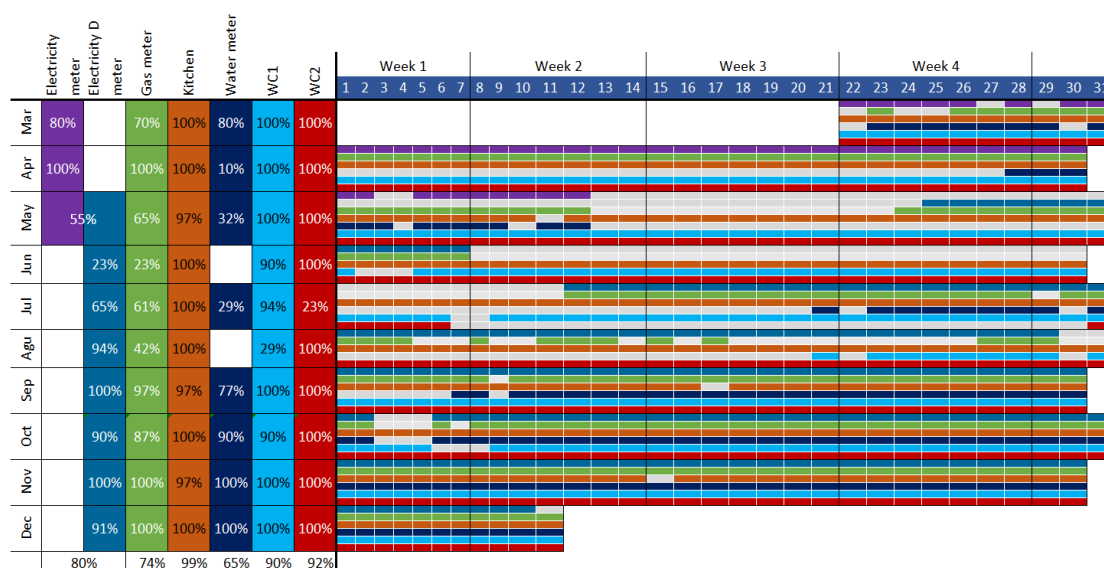


**Fig. 7. Files stored at central server between March and December 2017.**

For example, in Mars, 6 different files were received. The files from WC1 are represented by the light blue color and 10 files were received in 10 days, so 100% of files were successfully received. But, for example, gas meter files only have 7 files register in 10 days, i.e. 70% of files were successfully received. At bottom left, it can be seen that 99% of the files were successful received from Kitchen and only 74% of Gas meter files were successfully received.

In an overview, it is clear that from Mars to August it was a period of development and adjustment of routines, there were many missing files. Only at the begin of September WATERS system started to function properly, receiving almost all the files.

There were several reasons that contributed for the missing files which we highlight:

1. The first installed sensors to register faucets such as Fig. 6 a) were poorly insulated. After some time, they had water infiltration and stop working. Solution: new sensors were made and installed with rubber tape;
2. It was verified that SBCs sometimes stop working: sometimes due the power supply that required replacement, other times the software just crashed requiring reboot, or simple the household unintentionally disconnect the node. Solution: These situations lead to the development of the monitoring routine, implemented in server, and to the periodically verification of the all the nodes.
3. In May the electricity company informed the owners that the analogical meter "Electric meter" would be replaced by a digital meter "Electricity D meter". It was decided to remove all 3 webcams (water, gas and electricity) in 13 May. Although the new digital routine was implemented and installed at 25 May, several adjusts were necessary to have it works properly. The problem was solved in the begin of September, after the summer vacations.

Initial file analyses showed that in addition to missing files, several sensors had malfunctions. Data interpretation and validation is the next step. An approach based on simulation is under development with the objective to identify malfunctions and complete missing data from average consumptions, allowing an accurate estimation of water and energy consumption in a maximum period.

As final remarks, it can be said that the WATERS system is working properly, acquiring data as planned, but due to their off-the-shell essence, to low cost used equipment and to household context lot of situation disturb the normal function of the system leading to the need for maintenance. As result the WATERS system need a carefully monitoring for ensure that all nodes are properly working.



## 6. CONCLUSION AND FUTURE WORK

Water and related energy consumptions have been study through expensive systems that condition the period and detail of the data acquired at each home. In this paper the WATERS system architecture and implementation solutions was presented. The system has been thought to have low cost, acquire water and related energy with high detail and for long periods. The system is presently installed in 9 dwellings. For the dwelling, casa00, the costs with hardware and other material were approximately 371€, that was consider low in comparison with other systems. In order to illustrate their functioning, files acquired in 9 months from one of the dwellings were presented and highlighted the implementation issues and the solutions found.

Data interpretation and validation is the next step. An approach based on simulation is under development, with the objective to identify malfunctions and complete missing data from the average consumptions, allowing an accurate estimation of water and energy consumption in a maximum period.

## ACKNOWLEDGEMENTS

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# Water-Energy-Pollutant Nexus Assessment of Water Reuse Strategies in Urban Water Systems using Metabolism Based Approach

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## ABSTRACT

In this study a combined water-energy-pollutant nexus and water metabolism assessment was developed to study the impacts of implementing water reuse in an Urban Water System (UWS). The model was based on the WaterMet<sup>2</sup> tool which was able to track down water, energy and eutrophication flows over the main components of the UWS. The suggested method was demonstrated in a real case study in Mexico. Eight hypothetical reuse strategies including six greywater (GW) recycling options (decentralised) and two reclaimed water distribution (centralised) were simulated and compared with Business As Usual (BAU) strategy ('do nothing') over a long-term planning (30 years). The intervention options were set up at either 10% or 50% of adoption rates (proportional to household and demands within the UWS) to be implemented at years 10 and 20. The analysis showed that centralised strategies consume less energy but produce more eutrophication emissions than the BAU as opposed to GW strategies. The treatment technologies (efficiency, energy consumption) and adoption rates are key variables in selecting the least impacting reuse strategy. Combining GW strategies using low-energy treatment (such as wetlands) with high adoption rates the system outperforms the rest of the options in all of the impact categories. The proposed metabolic-nexus approach was able to provide useful information about the performance and environmental impacts of centralised and decentralised water reuse options to support management decisions.

*Keywords: decentralised water reuse, eutrophication, greywater, metabolism modelling, water-energy-pollutant nexus.*

## 1. INTRODUCTION

There has been a lot of interest in urban water reuse as a method to increase water supply sources in cities in the recent decades. Decentralised water reuse is one of the management options in which wastewater is divided into greywater (GW), yellow or black water for onsite treatment and consumption [1]. GW (or light-greywater) is referred to the effluents of the shower, hand basin and washing machine, yellow water denotes urine and black water represents toilet and kitchen effluents [2]. Centralised water reuse means the use of reclaimed water (RW) from the municipal wastewater treatment plant. Using GW in buildings or households can save ~40% of the freshwater demands albeit contradictory results whether or not the potential impacts on climate change surpass those obtained through centralised reuse [3, 4 and 5]. Information on the operation of decentralised water reuse can potentially reduce environmental impacts in cities albeit contradictory results [6, 7].

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Assessments of reuse systems are more frequent in recent years using different approaches. Under the environmental view, the most widely used methodology is the Life Cycle Impact Assessment (LCIA), which is able to compare the impacts of different Wastewater Treatment Works (WWTW) and other water management strategies considering pre and post consumption stages [1, 7]. A consequential analysis is the water-energy nexus analysis. Such an approach interconnects resources consumption within Urban Water System (UWS) in relation to water savings, economic costs and Green House Gases emissions (GHG) using material balances, dynamic modelling, LCIA, among others. The nexus has been useful to demonstrate the competitiveness of GW/RW against other supplies (e.g. desalinated or transboundary freshwater imports) or performance of wastewater treatments [6, 8 and 9]. In addition, some studies highlight the need to consider a pollutant nexus to give meaningful insights of operation of the water systems and health concerns [10]. A third approach based on a performance analysis is the water metabolism, which is a comprehensive framework to understand the water flows and other environmental fluxes (e.g. energy and emissions) and identify bottlenecks in the UWS. [11, 12]. Given the plethora of approaches, the water-energy-pollutant nexus in the UWS has not been addressed much in detail, especially investigating the possible impacts of future water reuse implementation. Thus, an integral framework of such an analysis is needed.

This study aims to analyse the performance of a set of hypothetical GW strategies based on a nexus-metabolism approach, using a real-world case study. The rest of the paper presents the methodology and case study followed by results and discussion, and concluding remarks.

## 2. METHODOLOGY

The framework used in the study compares the performance of centralised and decentralised reuse strategies throughout a combined nexus-metabolism approach. WaterMet<sup>2</sup> modelling tool was used here to simulate the performance of urban water metabolism in UWS [13]. WaterMet<sup>2</sup> is a conceptual mass-balance based model which is able to quantify flows of water and other environmental fluxes such as direct and indirect energy and eutrophication emissions within the boundaries of the UWS for a long-term planning horizon. The model uses a Material Flow Analysis (MFA) and Life Cycle Impact Assessment (LCIA). A set of key performance indicators was derived from urban water metabolism simulation in WaterMet<sup>2</sup> to form the analytical framework of water-energy-pollutants nexus for a number of water reuse strategies.

### 2.1 System boundaries

The UWS boundaries include four main subsystems: water supply, demands, sewerage and wastewater (Figure 1). The water sources and sinks are the water boundaries i.e. groundwater extraction and receiving water bodies for discharging treated/untreated wastewater. They also include processes directly affecting the operation such as chemical manufacture and allocation in the field, power use and generation, sludge management and fertiliser avoidance. The analysis is limited to the operational stage, the construction and disposal stages, as well as energy consumptions in households through appliances and fittings, were excluded. The results were referred to the 1m<sup>3</sup> of water supplied, reclaimed and reused in accordance with previous studies [1, 14].

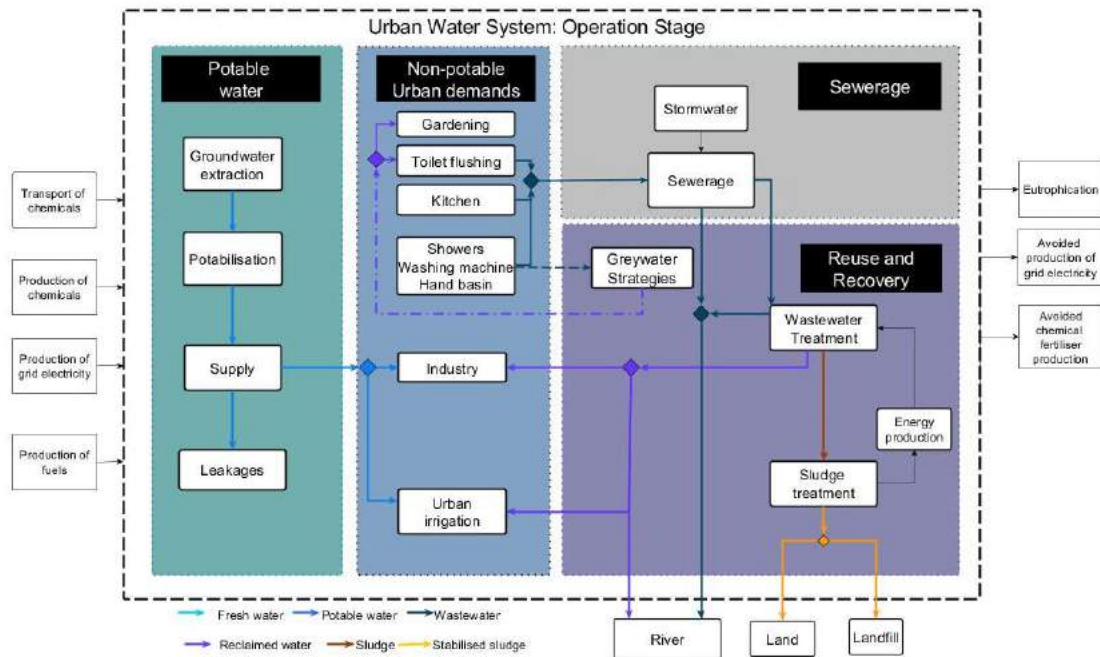


Fig. 1. System's boundaries

## 2.2 Performance indicators

Three performance indicators were proposed to analyse the metabolism performance and the nexus. All the analysis is based on daily water simulations of demands and distribution within the principal sub-systems of the UWS, according to the method stated for WaterMet<sup>2</sup> for a long-term period (here 30 year planning horizon) [14]. The indicators were calculated as follows:

### 2.2.1 Water saving

The water saving represents the reduction of water withdrawals relative to the BAU state. The percentage of water saving was calculated as:

$$S_W = \frac{W_{SBAU} - W_{Ssi}}{W_{SBAU}} \times 100 \quad (1)$$

where  $S_W$  is the saved water (%);  $W_{SBAU}$  is the total water supplied by BAU (m<sup>3</sup>/y);  $W_{Ssi}$  is the total water supplied by strategy  $i$  (m<sup>3</sup>/y).

### 2.2.2 Energy consumption

The net energy consumption considers direct energy sources from grid electricity and indirect energy embodied in chemicals (e.g. sodium hypochlorite and ferric chloride) and fuels (e.g. diesel). It also takes into accounts renewable energy produced in the wastewater treatment works such as biogas-electricity conversion:

$$TE = EE + EF + ECh + Ed - EBp - Eernw \quad (2)$$

where  $TE$  is the total net energy use;  $EE$  is the electricity provided by the network;  $EF$  is the energy obtained from burning fossil fuels (e.g. diesel);  $ECh$  is the energy embodied in the chemical products used in water or wastewater treatment (e.g. chlorine);  $Ed$  is the electricity used in distribution;  $EBp$  is the embodied energy in by-products which substitute fossil fuels or fertilisers, and  $Eernw$  is the electricity obtained from renewable sources. All values in kWh/m<sup>3</sup>.

The energy inputs of wastewater treatment technologies were taken from data reported in the literature [16,17] and the energy used in recycled water distribution networks was calculated assuming delivery to three main consumption sites.

### 2.1.3 Eutrophication

Eutrophication is the impact category representing the pollution of Chemical Oxygen Demand (COD), Total Nitrogen (TN) and Total Phosphorus (TP) in  $\text{PO}_{4\text{eq}}/\text{m}^3$ . A net balance was obtained similarly to the energy, accounting for direct and indirect flows. The net eutrophication in  $\text{gPO}_{4\text{eq}}/\text{m}^3$  considered the avoided fertiliser production of urea (45%) and single superphosphate (18%). Eutrophication factors were taken from Ecoinvent3 [15].

## 2.2 Strategies

The strategies comprised eight hypothetical intervention options including six decentralised and two centralised water reuse methods. The decentralised greywater options included three treatment technologies: Rotational Biological Contactor (RBC), Membrane Biological Reactor (MBR) or Vertical Constructed Wetlands (VCW) treatments. All of these technologies reported removal efficiencies above 90% of Biochemical Oxygen Demand (BOD) for GW treatment. Two centralised options were based on the existing Activated Sludge treatment. The strategies were set up to be implemented at two stages at years 10 and 20, within two rates of adoption 10% and 50%, based on the preferences obtained from key experts (data not shown). Table 1 presents a summary of the main assumptions for operating such technologies. The strategies considered an increment of population rate from 1-3% along the planning horizon. It is assumed that water will be reused for toilet flushing and irrigation uses.

**Table 1. Strategies analysed in the study**

| Secondary process               | Strategy acronyms | Adoption rates |      | Energy in treatment and distribution (KWh/m <sup>3</sup> ) | Efficiency (%) <sup>[18]–<br/>[20]</sup> |
|---------------------------------|-------------------|----------------|------|------------------------------------------------------------|------------------------------------------|
|                                 |                   | 2025           | 2035 |                                                            |                                          |
| Decentralised (D)               |                   |                |      |                                                            |                                          |
| Rotational Biological contactor | RBC10%            | 5              | 5    | 0.952                                                      | COD 88%; TN 71%; TP 58%; TSS 86%         |
|                                 | RBC50%            | 20             | 30   | 0.992                                                      |                                          |
| Membrane Bioreactor             | MBR10%            | 5              | 5    | 1.314                                                      | COD 64%; TN 79%; TP 91%; TSS 98%         |
|                                 | MBR50%            | 20             | 30   | 1.354                                                      |                                          |
| Vertical Constructed Wetland    | VCW10%            | 5              | 5    | 0.494                                                      | COD 81%; TN 69%; TP 71%; TSS 98%;        |
|                                 | VCW50%            | 20             | 30   | 0.534                                                      |                                          |
| Centralised (C)                 |                   |                |      |                                                            |                                          |
| Conventional Activated Sludge   | CAS10%            | 5              | 10   | 0.115                                                      | COD 90%; TN 60%; TP 60%; TSS 91%;        |
|                                 | CAS50%            | 20             | 30   | 0.085                                                      |                                          |

## 2.3 Case Study

The modelling framework was tested in a real-world case study in the region of San Francisco del Rincon (SFR) and Purisima del Rincon (SFR) cities, Guanajuato, Mexico. The UWS consists of two independent water potable systems and one wastewater treatment and reuse sub-system. Figure 2 presents a simplified layout of the configuration of the UWS. Groundwater from Turbio Aquifer is the only source of potable water in this region. Potable water is obtained through extraction of 23 boreholes, each one with chlorine dose of  $\text{Cl}_2$  or  $\text{NaOCl}$ . The potable water is stored in elevated tanks and distributed by gravity through the

drinking water network to the 114,651 urban dwellers [21]. Domestic supply varies from 90 up to 180 l/cap/d [22], less than the 250 l/cap/d recommended for similar areas in Mexico [23]. This situation is due to the potable water leakages (40-50%) and the semiarid climate. To cope with such water constraint, there is a water reuse scheme made up of "San Jeronimo" WWTW plus a non-networked reclaimed water distribution. The WWTW has a capacity of 21,600 m<sup>3</sup>/d, the inflow belongs to 60% from SFR and 40% from PR. The reactor uses an activated sludge treatment, coupled with primary and secondary sedimentation and UV or chlorination disinfection stages. The plant was designed to treat the effluent at a quality of 30 mg/L BOD to comply with the non-potable water reuse guideline in Mexico [24]. The users of reclaimed water are mainly the local water utilities and the construction industry, which transport the water using 20 m<sup>3</sup> tank lorries per journey to the parks or construction sites. Reuse rates reached only one percent of the treated wastewater in 2015 [26]. This estimation might increase due to the current construction of a distribution network of reclaimed water of a 250 m<sup>3</sup>/d. In addition to the water reuse, the sewage sludge sources two by-products: electricity and fertilisers. An anaerobic digester stabilises the sludge and produces biogas at rates of 47.5 m<sup>3</sup>/h. A pressure container stores the biogas and sends 45% of the total volume to the electricity generator. The system produces 0.03 kWh/m<sup>3</sup> which supplies 40% of the electric self-operation demand [25]. Unused biogas is burned before being released into the atmosphere. Dewatered stabilised sludge is often deposited into agricultural fields nearby.

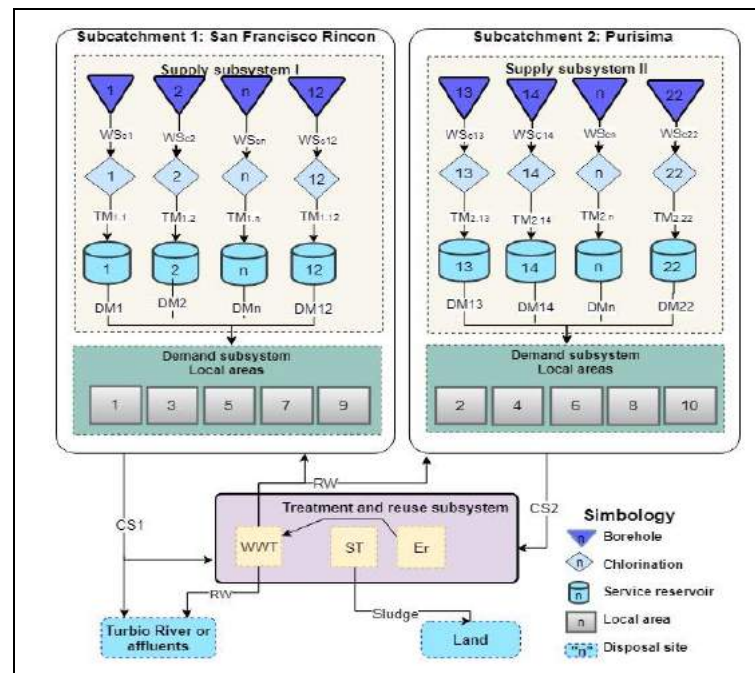


**Figure 2. Main components of the UWS in the case study**

WSc: Water supply conduit; TM: Trunk main; DM: Distribution Main; CS: Combined sewer; WWT: Wastewater Treatment; ST: Sludge Treatment; Er: Energy recovery; RW: Reclaimed water

## 2.4 Inventory data

All input data and main assumptions referred to the context of the region in study in Mexico. As such, the primary data was acquired from different Mexican institutions and water utilities. The missing or secondary data were obtained from the relevant literature (Table 2). Emission factors were obtained from Ecoinvent database, such data were not normalised due to uncertainties specified in the context of the case study.

**Table 2. Main data inputs of the case study**

| Category                                       | Input data                                                                                                     |
|------------------------------------------------|----------------------------------------------------------------------------------------------------------------|
| Climatic data <sup>[26]</sup>                  | Daily recorded data of rainfall, evaporation, and temperature from 1962-2012 in <i>Guanajal</i> station        |
| Area <sup>[21]</sup>                           | Total area 2844 ha: 58% pervious area, 26% impervious area, 16% roads                                          |
| Demographic data <sup>[21]</sup>               | Total population 1990-2010,<br>Total households: 24,751.<br>Occupancy per household: 4.4,                      |
| Potable water sub-systems <sup>[25]</sup>      | Daily water extraction, energy consumption and chemical use (2015-2016) in San Francisco and Purisima, Mexico. |
| Wastewater inflow and effluent <sup>[25]</sup> | Daily flows and wastewater quality,<br>Electricity 0.38 kWh/m <sup>3</sup>                                     |
| Sludge                                         | Quality, biogas production, and disposal rate                                                                  |
| Impact factors database <sup>[15]</sup>        | Cumulative Energy demand<br>Eutrophication CML 2001, world values                                              |

### 3. RESULTS AND DISCUSSION

The eight intervention strategies outlined above were analysed in the case study for each of the key factors selected to represent the water-energy-pollutant nexus framework to identify the more appropriate strategies in this context.

#### 3.2 Water performance

The water saving of implementing centralised and decentralised strategies within the UWS is shown in Figure 3. The water saving depends on the adoption rate regardless of the technology in use. Hence, the results were grouped as centralised and decentralised for 10% or 50% adoption rate (D10%, D50%, C10% and C50%). Water reuse decreases 1.7% and 7.8% of groundwater withdrawals at 10% and 50% adoptions rate, respectively. In addition, decentralised GW reuse reduced the inflows into the sewerage and wastewater treatment and subsequently the untreated overflows into the river. Centralised RW use had no effect on these flows but reduced significantly the treated water discharged. This is because centralised schemes gather the reclaimed water at the end of the WWTW, reducing the effluent into the river. The saving obtained in the study were smaller than those reported by Duong et al., (2011) [3], and Opher and Friedler (2016) [1] for similar water reuses. The possible differences are in modelling the gradual adoption rates and the low demand for toilet and irrigation for such adoption rates in the case study.

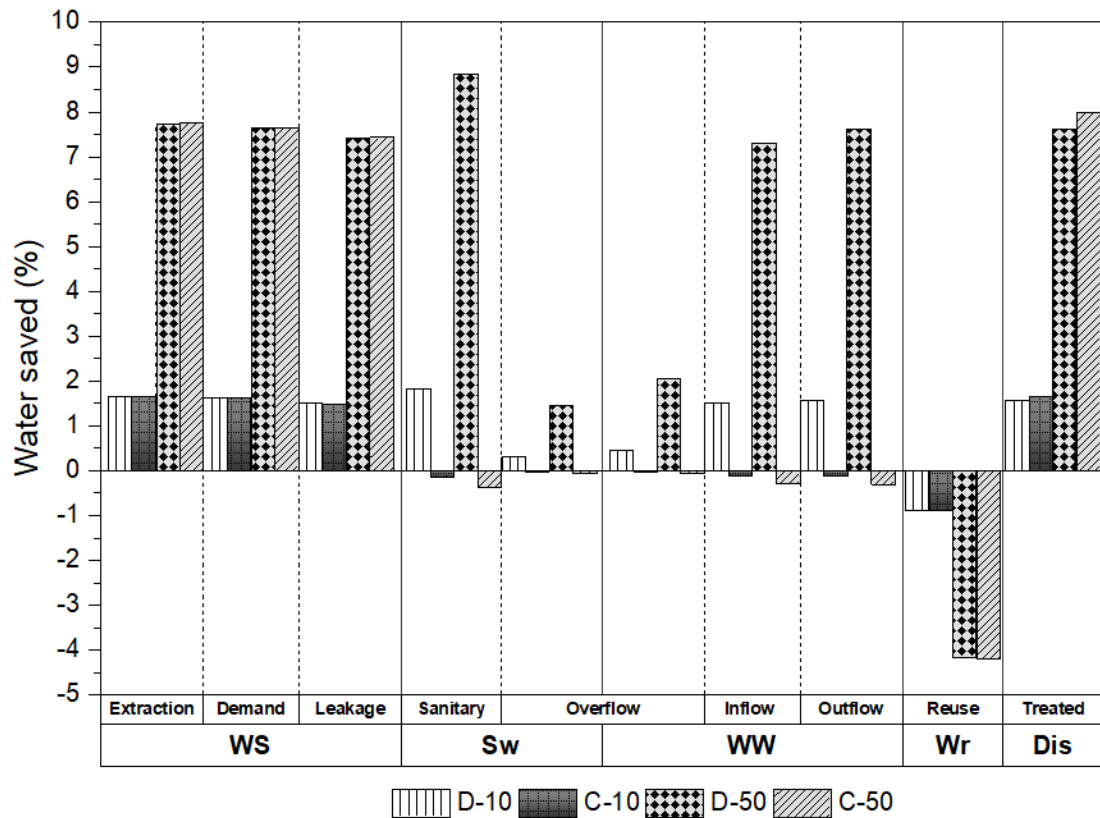


**Fig. 2. The proportion of water saved per subsystem component**

D: Decentralised; C: Centralised; WS: Water Supply, Sw: Sewerage; WW: Wastewater treatment; Wr: Water reuse and Dis: Discharged.

### 3.3 Energy

Total energy consumption of the UWS is affected by water reuse implementation, the proposed strategies considered the additional energy requirements for treatment and distribution. All centralised strategies reduced the consumption of energy in comparison with the current installed system. The highest energy savings were obtained in the strategy CAS50% (Figure 3a). In decentralised GW strategies, the energy consumption reduces or increases depending on the technology in use (Figure 3b). Implementing MBR and RBC technologies augmented the energy used at both adoption rates; on the contrary, using VCV dropped the energy consumption in respect to BAU.

A key factor affecting the total net balance is whether or not energy savings in the water supply and wastewater treatment surpass the additional requirements. For example, in MBR10% the total energy saved was calculated in  $1.2 \times 10^5$  kWh/y but decentralised reuse will require additional  $1.4 \times 10^5$  kWh/y, hence the system consumed more energy than BAU. These findings support that GW reuse is optimal from an energy point of view on a case-by-case study, depending mostly on the treatment and distribution configuration in the area studied.

### 3.4 Eutrophication

Eutrophication impact category represents the pollution of TN, TP and COD into the urban area. The eutrophication produced by each strategy varies according to the centralisation level, the decentralised GW strategies reduced the eutrophication impact while centralised strategies increased eutrophication as can be seen in Fig. 3b and 3c. An important difference between both scales is the fact that implementing GW would reduce the sewerage inflows and untreated overflows and subsequently the pollutants mass outflow discharge into the environment. Among the GW strategies, those with the highest adoption rates (50%)



achieved the highest reduction, from 45 gPO<sub>4eq</sub>/m<sup>3</sup>y in BAU to 42.6 gPO<sub>4eq</sub>/m<sup>3</sup>y in MBR50% and 43.1 g in VCW and 43.4 gPO<sub>4eq</sub>/m<sup>3</sup>y RBC50%. Particularly, MBR outperformed the rest due to the high nutrients removal efficiencies (see Table 2). Fewer adoption rates (e.g. VCW10%) do not reduce significantly eutrophication emissions, in fact, RBC10% caused almost the same amount of eutrophication. Thus, eutrophication of the UWS depends on efficiency, adoption rates (flows of reuse) and centralisation level.

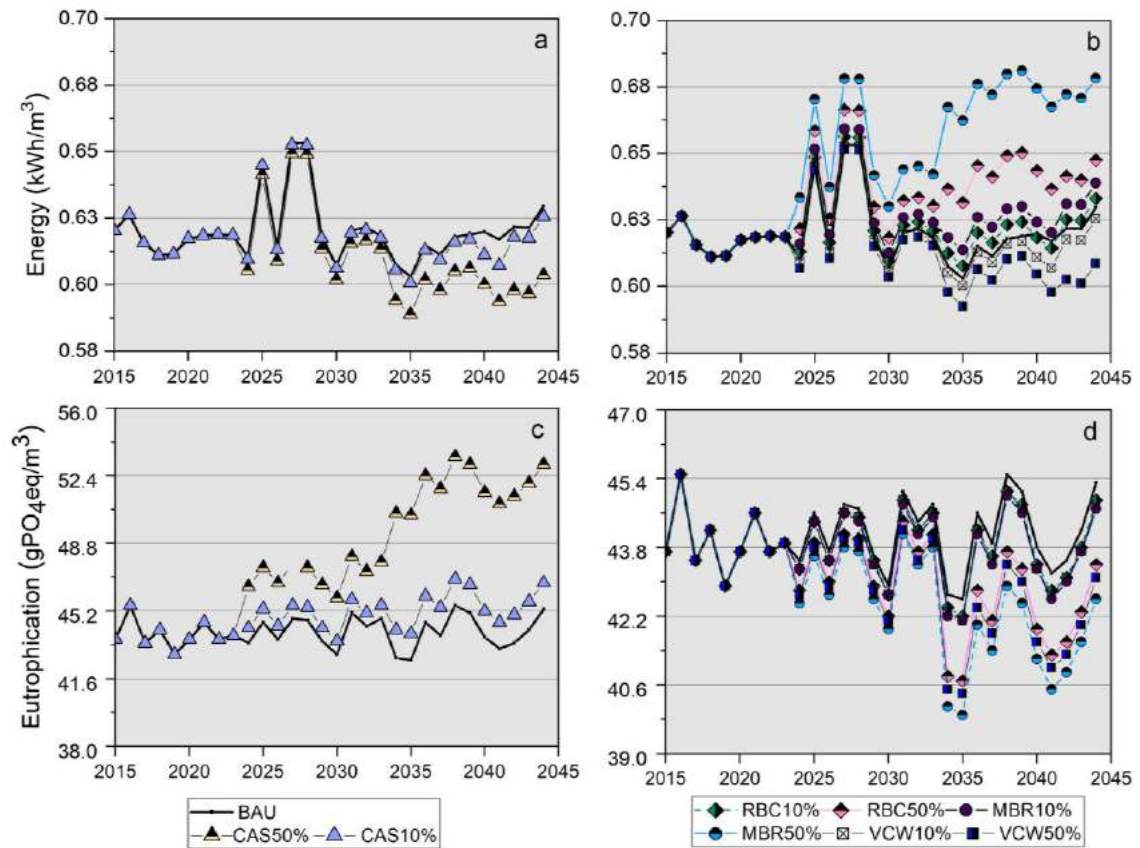


**Fig. 3. Energy consumption a) centralised and b) decentralised strategies, and Eutrophication potential in (c) centralised and d) decentralised strategies over the planning horizon**

#### 4. CONCLUSIONS

This study proposed a framework to analyse the energy-water and eutrophication-water nexus of an urban water system when reuse strategies are planning for implementation. It also provides information on the potential impacts of centralised vs decentralised reuse strategies to facilitate decisions among water managers in a real case study in Mexico. In addition, it also highlights the critical configurations variables on such strategies affecting the entire system. Thus, reusing water reduces the water withdrawals, but not necessarily the eutrophication generated or the energy consumption. Such further reductions mostly depend on centralisation level, the technology used and adoption rates, which depends on a case by case. For the current case study, combining decentralised GW using low energy treatment with high adoption rates would result highly desirable from the perspective of water-energy-pollutants nexus.

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## COMPETING INTERESTS

The authors certify that they have no affiliations or involvement with people or organisations that might have an interest in the submitted manuscript.

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## ENERWAT project: some preliminary results

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### ABSTRACT

Water and energy are two linked important resources and its use efficiency must be profoundly studied. On the other hand, it is believed that there are significant differences between the pattern of water and energy consumption in rural and urban areas, whose influencing factors require study too. Several research state a large difference in urban and rural household water consumption pattern. However, rural household's consumptions are under-researched compared to urban residential consumptions. This paper aims to provide some preliminary results of a research project named ENERWAT, supported by the Portuguese Science and Technology Foundation.

One of the parts of the referred project was the design, application and results analysis of a survey, in order to find the main differences in the water and energy consumptions at the end-use level, and the factors that influence it in urban and rural households. A total of 245 households participated in the research during the year of 2016 (urban: 110 dwellings) and (rural: 135 dwellings), responding to questions such as their family composition, dwellings characterization, water and energy consumption habits and conservation behaviors of these resources. Some of the obtained results will be here provided.

*Key-words: energy to water nexus, enerwat project*

### 1. INTRODUCTION

In a time where scarce resources and climate change are a concern, it is important to define water and energy efficiency strategies that minimize the damaging impact on the environment. It is therefore necessary to develop research work to quantify and characterize consumptions, in order to define strategies for the water and energy rational use. Water and energy systems have been treated independently. However, the consumption of water directly affects the consumption of energy, and therefore those consumptions are closely related. It is the so-called water-energy nexus, whose integrated study may lead to the identification of new solutions for saving these resources.

Human beings not only consume water directly, but also use it in food production, personal hygiene, sanitation and many other industrial and domestic uses, where energy consumption is also implicit. Since water is a strategic resource for the development of a country, its efficient use must be ensured, providing not only its preservation, but also energy, financial and environmental savings [1]. On the other hand, the growing demand for water, driven by population growth and increasing quality of life requirements has also led to increased energy

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consumption. There is indeed an interdependence between energy and water that becomes more complex as the energy crisis and the impacts of climate change intensifies and contribute to changes in water and energy consumption patterns [2].

Water-energy nexus has thus been recognized as a comprehensive concept to improve management practices in the water and energy sectors [3,4]. In this context, the relationship of interdependence between these two essential resources is receiving increasing attention, both from the scientific community and from the community in general.

The knowledge about the most relevant factors influencing the domestic, water and energy consumptions is a fundamental tool for efficient planning, operation and maintenance of their distribution and availability [5]. Portugal is an importing country of fossil fuels, which makes it dependent on energy resources.

Efficient use of energy is a key to building sustainability and is one of the priorities of European energy policy.

In 2013, the residential sector accounted for 16.7% of final energy consumption, 27.2% of which consisted of electricity consumption. In this context, this sector presents a greatest potential to implement energy efficiency measures [6]. In Portugal, there are some emerging ideas about this subject. However, there are still large gaps in information and the distinction between consumption patterns in rural and urban environments is not known. Concerning the Portuguese regulations, there has been some concern in the interconnection between the energy efficiency in buildings and water efficiency. The integration of the efficiency of household appliances for the use of water in the determination of the energy performance of buildings through the National Energy Certification System (SCE) is already a reality. However, further work is still needed in this area.

In order to recommend strategies for water and energy conservation, it is necessary to characterize domestic consumption and also to collect information about socio-demographic characteristics and housing, as well as household's consumption patterns. Research work has already been developed in this domain by Matos, C. [7, 8]. It is expected that there are significant differences between water consumption patterns and, consequently, energy consumption in urban and rural areas, but these differences are not yet evaluated. This analysis is of extreme importance and has been referred to as essential for the future planning and delineation of strategic-political considerations. These differences are influenced by several factors that need to be identified.

It was with this concern that the ENERWAT project was developed at the University of Trás-os-Montes and Alto Douro, counting on the participation of researchers from different areas. The project aims to characterize the energy consumption associated with domestic water consumption in rural and urban areas, identifying the factors influencing these consumptions. To achieve these goals, the project includes user surveys and *in situ* measurements of dwellings located in both types of environments and the installation of an innovative on-site monitoring system.

It is also intended to create a simulator that will help those who are going to build a new housing to opt for solutions that lead to the consumption of less water and consequently less energy and, for those who already have a home, to choose new solutions that lead to the reduction of these consumptions. At the same time, for each simulated case, a cost analysis will be carried out that will allow the user to make decisions. It also aims to create a manual of good practices and improvement solutions that contribute to the reduction of water and energy consumptions.

## 2. THE PROJECT

The following general tasks were defined for the project development and the pursuit of the intended objectives:

1. State of the art;
2. Design and application of a survey, data treatment and analysis;
3. On-site instrumentation and monitoring for the acquisition of water and energy consumption, in rural and urban environments;
4. Definition of a consumption simulator;
5. Economic analysis;
6. Practical recommendations and dissemination of results.

A brief description of tasks 2 and 3 and the main results obtained so far are presented below.

### 3. SURVEY APPLICATION

The survey was applied to 110 urban dwellings and 135 rural dwellings, during the year 2016, in the district of Vila Real. This survey allowed to collect diverse information that are grouped and summarized in Table 1. It integrated 74 questions grouped into 6 categories. All of these questions were based on the state of art. This survey was prepared using an online tool called "onlinepesquisa.com" and it was applied door-to-door between December 2016 and January 2017. The fact that it was applied door-to-door allowed a high number of valid answers given the fact that the questions were immediately clarified. Only one person per household responded to the survey.

**Table 1. Categories of the issues addressed in the survey**

| Categories                           | Collected information                                                                      |
|--------------------------------------|--------------------------------------------------------------------------------------------|
| 1. Characterization of the household | Number of members; age; qualifications; professional activity; family income.              |
| 2. Dwelling characterization         | Environment location (rural or urban); area and typology of housing.                       |
| 3. Energy consumption                | Energy source used; electrical equipment; total energy consumption.                        |
| 4. Water consumption                 | Type of water supply, number and duration of baths / showers, total water consumption.     |
| 5. Clothes washing                   | Washing machine; class of machine efficiency; number and duration of uses; hand wash.      |
| 6. Dish washing                      | Dishwasher; class of machine efficiency; number and duration of dishwasher use; hand wash. |

Regarding water and energy consumption, since most households were unable to provide the exact data of the monthly bill in relation to the year 2016, it was questioned, what was the range of values that were paid per month of water, electricity and natural gas consumptions. For the other sources of energy used (firewood, pellets, briquettes, diesel, bottled LPG, etc.) the annual costs were requested. After having the answers of all household consumption, monthly costs (€) (in the case of water, electricity and natural gas) were converted into monthly consumption ( $\text{m}^3$ , kWh), based on the EMARVR collection form and EDP Vila Real (local entities responsible for the distribution of water and energy (electricity and natural gas) respectively). In the particular case of electric power, the normal and double tariff consumption was calculated separately.

The mode of monthly and annual average consumption was calculated for rural and urban environments (Figures 1, 2, 3 and 4). For the remaining energy sources, the annual consumption value (toe - tonnes of oil equivalent) was calculated using the amount spent (€) and quantity (kg, l) using the conversion factors available for the various types of energy.

As a brief analysis of the results, it was possible to conclude that the annual water consumption was higher in the urban environment, with values between 6 and 16  $\text{m}^3$ , corresponding to 70% of the analysed cases (Figure 1). In what concerns to the natural gas consumption, it was observed, as expected, that its use has no significance in the rural environments, given the fact that these areas are not served by the respectively municipal infrastructures (Figure 2). With regard to annual average of electric energy consumptions, it is highlighted the predominance of use of simple tariffs when compared with the double tariff (Figures 3 and 4).

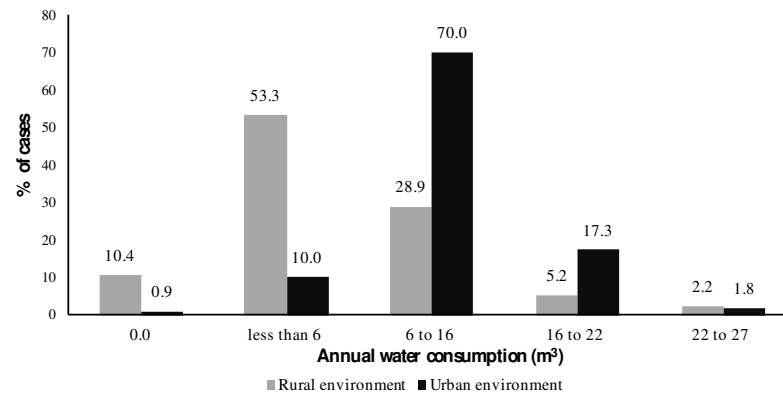


**Fig 1. Annual average of water household consumption in rural and urban areas**

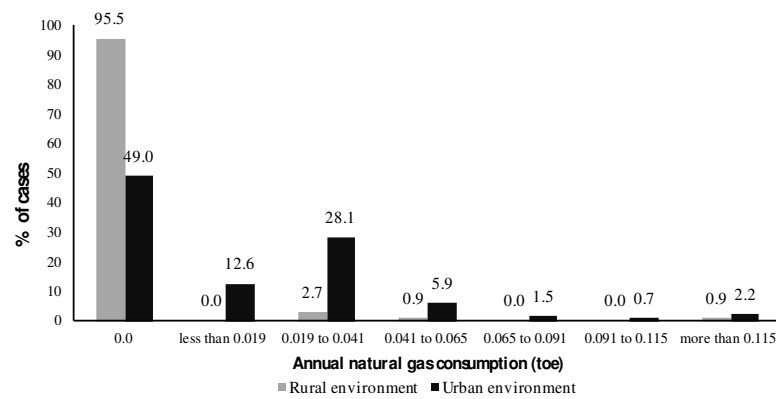


**Fig 2. Annual average of natural gas consumption in rural and urban areas**

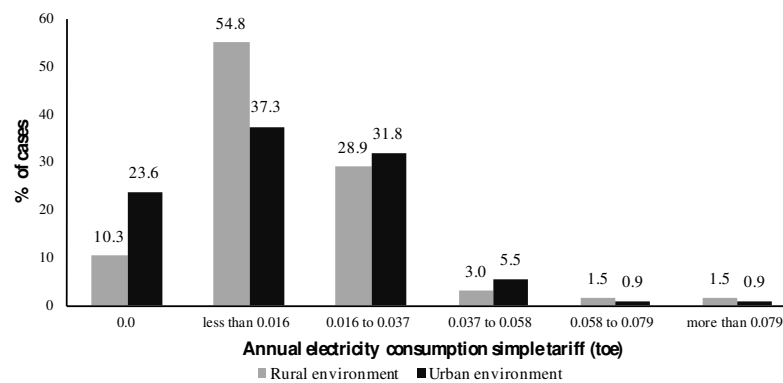


**Fig 3. Annual average of electric energy (simple tariff) consumption in rural and urban areas**

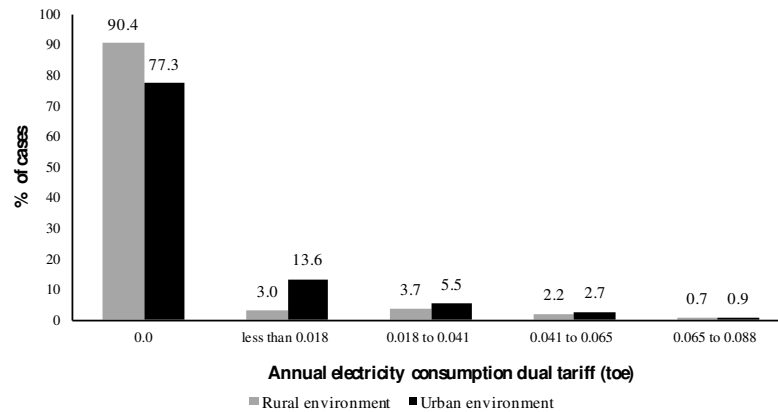


**Fig 4. Annual average of electric energy (double tariff) consumption in rural and urban areas**

The variables that may or may not influence the consumption of these resources in both environments are being analysed through an in-depth statistical analysis of the collected data. The final objective of this task is to obtain, if possible, the correlation between water and energy consumption in rural and urban environments and to know which factors influence the differences in the consumptions.

#### 4. INSTRUMENTATION AND MONITORING

It is intended with the instrumentation and monitoring of dwellings in rural and urban environment to quantify the water consumption and associated energy consumption. In addition to the measurements, the characterization of housing and the behaviour patterns of the members are also carried out.

Water consumption monitoring is carried out on all existing water use devices (wash basin, shower, bidet, toilet, dishwasher, washing machine and dishwasher) and also on the water meter. Energy consumption is quantified by monitoring the counters of their respective energy sources, namely electricity and gas.

The instrumentation and monitoring of the water consumption devices was carried out by placing magnets and magnetic sensors on the faucets and water flushing systems of the flushing cisterns and also on the placement of voltage sensing sensors between the washing machines and the respective sockets feed [9].

The placement of magnetic sensors on the taps made it possible to check the opening (ON) and the lock (OFF) and whether they were charging hot water, cold water or hot / cold water (Fig. 5).

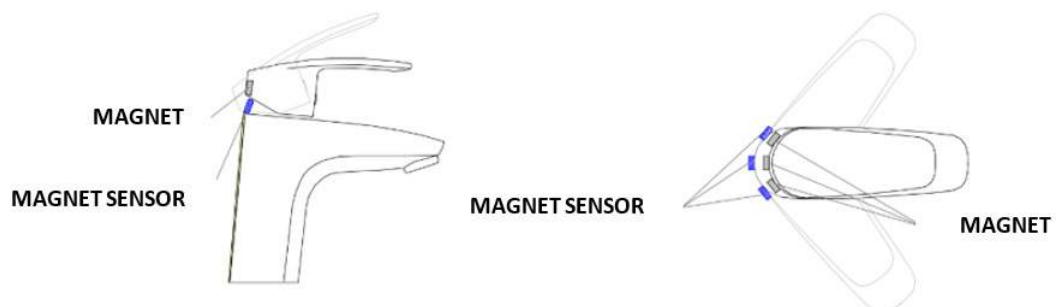


**Fig. 5. Placement of sensors on taps (adapted from [9])**



The data collected by the different devices are stored in a Single Board Computer (SBC), installed in each room where there are devices for consumption measurement. In the water, gas and electricity meters, cameras were used to capture images of the values recorded in the counters whenever there is a change in the digits, which corresponds to a change in consumption. Subsequently, it is necessary to compare the results obtained by triggering the sensors with those obtained by changing the digits shown in the meter display. This comparison will make possible to identify the water consumption devices used, the consumption of water (hot or cold), the period of use and the source of energy used (electricity or gas) and their consumption.

Figure 6 shows an example of the type of results that can be obtained through the instrumentation and monitoring of household consumption. The hourly and hourly average values for water and energy consumption (electricity and gas) obtained for a day of the week in one of the dwellings under study are presented.

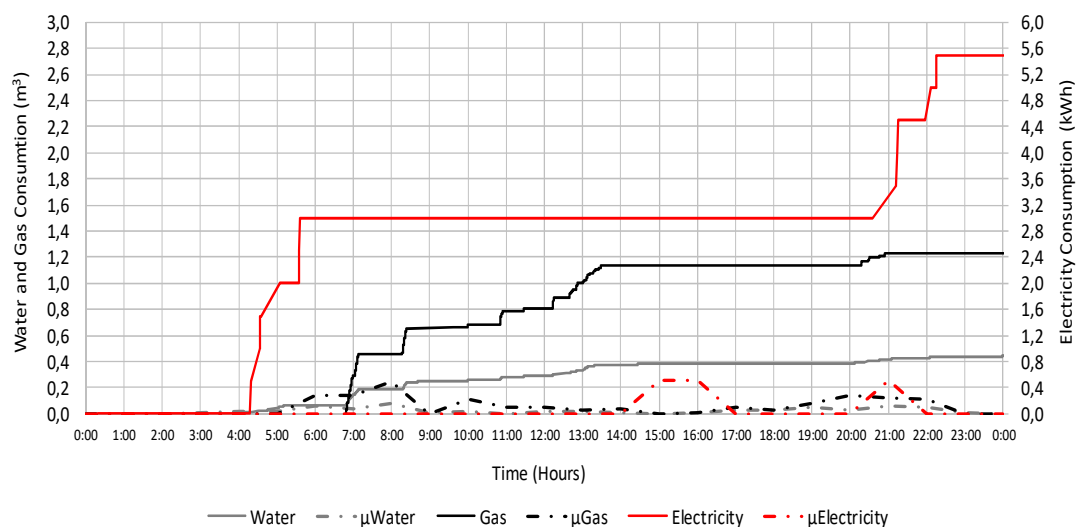


**Fig. 6. Hourly and average hourly ( $\mu$ ) of water, electricity and gas consumptions**

## 5. CONCLUSIONS

The preliminary results revealed by the surveys indicate differences between domestic consumption of water, electricity and natural gas, between rural and urban areas. There appears to be some seasonality in the collected data. It reveals significant differences between the sociodemographic variables in the rural and urban environments. So, it is important to identify the predominant variables in the differences found in the consumption of water and energy, which analysis is in progress at the moment. In the future, it would be interesting to extend the application of the survey to other regions of the country in order to identify the main differences between the different regions.

The work developed so far allows the continuous collection of data *in situ* through a simple monitoring system. The system allows identifying the water consumption devices used, the consumption of water (hot or cold), the period of use and the source of energy used (electricity or gas) and their consumption.

The results obtained until now are available at <http://enerwat.utad.pt>. In the second semester of this year will also be available the consumption simulator and the manual of good practices and improvement solutions as well as all future results. In November, a seminar will be held with the dissemination of the project results.

This project will contribute to the knowledge and will allow the advancement of science in this area and also the definition of new strategies for the efficient management of water and energy resources.

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# Skills for Water Efficiency and Water-Energy Nexus in Building Construction and Retrofit

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## ABSTRACT

Water scarcity is a serious problem for many European regions, with ca. 45% of the territory expected to face water scarcity problems by 2030. As result of climate change, the damage caused by floods may increase fivefold by 2050. This situation is driving growing attention and increasing regulation on water efficiency and water management across Europe, both in response to water scarcity problems and to climate change mitigation and adaptation goals. Despite the share of context, the 4 participating South-European countries of ERASMUS+ “WATTer Skills” Project (Portugal, Spain, Italy and Greece) have shown dissimilar awareness and different ways of approaching the problem, with more regulatory measures going on and with the possibility of tuning into demand-side management strategies more rapidly on one side, and still beginning the path for legislation and increasing awareness levels on the other. In terms of the water efficiency qualifications and accreditation systems, results show that there are variations in description and length, specifically in the number and extension of national qualifications, vocational education and training. As suggested, the “water efficiency technician” and “water efficiency expert” show different professional profiles necessary to cover all required skills and being able to achieve water and energy (related to water) savings in buildings. This more structured skill framework for these professionals has been identified as necessary by the participating countries, with the “Watter Skills” project constituting an opportunity to set harmonized criteria at an European level. With this basis, the path for getting a skills map at European level and the next step of proposition and pilot implementation of a European common curriculum for each profile, with improved water efficiency in buildings rollout, will succeed.

*Keywords: water-energy nexus; building water efficiency; water efficient products; common qualification framework.*

## 1. INTRODUCTION

Water scarcity is a serious problem for many European regions, with ca. 45% of the territory expected to face water scarcity problems by 2030. Also as result of climate change, the damage caused by floods may increase fivefold by 2050. This situation is driving growing attention and increasing regulation on water efficiency and water management across Europe, both in response to water scarcity problems and to climate change mitigation and adaptation goals. This may be particularly important and critical in urban areas, considering both the economic and environmental benefits that can rollout due to water savings. In buildings, the water saving potential is estimated to be 30% in the EU [1]. Also pertinent is the consequent reduction in energy consumption and CO<sub>2</sub> emissions. However, the water demand per capita in cities

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continues to increase, as result of population growth, growing economies and increased standards of living, together with consumption patterns' changes [2].

To guarantee water efficiency and effectively contribute to water use reduction, demand-side management strategies need to be put in place. Otherwise, management strategies may not be effective to the necessary overall decrease in demand [2]. In the United States, sponsored by the Environmental Protection Agency (EPA), the Water Sense program launched in 2006 [3] is designed to promote water efficiency by both supporting a market for water-efficient products and working as a resource for helping consumers to save water. In this program, water savings of 20% are expected to take place only through the installation of water-efficient fixtures and appliances. On top of that, consumers may apply water efficiency behavioral measures, e.g. by turning off unused taps or using buckets instead of hoses. According to EPA and to the Alliance for Water Efficiency, this voluntary public-private partnership has already helped American consumers to save a cumulative 8 billion liters of water and 284 thousand Gigawatt-hours (GWh) of electricity, resulting in more than 37.2 billion euros on their water and energy bills since 2006 (released data from March 2018) [3].

Water specific plans and programs, such as the Communication from the Commission "The Blueprint to Safeguard Europe's Water Resources", were presented in 2012 to drive EU water policy over the long term, with a scope that goes beyond 2030. As established in the European Community (EC) Blueprint's communication [4], the Eco-design Working Plan 2015-2017 was expected to include water-related products, with intense debate already underway in Europe [5] due to the ongoing EC work to promote standards for water efficiency products and systems in buildings. In addition, efforts are being made to move towards an EU framework of core indicators for the environmental performance of buildings, including the efficient use of water resources. This framework will set harmonized criteria at European level for evaluating and certifying buildings on their environmental and water use performance. More recently, the International Organization for Standardization (ISO) revealed its plans to take forward a new water efficiency labelling standard (Standards Australia, British Standards development). However, the ongoing efforts to product and building certification need to be in line with growing market readiness and adaption, or the implementation may be limited or inadequate, as it was the case of solar thermal introduction in Portugal, which generated market distrust due to lack of skills and qualification of the technology installers and providers.

These initiatives will progressively transform the market with a growing introduction of efficient water devices and products, labelled on an efficiency-level basis. The gradual replacement of old products by more efficient ones is expected to generate considerable water and energy savings, since a large part (ca. 23%) of the water consumed by households is heated (the national building energy certification system, ADENE, Portugal). In addition, water savings are estimated to represent about 30% of the current building consumption in the EU, as well as the consequent reduction in energy consumption and CO<sub>2</sub> emissions (which estimated energy savings are equivalent to 3.5 % of total residential energy use in the EU), according to data from the Communication from the Commission "The Blueprint to Safeguard Europe's Water Resources" (European communication, 2012).

Addressing these new needs, trends and obligations for water efficiency solutions in buildings will carry market opportunities and challenges. For these opportunities to truly succeed and overcome the challenges, it is important to ensure, in the European market, the necessary skills in the construction sector and in other related sectors, as well as the market readiness and adaptation within energy and "green" professions. Furthermore, when dealing with water systems in buildings, water preservation and consumer safety and confidence should be guaranteed, by providing the means to guarantee that water quality is preserved while water efficiency solutions are being implemented. Ideally, these solutions should be sought in a collaborative and integrated approach, namely in collaboration with drinking water supply system management. It is also important to assure that these new solutions and technologies will not increase the demand for energy in buildings, which can take place if there are no integrated approaches or integrated skills on the new energy uses, associated with the applications of water efficiency systems and technologies. The main goal shall be to maximize combined water and energy efficiency opportunities in buildings, rather than having isolated

analyses and ambiguous solutions, where single improved efficiencies may not lead to the necessary overall decrease in demand (UN 2014, Water and Energy).

To overcome all these challenges into effective water efficiency in building construction and retrofit, there is need of adequate training and qualification schemes for the construction professionals (plumbers, technical agents and designers) and “green” professionals (e.g. water and energy consultants, service providers), that should be sustained on reliable and independent accreditation standards, ensuring the technical knowledge and capacity building of those professionals (vocational education and training – VET and certified training). The several ongoing changes at a European level will require these skills to be harmonized in a common Water European Curricula for all technical professionals and experts, as a key factor to guarantee EU market's and consumer's confidence in the adoption of water efficiency solutions for buildings, but also to allow mobility and recognition of these professionals in the European market.

With this intent, WATter Skills project (2017 – 2020), co-financed by ERASMUS + Programme, intends to absorb the best practices drawn from the execution of previous projects on water efficiency training, such as “AQUAVET – Strategic Partnership for the Development of a VET course on water efficiency technologies for water technicians”, also co-financed by ERASMUS+ Programme, and from few initiatives taking place in some EU countries to provide training on water efficiency installations and technologies. WATter Skills is complementary, building upon these projects and going further, and moving towards a European common qualification and accreditation system for professionals on water efficiency and water energy nexus in buildings.

Accordingly, this paper aims to present the methodology and the expected results of the ERASMUS+ WATter Skills project, including the framework for setting a perimeter for a skills map at European level on water efficiency and water-energy nexus in building construction and retrofit, with the expected learning outcomes, monitoring metrics and indicators. This skills map will constitute the step forward for the proposal and pilot implementation of a common curricula, qualification framework and accreditation scheme at a European level, for the training and skill upgrading of construction and green professionals on water efficiency and water-energy nexus during construction and building retrofit. Overall, the WATter Skills project intends to establish and test a common qualification framework for training and skill upgrading of construction and green professionals on water efficiency and water energy nexus in building construction and retrofit, with ADENE – National Energy Agency (Portugal), FLC – VET training center for construction workers (Spain), CRES – National Energy Centre (Greece) and FORMEDIL – VET management entity (Italy) as project partners.

## 2. METHODOLOGY

### 2.1 Background

The WATter Skills project is being developed in countries of the Mediterranean region (Portugal, Spain, Greece and Italy), where water scarcity and severe drought are already happening and may continue to take place in the near future. In fact, ca. 40 % of the inhabitants lived under water stress conditions in the summer of 2014 while ca. 80 % of total water abstraction for agriculture occurred in the Mediterranean region [6]. In 2014, around 13 river basin districts in the Mediterranean region, including Greece, Portugal and Spain, were facing water stress conditions. In Portugal, the extreme drought of 2017 affected 96% of the country's territory [7].

In some European countries, important steps are already being taken to fully seize these challenges and opportunities, both for cities and for the construction sector, which requires market readiness and adaptation. This happens in a time when the building sector is recovering, not only with new construction growth but also with growing investments and projects in deep building retrofits, including energy and water systems retrofits.

In Portugal, for instance, a new regulation for water distribution and drainage systems design and construction in buildings is expected to be published, replacing the current regulation that

stood for over twenty years (a 1995 Decree Law). In the nearly future, there will be specific requirements and incentives for water efficiency in buildings, paving the way for new markets and opportunities, such as water efficiency audits, water-efficient products and smart technologies, hot water recirculation systems, rainwater harvesting, grey water reuse, landscape redesign and irrigation systems. Along with this transformation, Portugal will also need to continue to invest on building retrofit (considering its building stock with low water performance) and to make efforts to increase awareness for improved water efficiency in buildings.

In Greece, despite of having one of the greatest water resources potentials per capita in the Mediterranean area, the water is not evenly distributed in space and time. Due to this inequality, some areas are now facing long-term water shortage problems. New compliance measures, including new building regulation (Law No. 4067, 2012), which include a provision for the installation of water saving equipment in new residences, equipment to be specified by subsequent decisions of the Minister of Environment, Energy and Climate Change. In addition, the Ministry of Environment, Energy and Climate Change through the Special Secretariat of Water initiated in 2011 the preparation of an Institutional Framework and a Program of Measures for household water conservation. The study, conducted in support of this action, showed that simple interventions to equip a household can achieve significant water savings. Several institutional, regulatory and dissemination measures were proposed in the context of the study.

In Spain, the situation of water resources is especially emergent, due to the existing level of drought, where, on average, 15% less rain water and higher evaporation rates occur in comparison to other EU countries. Paradoxically, the water efficiency in buildings is not yet on top of concerns, as it is mainly applied in buildings with both high sustainable and environmental perspectives. The challenges in Spain include the raise of awareness concerning the need of introducing water efficiency in buildings; to set up the basis to start up qualifications processes on water efficiency; to increase the number of buildings with demonstrable water efficiency in Spain; and to contribute for water savings.

In Italy, the average volume of rainfall is above the European average. However, it is the EU country with the highest water demand 980 m<sup>3</sup>/person/year and household use (249 L/person/day), together with the worst water consumption indices per unit of product and highest consumption of water per irrigated hectare. Despite this, Italy may suffer from severe water shortages, especially during summer and in the south of the country, where about half of the population may not have enough water for at least a trimester of a year. To counteract this, Italy will need to invest on better distribution and more efficient networks while promoting a water saving culture. One of the possibilities is to work with families, as the water is heated by a low-energy consumption plant for each flat, allowing each family to manage its energy and hydraulic expenses.

Despite the share of context with respect to water stress in countries from the Mediterranean area, the participating countries have shown dissimilar awareness and different ways of approaching the problem, or amongst each country regions. On one side with more regulatory measures going on, paving the way to implement demand-side management strategies more rapidly at some regions, and on another side still beginning the path for legislation and increasing awareness levels, with exceptions for other regions.

## 2.2 Outputs

The WATTer Skills project structure is based on 4 main outputs:

Setting the Perimeter of WATTer Skills: Development of the WATTer skills map, both at a European and at national level, for the two water professional profiles (technical and expert). The skills will be defined in terms of learning outcomes. In parallel, metrics and indicators will be collected and defined, to compare water efficiency and energy efficiency in buildings before and after the implementation of the training and qualification system, including data collection of water and energy consumption.

Proposal of a Qualification Framework: Adaptation of the WATTer Skills learning outcomes map, based on the learning outcomes defined in the previous output, to be in line with the European Qualifications Framework (EQF). This harmonization will need to adopt and adapt, nationally, the training and qualification of the different types of professionals targeted, including areas of knowledge, number of hours, trainer and trainee profiles, pre-qualifications required, amongst other relevant criteria.

Delivery of the training courses curricula (for both technician and expert profile), delivery of contents, pilot implementation and development of e-learning platform: Following to the definition of the scheme requirements, the training courses' structure and curricula will be formulated. These curriculums will be validated by the project's Advisory Board. In the end all training contents will be available as classroom training manuals for trainers and trainees, and as e-learning contents.

Delivery of an accreditation system based on EQF and ECVET: It will be defined an accreditation system for water technicians and water experts, with compulsory minimum requirements, defined in accordance with each national status. A recognition system will be developed for the different types of professionals and integrated into national (NQF) and European qualifications frameworks (EQF), by defining a Memorandum of Understanding (MoU) that would eventually put into force the new skills and provide ECVET to participants. Also, the European accreditation system will be developed, based on ECVET training credits for mobility and recognition of these professionals in all EU Member States.

The participating countries, alike other European countries, count on a National Qualification System. With this basis, the existing qualifications on which the participating countries can build on for setting up a vocational education and training framework on water efficiency targeted at building professionals may be identified. This will be complemented with the identification of further training needs to fully address water and water-energy nexus challenges and opportunities in buildings, leading to the definition of the WATTer skills map at a European level. With this purpose and to share a national background, each partner has selected the qualifications related to water efficiency and water-energy nexus, and, secondly, those related with formal training, including the target public and the entity providing the qualification.

Next step is to filter the existing tasks and skills into general and common terms, herein identified as "water efficiency technicians" and "water efficiency experts". The first may refer to skilled and experienced craftsmen working with the daily response system actions (e.g., plumbers, installers, maintenance staff), and the former to the more educated people handling water related works in system design, construction and management (e.g., engineers, architects, auditors). There should also be an identification of those work activities that result in water efficiency and water-energy nexus performance in buildings. All these activities are to be outlined in terms of work functions and linked to the construction or refurbishment stage of a building, regardless of the professional who usually carries out the task. In fact, only considering all water professionals in buildings it will be possible to develop "water efficiency technician" and "water efficiency" expert qualifications. An example of draft information collected for a "water efficiency technician" is presented in Table 1.

**Table 1. Example of a technician job position (plumber) and the current work functions/activities related to water use in buildings.**

| Construction system/stage            | Job position | Work functions / activities                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|--------------------------------------|--------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Sanitation and plumbing installation | Plumber      | <p>Install, maintain and repair the cold and hot water pipelines and fittings in buildings and plots.</p> <p>Install, maintain and repair wastewater and rainwater drainage systems in buildings and plots.</p> <p>Install, repair and replace the water using appliances/fixtures.</p> <p>Install, maintain and repair all kinds of domestic hot water (DHW) preparation and storage systems (water heaters).</p> <p>Install the piping systems for central air-conditioning in buildings.</p> <p>Maintain, repair, replace and modernize the piping of air conditioning systems.</p> |

Herein are the concepts defined, to frame the terms used to describe them:

**Site conditions and building type:** Site conditions, like the climate, orientation, the influence of heat island effect, etc., can be used to enhance energy efficiency related to water use and reduce water consumption, if considered as integrated in urbanization, building type, composition and distribution of spatial elements and thermal and hydraulic installations based on conventional or renewable energy.

**Construction materials:** Materials embed energy and water in their life cycle: in their manufacturing process, transportation (if carried from far distances), construction techniques, sometimes in their use or maintenance, and in their reuse or disposal. Local, recycled or products with some energy/environmental tags can minimize the negative impacts.

**Construction techniques:** Like materials, some constructions techniques employ more energy and water than others: ecological construction techniques, dry construction or industrialized construction, for instance, can minimize the negative impacts;

**Energy and water efficient home appliances:** Equipment and devices can save water and energy in different aspects of the construction and use of the building, especially those that are related to hydraulic and thermal installations.

The next step in the skill map shaping is the identification of the required competences skills and knowledge, needed for professionals to get a water efficiency and water energy nexus performance in buildings. The definitions will necessarily be the baseline for outlining the skills map, where they are further gathered, grouped and set in terms of learning outcomes, a key element in the process of designing qualifications. In table 2, it is presented an extract from the work undertaken in the identification of skills, knowledge and competences needed on the *Installation, maintenance and repair of wastewater and rainwater harvesting systems* to be performed according to water efficiency criteria.



**Table 2. Example of the required skills for a technician (plumber) to be able to achieve water and energy (related to water) savings in buildings**

| Areas related to water efficiency                                                 | Profession | Water and energy saving skills<br>(i.e. ability to accomplish...)                                                                                                                                                                                                                                                                                                                                                          |
|-----------------------------------------------------------------------------------|------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Installation, maintenance and repair of wastewater and rainwater handling systems | Plumber    | <p>Customised selection and design of the most suitable water efficient treatment systems.</p> <p>Installation and management of automatic systems for rainwater harvesting (capturing and storage for future re-use).</p> <p>Application of methods for re-use of the collected “grey water” to recycle for further domestic use.</p> <p>Installation, commissioning and maintenance of grey-water recycling systems.</p> |

With the qualifications required for the development of the “WATTer skills” perimeter at a European level, it may be possible to set performance indicators and targets, that shall be tested with basis on a reference scenario. Definition of performance indicators will be useful for comparison between different countries and for establishing the necessary actions to evolve from the baseline scenario, particularly when targets are clearly defined (e.g., capacitate 20% more water efficiency professionals).

### 3. RESULTS AND DISCUSSION

#### 3.1 Qualifications and accreditation system

The data collected from each country for the existing qualifications and accreditation systems was varied in description and length, specifically in the number and extension of national qualifications, vocational education and vocational training. In general, all countries count on national qualification frameworks as basis of their VET, but with qualifications differing from each other whilst levels, structure and functioning, and with qualification sometimes referring to a specific occupation or to a productive process. Partners count on several qualifications related to energy and water efficiency, but, in any case, they refer to the holistic qualifications raised in this project.

The development of the project confirms the added value of getting common qualifications at a European level, where water efficiency technician and water efficiency expert coming from different regions may get training, qualification and work in several countries. These will be learning from different realities and sharing diverse experiences, for continuously achieving the required skills and be able to better perform water and energy (related to water) savings in buildings.

With reference to performance indicators, as previously explained, they will be used for comparison and establishing the necessary actions needed to evolve from the baseline scenario, to reach the defined targets. Some projects developed under the Build UP Skills initiative have also been reviewed to find success indicators, adaptable to the WATTer Skills project.

### 4. CONCLUSIONS

The development of the project so far confirms the need and added value of defining a common training and qualification framework to properly address and seize water efficiency challenges

and opportunities in buildings, where the new qualifications of the “water efficiency technician” and “water efficiency expert” are outlined in terms of work functions and linked to the construction or refurbishment stage of a building. This will constitute a consistent and standardized water efficiency framework for these two professional profiles with common curriculum for the training and upskilling of professionals towards new changes, at a European level.

The qualifications will be elaborated under European criteria, allowing water professionals to: get their skills recognized into a qualification and make the path easier to get those qualifications and, on the other hand, allow mobility opportunities for these professionals at a European level. At the end of the day, qualifications frameworks are meant to promote employability, mobility and permeability, and giving individuals scope and opportunities for lifelong learning, at the same time. Is therefore critical to develop a common framework for upskilling and certificate competences in professional activities that may lead to relevant water savings, as it is the case for the building construction sector. The common framework shall be set on a European basis, allowing the developed system to be mainstreamed and to foster water efficiency professional’s mobility, job opportunities and market influence in all EU member states.

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## Increasing water and energy efficiency in university buildings: A case study

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### ABSTRACT

Nowadays humanity is consuming unsustainably the planet's resources. In the scope of energy resources consumption, e.g., the intense use of fossil fuels has contributed for the acceleration of climate changes on the planet, and the overriding need to increase energy efficiency in all sectors is now widely recognized, aiming to reduce greenhouse gases (GHG) emissions by 69% in 2030. Largely due to climate changes, water has also become a critical resource on the planet and hydric stress risk will rise significantly in the coming decades. Accordingly, several countries will have to apply measures to increase water efficiency in all sectors, including at the building level. These measures, in addition to reducing water consumption, will contribute to the increasing of energy efficiency and to the decrease of GHG emissions, especially of CO<sub>2</sub>. Therefore, the nexus water energy in buildings is relevant because the application of water efficiency measures can result in a significant contribution to improve buildings' energy efficiency. This applies not only to the efficiency in the use of sanitary hot water but also to cold water, taking into account energy consumption in the urban water cycle (namely in abstraction, treatment and pumping). In Portugal, some studies were conducted recently in order to assess the extent and impact of this nexus. The study described in this paper was performed in a university building located in mainland Portugal central region (University of Aveiro), aiming to assess the reduction of water consumption obtained as a result of the application of efficient devices in the building and the consequent increase in energy efficiency and in the reduction GHG emissions. Complementary energy efficient measures were implemented to reduce the energy consumption. It was concluded that the significant reduction of the building energy consumption did not influence the indoor comfort.

*Keywords: Water-energy nexus, Water efficiency, buildings, Sustainability*

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## 1. INTRODUCTION

Water efficiency is an issue of increasing importance due to unsustainable water use worldwide, due to the exponential population growth on the planet and the current global model of economic growth, highly resource-intensive consuming and generator of pollution. Climate change has exacerbated this scenario and it is expected that in many countries, especially in Mediterranean region, the predicted reduction in rainfall or pluviometry regimen changing can in the short/medium term create or aggravate situations of scarcity or water stress [1,2].

Accordingly, sustainability reasons impose, efficient water use measures in all sectors, including the urban sector, embodied in the so-called principle of "5R". The first R, reduce consumption, is a priority measure and consist on the adoption of efficient products or devices, without impairment of other non-technical measures (economical and of awareness). The second R, reduce losses and waste, can involve interventions such as the control of losses in toilets or installing circuits of circulation of sanitary hot water (SHW).

The reuse and recycling of water constitute the third and the fourth R, which difference result in considering "serial" use or reintroduction of the water at the beginning of the circuit (after treatment). Finally, the fifth R, the use of alternative sources, may involve the use of rainwater, ground water or salt water [3,4]. For existing buildings, the best technical-economic options for increasing water efficiency within these 5R principles should be found by conducting water efficiency audits.

The Portuguese Association for Quality and Efficiency in Building Installations – ANQIP, is an association of civil society dedicated, among other objectives, to buildings' water efficiency. In order to provide consumers with information about water efficiency of water using products (WuP), ANQIP developed a voluntary system of certification and labeling of water efficient products for Portugal, based on letters (A to E), similar to the practice followed in relation to energy efficiency [5]. Currently, almost 900 WuP have already been labeled and the respective catalog is available on ANQIP website ([www.anqip.com/index.php/en/certifications](http://www.anqip.com/index.php/en/certifications)).

According to ANQIP studies, most of the WuP in the Portuguese buildings correspond to a C and D label, which represents a potential to reduce water consumption by more than 30% in the buildings' sector. However, the excessive reduction of flow rates or volumes in the devices can have some constraints, at the level, for example, of the users comfort, of the performance of the drainage system or even in terms of public health. The aspects of comfort are very relevant, as they can lead to the rejection of the efficiency measures or to changes in user habits, invalidating partially or totally the benefits of increasing the WuP efficiency. Some studies on this issue have already been published by ANQIP [6, 7, 8, 9].

Considering the water-energy nexus, the reduction of water consumption in the building cycle is also reflected in significant energy efficiency, taking into account the reduction of energy consumption to heat sanitary hot water to pressurize the water, and in the public systems in the abstraction, pumping and treatment of water and wastewater [10].

This paper describe an audit of water efficiency carried out by ANQIP in the Department of Civil Engineering of the University of Aveiro, Portugal (Figure 1), and the results obtained in terms of reduction of water consumption in the building, as well as the corresponding estimates for the reduction of energy consumption, as a consequence of the water-energy nexus. The overall objective of the Department was to increase the water and energy efficiency of the building, so the results of a complementary energy efficiency audit are also mentioned.



**Fig. 1 – Building of the Department of Civil Engineering of the University of Aveiro (Portugal)**

## 2. METHODOLOGIES

In November 2016, ANQIP conducted a water efficiency audit in the building under study, in which sequence was decided to adjust the flow rates/volumes of the various water devices to the reference values of letter "A" of the ANQIP labelling system. Although this labelling system covers devices with higher efficiency (categories "A+" and "A++"), their application is not generally considered for public buildings, in order to ensure proper functioning of drainage systems, adequate levels of users' comfort and for health reasons.

The building has 69 water devices distributed by:

- Urinal flush valves (17);
- Showerheads (2);
- Flushing cisterns, complete discharge (16);
- Flushing cisterns, double discharge (3);
- Self-closing taps (23);
- Laboratory taps, conventional (11)

The proposed measures, technically and economically justified throughout the audits, were:

Urinal flush valves (Figure 2) - In 14 of the urinals, only a small reduction on the discharge time was made, from 7.12 seconds (on average) to 5 seconds.

Showerheads (Figure 3) - The initial flow rate was 12 L/min, which was reduced to 8 L/min by the application of a reducer previously tested by ANQIP, in order to guarantee the desired flow rate for the local pressure conditions.

Flushing cisterns, complete discharge - By simple regulation of the water inlet mechanism, it was possible to reduce the initial discharge volume from 9 L (on average) to 6 L.

Flushing cisterns, double discharge (Figure 4) - By simple adjustment of the water inlet mechanism, the average volume of the discharge was reduced from 6 L to 4.5 L.

Self-closing taps (Figure 5) - These taps had an average flow rate of 7.6 L/min, which was reduced to 4.0 L/min by application of a calibrated reducer, as in the case of showerheads. It was not considered advisable to reduce the opening time (close between 6 and 8 seconds), since lower values lead to successive actuations.

Laboratory and service taps, conventional ones (Figure 6) - In these taps, due to their functions, it was not considered appropriate any operation.

|                                                                                     |                                                                                     |                                                                                     |                                                                                      |                                                                                       |
|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
|  |  |  |  |  |
| <b>Fig. 2 – Urinal with flush valve</b>                                             | <b>Fig. 3 – Shower head</b>                                                         | <b>Fig. 4– Toilet with flushing cistern</b>                                         | <b>Fig. 5 – Self closing tap</b>                                                     | <b>Fig. 6 - Example of laboratory tap</b>                                             |

Between 13th of October and 20th of November 2017, an energy audit was performed to assess the major energy consumption by building floor level including with air conditioning. In 2016/2017 several energy efficiency measures were introduced, namely the changing of lamps type and electric lighting control:

Replacement of corridors' lighting systems: In corridors, all the projectors were replaced by new LED solutions (Figure 7 and 8) reducing installed power by 25 times, and consequently a decrease in luminous power was introduced.

The set point of the AVAC system was reduced from 24/25° C to 20/21°C.

The classrooms and offices lighting systems are gradually been replaced by LED systems.



**Fig. 7 – Corridor projector: old systems with 250 W lamp**

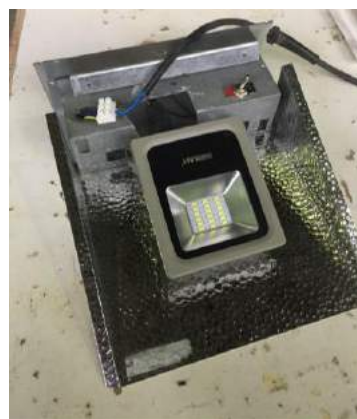


**Fig. 8 – Corridor projector: LED systems with 10 W lamp**

Table 1 summarizes the average reductions calculated in water consumption by applying the measures proposed in the water efficiency audit, by type of device. Based on the forecast of consumption by type of devices (Table 2), it was possible to value a total reduction of 27% in consumptions, corresponding to an annual saving of € 253, taking into account the current consumption value.

The investments required (the installation of reducers) were estimated in a total of only € 150, which corresponds to a payback period of seven months. The audit was accompanied by a campaign to raise the importance of water efficiency responsiveness that included informative sticky labels in all sanitary facilities, among other measures.

**Table 1 – Water consumption reduction by type of device, in percentage**

| Device                             | Number of devices | Average reduction |
|------------------------------------|-------------------|-------------------|
| Urinal                             | 17                | > 0%              |
| Shower                             | 2                 | 33%               |
| Toilet (complete discharge)        | 16                | 33%               |
| Toilet (double discharge)          | 3                 | 25%               |
| Washbasin (self-closing tap)       | 23                | 40%               |
| Laboratory sink (conventional tap) | 11                | 0%                |

**Table 2 - Water consumption of the building per device (estimated values)**

| Device                        | %     |
|-------------------------------|-------|
| Urinals                       | 12.5  |
| Showers                       | 2.5   |
| Toilets                       | 40.0  |
| Washbasins                    | 35.0  |
| Sinks (and other consumption) | 10.0  |
| Total                         | 100.0 |

The water efficiency measures proposed in the audit have been progressively implemented. The flushing cisterns adjustment were implemented during the auditing (November 2016) and the placement of flow reducers in the taps in October 2017. In 2016 the energy management in the Civil Engineering Department reached 11% of electricity savings with regard to the previous year (Figure 9). In 2017, to maximize the overall building energy performance, measures to reduce the lighting energy consumption by the replacement of 14 vapor sodium lamps of 250W for 10W LED' were adopted and was installed a lighting control system with presence sensors in the common areas such as corridors and stairwells. In addition, since mid-2017 200W LED replaced all the 16 laboratory 250W light projectors.

Beyond the deep renovation in the lighting system, which still is ongoing by the gradually replacement of tubular fluorescent lamp by LED in the classrooms, new heating and cooling set points in the buildings spaces from 24/25°C to 20/21°C were implemented. Therefore, in 2017 the energy savings were even higher than in 2016, achieving 25% as depicted in 9. With the energy efficiency plan implemented by the energy management the total's building electricity needs were reduced by 30% in the last 2 years, which represents savings around 5260 € per year.

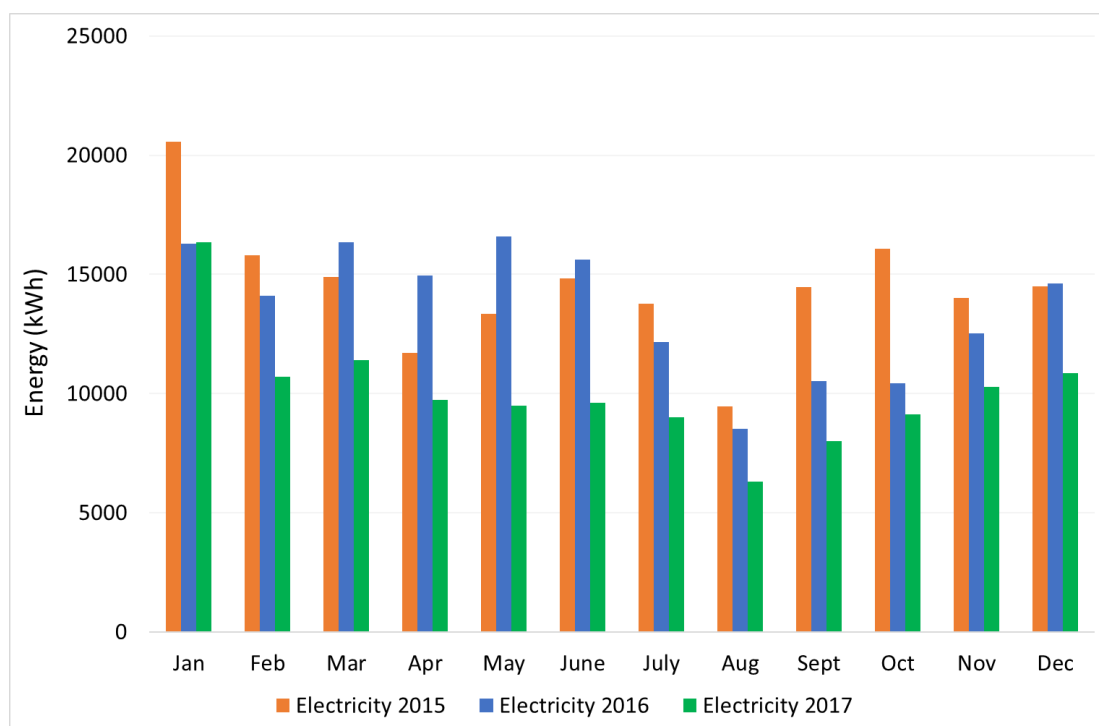


**Fig. 9 - Monthly average energy consumption in 2015, 2016 and 2017**

### 3. RESULTS DISCUSSION

The measurements of building water consumption for 2017 essentially reflect the effect of reducing the volumes discharged into the toilets, because the flushing cisterns regulation (measurements completed in late 2016). The effect of reducing flow rates on self-closing taps also have influenced the results, but on a smaller scale, as this measure only covered the last months of the year.

The water consumption records show a reduction from 568.8 m<sup>3</sup> in 2016 to 358.8 m<sup>3</sup> in 2017 (36.9% less). This reduction exceeded the objectives set out in the audit in terms of possible outcomes with technical measures, a situation that can be partly attributed to the student number reduction that occurred progressively in recent years in the Department, and due to the measures to increase user awareness.

The reduction in the number of students in the Department in recent years, justified by the crisis in the construction sector in Portugal, can be considered significant. However, the fact that consumption records show a decrease in values immediately after the implementation of the measures means that this reduction is not the main reason for the decrease of consumptions, although it may have contributed to better results than expected. According to studies carried out in Portugal by ANQIP (in the region of Aveiro) [8, 9], the energy consumption related to the consumption of water in dwellings corresponds to almost 75% of sanitary hot water (SHW) heating and of about 25% of energy consumption in the public water supply network, in the public drainage network and in the wastewater treatment. However, the implemented measures in the building under study, until the current date, essentially respect the reduction of cold-water consumption, being analysed in this paper only this component. According to data provided by the local water authority (AdRA), energy consumption in the supply public water network of the municipality of Aveiro is 0.838 kWh/m<sup>3</sup>, and in the public



drainage network and wastewater treatment is  $0.818 \text{ kWh/m}^3$ . However, in the case of water supply, this unitary value should not be applied directly to consumption measured at the entrance of the houses, as there are leaks throughout the water supply system, which imply that the volume abstracted and treated should be higher, with obvious repercussions in the energy consumption. According with the records of AdRA, in the municipality of Aveiro an increase coefficient of 1.33 should be considered to include water losses, affecting essentially the volumes abstracted, treated and pumping. With respect to wastewater, it is estimated that almost 90% of the water consumed in buildings in the municipality of Aveiro is discharged into public sewers after use. However, in contrast, exist infiltration flows along the sewer network that increase the volumes to pump and treat downstream, and therefore can be assumed that the energy consumption in this component can be determined in a first approximation without any correction factor, i.e., directly based on the water consumption in buildings [8, 10]. Based on these considerations, it can be concluded that each  $\text{m}^3$  consumed in a building implies the consumption of  $1.115 \text{ kWh}$  in the water supply network and the consumption of  $0.818 \text{ kWh}$  in the drainage network and wastewater treatment, preforming  $1.933 \text{ kWh/m}^3$ . So, in the building under study the reduction of the annual water consumption from  $568.8 \text{ m}^3$  to  $358.8 \text{ m}^3$  ( $210 \text{ m}^3$  in total) imply a reduction of energy consumption in public system of  $406 \text{ kWh/year}$  ( $210 \text{ m}^3/\text{year} \times 1,933 \text{ kWh/m}^3 = 406 \text{ kWh/year}$ ). The type of energy used in the public systems of water supply and drainage is exclusively electricity and, according to the main power operator in Portugal (EDP), the commercialized electricity is produced from a mixture of sources, including hydro, coal, wind, nuclear, natural gas and other (including national production and imports). The most significant contribution to GHG emissions in Portugal, in the energy sector, corresponds to  $\text{CO}_2$  emissions. These emissions were weighted, in 2017, in  $235.0 \text{ g/kWh}$  electricity. Other gases such as  $\text{SO}_2$  or  $\text{NO}_x$  have a negligible contribution. On the basis of this figure, it can be concluded that the measures already implemented as a result of the building audit will lead to a reduction in emissions of almost  $100 \text{ kg CO}_2/\text{year}$ . The energy audit took place between 13<sup>th</sup> of October and 20<sup>th</sup> of November 2017. In this period the energy consumption was measured, as the temperatures and relative humidity in different building spaces. The average daily electricity consumption measured differs less than 3% from the building energy monitoring system values. Figure 10 and 11 show the building energy consumption for two different periods, 3<sup>rd</sup> week of October with low heating demand and the 3<sup>rd</sup> week of November with higher heating demand. It is noticeable the effect of the weather conditions in the building energy consumption, mainly in the heating energy consumption, which increased 500% comparing the end of October with the end of November. On this period the heating set point was increased one degree, from  $20^\circ\text{C}$  to  $21^\circ\text{C}$  which could in part explain the increase in the heating (HVAC) energy consumption. The energy consumption in Floor 1 and 2, where are most of the classrooms and offices, increased 35%, which may be explained by the increase in the use of individual oil heaters and/or fan heaters during the heating season. In contrast, the building lightning energy increased 11% and the energy consumption in Floor 0 decreased 35% in comparison with the October week. It worth noting that in October the sunset happens at 19h00 while in November occurs at 17h20, meaning at least 1h40 additional use of electric lighting. In almost 70% of occupancy time, the spaces comply with adaptive thermal comfort criteria, and some rooms due to their occupancy (PhD room, classrooms) had some periods above  $25^\circ\text{C}$ , Figure 12, regarding EN 15251 [11]. To address some user complains concerning indoor low temperatures during the winter season, the building energy management increased the set point in  $1^\circ\text{C}$ . During the audit period was noticeable the decrease in the outside temperature which led to a significant increase in the building electricity consumption, particularly in the HVAC system (Figure 13).



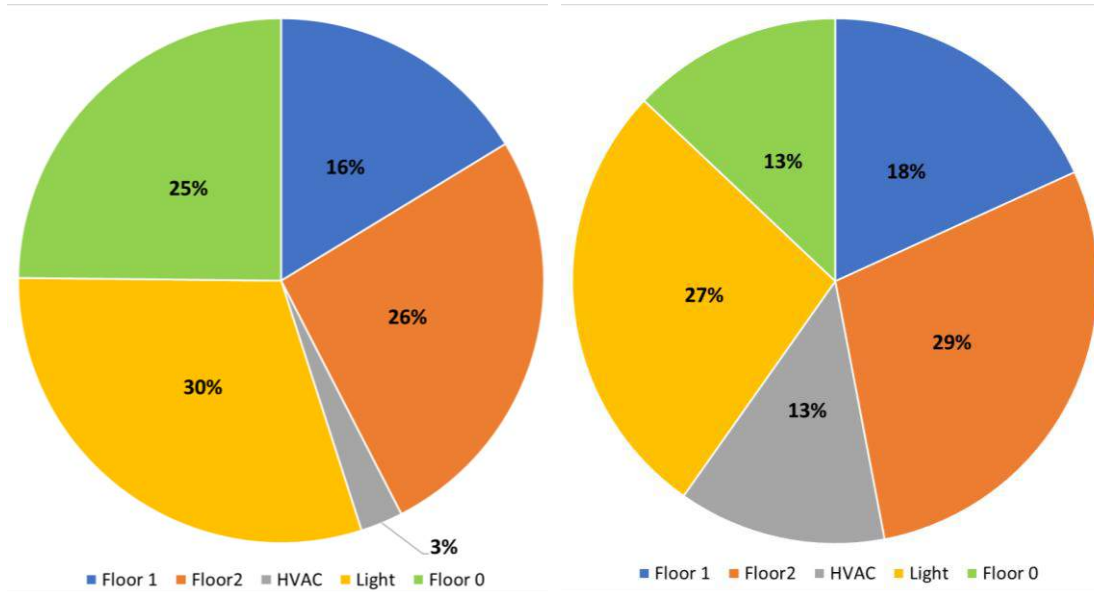


**Fig. 10 - Energy consumption between 16th and 22th of October, with an average energy consumption of 295 kWh/day**

**Fig. 11 - Energy consumption between 13th and 19th of November, with an average energy consumption of 361 kWh/day**

According the European standard EN 12464-1 [12] the illuminance requirements are 300 lx for classrooms and teacher offices, 100 lx for corridors and circulations areas, 150 lx for stairs and 200 lx for entrance hall. The lighting intensity measurements show that corridors were sub lighted, while classrooms were over lighted, and offices had illuminance around the required level. The energy efficiency of electric lighting systems assessed by the normalized light power density (LPDN) is higher in corridors with the new LED projectors, while is around the Portuguese requirements at offices and classrooms, showing potential to save energy with a retrofit of electric light system, Figure 14. Figure 15 depicts the energy efficiency increase in the sequence of replacing the sodium vapour projectors by LEDs lighting systems.

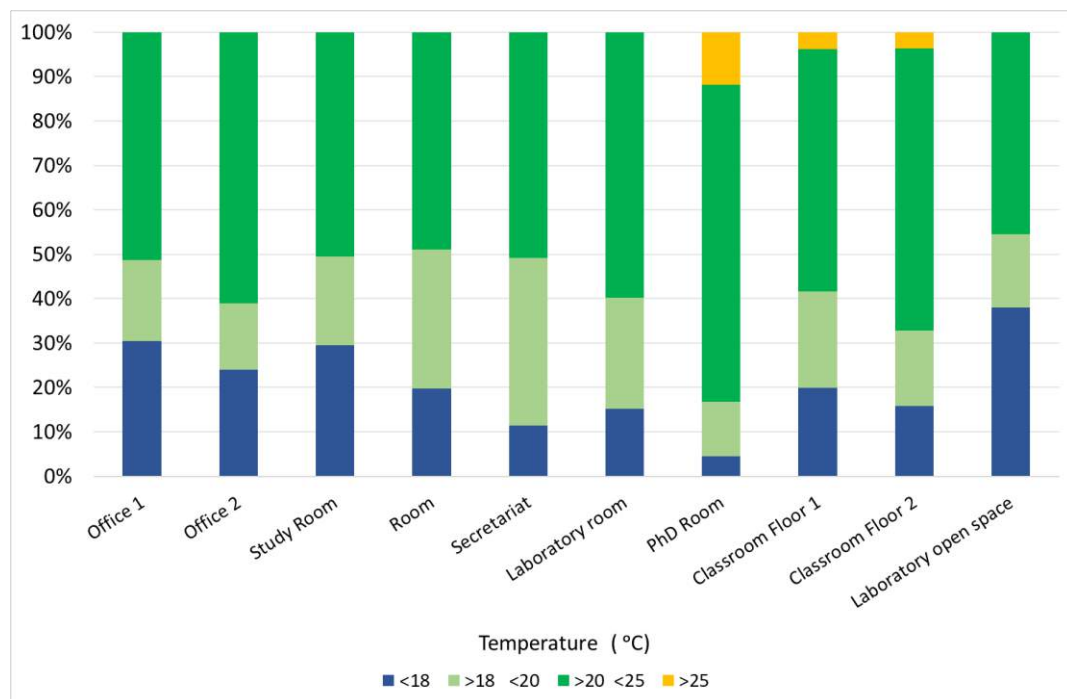


**Fig. 12 – Spaces temperatures for working days between 8am and 8pm**

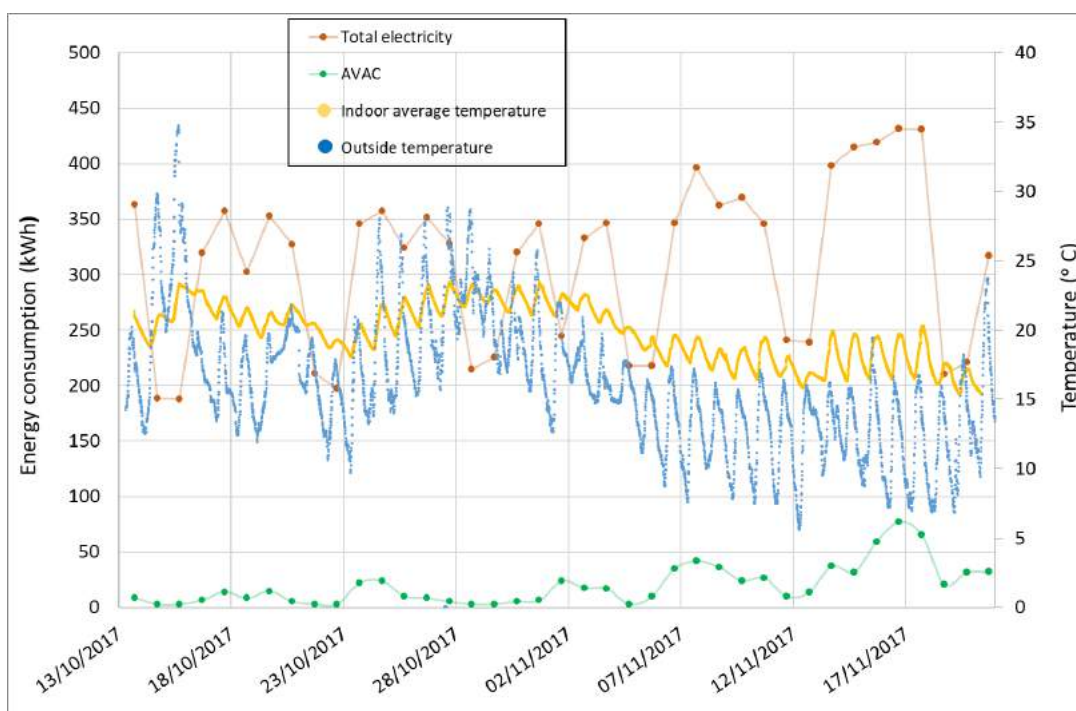


**Fig. 13 – Comparison of the inside building average temperature with the daily average total building electricity consumption and HVAC electricity consumption**

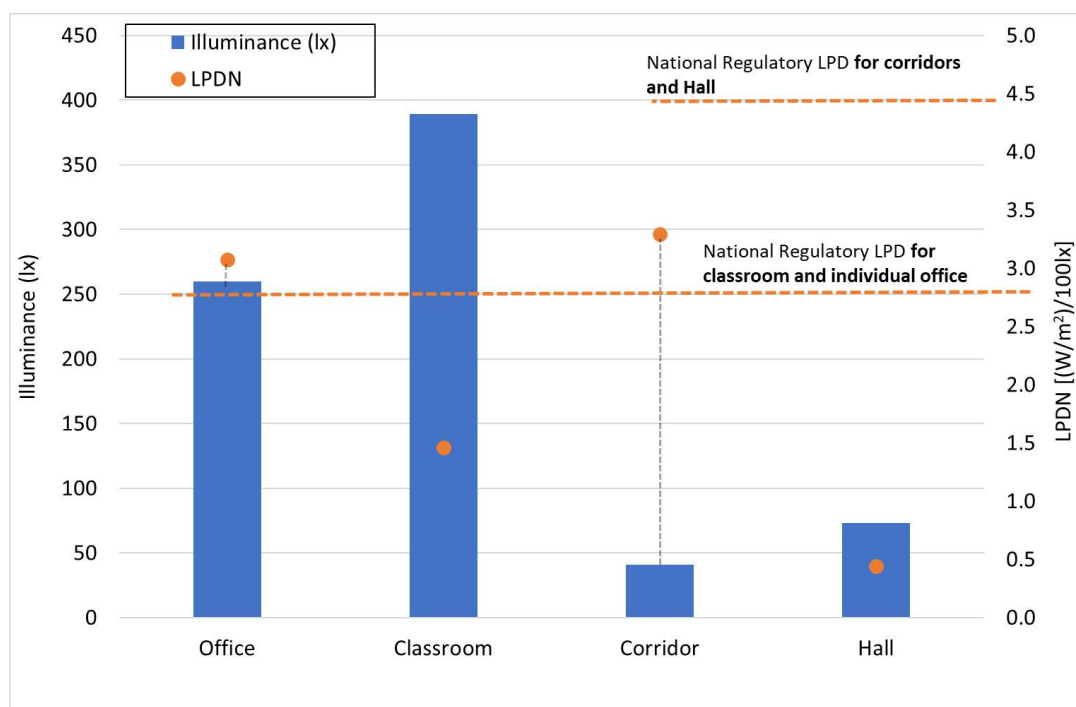


**Fig. 14 – Illuminance and Normalized Light Power Density**

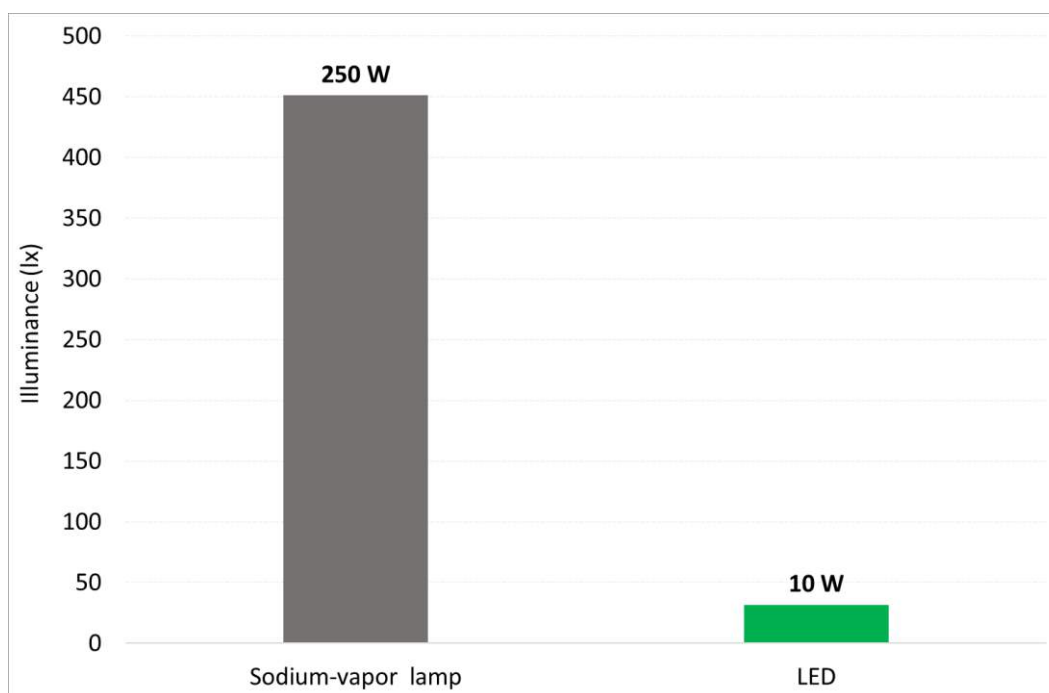


**Fig. 15 – Energy consumption and LPD for Sodium Vapour and LED lighting projectors**

#### 4. CONCLUSIONS

The water efficiency audit shows that with simple measures it is possible to significantly reduce water consumption in the building as well as associated energy consumption within the energy and water nexus. With the implementation of all the measures foreseen in the water efficiency audit, the possibility of total consumption savings of 27% (162 m<sup>3</sup>/year) was foreseen, with a short reduced return period of around seven months. However, after the implementation of the first proposals, it can be seen that the audit forecasts are conservative, as the results being obtained show savings above those originally forecast. The estimated reduction of 162 m<sup>3</sup> in water consumption in the building leads to reductions in energy consumption in public water supply and wastewater networks of around 313 kWh/year. In the building, only 2.5% of the consumptions (showers) imply the water heating, being the majority of the water consumption in the building of cold water. Thus, the effects of the nexus water-energy are not significant in this case at the building level, where there is a reduced production of domestic hot water, but are significant at the level of public networks.

In the energy audit, it was observed that thermal comfort conditions are provided to the building occupants in most of the time (70%). In cold months (November to March) the building tends to be cold and the heating system are required to provide thermal comfort, increasing the building energy demand from 17 MWh/month to 26 MWh/month, meaning that building thermal envelope should have better thermal insulation.

With the implementation of energy efficiency measures involving the electric lighting system and better management of the building energy systems, the electricity consumption decreased by 30%. In the building almost 30% of electricity consumption is related with electric lights and 45% with office and testing equipment's. The efficient electric lighting measures contribute for around 35%, 14200 kWh/year, of the electrical consumption reduction reached between 2016 and 2017. Albeit the positive impact in the electricity consumption by the electric lighting system retrofit, the illuminance decreased significantly. The remaining energy reduction can be explained by the occupancy variation, by the activity in the building rooms and by the decrease of the HVAC setpoint temperature. Despite the holidays period in August, a large energy consumption occurs due to the fact of several equipment stay working and also several researchers in spite of the holiday period stay working in the building. It can be also concluded that the significant energy reduction in the last two years, has a relative small impact in the thermal comfort conditions.

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