A Matrix to determine housing technologies

Michael Baeuerle

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Smart
Renovation
Factory
by INDU-ZERO

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North Sea Region
INDU-ZERO
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A Matrix to determine housing technologies for serial renovation

- Project Review –

Module 2.1. of the master's degree Sustainable Energy Competence (SENCE)

Written by
Michael Bäuerle
- Technical University of Applied Sciences Ulm -
Mat. Nr. 3136652

Mentors:

M. Sc. Frank Hettler
University of Applied Sciences and Forestry Rottenburg

Ulla-Britt Krämer
Province of Overijssel

Johan Goezinnen
Comfort Partners | TBI

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Housing technologies for serial renovation

The energy supplied by the sun to the roof of a house can be enough to reach the Net-Zero-Standard by using PV-generators only. For buildings with more stories and many inhabitants, the roof becomes in some cases too small to gain enough energy using PV-generators only. To still be able to collect enough energy from the rooftop without the need of PV-integration into the façade the first task of this project was to investigate, whether PVT-Collectors are a method to increase the solar gains on the roof, so that even large houses with many inhabitants will become net Zero.
For this, there was a literature research done, to provide information about PVT-Systems and components, that belong to the technology or that have an impact on the performance of the collector.

As the second task of this work, a Matrix was created, that allows easily to determine necessary housing technologies for reaching the Net-Zero Standard for nearly every building, that is within the scope of the INDU-ZERO project. For this, the matrix allows to alter all necessary parameters that are relevant for the calculation of the Net-Zero-Standard and housing technologies, that are connected to the matrix. The matrix can directly gain information from the PHPP tool to calculate the solar gains throughout the year, that are available to cover the demand of one square meter of living are. To do so, it uses the information about the inclination of the roof, the roofs orientation, and the buildings climate data, that need to be provided to the PHPP tool. With a second and third matrix, the Excel-Sheet helps to determine the amortization time of heat pumps, so that a decision about the invest can be done easily.

In the third part of this work, there will be a conclusion, that shows that heat pumps are the best measure to supply houses with heat and that PVT is in fact not the solution, that will help to get buildings Net-Zero, but rather a solution to provide heat at a low noise level.

Introduction of the INDU-ZERO project

The Vision

The Climate-neutrality of the EU by 2050 is an ambiguous aim which the EU has set itself. Whereas in the electric power sector great progress has already been made, the building sector is at the beginning of its transformation to climate-neutrality. Currently 40 % of the EU's energy consumption and 36 % of greenhouse gas emissions are still accountable to buildings. With the current rate of energetic renovations of only one percent, there is no fast improvement to expect. To change this undesirable status quo, the EU introduced the renovation wave strategy, aiming to at least double the renovation rate by providing more funding (European Comission - Press Release).

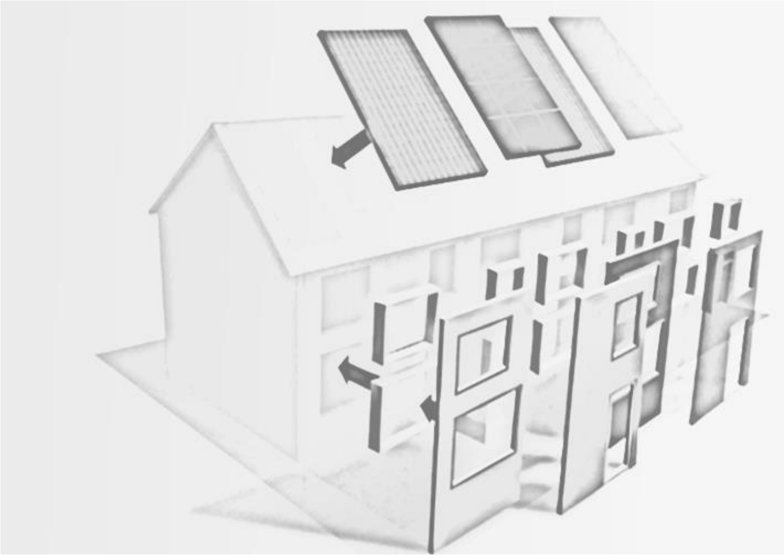
However, doubling the renovation rate using the standard methods, lets this aim appear very ambiguous: The energetic renovation of a building is a difficult and effortful process, that takes a lot of planning and the will and ability to carry financial burdens after the installation. The solution to this is using new methods like INDU-ZERO. INDU-ZERO follows the strategy to industrially and serially renovate terraced houses using automation and industrialization to accelerate the planning, fabrication, and implementation of the renovation. By manufacturing prefabricated curtain facade elements with integrated renewable energy technologies, the INDU-ZERO-Concept transforms the construction site to an installation site and shifts costly manual labor into highly automized fabrics. The combination of renewable energies, smart technologies and high insulation standards will make it possible to cost effectively turn existing buildings into Net-Zero buildings within less than a day of work.

The INDU-ZERO project aims to be a sustainable solution for everyone, to have a renovation of their home, which will be affordable, comfortable and climate friendly.

Installations of INDU-ZERO

The Aim of INDU-ZERO are climate friendly, cost-effective, and convenient renovations. Since every housing unit has different needs and the cost of a renovation can significantly vary, the following table shows, what the INDU-ZERO services cover and what the properties of the renovations are. Defining the packages makes it also possible to compare INDU-ZERO with other renovation methods.

Targets	Description
Preferred type of house	➢ Terraced Houses ➢ Semi-detached houses ➢ Apartments
Preferred year of construction	➢ 1965 – 1975 (focus of construction years) ➢ Other years also possible
Costs	Ordered by rising expenses per unit: ➢ Apartments (only done for entire dwellings, single apartment not possible) ➢ Terraced House ➢ End-of-Row or Semi-Detached General: Only 50 % of the conventional costs for a renovation

Package and Pricing	
Included	➢ Design costs ➢ Demolition costs of the chimney and roof including roof tiles. ➢ New windows and doors – the new doors and windows are included in the façade elements. ➢ Standard technical Installations
Description of the Panels	➢ Façade-Elements for the façade and roof ➢ Triple Glass in the integrated windows and doors as a standard, which will mee the requirements for passive houses. ➢ Thermal Resistance of 7 m^2*K/W for the components, limiting the thermal conductivity to 0,15 W/m^2*K (passive house standard) ➢ Airtight ➢ Compliant with the flora and fauna law of the EU-Countries ➢ Fulfillment of all legal requirements, for example fire resistance  *Figure 1: Concept of the INDU-ZERO Panels (INDU-ZERO 2019, S. 13)*
Technical Installations	➢ Need for determination: Centralized ventilation unit with integrated channels in the façade-elements or use of the existing decentralized ventilation concepts (including windows) with heat recovery ➢ Control and monitoring Panel for every housing for viewing the energy consumption of the unit and adjust settings ➢ No Standard: Heat pumps or connection to district-heating
Heating	➢ Bathroom heating with infrared panel ➢ Domestic hot water (DHW in the following) heater small storage for bathroom and shower ➢ Fan for bathroom with 95 m^3/h of ventilation power ➢ Boiler with 4,5 liters of water at 60°C for the kitchen ➢ Electric heating included in the package. ➢ No Standard: Central heating system of the house

Energy generation	➢ PV-Generator on roof. Depending on the size of the roof: 11.4 kWp or by approximately 30 PV-panels ➢ Expected annual Production: 9.120kWh/year in the Netherlands
Timeframe	➢ Performance: 20 years for the total package ➢ Building time: Within one day for terraced houses or terraced houses – allowing the occupiers to stay at home during the renovation
Energy Performance	➢ Net Zero Standard (EU)

Table 1: Description of the INDU-ZERO Package (INDU-ZERO)

Description of the energy Performance

Within the scope of INDU-ZERO "Net Zero" is defined as "zero on the meter". This means that a housing unit can consume as much energy as it produces within a year. By combining smart heating engineering technologies, high insulation standards and renewable energy generators, the consumption becomes so small, that the renewable energy produces enough energy to keep the balance between consumption and generation. In the Netherlands, the metering system allows customers to spin their meter back by generating more solar energy than they use during the summertime, what makes the meter look as if there was zero consumption.

Description of the PHPP-Tool

The PHPP-tool is an EXCEL-based tool, that helps to calculate the energy consumption of a house according to its installations. The PHPP-Tool is optimized for passive houses and regards all outside areas for transmission losses and housing technologies, that help to regain and generate energy. The tool can be used for calculations to obtain federal funding if a building is renovated or build very well. The PHPP tool is a production of the passive house institute in Germany in Darmstadt.

Concepts of PVT-Collectors

PVT collectors combine the possibility to generate energy with a PV-Panel and use the excess energy for heating applications. Since they mix the PV-technology with the ST-technology, the are also called hybrid collectors.

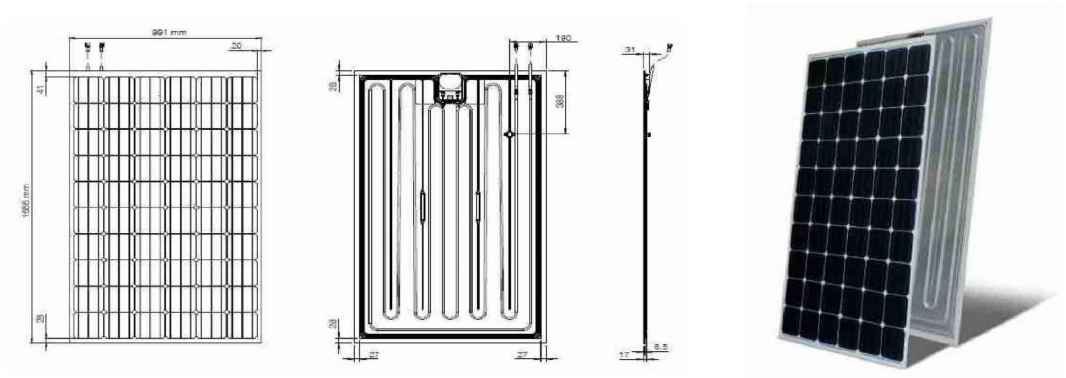


Figure 2: Technical Drawing of a PVT-Panel (Sperr Nadia 2019, S. 32) and Figure of a PVT by Meyer Burger (Sperr Nadia 2019)

In general, the existing PVT-Collectors on the market can be divided by their heat transfer medium. So, some PVT-Collectors operate with fluids and the other kind operates with gaseous media. A further division of the collectors can be made by their insulation to the surrounding environment. The following table gives a quick overview about the properties of the collectors.

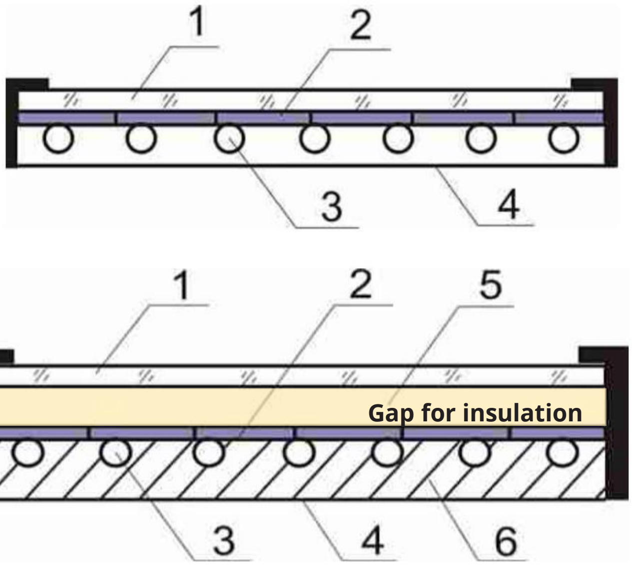
Properties of PVT-Collectors		
Heat transfer media	Fluid or Gaseous	
Insulation	Covered	Uncovered
Properties	➢ Well insulated ➢ low thermal conductivity to the surrounding area	➢ Bad insulation ➢ high thermal conductivity
Energy sources	➢ Mainly from the radiation, little influence from the surrounding environment	➢ Radiation and greater influence from the surrounding environment ➢ The connection to the environment also represents a possibility of heat loss ➢ Can supply more energy, as the radiation supplies ➢ Can be used with a heat pump
Other names		➢ WISC – Wind and infrared sensitive collector (Popp et al., S. 5)

Table 2: Properties of PVT-Collectors

Facing the fact that many collectors are covered with a glass plate to protect the PV-generator but not to mitigate thermal losses, the classification into covered and uncovered was updated in the new preliminary version of the Vocabular of sun energy (DIN EN ISO 9488 from 2020), which refers to uncovered collectors as WISC-collectors now. The main constructive difference between the covered and uncovered collectors is a gap between the PV-generator and the glass cover (see the figure below). This gap is mostly filled with air and mitigates thermal losses. Additional to the insulation on the frontside, some panels are also insulated on the back. (Adam Mario, Wirth Hans Peter, Radosavljevic Rada 2014, S. 14–19).

PVT-Collectors with fluid heat transfer medium

PVT-Collectors with a fluid heat transfer medium are constructed like the standard PV-collector. Many collectors resemble standard PV-generators, to which a thermally well-connected piping system were affixed. The fluids need to be suitable to the possible lowest temperatures, so that they need to be frost-proof in areas, where low temperatures can be expected. The heat absorbers with the fluid media inside are arranged in various flow patterns at the back of the generator, where many manufacturers choose a flow patter with meanders.



Description of the elements	
1	Transparent glass plate
2	PV-Generator
3	Heat absorber pipes: parallel or in loops
4	Back of the collector
5	Gap for insulation to mitigate thermal losses
6	Insulation (optional)

Figure 3: Covered PVT-Collector with fluid heat transfer medium (Adam Mario, Wirth Hans Peter, Radosavljevic Rada 2014, S. 14)

The Smart Roof by Tegnis

A solution, that uses a similar principle as the principle above is the “Smart-Roof” by Tegnis. Instead of collecting the air behind every single panel, the panels are connected to a whole roof area. The air of the back-ventilation of the panels can heat up during it rises along the slope of the roof. At the purlin, there is a heat collector, that collects the heat from the air, that is going through it by natural convection. Within the heat collector, a fluid heats up. This fulid is led inside the building, where it is used as a heat source for a central heat-pump.

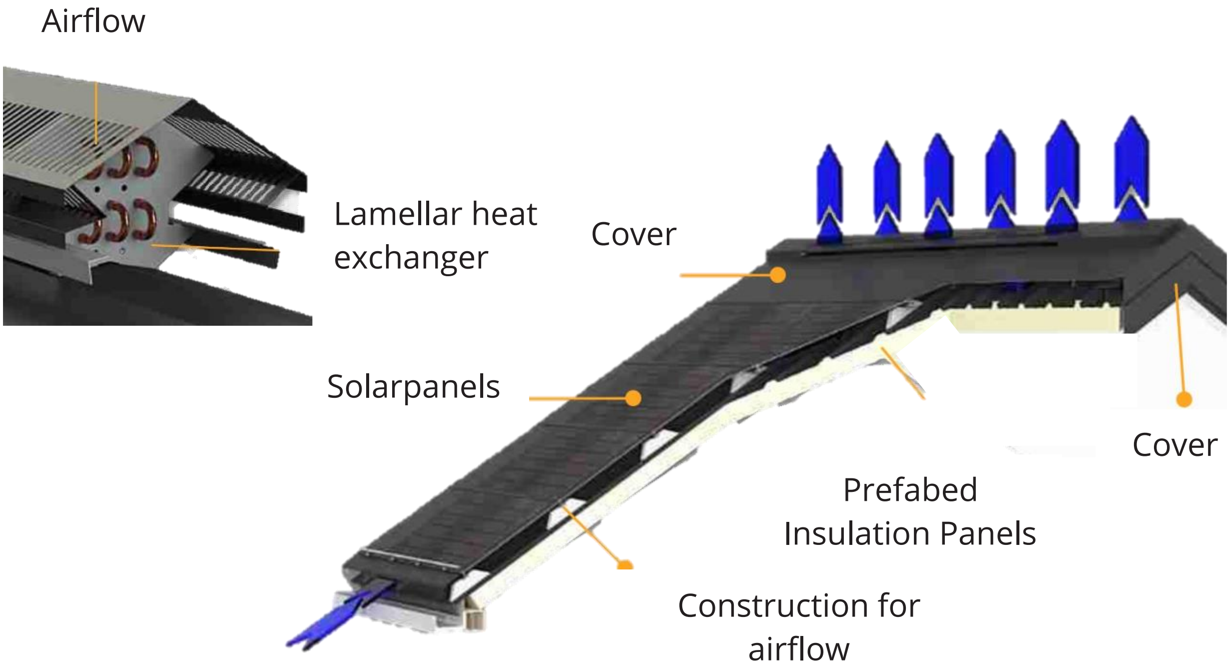


Figure 4: The Smart roof uses the excess heat of the solar panels by natural convection through an evaporator at the purlin (Tegnis 2019)

Solar-Air-Absorbers underneath Solar Panels

The following technology combines a standard solar heat absorber/air-heat-collector with standard solar panels – making it the “Kraftdach”. The solar heat absorber is placed underneath the solar panels, so that two standard technologies are combined with each other. The construction can also be mounted vertical. Like the smart roof, the solar panel is not directly connected to the heat absorber itself, so that convection helps for the heat transfer to the medium. Further the solar heat absorber can also be used as a heat source for a heat pump.

Figure 5: Kraftdach (Metternich Haustechnik 2021)

PVT-Collector with air as a heat transfer medium

The structure of PVT-Collectors with gaseous heat transfer media is less complex than the structure of the PVT-Collectors with liquid media. The used components have a smaller potential for leakage. Just as in the case of the PVT-Collectors with a liquid heat transfer medium, most collectors also use standard PV-only Panels. These PV-Only panels are mostly connected to a ventilation system, that collects the warm air at their back. Since large housing units have in some cases already an existing heating system, the following systems could be easily adapted to the existing structures. Further it might also be possible to CNC-mill air pipes for a central heating system into the panels and create a structure, that could use the heat directly in an efficient way.

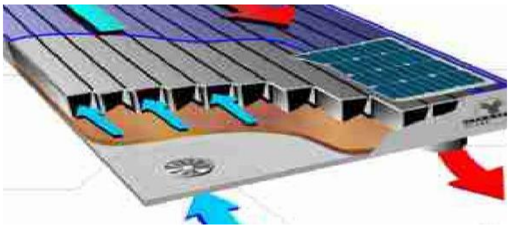
Solar Cell with back ventilation (uncovered collector)

Solar Panels heat up during operation, because a large fraction of the arriving sunlight cannot be converted to electric energy. The Solarwall concept uses this excess heat. The solar panels are placed on a metal sheet with many small holes, through which the warm air of the back-back ventilation is sucked into a piping system. The air can be used to preheat or even heat the air going into buildings. The concept was originally developed without PV-panels and was sold as a façade element. Both concepts can be combined to support the heat changer for fresh air or increase the efficency of a heat pump since the air going to the pump has a higher temperature level, which will be beneficial for the COP of the heat pump. (Adam Mario, Wirth Hans Peter, Radosavljevic Rada 2014, S. 19–23)

Figure 6: Working Principle of collecting warm air with PV-Modules using the back ventilation – Applicable on entire roof (Solarwall.com)

<u>ST-Collector with a small PV-Panel for operating a ventilator</u>

This concept does not resemble an actual PVT-Collector. A solar cell is placed on top of an absorber, so that the absorber has a heat source for driving a ventilator, that pushes outside air through a labyrinth of pipes that are heating the air. The excess heat of the panel does support the heating of the air. Since the PV-panel, however, is only there to supply the power for the fan, it is no classic PVT-panel, which would generate energy for other devices. The concept reminds of a Trombe wall, with an additional PV-Panel and a ventilator.



Inlet Air is heated by the panel
and directly ventilated into the
house.
At Radiation of 1000 W/m^2 ->

Figure 7: Solar-Air-Collector – Implementation in a house (Grammer-Solar.com) and Principle of the Collector (Grammer-Solar.com)

Covered PVT-Collectors

Covered PVT-Collectors have a glass cover with a gap between the heat absorber and the environment, which helps to mitigate heat losses. The following figure shows different positions of the PV-generators and the airflow.

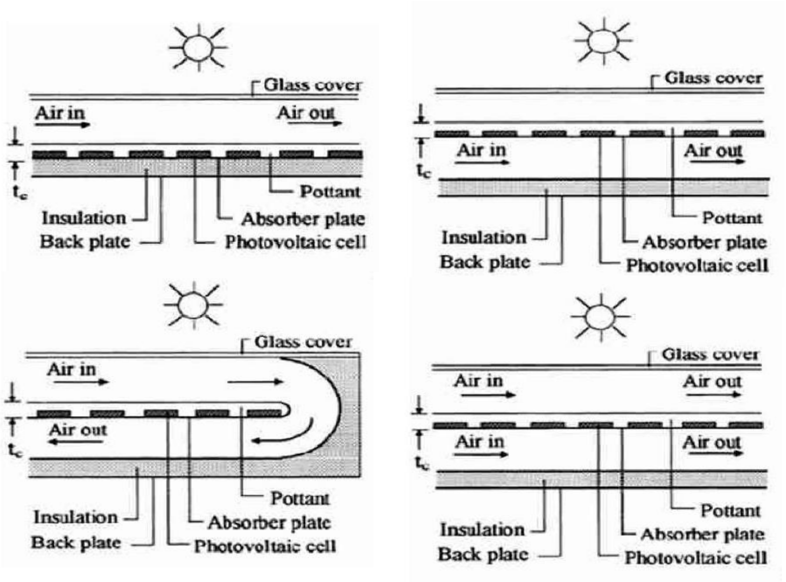


Figure 8: Covered PVT-Air-Collector – Different Working Principles (Brahim und Jemni 2017, S. 551)

Concentrating PVT

A concentrating PVT system heats the circulating fluids to a higher temperature, so that the energy has more exergy, which makes the energy more useful. The heat could be used to supply process energy, heat DHW and it could also be stored in a tank easily. The disadvantage of concentrating PVT-Panels is, that the mostly need a sun-tracking system. This makes them not suitable for an integration in most of the existing buildings within the INDU-ZERO concept. The only concentrating PVT-Collectors that could still be used would be systems with a small concentration factor, because they do not need to track the sun. Such a solution, however, does currently not exist on the market and would probably be extremely expensive. A further severe problem with the concentrating PVT-technology is, that for the concentration direct irradiation is needed (Adam Mario, Wirth Hans Peter, Radosavljevic Rada 2014, S. 23–24) . Considering the weather and the irradiance in the INDU-ZERO region in comparison to the areas, where concentrating systems reach high efficiency levels, the concentrating PVT solution will not be regarded any further in this report.

Comparison between the fluid and gaseous heat transfer media

	Fluids	Air
Handling of heat transfer media	Smaller pipes/higher energy density	Bigger pipes needed due to large air volumes
Heat transfer to other systems	Heat transfer to other systems with smaller heat transfer surface possible.	Larger surface for heat transfer needed
Storage	Storage in tank at collector exit temperature or at higher temperatures generated by heat pump.	Hypocaust, stones, transfer the heat to a liquid medium, that can be handled with standard pumps and pipes. Using a heat pump to generate higher temperatures to store the energy at higher temperatures.
Leaks of pipes	Loss of fluid can result in a damage to the building	Leaks in Air pipes do not lead to a damage on the building but will probably lower the performance.
Use in the INDU-ZERO Project	➢ Integration in the central heating system. ➢ Using a similar technology like a heat collector at the purlin	➢ Support for centralized ventilation system, using channels in the curtain façade elements ➢ Using the hot air as a heat source for heat pumps
General Advantages of the PVT Technology	➢ Uncovered collectors can produce the same amount or even slightly more energy than PV-only panels ➢ Suited for preheating or direct heating of domestic water at ➢ Heat can be used as a heat source for a heat pump ➢ PV-Power and the ST-heat can lead to a 100 % solar solution ➢ PVT collector can be used for solar cooling in the night ➢ Low social impact of the system ➢ Lifetime from 20 – 40 years expected, case studies pending (International Energy Agency 2020b, S. 1–2)	
General Disadvantages	➢ Technology is more complex than two standard solutions ➢ Covered collectors produce due to higher collector temperatures less electric energy (in an optimized system only 5 % less) (Wenker Kai, Jäger Helmut, Dolezal Adam 2012, S. 13)	

State of the Art Applications

The following table shows possible applications for PVT-Collectors, that are currently the state of the art.

	DHW	Space Heating	Heat Pump Optional = If More Energy is needed or temperatures are not reached
WISC Collectors			
Renovated building	Yes (heat pump)	Yes (heat pump)	Needed
New buildings	Yes (heat pump)	Yes	Optional
Low energy houses	Yes (heat pump)	Air in the ventilation system/water in the floor heating solution	Optional
Covered PVT-Collectors			
Large buildings (Hotels, commercial, residential….)	Yes	Yes	Not recommended

Table 3: Current Applications grouped by collector type (International Energy Agency 2020b)

The reason for operating covered collectors without a heat pump is, that well insulated collectors hardly absorb warmth from the surrounding environment. This effect leads to a cooling of the panels, so that the COP of the heat pump gets lower than in a WISC-system, in which the panels can gain warmth from the surrounding environment. (Adam Mario, Wirth Hans Peter, Radosavljevic Rada 2014, S. 69) Using a larger area of PVT-Panels can mitigate this effect, so that they will behave similar to covered ST-Only cells, that can be used to produce DHW or support the heating system during the wintertime without a heat pump. (Adam Mario, Wirth Hans Peter, Radosavljevic Rada 2014, S. 125)

Technical details of collectors regarding the efficiency

The performance of PVT-Collectors is a combination of several influence factors. While the annual output of a grid connected PV-panel does not depend on the own-consumption because the produced energy can be sold at any time, the output can easily be calculated for PV only systems, because the gains depend on the orientation and the radiation only. Calculating the thermal gains of a PVT-panel, however, is much different. The gains depend on the own consumption of energy for heating and domestic hot water. This fact leads to the need of a well dimensioned system in which the PVT-Generator in now only a part anymore. The gains of PVT-Generators could be compared to a PV off-grid system with a battery. For a deeper understanding, important parameters and technical details are shown, that explain more about the combination of PV-Generators, ST-Generators, heat-pumps and domestic hot water systems.

Thermal influence on the power of PV-Generators

The efficiency of the solar panel represents the percentage of the radiation that can be converted to electric power. In the technical datasheets of solar cells, the efficiency is rated under standard test conditions (STC). The standard test conditions represent an irradiance of 1000 W/m^2, an Air Mass (AM) of 1.5, a temperature of 25 °C and no wind. If other conditions are used, they are specified. The measured values at STC only count for new modules because the modules degrade over time, although they are very low. Some manufacturers advertise with degradation rates of only 0.5 % and offer a linear performance warranty.

By choosing efficient PV-generators, the cell-technology has a strong influence on the efficiency of the solar panel. For cells in the mass production the efficiency is rated at 17 – 23 % for monocrystalline silicon cells, 15 – 18 % for polycrystalline silicon cells and 8 – 14 % for thin layer cells. Concentrating solar cells can reach an efficiency of 30 %. If the efficiency is rated for cells in the laboratory, the values are significantly higher. (Watter 2019, S. 43) Besides the efficiency, the cell technology is also a main criterion for the primary energy consumption of the cells. The monocrystalline silicon cells for example have the largest footprint in the production.

Since the solar panels within the PVT panels, that are cooled on their back, the temperature dependency of the performance can be seen in the figure below. At lower temperatures, the efficiency increases and at higher temperatures the efficiency decreases. The performance loss depends on the module type and tends for Si-Cells to be at - 0,45 %/K at standard test conditions.

Temperature dependency of U_{OC}, I_{SC} and P_{max} of Si-Cells

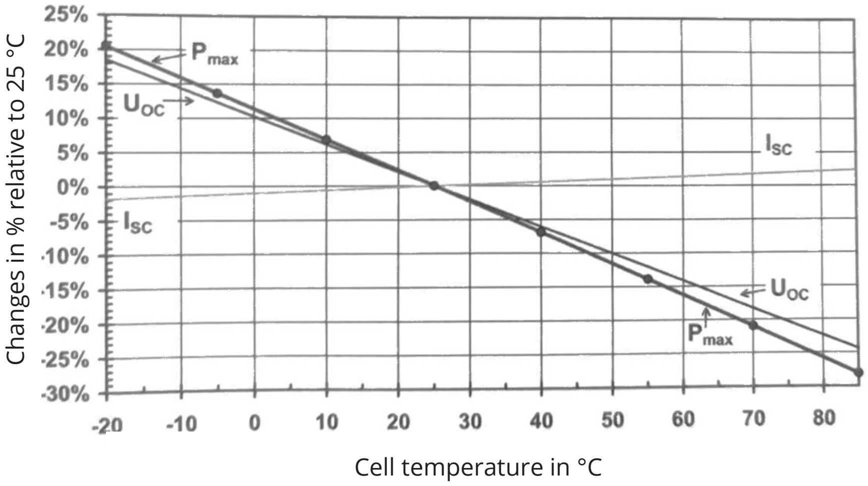


Figure 9: Performance of PV-generators at different cell temperatures (Häberlin 2010, S. 93)

Looking at Figure 9, the impact of the temperature on solar cells becomes visible. PVT-collectors can increase the PV-output by cooling the panels. If the irradiation is not too far away from the STC, the output power and the temperature are in a linear coherence.

To determine the temperature of the solar cells, the following formulas can be used:

$$T_{Cell} = T_{ambient} + (NOCT - 20\,°C) \times \frac{\dot{G}}{G_{NOCT}}$$

T_{Cell}:	Temperature of the Solar Cell in °C
$T_{ambient}$:	Ambient Temperature in °C
NOCT:	Normal Operating Cell Temperature in °C
$\dot{G}$:	Current Radiation in W/m^2
E_{NOCT}:	Radiation for NOCT - value from Datasheet – 800 W/m^2

With the determined Temperature, the power P’ can be calculated with the power at standard condition PSTC using the temperature coefficient TKP from the datasheet of the solar panel.

$$P' = P_{STC} \times [1 + TK_P \times (T_{Cell} - T_{STC})]$$

With P’ the output power P” can be calculated as follows:

$$P'' = P' \times \frac{\dot{G}}{G_{STC}}$$

(Brunotte Martin, S. 15)

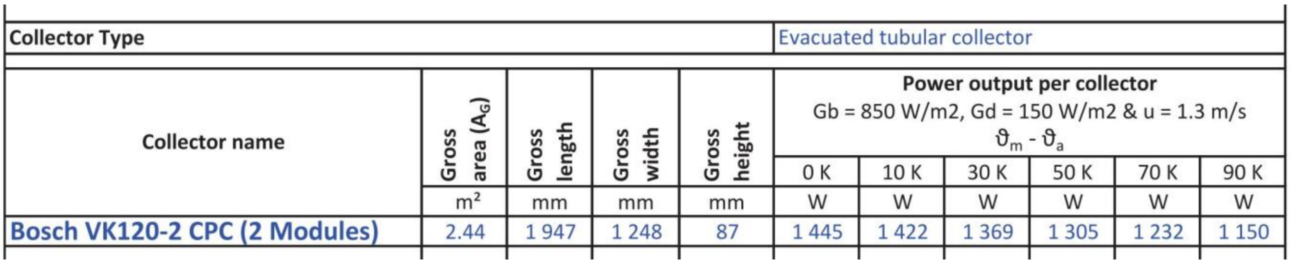
Influence factors to the efficiency of the DHW-Preparation and Heating System

Since thermal gains of the PVT-System dependent on the own consumption within the building the housing technologies must be regarded, too. The following paragraph will deal with important parameters of the collector system, heat pumps, domestic hot water storage tanks, and radiators.

Collector System

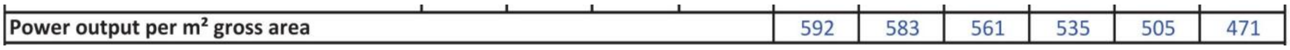
Like for PV-Panels, there are also professional test for Solar thermal collectors, that help to determine their output. An established certificate is the Solar Keymark Certificate. It is a quality label, that assures to the customers, that the collectors has the specified properties and that the collector meets the European standards. (Solar Heat Europe) For a better understanding of the Solar Keymark Certificate, the most relevant parts of the certificate are briefly explained:

The collector output is calculated in the test at various temperature differences to the ambient air. Additional to these results, there are information about the testing conditions and data about collector.



Collector Type					Evacuated tubular collector					
Collector name	Gross area (A_G)	Gross length	Gross width	Gross height	Power output per collector Gb = 850 W/m2, Gd = 150 W/m2 & u = 1.3 m/s ϑ_m - ϑ_a					
					0 K	10 K	30 K	50 K	70 K	90 K
	m^2	mm	mm	mm	W	W	W	W	W	W
Bosch VK120-2 CPC (2 Modules)	2.44	1 947	1 248	87	1 445	1 422	1 369	1 305	1 232	1 150

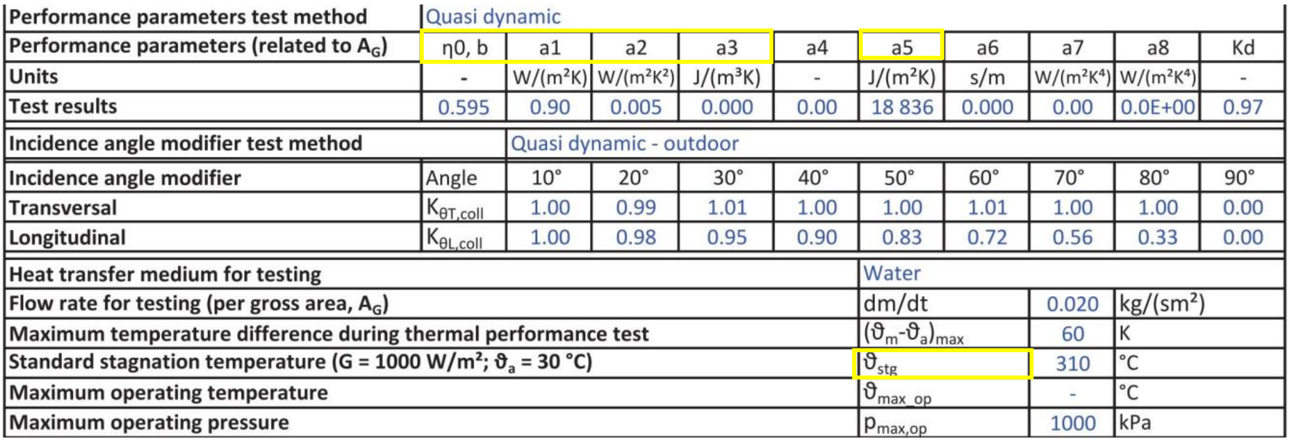
[more lines for other collector types]



Power output per m² gross area	592	583	561	535	505	471

Figure 10: Solar Keymark Test - Collector Output at different temperature differences (TÜV Rheinland Energy GmbH 2020, S. 1)

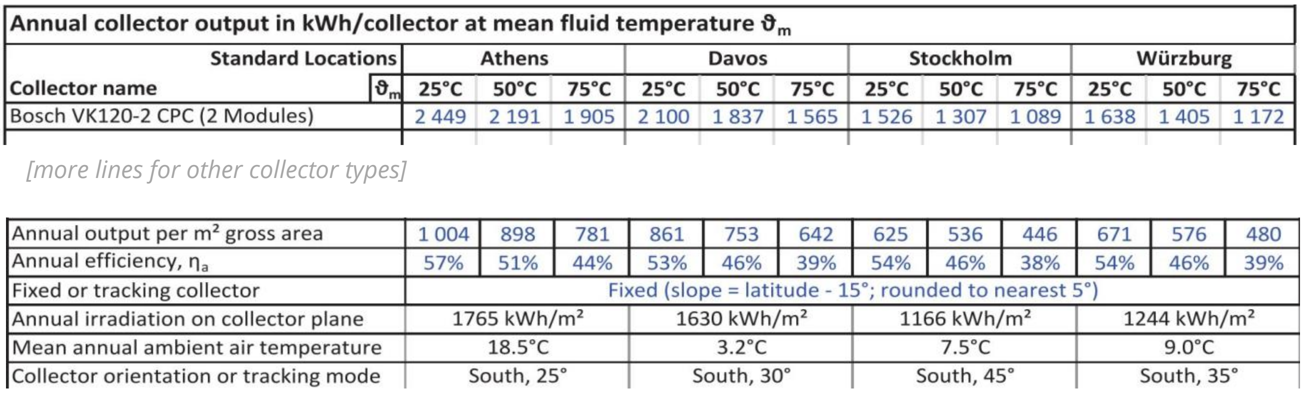
In the next step, the results for important performance parameters are presented. The important performance parameters are marked yellow in the figure below and they are also described more detailed in Table 4.



Performance parameters test method	Quasi dynamic									
Performance parameters (related to A_G)	η0, b	a1	a2	a3	a4	a5	a6	a7	a8	Kd
Units	-	$W/(m^2K)$	$W/(m^2K^2)$	$J/(m^3K)$	-	$J/(m^2K)$	s/m	$W/(m^2K^4)$	$W/(m^2K^4)$	-
Test results	0.595	0.90	0.005	0.000	0.00	18 836	0.000	0.00	0.0E+00	0.97
Incidence angle modifier test method		Quasi dynamic - outdoor								
Incidence angle modifier	Angle	10°	20°	30°	40°	50°	60°	70°	80°	90°
Transversal	$K_{\theta T,coll}$	1.00	0.99	1.01	1.00	1.00	1.01	1.00	1.00	0.00
Longitudinal	$K_{\theta L,coll}$	1.00	0.98	0.95	0.90	0.83	0.72	0.56	0.33	0.00

Heat transfer medium for testing	Water		
Flow rate for testing (per gross area, A_G)	dm/dt	0.020	$kg/(sm^2)$
Maximum temperature difference during thermal performance test	$(\vartheta_m-\vartheta_a)_{max}$	60	K
Standard stagnation temperature (G = 1000 W/m²; ϑ_a = 30 °C)	ϑ_{stg}	310	°C
Maximum operating temperature	ϑ_{max_op}	-	°C
Maximum operating pressure	$p_{max,op}$	1000	kPa

At the end of the report, the annual output of the collector is described for four cities in different climate zones all over Europe at different mean fluid temperatures. For southern regions, a higher solar yield can clearly be seen.



Annual collector output in kWh/collector at mean fluid temperature ϑ_m												
Standard Locations	**Athens**			**Davos**			**Stockholm**			**Würzburg**		
Collector name ϑ_m	**25°C**	**50°C**	**75°C**	**25°C**	**50°C**	**75°C**	**25°C**	**50°C**	**75°C**	**25°C**	**50°C**	**75°C**
Bosch VK120-2 CPC (2 Modules)	2 449	2 191	1 905	2 100	1 837	1 565	1 526	1 307	1 089	1 638	1 405	1 172

[more lines for other collector types]

Annual output per m² gross area	1 004	898	781	861	753	642	625	536	446	671	576	480
Annual efficiency, η_a	57%	51%	44%	53%	46%	39%	54%	46%	38%	54%	46%	39%
Fixed or tracking collector	Fixed (slope = latitude - 15°; rounded to nearest 5°)											
Annual irradiation on collector plane	1765 kWh/m²			1630 kWh/m²			1166 kWh/m²			1244 kWh/m²		
Mean annual ambient air temperature	18.5°C			3.2°C			7.5°C			9.0°C		
Collector orientation or tracking mode	South, 25°			South, 30°			South, 45°			South, 35°		

Figure 13: Collector Annual Output for different places in Europe (TÜV Rheinland Energy GmbH 2020, S. 2)

Parameter	Formula	Unit	Description	Source
Gross collector surface	A_G	m^2	Projected area of a collector without parts for affixation and piping connections.	(DIN Norm 9488, S. 23)
Absorber area	A_A	m^2	Non concentrating collector: Areas of the absorber, that are reached by incidental radiation, that arrives perpendicular to the collector. Concentrating collector: Area of a collector that is intended for absorbing radiation and which is also directly reached by the sun. For tubes with flat absorbers inside, the absorber area is the projected area. For tubes with	(DIN Norm 9488, S. 24)

			tubular absorbers inside, the absorber area is the tubular surface exposed to the sun.	
Aperture area	A_a	m^2	Largest projected Area, through which unconcentrated radiation enters the collector. Flat Plate collectors: Glass surface, that is directly exposed to the sunlight. Tubular Collectors: Area of unshaded and transparent cross section of the inner tubes. Tubular Collectors with Reflectors: Projected Reflector area.	(DIN Norm 9488, S. 21)
Fluid inlet temperature	ϑi	°C	Temperature at the inlet of the collector	(DIN Norm 9488, S. 25)
Fluid outlet temperature	ϑe	°C	Temperature at the outlet of the collector	(DIN Norm 9488, S. 25)
Mean fluid temperature	ϑm	°C	Mean temperature of the fluid.	See above.
Linear collector efficiency factor	a_1 / c_1	$W/(m^2*K)$	Escaping heat per square meter and degree of Celsius temperature difference.	(DIN Norm 9806, S. 16)
Quadratic collector efficiency factor	a_2 / c_2	$W/(m^2*K^2)$	Rising heat loss value per degree of Celsius temperature difference.	See above.
Wind dependent heat transmittance value	a_3 / c_3	$J/(m^3*K)$	The heat transmittance value changes with the speed of wind.	See above.
Effective specific Heat Capacity	a_5 / c_5	$J/(m^2*K)$	Specific heat capacity of a square meter of a device.	See above.
Heat capacity per unit area (filled)	C	J/K	Energy that is needed to heat the for the thermal important parts of the collector up by one degree of Celsius.	(DIN Norm 9806, S. 66)
Effective thermal output	$\dot{Q}$	W	Thermal output of the collector that is extracted out of the collector with the heat transfer medium.	(DIN Norm 9806, S. 61)
Collector efficiency, based on direct radiation	η_b	%	Efficiency of the collector for direct radiation	(DIN Norm 9806, S. 16)
Collector efficiency, based on hemispheric radiation	η_{hem}	%	Efficiency of the collector for hemispheric radiation. The hemispheric radiation is the sum of direct irradiation and the diffuse radiation.	See above.
Norm-Stagnation temperature	ϑstg	°C	Temperature at a given ambient temperature and given irradiance that the collector can reach when no heat is extracted.	See above.
Direct Radiation	G_b	W/m^2	Radiation that reaches the collector perpendicular to the collector surface.	See above.
Diffuse Radiation	G_d	W/m^2	Diffuse Radiation, that reaches the collector by no specific angle other than 90° to the collector surface area	See above.
Hemispheric/Global Radiation	G_{hem}	W/m^2	Sum of diffuse radiation and direct radiation.	See above.
Maximum efficiency (based on G_{hem})	$\eta_{o,hem}$ / η_o	%	Maximum efficiency of the collector based on the hemispheric radiation when the mean fluid temperature is equal to the ambient temperature. This is also called the zero-loss-efficiency.	See above.

Incidence anlge correction factor	K (Angle °)	-	Relation of the maximum efficiency at a given incidence angle compared to the maximum efficiency at perpendicular incidence.	(DIN Norm 9488, S. 26)

Table 4: Parameter for solar thermal collectors

Choosing the right size of a collector field is important for the efficiency of the complete system. For a maximum efficiency of the collector gains, the weak-load period is the best time to choose the minimum water demand. The weak-load demand can be determined by the measured consumption or made by the assumption that it is in the summertime with only 22 l/person*d. (DIN Norm 6002-1, S. 26) Looking at the solar gains of the collector area, they are at 3,5 kWh/m2 to 4,0 kWh/m2 for ST-only collectors, if the collector is south oriented (+/- 30°) and the inclination is between 20° to 50°. This means that a single square meter of the aperture area can heat 60 – 70 liters of water to 60 °. (DIN Norm 6002-1, S. 31).
Looking at the solar fraction D_Z (red line) in the provided figure below, it can clearly be seen that with a rising solar fraction the utilization rate of the collector η_N (blue dashed line) decreases.

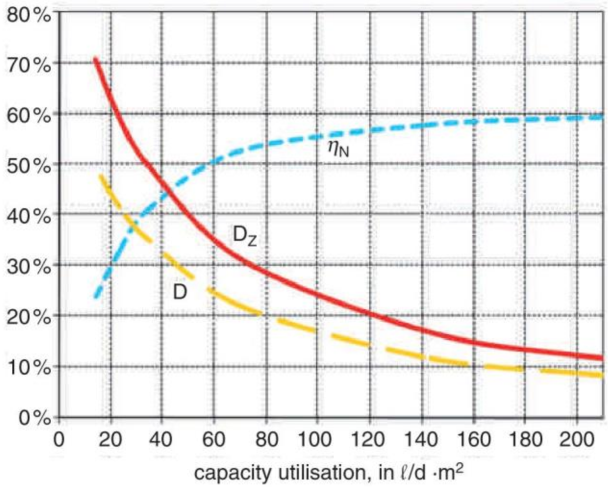


Figure 14: Utilization rate of the collector (DIN Norm 6002-1, S. 28)

If the aperture area is chosen to cover the minimum demand of solar domestic hot water, the solar collectors will then however not contribute a mentionable amount of energy to the space heating anymore. If the solar system is supposed to work at the maximum utilization rate of the collector, the aperture is to be dimensioned smaller.
If the intention is to switch the domestic hot water heater off during the summertime, as a rule of thumb 1,0 to 1,5 m2/person are enough – for evacuated tubular collectors the value for the rule of thumb is at 1,25. If the system is supposed to support the space heating, the area is then multiplied by factor 2,0 for non-evacuated systems and by factor 1,5 for evacuated systems. (Acker Ursula)
Looking at the yields of ST-Only systems throughout the year in combination with a heat pump, then the gains of the combination PV and heat pump are in many cases higher, so that a PV + heat pump solution is the better solution.

Heating Storage

Heating storage is necessary for thermal solar systems because the energy generation happens in most cases at a different time as the energy consumption. There are high requirements, that a heating storage needs to fulfill, since it needs to be hygienic, non-harmful to health, temperature resistant, long lasting, and reasonably priced.

To meet these requirements, three different principles of heating storages, shown in the Figure 15 below dominate the market. The depicted heating tanks show the concepts of the systems without additional equipment like internal electric heating elements or layer lances. Further, there are also heating tanks with more coils inside than only two.

Figure 15: Three different principles of heating storage. Bivalent storage for potable water, buffer tank and a Combined tank with a smaller tank for potable water inside. The coils inside the tanks work like heat exchangers. (Schabbach und Leibbrandt 2014, S. 51)

For potable water heating tanks or parts that are in contact with potable water, the hygienic and material requirements are higher than for the parts, that only touch liquids, that serve as a buffer. For residential homes with a heating storage with less than 400 liters a bivalent heating storage is a good option for a connection to a solar thermal system. In the lower heat exchanger, the incoming water can be heated to the temperature of the collector outlet and the second heat exchanger can be used with an additional heater to increase the water temperature for reaching the desired level or for hygienisation. A buffer is only used when a large amount of energy needs to be stored. This is an option in large buildings or buildings with a high demand for water or if the heat pump is switched of for a couple of hours during the day, if the heat pump is for example part of the load management. Together with a freshwater station, a buffer can be used to preheat or even heat hygienic potable water without the need to be kept a 60 °C. For solar heating support, tanks with integrated smaller tanks have been developed. The advantage of the tank-in-tank system is, that more energy can be stored and that the size of the potable water can be kept small. (Schabbach und Leibbrandt 2014, S. 50–51) Further, a volume smaller than 400 liter also helps to keep the tank at lower temperatures, because the water does not have to be heated to 60 °C once in a day for hygienisation. (DIN Norm 6002-1, S. 18–19)

For a heat pump, the heat exchanger within the tank is very important. If the Heat exchange capacity is lower than the heat output of the heat pump, the heat pump will always have a higher temperature at the outlet side, that feeds the tank, so that the COP of the heat pump can be significantly lower.

Because of this, the following table was supplied with important parameters, that need to be regarded, when a tank is exchanged, or a tank is connected to a heat pump.

Property	Letter in datasheet and/or unit	Description
Volume	V in liters	Volume of the tank
Area of heat exchanger	A in m^2	Describes the surface of the heat exchanging materials.
Heat exchange capacity	k x A in kW/K	Describes which power can be conducted through the heat exchanger to another medium per Kelvin temperature difference. The heat exchange capacity is important for the temperature difference of the heating circle of the heat pump. The higher the value of the heat output by the heat pump divided by the heat exchange capacity of the heat exchanger is, the lower is the flow temperature of the heat pump, and the lower is also the electric consumption on the heat pump.
Specific heat loss	W/K	Describes the heat loss of the storage tank in Watts for every degree of temperature difference to the environment of the tank.
Performance Indicator	N_L [dimensionless]	The performance indicator shows, how many standard apartments can be supplied by a heating device. (DIN 4708-1) The standard apartment has 4,0 rooms, 3,5 people living inside and an energy consumption of 5820 Wh per filling of a bathtub. (DIN 4708, S. 4) A heat storage must fit to the heat generator and the heat generator must also fit to the number of people living inside the house.

Figure 16: Important properties of heat storages – source if not closer specified: (Consolar 2020, S. 12)

The right dimension of a storage tank is oriented at the size of the collector field or at the number of people living inside the house and their behavior. In the case of solar thermal only collectors, there are practical volumes for the storage tank, that are oriented at the desired solar fraction, the field of the collector and the use of hot water per day. If a solar fraction of 35 % is desired, a storage volume of 50 l/m2 is a good practical value. For a solar fraction of 50 % to 60 % a volume of 65 l/m2 is necessary. If the storage tank needs to support the heating system, 70 l/m2 are necessary. Choosing more than 100 l/m2 collector will not increase the efficiency of the storage tank but only increase the cost. (Schabbach und Leibbrandt 2014, S. 52) Looking at small systems with up to 15 m^2 of collector area, the recommended value is between 50 and 75 l/m2. (DIN Norm 6002-1, S. 42)

For other required domestic hot water volumes and other solar fractions, the following figure is provided.

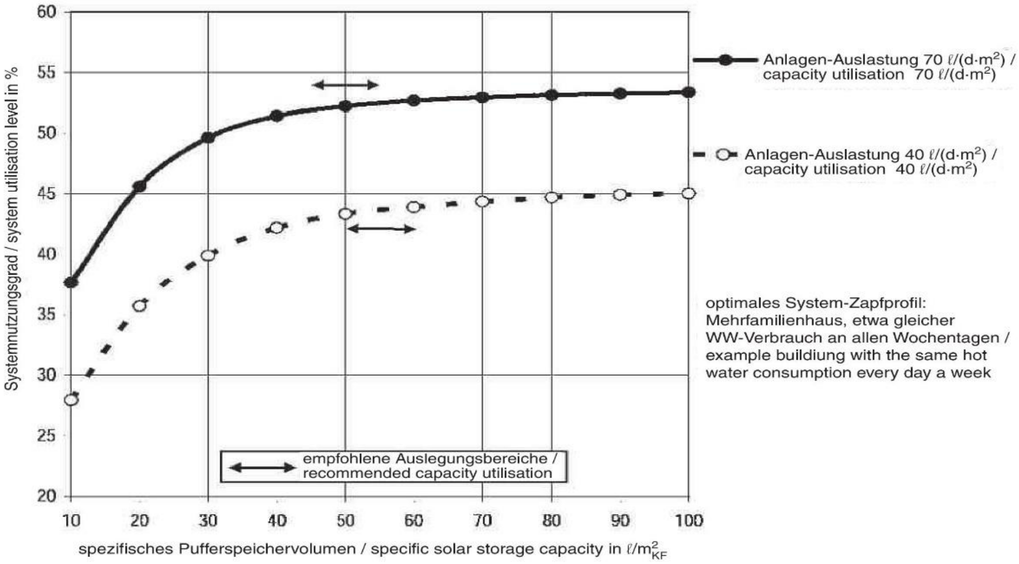


Figure 17: Utilization rate of a heating system and the specific solar storage capacity (DIN Norm 6002-1, S. 42)

By using a heat storage tank, the effect of the heat losses must be considered, too. The losses of an oversized heat storage can quickly amount up to 50 % of the actual DHW demand or even more. For very small demands of DHW, a storage tank does not resemble the best choice, so that a direct electric flow heater might be better. Looking at a storage tank for hot water in the wintertime, that is put up within the insulation of a dwelling, the storage tank can be seen as an internal heat source, so that the impact of the heat loss aspect is reduced. Further, the heating power of the heat generator should also be regarded by the choice of the storage size. The larger the power of the heat generator is, the smaller can be the dimension of the storage. Since heat pumps are intended to run multiple hours throughout the day, the heat output power will be small, so that a larger storage will be necessary.

For the renovations within the scope of INDU-ZERO, 50 l/person and day will probably the best choice since the DHW demand per person is calculated in the PHPP tool suggest a use of only 25 liters per person and day. Doubling this value will allow the housing technologies with a low heat output power to meet the demand still in most of the cases, even if the consumptions in some houses might be much higher.

Heat Pump

Heat Pumps can upvalue heat energy at a low temperature level to heat energy at a high temperature level by only adding a fraction of the energy through a compressor. The working principle is a cycle process that uses evaporation at low temperatures and low pressures and condensation at higher temperatures and higher pressures. (Viessmann Deutschland GmbH 2011, S. 19)

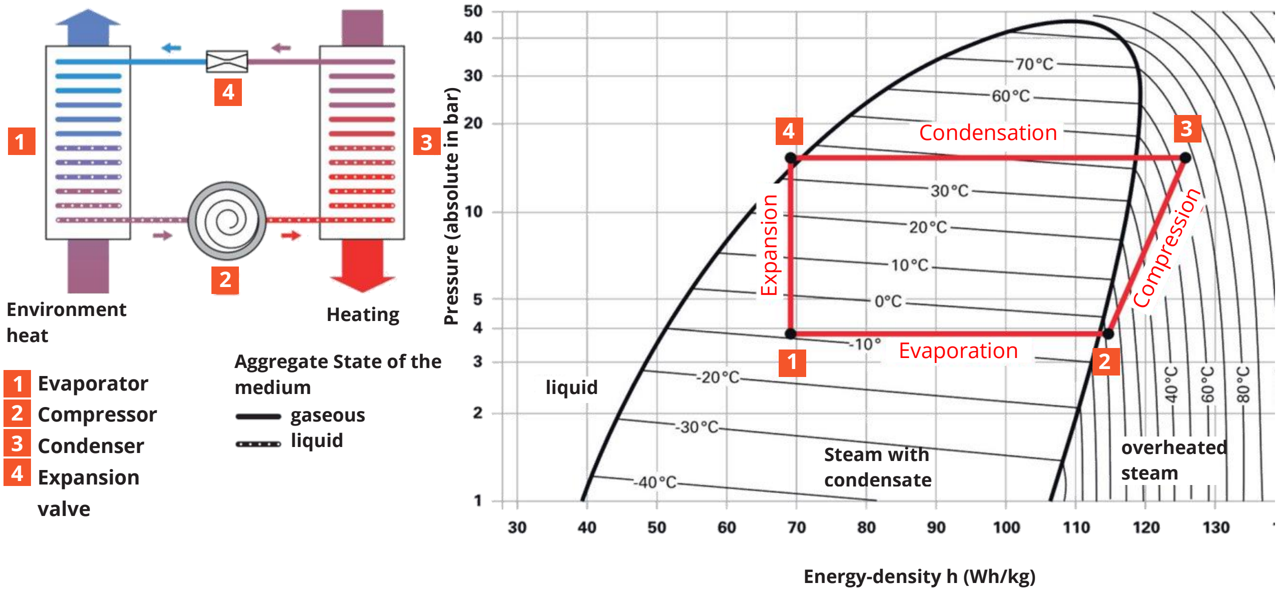


Figure 18: Working principle of a heat pump (Viessmann Deutschland GmbH 2011, S. 19)

For the efficiency, the most important parameter is the temperature difference between the temperature of the heat source and the heat sink. The lower the temperature difference is, the lower is the need for electricity to lift the energy up to the desired temperature level. As a result of this, the efficiency of a heat pump in a heating system can be improved by separating the DHW preparation with its high temperatures and use radiators that require low flow temperatures.

Apart from the COP, that describes the efficiency of a heat pump at a specific point, the seasonal performance factor allows a better comparison for the efficiency of heat pump systems throughout the year. Further the seasonal performance is also decisive to obtain federal funding in some countries. To calculate the seasonal performance factor, the heating energy supplied in one year by the heat pump is divided by the electric power consumption of the heat pump during the year.

$$Seasonal\ Performance\ Factor\ SPF = \frac{Q_{CompleteYear}}{ElectricPower_{completeYear}}$$

Modern Air/Water heat pumps need for example a SPF higher than 3,5 to be eligible for federal funding through the BAFA in Germany, if the heat pump is used in an existing building. This means, that a heat pump could in the average supply 3,5 kWh of heat energy to the heating system over the year when it only consumed 1 kWh of electric energy. For the federal funding of a brine/water or water/water heat pump in a existing residential buildings the SPF needs to be greater than 4,0 and in new buildings even greater than 4,5. (Bundesamt für Wirtschaft und Ausfuhrkontrolle 2021)

For making the heat pumps more comparable in the planning stage, it is important to know the COP at different source and flow temperatures. The abbreviation COP stands for “coefficient of performance”, which is the quotient of the heating power to effective power needed to run the heat pump.

$$COP = \frac{\dot{Q}}{P} = \frac{heating\ power}{effective\ power\ consumption}$$

(DIN-Norm 14511-1, S. 10)

For the practical planning, the manufacturers specify the COP at various heat source temperatures for different flow temperatures in the heating or domestic hot water system.

These specifications are described as the following example:

A7/W35 -> 14,4 | 4,3

(Alpha Innoctec Germany 2021, S. 28)

This means that the heat pump is an air water temperature heat pump, that can supply at an air temperature of 7 °C and flow temperature of 35°C a thermal output of 14,4 kW by needing an electric power of 4,3 kW. When the heat pump operates with other heat sources, the letter “A” is exchanged for a “B” or “W”. The “B” stands for brine and the “W” for water. (Viessmann Deutschland GmbH 2011, S. 22)

For the planning there are two rules of thumb, that can be described as follows.

Heating System side:	Flow temperature down by 1 °K, performance up by 2,5 %
Source side:	Source temperature up by 1 °K, performance up by 2,7 %

(Viessmann Deutschland GmbH 2011, S. 21)

Looking at the data above, a well dimensioned COP field has the advantage, that the panels will have a higher temperature than the ambient air once they are directly exposed to the sunlight. The next advantage is, that brine water heat pumps tend to have higher COPs than air water heat pumps, which will be again beneficial for the annual collector gains.

Since there are many heat pumps on the market, a comparison of the COPs between brine/water and air/water heat pumps was made within the scope of this research. As the data source, the database of the simulation software Poly Sun Database was used. From there, an excel sheet was filled with the data. So the sheet contained 1177 brine water heat pumps and 700 air water heat pumps. The air water heat pumps were sorted by the test standards, so that only heat pumps tested according to EN left in the list. After this, the COPs of the heat pumps were calculated out of their supplied heat and their electric power consumption at different values. At this point it is necessary to mention, that for brine water heat pumps an artificial increase of the electricity demand was calculated, because of the power of the circulation pumps. While the electric consumption of the air water heat pumps in the Polysun database regards the consumption of the circulation pump, this is not the case for brine water heat pumps. This would create an advantage for the brine water heat pumps because bad dimensioned circulation pumps can have up to 13 % of the compressors power. A well dimensioned pumps consumes only as much as 2 – 4 % of the compressor power (Jan Meyer 2008). Since the COPs of the heat pumps at low flow temperatures can for goo heat pumps be multiplied with four, the low percentage of the power from the circulation pipes can create a significant advantage for the brine water technology, which it would not have.

Since the end of the investigation had a few extraordinarily good results, a plausibility check was done, that found out, that the exceptional results were based on wrong data or that the heat pump manufacturers were not producing the model anymore or were not in the business anymore. After this, the 100 best heat pumps for each technology of all power classes could be compared. Since the testing Points for Air/Water and Brine/Water are different, only very similar pairs for COP values were used for the comparison of the best hundred models of each kind. The chosen temperature level for the comparison were 2 °C for air water heat pumps and 0°C for brine water heat pumps. The list was not changed for further comparisons at other temperatures, even if the heat pump did not have a specified value at the other test point. In such cases, the missing values were left out for the average of the COPs.

Evaluation for different COPs	Air/Water	Brine/Water (Cop with recirculation pumps)	Air Water heat pump: Less energy delivery (with recirculation pumps)
	COP A2/W35	COP B0/W35	
Maximum	4,2	5,00 (4,81)	12,7 %
Average	4,0	4,9 (4,71)	15,1 %
Minimum	3,8	4,8 (4,62)	17,7 %
	COP A2/W50	COP B0/W50	
Maximum	3,4	3,5 (3,37)	- 0,89 %
Average	2,9	3,2 (3,08)	5,84 %
Minimum	2,5	2,7 (2,60)	3,85 %

Table 5: Market Analysis on different COPs of air/water and brine/water heat pumps. Values in brackets are with an assumed 4 % increase of the electric consumption when for the brine water heat pumps the electric consumption was also regarded.

Looking at the results, it was found, that a few very well-designed heat pumps for low flow temperatures had lower COP values for higher temperatures than the top performing models that were found for higher temperatures. This observation leads to the conclusion, that heat pumps could be chosen by their COP of the heat level, at which the heat pump will mostly work at.

Regarding the fact, that a PVT-Collector can be used as a heat source for a brine/water heat pump, the choice of the COPs at a temperature of 2 °C for the air and the 0 °C for the brine is fair. The brine going back to the PVT collector out of the heat pump is colder than 0 °C, a temperature of – 3 °C is usual for the exit of the heat pumps (Jürgen Bonin), which appears plausible, if the flow rate of the brine and the heat output of the source are compared. In the case of using the PVT-panel as a heat source without a significant irradiation, the surrounding air might still heat up the brine up to the ambient air temperature if the system is over dimensioned. However, If the PVT-collector field is too small, so that the energy from the ambient air does not flow into the system quick enough, the temperature of the brine to the surrounding area will increase, so that the collector field will be likely to be below the ambient temperature. This effect can even be seen in the simulation analysis of Polysun. Nevertheless, it is a positive fact, that the brine/water heat pumps can help to reduce the power consumption in comparison to the air water heat pumps by 15 % and for DHW preparation for 5,8 %, if average heat pumps are chosen and the collector field Is large enough to collect the heat, that is extracted by the heat pump.

Apart from the COP, there are other important parameters of a heat pump, that count for the INDU-ZERO project. The following list contains these and describes these if a heat pump solution is necessary for a dwelling.

Property	**Letter in datasheet and/or unit**	**Description**
Heating capacity	kW	Specifies the heating capacity of the heat pump. The heating capacity must match the heating demand of the house. The heating capacity is mostly provided at operating points according to EN 14511. Some manufacturers also provide the COP of the heat pump together with the heating capacity at the specified point.
Heating circuit flow max.	°C	Maximum flow temperature of the heating circuit – this specifies, whether the heat pump is suitable for the temperatures for the chosen heating system. Some heat pumps are specifically designed to only power systems with a

		low flow temperature, so that they cannot be used for DHW preparation.
Heat Source return min. |max.	°C	Minimum/ maximum temperature of the fluid going back to the heat source. This is a very important value since many brine water heat pumps do not operate at very low temperatures like -15 °C anymore. If a PVT-solution is chosen, it is important that the heat pump can work with these temperatures.
Anti-freeze concentration: Minimum frost protection	°C	Temperature, below which the medium at the heat-source-side will freeze. The anti-freeze concentration needs to be chosen according to the specified values and the climate conditions.
Sound pressure level at distance X	dB(A)	The noise of the heat pump at a specified distance. Not to be confused with the sound power level, which is not coupled to a distance. The Sound power level is especially important for air-water heat pumps since they have a high social impact factor due to their noise emissions.

Table 6: Properties of heat pumps (Alpha Innotec Germany 2019, S. 26–29)

Radiators

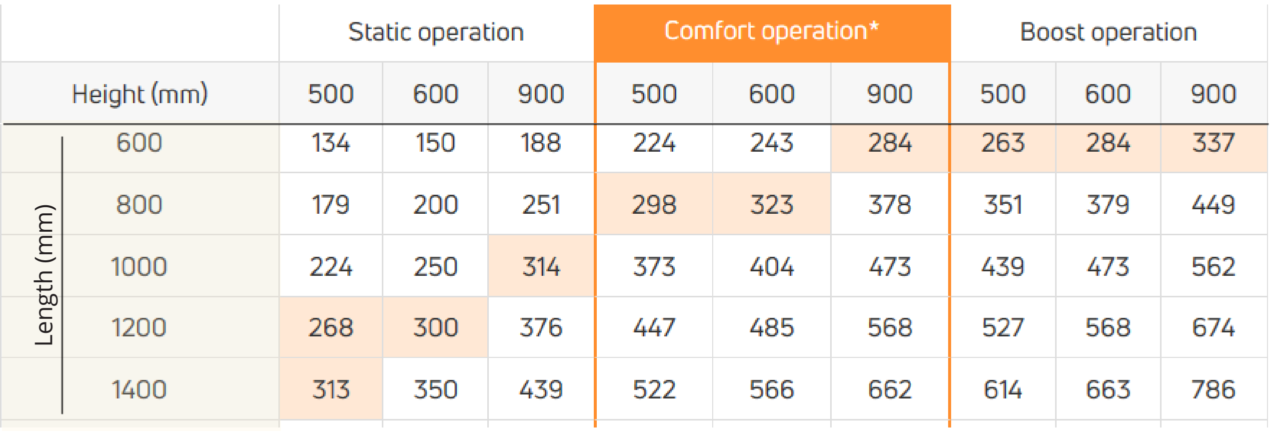
Keeping the existing Radiators

In comparison to direct electric heating, a heat pump will significantly help lower the consumption. For an efficient use of the heat pumps, the flow temperatures of the radiators need to be as low as possible. This will, however, lower the heat output of the radiators, so that the radiators will not be able to supply the original heating power anymore. Since the INDU-ZERO project deals with the renovation of old builds with radiators, that need to cover a heating load of possibly 100 W/m2, it is very likely that they might still work at 10 – 15 Watts per square meter. Further, old buildings have in many cases over dimensioned radiators, what increases the likelihood, that it is possible to cover the new lower heating load at low flow temperatures. (Acker Ursula)

A further possibility to make the existing radiators work at lower flow temperatures would be adjusting the flow temperature to the temperatures outside. During the few very cold days in the year or during the heat up time of a cold room, when a higher heating load is needed, the control of the heat pump could automatically adjust the flow temperature to a higher level, so that the radiators can still supply the demanded heat energy. A higher flow temperature on cold days should not significantly affect the seasonal performance.

Replacing the existing Radiators

If the existing should be despite of a good renovation be too small, the old radiators can be replaced with larger radiators or radiators with forced convection. Radiators with forced convection are produced by different manufacturers and their working principle is to make the air move faster through the radiator, which lowers the heat transition resistance, so that the radiators can supply more heat to the room.



Length (mm)	Height (mm)	Static operation 500	Static operation 600	Static operation 900	Comfort operation* 500	Comfort operation* 600	Comfort operation* 900	Boost operation 500	Boost operation 600	Boost operation 900
600		134	150	188	224	243	284	263	284	337
800		179	200	251	298	323	378	351	379	449
1000		224	250	314	373	404	473	439	473	562
1200		268	300	376	447	485	568	527	568	674
1400		313	350	439	522	566	662	614	663	786

Figure 19: Radiator with optional forced convection for a higher heat output (VOGEL&NOOT 2021)

Since renovations within the scope of INDU-ZERO aim to have minimal changes on the inside, exchanging the radiators will definitively not be a standard operation. For the economics it is the best solution to exchange the radiators only, if one or maximal tow radiators needs to be exchanged. The alternative to exchanging radiators would be to install an infrared direct electric panel heater, so that the desired room temperature will still be reached on cold days, too. Further, exchanging radiators will only be an economic solution, if the COP of the heat pump will be extremely low, or the radiators need to be replaced anyways or if the Net-Zero-Standard is not met. If a heat pumps SPF went down from 4 to 3, the difference of the heating costs would be at 45 Euros per year for a 120 m2 house at an electricity price of 0,30 €. With this price difference, an exchange of all radiators for efficiency reasons would be hard to justify. Looking at the federal funding however, it might be useful to still exchange the radiators, because an SPF of 3,5 is necessary to obtain it. If this will then lower the costs in total or bring a reasonable amortization time, must then be checked for each single case.

A different method for a low flow temperature is to use an underfloor heating system or a heating system, that is integrated into the walls, like an underfloor heating system. The advantage here is, that the walls are warm, which increases the comfort of a room. These systems can also be installed with electric heating using resistance wires, the COP advantage of the heat pump is however lost then. An advantage of a system like this is the ability to be used as a power to heat system. The system is connected to large masses, so that it has a slow response if energy is added to it. This allows to store energy within the building for example when solar power is available. A very important disadvantage of this system is, that the systems can be damaged in an affixation process of furniture or other housing goods. Apart from this, the system is very costly and difficult to install. Within the scope of the INDU-ZERO project a solution like this could be done within a renovation that aims for the maximum comfort within the home, but not in the standard package.

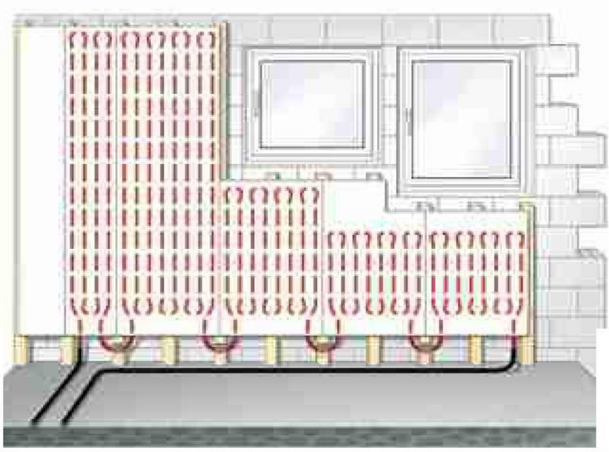


Figure 20: Low flow temperature heating system for wall integration (selbst.de 2017)

<u>Other concepts</u>

Heating with Fresh Air

If the renovation of a home is very good, a centralized heating system exists and the heating load of the home is less than 10 W/m2, then it will be possible to heat the home with fresh air going into it for ventilation. (Passivhaus Institut GmbH 2019) Within the INDU-ZERO Project this might be a considerable option since a ventilation system can be milled or cut into the panels. This way of integrating the ventilation system into the panels, however, will need more research. For houses with an already existing centralized ventilation system, this will probably be one of the easiest installations to ventilate and heat the home. This system can also be combined with a heat pump, but the COP of the heat pump will not be too high, since the temperatures of air heating systems are very high, what is in fact not beneficial for the heat pumps. However, since a renovation with a heating load of only 10 W/m2 is a very good renovation, that will surely not be reached in every case, the feasibility of the solution will depend on the object. Further, the least semi-detached houses have a centralized ventilation system, so that this solution will definitively not belong to the standard solutions.

Heating with electric power / Infrared heating

Since the heating energy demand will be very low after the renovation, it might also be possible to still heat cost and energy efficient by using convector heating systems or infrared panels only. The demand of a renovated INDU-ZERO-house might be at only 15 kWh/(m2a), if for example the passive house standard is met. (Passivhaus Institut GmbH 2019) With the low consumption, especially small houses could profit from the low invests of the direct electric heating panels. Apart from the costs, the room climate will improve, because there is no convection, and the warmth is directly felt on the skin. Further the heat-up time of the system is much shorter than for convection heating systems, so that the system can be used in rooms or situations where the warmth is only needed for a short time. This is an advantage if for example the kitchen is only used in the morning for breakfast, before the people go to work or to school. Instead of heating the entire room up, the panels can be switched on and the room feels warmer. Apart from the comfort advantages, the heating panels can be coated in any color, so that the panels can be decorative elements or even paintings, too. (ThermIQ 2021)

Figure 21: Example of infra-red heaters (ThermIQ 2021)

Within the scope of the INDU-ZERO project, this solution might be especially useful in bathrooms or in complete houses that need a complete renovation of the pipping system.

Air/Air heat pumps

A different concept for heating is the use of an air/air heat pump. Air/Air heat pumps are easy to install. If an entire heating system needs to be replaced, this will be a very desirable option if the building layout allows the use of only few devices. Looking at the expenses, there are many cheap systems, that come with high noise emissions, what makes cheap systems not suitable for INDU-ZERO installations. Quiet systems, however, will only be a reasonable solution if few units are needed per dwelling.

Technical details about PVT-Panels and ST-Panels

Collector Parameters

Looking at certain collector parameters, significant differences can be seen that help to explain the different solar gains and possible applications of the different collector types. The data provided int the table below are taken from datasheets of Solar Keymark tests. The comparison focuses on the properties η0, a1, a2, a3 and a5, that are described in Table 4.

Collector Type	η0, b	a1 (or c1) W/(m²*K)	a2 (or c2) W/(m²*K²)	a3 (or c3) J/(m³*K)	a5 (or c5) J/(m²*K)	Source
Tubular Collector (ST-Collector) Consolar TUBO II C	0,56	0,660	0,010	-	-	(TÜV Rheinland Energy GmbH 2017)
Flat Plate Collector (ST-Collector) EURO L20 AR	0,777	3,25	0,013	-	4960	(TÜV Rheinland, S. 1)
PVT-Collector (ST and PV) Solator PVTHERMAU	0,535	10,74	1,0997	-	-	(TÜV Rheinland 2014)
PVT-Collector (ST and PV) Triple Solar PVT Warmtepomppaneel	0,468	22,99	0,000	7,573	-	(TÜV Rheinland Energy GmbH 2019)

Table 7: Collector parameters of different collector systems

By comparing the peak efficiency η0 of the collectors, the flat plat collector type has the highest value, while PVT-collectors have the lowest value. The high peak efficiency for flat plate collectors is connected to low reflective losses on the glass plates. Looking at the performance of the PVT-Collectors, it appears to be low at first. Regarding the fact, that the thermal efficiency was measured under standard reporting conditions while the integrated solar panel was operated at the maximum power point, the efficiency is not as low as it appears at first. The solar panel was operated at a temperature of 20 °C (DIN 9806, S. 60), which means that the solar panel operated at a very efficient level of roughly 20 %, what means, that the electric gains could not contribute to the thermal gains any more. If the electric contribution is added to the thermal gain, the η0-value is in a similar order of magnitude than ST-only collectors.

Further it is also interesting to compare the linear collector efficiency factor a1 (heat loss coefficient) of different collector types. For heat pump panels, this parameter is 35 times higher than for evacuated tubular collectors. This has to do with the intended use for the systems: while the tubular collector is used to collect the heat by the sunlight at a high temperature levels, the PVT-Collectors should be used to collect environment heat for heat pumps what does not require high temperatures or the presence of irradiation. With the linear collector coefficient, the size of the collector field can be dimensioned for a heat-pump application if the heat extraction of the field and the maximum allowed temperature difference to the environment is known.

By looking at the quadratic collector efficiency factor a_2, which describes, how the efficiency of the collector decreases at rising temperatures, the evacuated tubular collectors and flat plate collectors have very low values, because they are supposed to keep the heat inside. For PVT-collectors with their intended use as a heat source the quadratic factor is not that important anymore, because they will not reach much higher temperatures compared to the ambient temperature during operation. So, these losses will not have a significant effect anymore. The same aspects count for the wind dependent heat transmittance value a_3.

The effective specific heat capacity a5 helps to determine the heat-up time of the collector. A low value is beneficial for systems with a high desired temperature on days with a short-time and low irradiation. For PVT panels that serve as a heat source, this value is again not too important, because the environment heat is crucial for the heat pump.

For a comparison of collector types, there are collector efficiency curves, that can be calculated with η_0, a_1. These curves are important for simulations, and they are also a good possibility to visualize, the behavior of the different collectors. An example of these curves for different types of collectors is provided below. (Schabbach und Leibbrandt 2014, S. 39)

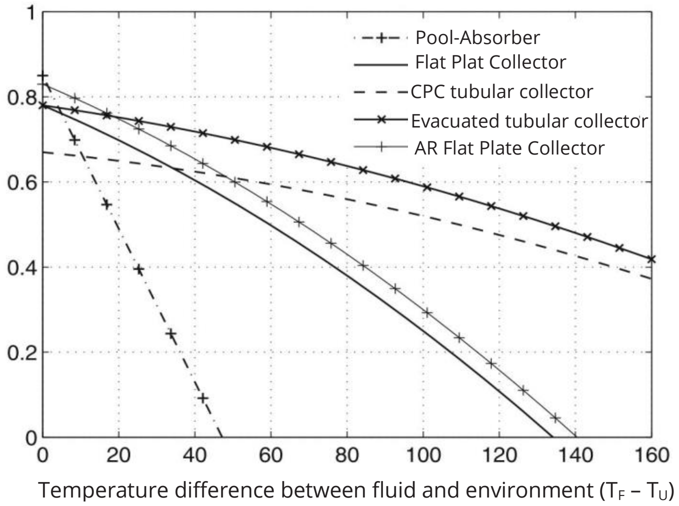


Figure 22: Efficiency of different collector types according to DIN EN 12975. The heat pump collectors behavior will be similar to the pool absorber, because pool absorbers are not insulated, too. (Schabbach und Leibbrandt 2014, S. 28)

Collector Gains and possible applications

The Solar Keymark Test also provides information about the collector annual output. The annual output of the collector is provided for Athens, Davos, Stockholm and Würzburg at operation temperatures of 25 °C, 50 °C and 75 °C. The following table contains an overview of the solar gains of different collector types. The collectors in the table are arranged in the same order as in Table 7 above. Since the INDU-ZERO project sets its focus on the North Sea Region, the values from Stockholm were chosen, because Stockholm is the closest city to the North Sea region. The data from Athens were added to show how a PVT-Collector can be used as an air-heat collector.

Collector Type	Stockholm			Athens			Source
	25 °C	50 °C	75 °C	25 °C	50 °C	75 °C	
Tubular Collector (ST-Collector) (Bosch VK120-2 CPC)	642	546	436	1004	898	781	(TÜV Rheinland Energy GmbH 2020, S. 2)
Flat Plate Collector (ST-Collector) EURO L20 AR	680	458	287	1202	879	592	(TÜV Rheinland, S. 2)
PVT-Collector (ST and PV) Solator PVTHERMAU	141	3	-	405	18	-	(TÜV Rheinland 2014)
PVT-Collector (ST and PV) Triple Solar PVT Warmtepomppaneel	55	-	-	474	-	-	(TÜV Rheinland Energy GmbH 2019)

Table 8: Comparison of the solar gains of different collector types

Looking at the solar gains, the PVT-Collectors are completely different from the solar only collectors, because their solar gain is much lower than the gain of the ST-only collector types.

Comparing the PVT-collectors to each other, the PVT-Collector with the higher linear efficiency factor has a higher yield at higher temperatures. For the heat pump panel with the low insulation, the heat gains by the sun cannot even be measured at 50 °C. Investigating the gains at 25 °C in Athens, there is an interesting observation to be made: Although the insulation of the heat pump panel is worse than for the PVT-Panel with the better insulation above, the yields are higher. The reason for this is, that the panel is well connected to the environment, so that the heat flows into the panel if the ambient temperature is higher than 25 °C, which is in Athens the usual case in the summertime. This shows, how the low insulation level can be beneficial at low temperatures when the panel is used as a heat pump panel.

Later in the document, there is an approach to calculate the solar gains of a PVT-Panel and more information about sizing the area for heat pump panels of an especially for this purpose designed panel.

Choosing housing technologies

Heating-, DHW- and electric energy before and after the renovation

Looking at the energy consumption before the renovation, the total demand will significantly change after the renovation and the main consumption will not be caused by the space heating anymore, but by the electricity consumption in the household. The reason why the heating energy demand has lost its status as largest position in the energy consumption, is that poorly insulated buildings could have a space heating demand of more than 250 kWh/(m2*a) instead of 15 kWh/(m2*a). To illustrate this, the figure below was created for a fictional house with 110 m2 of living area and 3 inhabitants. Regarding the electric consumption, the order of magnitude per capita has not significantly changed over the years (Bundesministerium für Wirtschaft und Energie 2020, S. 59). The average household with 3 people needs 3.500 kWh/year for the household electricity and in a single-family house and 2.500 kWh/year in a multi-family house without the energy for DHW preparation. Looking at the energy consumption of the DHW preparation, the DIN-Norm 4701-10 suggests the same value of 12,5 kWh/(m2*a) for the DHW preparation as a rule of thumb for years now, so that the value will probably not change significantly in the future, too. These values went into the calculation for the following figure.

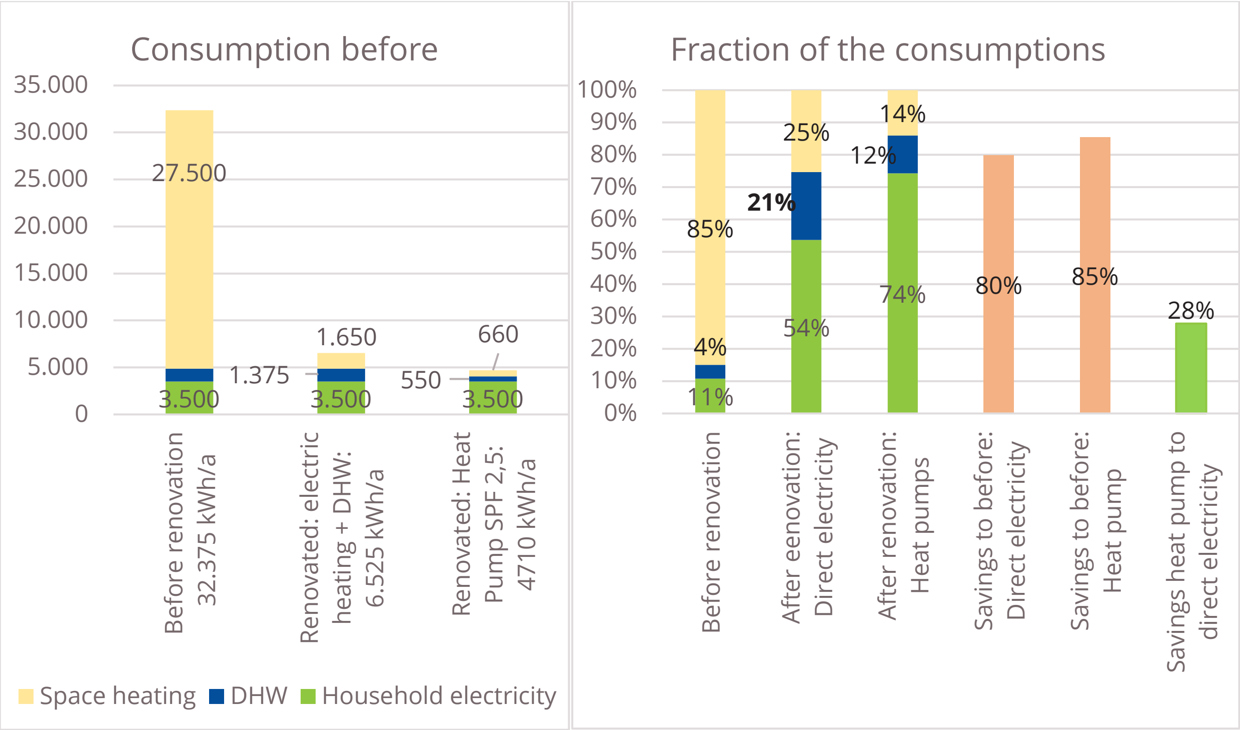


Figure 23: Comparison of the consumption of a house before and after the renovation for a fictional house with 110 m^2 and 3 People consuming 3500 kWh of electricity per year. For the Heat Pump a low SPF of 2,5 was assumed, since storage and piping losses were neglected.

The figure shows, how the consumption of a house will change after the renovation. It also shows that the heating energy demand has become so small, that efficiency improvements on the heating system are in some cases not crucial any more for reaching the Net-Zero standard, especially if the roof areas are large. Further, the heating engineering technologies have now in many buildings rather the task to help to increase the own consumption of the generated energy and be supportive to the energy grid. From the point of view, what regards the primary energy consumption, the heat pump technology will in many cases help to save energy in the wintertime when the solar gains are low, and the power might otherwise be generated by burning fossil fuels.

Looking at the savings generated by using a heat pump, then the heat pump decreased the consumption by 1800 kWh per year. This makes an annual difference of 540 euros per year for an electricity price of 0,30 €. For houses with a higher consumption of DHW and space heating, the effect of the heat pump will be even better. Since every house is different, the following section deals with strategies, that can help to quickly choose housing technologies. In the following paragraph the fact is also regarded, that the technology parcels must work in a large scale, because in the future similar systems might be used for about 22 million homes.

Strategy: As much solar power as possible

Generation of Solar energy

Solar power is an easy, low-social impact and cost-effective way to generate energy. The solar gains, however, do not match the demand over the year. Especially in the winter months, the generation of a solar roof is already below the demand of electricity, without regarding the need for electricity to power a heat pump or heat with direct electricity. Within the scope of INDU-ZERO, regarding the vast volume of 22 million houses, the strategy must become to fully cover every roof, so that as much energy as possible is available in the wintertime. Additional to this, the strategy must also become to use as less energy as possible during the wintertime as well.

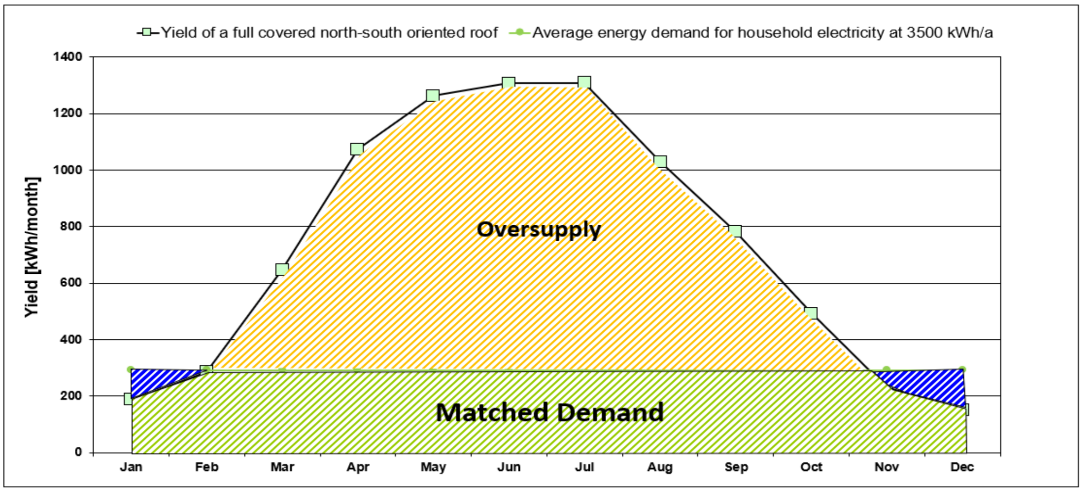
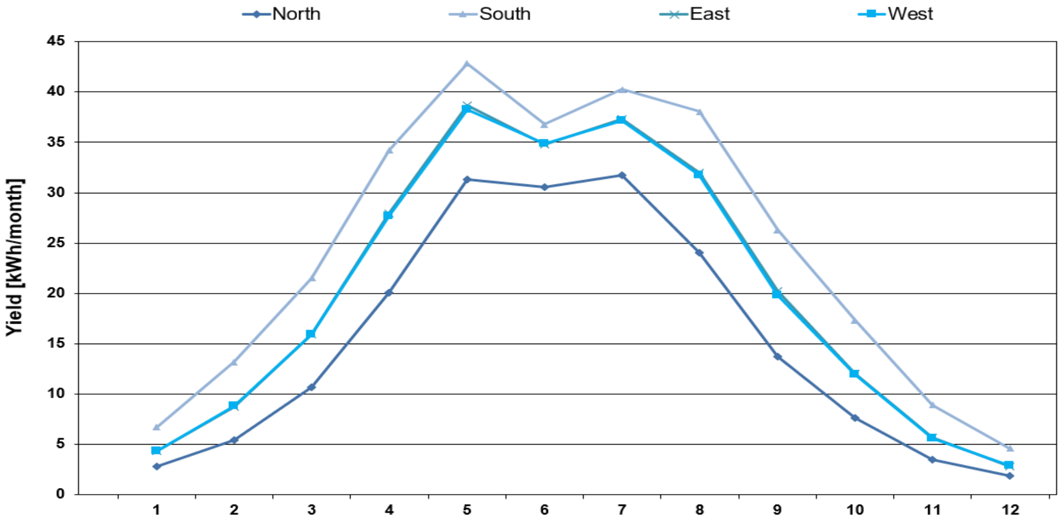


Figure 24: Solar gains over the year regarding only the household energy of 3.500 kWh/a. The yield comes from a North-South oriented solar roof with 40 solar panels in total. The blue marked areas show the missing supplies by the solar energy. The graphic shows, why an oversized solar roof is beneficial for the supply in the wintertime.

Although fully covering a roof with PV panels will lead to a massive overproduction during the summertime, the following figure was created to show, how large the seasonal variations can be.



	North	South	East	West
Variation: Month with minimum gain/month with maximum gain	17,1	9,3	13,6	13,0
Gains in December compared to a South oriented roof.	40 %	100 %	64 %	64 %

Figure 25: Seasonal performance of solar modules by their orientation - inclination of roof: 31 ° - Bremen – Source of the diagram: PHPP-Tool

Looking at the solar gains of a north-roof, the roof delivers only 40 % the gains, that a south oriented roof would deliver, which means, that still more than a quarter of the gains during the worst month in the wintertime are generated on the North side of the roof. Regarding the energy production in the summertime on the north side of the roof, this side becomes crucial for most houses to become Net-Zero. Regarding the fact, that solar cells degrade over the years, that the mobility sector is about to be electrified and that there are multiple things, that can change the individual consumption of a house depending on the life situation of the people living inside, a full covered roof with solar cells appears like a safety belt for the Net-Zero standard, even if for some houses the Net-Zero-Standard might be possible with a not fully covered roof.

Regarding the fact, that the north-oriented-roof is the least valuable area during the wintertime, the north-side is then the area for a maintenance window. Looking at the cut out for an air-water heat pump there will be further investigations necessary, whether the south-side might not be more beneficial, since the air should be warmer on the south-side roof. For collecting the possible warm air, the air Water heat pump could probably be placed best on the purlin.

Need for storage and a high own consumption

Energy cannot be just stored in the grid. If the consumption and production of 22 million houses is not designed in a smart way, there will be effects on the large systems. The energy production and consumptions do very often occur at different times of the day. This creates the need for storage, or at least to the need to be able to consume the generated energy at the same time, when it is produced. While for a seasonal storage a solution has not yet been found, several manufacturers have already marketable battery solutions, that can help to cover the demand throughout the day.

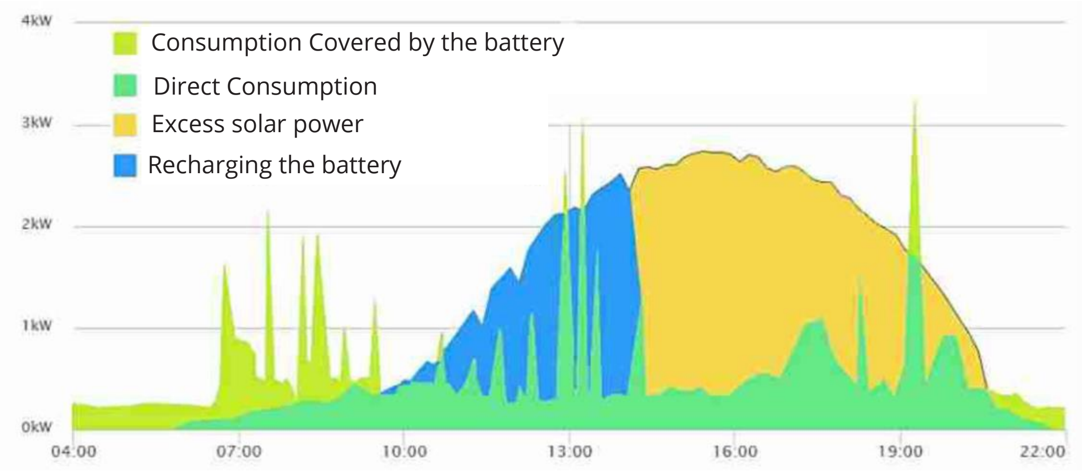


Figure 26: Effect of a battery on the own consumption (PYLONTECH 2021)

For dimensioning the storage, several rules of thumbs were found. For example there is a suggestion to use a kilowatt hour of storage for every 1000 kWh of energy consumption per year. (Acker Ursula) Other sources take the size of a well-to-the-consumption adjusted solar roof as an orientation and suggest one kilowatt hour of storage for every installed kilowatt peak of solar power (Wegatech 2021) or one kilowatt hour for 1,2 kWp (Ministerium für Umwelt Klima und Energiewirtschaft Baden-Württemberg 2021). The value 1,2 is also used by the L-Bank within a funding program for grid serving PV, providing 200 € of funding for every kWh of storage capacity (L-Bank 2021). Regarding the fact, that the solar roofs should be oversized in many cases due to the higher yields in the wintertime, the first rule of thumb, that has the annual consumption as a guideline, appears as the best rule of thumb for INDU-ZERO. Apart from this, the rule of thumb will lead to smaller storages, what will help to keep the costs for the storage at a sustainable level, since the costs are relatively high. For Lithium system, the prices are between 578 €/kWh and 1.975 €/kWh with an average of 946 €/kWh and for saltwater systems the average price is at 882 €/kWh. (Georg Eberle 2021) By integrating electric storages in a package for a renovation, INDU-ZERO would probably be also the first project, that introduces storage systems in a large scale.

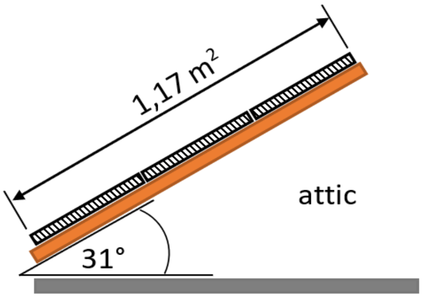
Apart from the storage, it is possible to increasing the own consumption by using smart home devices or heat pumps that switch on automatically when excess solar energy is present. Regarding air/water heat pumps, the operation during the daytime is in most cases more beneficial for getting a higher COP than at nighttime, because the temperatures during the daytime are in many cases higher than at night. For devices, that cannot be integrated into a smart home system, an energy manager (see in the figure below) can be used to switch relays, so that consumers are switched on automatically. Within the scope of INDU-ZERO a smart energy management system could be introduced in a package, that is a higher priced than the standard package, in which this technology is not included.

Figure 27: Methods for increasing the own consumption of the solar energy: Storage or direct use. Left: BYD Battery-Box with 5,1 kWh of storage capacity for 3.500 €. Right: Energy manager SMARTFOX Pro - This device switches consumers on and off, if energy is available, so that the own consumption of the generated PV-power is higher. (Cost for this device – 800 Euros) (Voltus.de 2021)

Strategy: Increasing the energy generation

PV-Only Systems

The first strategy, that aimed at fully covering the roofs with solar panels, aimed at covering complete roofs with PV-Only systems, however, in some cases solar only systems just do not supply enough energy to a roof, to make the Net-Zero-Status possible. For a general rule, the following figure was created, that shows, how the number of stories affects the Net-Zero status of a home, if only average values are assumed. However, the provided graphic will mostly not fit to the situation in semi-detached houses or multi story buildings with many apartments, since in these cases the available living space is in smarter used and the consumption is in total higher, although it is actually more sufficient. (Institut der Deutschen Wirtschaft 2021)



Demand per m²	
DHW	12,5 kWh/a
Heating	15 kWh/a
Electricity*	32 kWh/a

Per Story $\sum 60 \frac{kWh}{a}$

* For 47 m² living space + 1500 kWh/a per capita.

Solar gains in kWh/year and possible strategies

Gains per m²	North	South	East	West
roofage	102	162	134	133
projected footprint	119	189	156	155
Average	154		156	

Conclusion for passive houses with gabled roofs:

One story building:	Always possible! - Oversupply
Two story building:	Always possible!
Three story building:	Likely to work with heat pump!
Four story building:	Possibly Heat Pump + PVT. (living space is smarter used!)
Five story building:	Not possible any more (Electricity demand to high!)

Figure 28: Comparison between annual consumption of a passive house the solar generation on the roof of the passive house throughout the year. The data for the solar gains were calculated with the PHPP-Tool for Bremen. The electric consumption was taken from Federal Ministry for Economic Affairs and Energy of Germany and rounded to the closest hundred.

Staying at the average values, the graphics above shows, that bungalows with a full covered solar roof will probably always reach a Net-Zero standard, even if only direct heating technologies are used. The solar gains for every square meter of the projected living area are far above the demand for a passive house. This means, that direct electricity for heating and DHW preparation can be used as housing technologies, and that on the rooftop is still more energy generated, than the house needs.

For houses with two stories and a gabled roof, the generation of solar energy will for average values still outweigh the consumption, even if no smart technologies were used.

For buildings with three stories, the average predicted electric consumption will be so high, that there will not be enough energy left to cover the space- and DHW-energy demand if the energy is directly used. Smart housing technologies and a sufficient lifestyle will be necessary to reach the demanded Net-Zero standard. The number of three stories could be seen as the border for the Net-Zero standard.

Since the possibilities for the PV-only technology are reached at three stories, there will be the need for more efficiency for buildings with four stories. Since in four story buildings, or even already in three story buildings people obtain less living area per capita, the three-story building could in some cases already be the border to the net Zero Standard.

An approach to solve this issue without improving the insulation of the building, which might be a good idea since there are higher internal gains inside, would be using PV-Panels, that are placed at the façade or near the building. Additional PV-Panels could be placed in these cases on the façade of the highest story or at the gable of the house. The advantage of placing the PV-Panels at these positions would be, that they will have less or no shading throughout the year, if the houses in the surrounding area are all build up to the same height. A second option could be the parking lot, what would have the additional advantage, that the cars would be protected better by the weather.

ST-Systems

Solar thermal systems have the advantage, that they can collect a multiple of the gains of a PV-only system. If they are dimensioned in the right size and well oriented, they can fully supply the energy needed for the DHW-preparation during the summer months. This is beneficial for reducing the auxiliar energy (Q_{Aux}) that is otherwise supplied in a different way. (Schabbach und Leibbrandt 2014, S. 70). Apart from that, a system like this has almost no noise emissions. This is beneficial for the inhabitants, because people will spend more time outside during the summer than in the wintertime, so that a noise free environment is desirable, when they are sitting on the balcony or trying to rest themselves outside. Further there would also be fewer working hours for the heat pumps per year, what might also improve the lifespan of the heat pump.

However, if the just mentioned advantages are neglected, and the annual generation of a ST-only solution is compared to a PV-solution combined with a heat pump, then the combination of the heat pump and solar thermal panels can be significantly more efficient, just as the following figure shows. An additional advantage of the combination is, that the gains are also higher in the wintertime, so that the gains are then more useful.

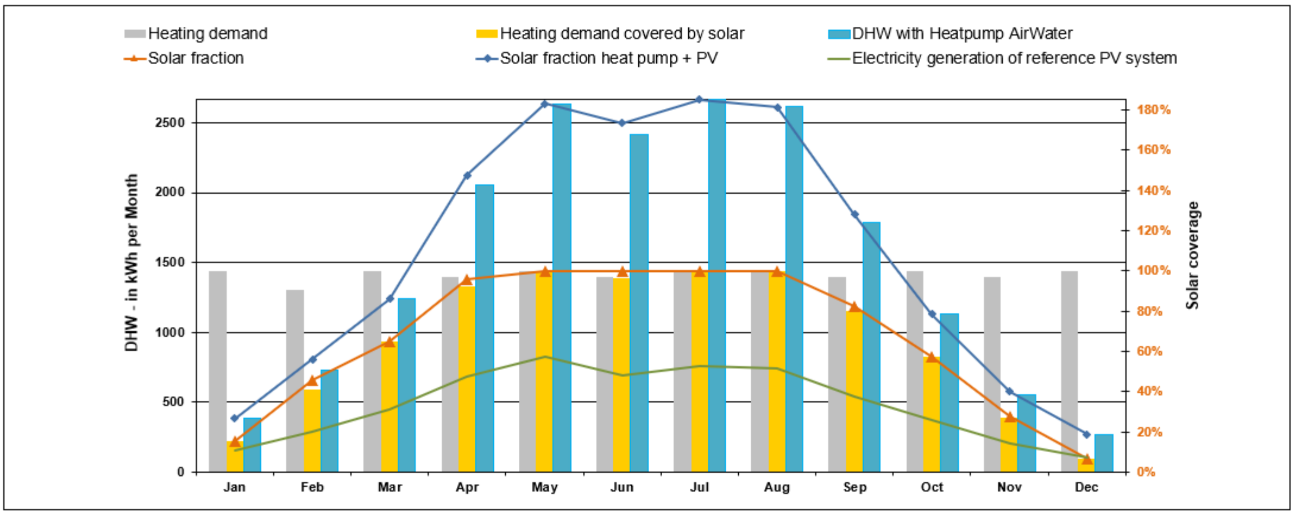


Figure 29: Comparison of the thermal gains of a 36 m² evacuated tubular collector field on a roof in Bremen (45° inclination, south oriented) of an apartment building with 29 inhabitants. The solar coverage (orange line) is in the summer months close to the 100 % for a solar thermal only system. As it can be seen easily, the solar generation of a PV-Only system (green line) is smaller. The COP of the heat pump, however, helps the PV-Panels to be in total more efficient.

Apart from the possibility of using a heat pump for the DHW preparation only, it would also be possible to use an indoor DHW heat pump to cool the house in the summertime. The heat would be captured in the tank and disposed, when DHW is used.

PVT-Systems

Looking at PVT-Solutions, a report of the International Energy Agency was viewed, that presented Existing PVT systems and solutions all around the world. The report identified worldwide 22.920 PVT Systems, that had roughly 1,1 Million square meter of Collector area and a total electric capacity of 0,18 GW-peak (International Energy Agency 2020). The largest share of the installed collector area had solar-air-systems with 41 %. Apart from that, they are also the most common PVT-application since this technology represents 88 % of all PVT-installations. When it comes to houses, there are also less than 2.500 houses that have a PVT-solution globally installed. In comparison to the 117 GW-peak of PV-only systems alone in the EU, it becomes clear, that PVT-has a subordinated role in the solar generation (Joint Research Center 2019).

By investigating the report further, the presented marketable non concentrating PVT systems were designed as a heating support or as a heat source of a heat pump. In the case as of the solutions with the heating support, the fluid coming from the PVT-panels was conducted through a heat transfer coil of a DHW system or a buffer, that was used to preheat cold water. In the case of the PVT-Collector as heat source for a brine water or water/water heat pump, the heat of the PVT-Panels was used for preheating the ground water, regenerating an ice storage or geothermal heat collector field, or as a direct heat source. All the presented solutions, that involved heat pumps aimed to increase the annual COP of the heat pumps. In the case of the presented PVT-systems, that used air ais a heat transfer medium, the warm air was used directly within the buildings or as a source of warm air for an air/water heat pump.

For calculating the gains, it needs to be mentioned, that there are just too many influence factors, so that an exact calculation of the gains of the collector field will only be possible of a professional simulation software is used. Further, this value would then also just be true for the specific dwelling with the constellation of people living inside. Since the exact gains will not matter within the scope of INDU-ZERO, because every house will be different anyways, the approach was made, to find several rules of thumb to describe the order of magnitude, that the additional solar gains will probably have.

1. <u>Direct use of the solar gains for preheating hot water</u>

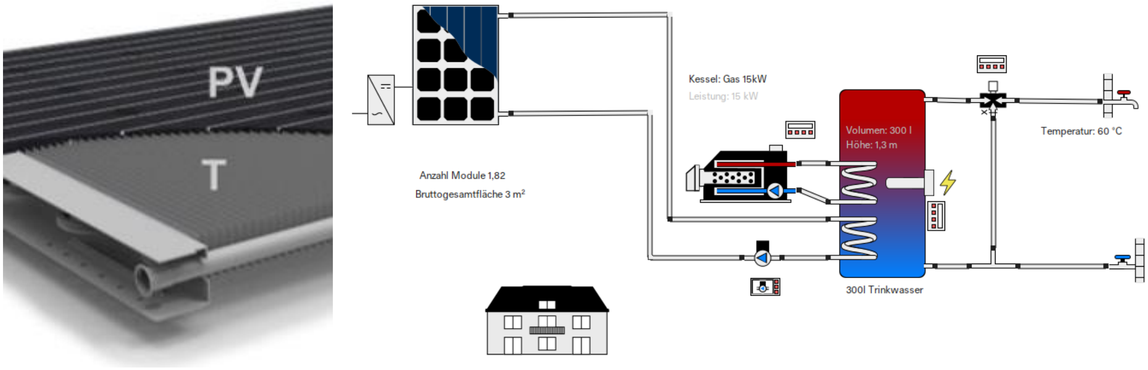


Figure 30: PVT-Panel, with lamellar connection (Triple Solar BV 2021) and a PVT-Collector with a heat pump and a hydraulic, that can be used to heat the bottom part of the cylindrical heat storage.

A heat pump panel or a standard PVT panel can be connected to the DHW storage tank as shown in the hydraulics int the figure above. For the following investigation it is not important, whether the rest energy for delivering DHW at the desired temperature is generated by a heat pump, gas heater or electricity, because only the additional solar gains of the panels were regarded.

For the investigation, the simulation software Polysun Version 12.0 was used. The situation was done for a house with a storage tank of 300 liters and a consumption of 300 liters per day at a temperature of 50 °C. The roof on this fictional house had an inclination of 31 °. For the gains of the system, different orientations, technologies, and sizes of the collector fields were used. A volume of 300 liters would fit well to a household or supply system for 6 people.

Systems

System	Description	Variations
System 1	ST-Only System (Reference System) Flat Plate Collector Electric efficiency: 0 % Zero loss efficiency: 82,1 % Linear loss coefficient: 3,22 W/(m^2*K)	3 m^2 6 m^2 12 m^2 (DHW heating support)
System 2	PVT-System Insulated PVT-Panel by Dual Sun (Spring 310 M Isolated) Electric efficiency: 19 % Zero loss efficiency: 55,3 % Linear loss coefficient: 7,4 W/(m^2*K)	3 m^2 6 m^2 12 m^2 (DHW heating support)
System 3	PVT-System Heat Pump Panel Solink by Consolar Electric efficiency: 17,5 % Zero loss efficiency: 46,8 % Linear loss coefficient: 22,99 W/(m^2*K)	3 m^2 6 m^2 12 m^2 (DHW heating support)
System 4	PVT-System Heat Pump Panel by Triple Solar BV Electric efficiency: 17,5 % Zero loss efficiency: 25,3 % Linear loss coefficient: 60,44 W/(m^2*K)	3 m^2 6 m^2 12 m^2 (DHW heating support)

By looking at the thermal gains, that Polysun supplied after the simulations, it was found, that for the systems that had only 3 m2 the thermal gains per square meter were significantly higher, than the gains per square meter of the systems, that had larger areas. Since the housing technology needs to be able to supply households, that do not have the most sufficient behavior, too, the gains for 1 m2 per person are presented here.

City (South->North)	System 1 (Reference ST-Only)	System 2 kWh/person	System 3 kWh/person	System 4 kWh/person
Amsterdam (South)	*489*	184	62	38
Bremen (South)	*483*	186	67	41
Copenhagen (South)	*439*	118	29	26
For Bremen there was also a West-East comparison made….				
Bremen (West)	*387*	160	64	41
Bremen (East)	*365*	137	50	35

If for every person are 2 m^2 of collector area calculated and the consumption stays at 50 liters per day, then the solar gains per area become smaller:

City (South->North)	System 1 (Reference ST-Only) kWh/person*a (2 m^2)	System 2 kWh/person*a (2 m^2)	System 3 kWh/person*a (2 m^2)	System 4 kWh/person*a (2 m^2)
Amsterdam (South)	*640*	238	68	40
Bremen (South)	*642*	242	74	44
Copenhagen (South)	*604*	140	30	28
For Bremen there was also a West-East comparison made….				
Bremen (West)	*550*	208	72	44
Bremen (East)	*502*	176	54	38

Table 9: Thermal gains of PVT-Panels. The well isolated Panels (Dual Sun Panels) deliver much more additional energy than the heat pump panels. This was to expect since the heat pump panels (System 3 and 4) are alienated from their intended use.

Further, the monthly gains are also provided here:

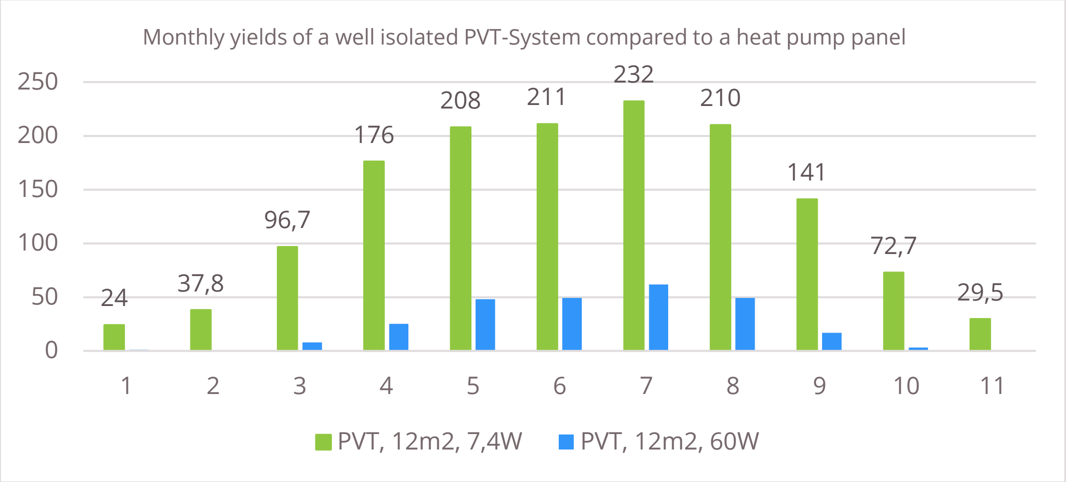


Figure 31: The figure shows the monthly yields of a well isolated system (System 2) and a heat pump panel (System 4). The gains of the well isolated panel are significantly higher. However, since the main gains are to be expected in the summertime, when a lot of solar energy will

already be present anyways, the question could be asked, whether the system will have a considerable effect on the savings, if the energy supplier must change their way of billing their customers. Further, it needs to be mentioned, that the solar fraction in mot of the cases lower than 50 %, what gives a hint to the fact, that the harvested energy is not too valuable anymore, since it could also be produced with a much higher COP than only 3 by a heat pump.

The thermal use of these panels could in fact also be produced by a heat pump, what would divide the gains by factor 3 or even more, since most of the gains are won during the summertime. This circumstance leads to the fact, that a PVT-collector with one square meter per person can save a Maximum of 61 kWh per person per year, what represents a value of 18,40 €. If two square meters of the well-insulated panels are used, the savings will be at 23,80 €, if the energy price is at 0,30 €. For a live expectancy of over 25 years, however, it shows, that a high insulating PVT-Panel will pay back itself, even if only the thermal gains are considered. This however only counts if the energy suppliers do not change the pricing and the ability of the customer to spin the meter back during the summertime.

Further, if a well-insulated panel is supposed to serve as a heat source for a heat pump to cover the heating load of a large building, then the low thermal conductivity will prevent this. At a low conductivity of 7,4 W/(m^2*K) it will be very hard to cover a heating load of several kilowatts. In such a case, a second system, that uses real heat pump panels would be the better option.

2. Use of the collector as a heat source

If a heat pump is supposed to be used as an almost noise emission free solution, the following rules of thumb will help to size the collector field. For calculating the size of the collector area, there are two rules of thumb by two manufacturers, that developed a heat pump panel together in a cooperation. (Triple Solar BV 2019, S. 8)

Rule of thumb for Consolar heat pump panels:

$$Module\ area\ [m^2] = F * \ HeatPumpOutput\ [kW]\ at\ design\ temperature\ (usually - 15°C)$$

The factor ***F*** can be taken from the following table*:*

	Freestanding	Parallel to roof
Multi-stage/Inverter	F = 3,3 m^2/kW	F = 3,6 m^2/kW
Single-stage heat pump	F = 4,0 m^2/kW	F = 4,3 m^2/kW

(Consolar 2019, S. 9)

Rule of thumb for Triple solar heat pump panels:

The rule of thumb to dimension the module are for the Triple Solar Panels is adapted for the Netherlands, which is their main distribution area.

$$Module\ area\ [m^2] = 2{,}7 * \ HeatPumpCapacity\ [kW]$$

(Triple Solar BV 2019, S. 3)

Comparison between the rules of thumb:

Since the Consolar-Panels and the Triple-Solar Panels were designed in a cooperation, there should not be a difference in the sizes of the collector fields. The explanation for this lies in the design temperature of heating systems in the main distribution areas. While the design temperature for the Consolar panels assumes minimum temperatures of -15 °C, the rule of thumb for the Triple Solar B.V. panels was created for the Netherlands with a maritime climate, where extreme low temperatures are not to expect. So, the rule of thumb from Triple Solar BV will work well for the Netherlands.

However, regarding the fact, that the panels will be used all around the North Sea region, where the temperatures are lower, the rule of thumb from Consolar for parallel panels operated with Multi-Stage/Inverter heat pumps is recommended: Their rule of thumb is adapted to extreme climate conditions, so that the system should always work within the North Sea region, no matter where the system is finally put up.

$$\boldsymbol{Module\ area\ [m^2] = 3{,}6 * \ HeatPumpOutput\ [kW]}$$

The rules of thumbs given by the manufacturers, is however supplied with the recommendation of a simulation of the home before the installation is made. The benefits of the simulation will be the assurance that the system will work, and that the collector field and the components are not oversized, so that a check is given, that the best economics is chosen. Apart from this, a simulation will make the heat pump eligible for federal funding at the BAFA or BEG. For this, it is necessary to have a simulation with Polysun version 11.0+ or to commission the manufacturer with a simulation. The result of the simulation must be a SPF_PVT of at least 4.3, so that the system will be funded (Consolar 2019, S. 17). Regarding the funding, the costs can be cut by 35 % - 50 % depending on the former heating system. (Consolar 2021) Apart from this, the SPF_PVT regards only the energy, that is drawn from the grid during the heat pump produces the heat, so that the PV-generation of the panels helps to obtain the funding. (Consolar 2019, S. 8).

Cost for PVT-Systems

PVT-Systems have a significantly higher price than PV-Only systems. Completely installed PV-Only Systems have a price from 1.300 – 1.900 €/kWp inclusive tax (Verbraucherzentrale.de 2021) depending on their size, technology and mounting.

Looking at the list prices of several PVT-Collectors, they tend to be at 2,23 €/Wp (Consolar) and 2,83 €/Wp both values exclusive tax. (Triple Solar 2020). Regarding their efficiency, the modules are highly efficient with a value of 19,5 %. Comparable PV-Panels, however, can already be bought for less than 0,34 €/Wp exclusive tax. (Alpha Solar 2021). Regarding the thermal heat output power of the panels, the rules of thumb from above come into account. An installed kilowatt hour of heat pump output needs 3,6 m2 of module area. Since the heating loads of a passive house is small, the collector field could in theory stay also small. The heating load for a 120 m2 passive house with 10 W/m2 lies at 1,2 kW, so that 4,32 m2 of collector area are necessary. This would be more than 2 collectors for more than 1700 euros, so that a kilowatt peak of heating load causes cost of 1460 € for the collectors if the costs could be divided.

Additional to the higher price of the PVT-panels, the panels also need collectors for the hydraulics which cause additional costs for the system. Besides these costs, a heat storage will also be necessary, which might not exist within the building.

The next share of the costs for PVT-solutions is the heat pump. The heat pump for a PVT-solution must be a special heat pump, since it must work with temperatures down to -15 °C. These temperature levels are no usual operation levels for brine water heat pumps, so that there are according to the manufacturers of PVT-panels only few manufacturers, that provide solutions for this purpose. According to Consolar WATTERKOTTE produces heat pumps that can do this and according to Triple Sun, Alpha Innotec has also models that can operate at these levels. Looking at the heat output of the recommended models, that are in the prospectus of the Consolar panel, the smallest heat pump can supply 4,6 kW and costs over 10.800 Euros excl. tax. (Consolar, S. 15) This heat pump, however, is no inverter heat pump, so that the collector field needs to be multiplied not by the factor 3.6, but with factor 4,3. To properly supply this heat pump a collector field with 10 collectors for nearly 8.700 Euros would be necessary. Looking at the needs for the passive house standard a heat pump like this would be totally oversized. With rising heating powers, the ratio of the heat pumps decreases to roughly 600 €/kw for a model with 55,3 kW or 877€/kW for 17,3 kW, what will be enough to cover the needs of a multi-story apartment with over 1,000 square meters.

To gain a better overview over the cost for the heat pump system, an overview was created to list obvious proportional costs per kW:

Component	Calculation	Medium Systems €/kW heat output	Not proportional small house with over dimensioned heat pump (non-inverter heat pump)	Large systems €/kW heat output
Collector	3,6 m^2/kW * 425 €/m^2 (Inverter heat pumps)	1.827,50	8.700 (10 panels)	1.530
Value of the PV-generator at 19 % efficiency and 0,34 €/Wp	(- 232 €/kW heat output)	(- 232 €/kW heat output)	(- 297 €/kW heat output) * 4,6	(- 232 €/kW heat output)
Storage	(3.000 €)	-----	3000	-----
Heat pump	Medium Systems: 10.800/4,6	2.356	10.800	877
Mounting and other hydraulic components	Additional costs	Additional costs	Min. 2.000	Additional costs
Summary		3.654	23.134	> 2.175
Specific costs €/m^2 at a heating load of 12,5 Watts		45,66 Small components missing!	192,8 120 m^2 (4,6 kW -> 368 m^2 -> 62 €/m^2)	27,19 Small components and heat storage components missing!

Figure 32: Costs for PVT-Systems from the official price list. The prices may be lower for a concrete offer. According to offers by the manufacturers, the prices can be 50 % lower than in the prospectus. For the end customers there will also be taxes. (Consolar, S. 15)

Looking at the prices above, it can be clearly seen, that an oversized heat pump causes costs, that make no sense for the renovation anymore. Looking at the low price for the two panels, that cover the heating load or maybe a third panel to have a solution for the DHW-preparation, the costs for the collectors stay at a reasonable level. What needs to be found or developed for the INDU-ZERO project is a small heat pump, that can work with these temperatures and that has also the right size for a passive house, without causing high costs. Generally looking at the costs, the prices will be significantly lower, if they are not bought from the list of the manufacturers, however, these are the only prices, that were supplied by the manufacturer, which was the reason, why the prices were used.

To lower the costs, there needs to be more research within the INDU-ZERO project, to find a bivalent point of the covering the heating load with a heat pump and using direct heating during the few days that are exceptionally cold. Regarding the funding, it is further important to search for PVT-panels that are available to obtain the funding.

Looking at the costs of PVT-systems, there might be a different point of view, to justify the higher investments: The wish for comfort in front of the background of the price for housing and rents. The list price for a large building is under 27 Euros, without any discounts by the manufacturers, but also without any mounting costs. If a house or an apartment is bought, prices for more than 3.000 € per square meter are not unusual. If one percent of the total price can help to have a noise free environment close to the own house, then the money is probably well invested. The noise argument, however, might also become invalid, when the neighborhood is close to a road, then an oversized air water heat pump working at a reduced noise level with less than 35 dB(A) will probably be the better option. Further, if the systems could be sized down fit to the demand of a passive house for a material costs of less than 30 Euros per square meter, then the total material costs would be less than 3,600 Euros for all heating components in the renovation, what is completely affordable. This calculation, however, does not consider the additional costs for the DHW-storage, which has the character of fix costs.

Strategy: DHW heat reduction and recovery

For the reduction of the DHW-demand a water saving showerhead can be a good solution. While the average shower heads use 12 – 15 liters per minute, water saving shower heads reduce this amount down to 7 – 9 liters per minute. (WEMAG 2020). This change will help to reduce the water and energy consumption of people without forcing them to change their shower habits.

Figure 33: Water saving shower head - this Model (Bubble-Rain espresso XL) only needs 6 liter/minute – price 100 € (Gesundheitsmanufaktur 2021). For finding a sustainable shower head, that also customers with a low consciousness for sufficient living will accept, more research will be necessary. A good option would be, to provide an adjustable shower head or to have a shower head with an adjustable flow level, so that at least some water would be saved.

A different concept to lower the DHW-energy demand is regaining the heat from the shower water. This concept involves a much higher effort with, but it has the advantage, that the savings are not directly dependent on the personal shower habits of the people. Apart from this, the concept will also work, if a water saving showerhead is exchanged for a model with a higher consumption. As the figure below shows, the hot water from the shower is not just released any more but used to heat the cold water in a heat exchanger, that is integrated in the drain of the shower, before the cold water passes the mixing valve. This can help to reduce the complete DHW-heat demand by 25 – 35 % (Passivhaus Institut GmbH) or, if the reduction of the shower heat itself is regarded, then some manufacturers promise a heat recovery over 40 %, depending on the flow rate (Franke 2018).

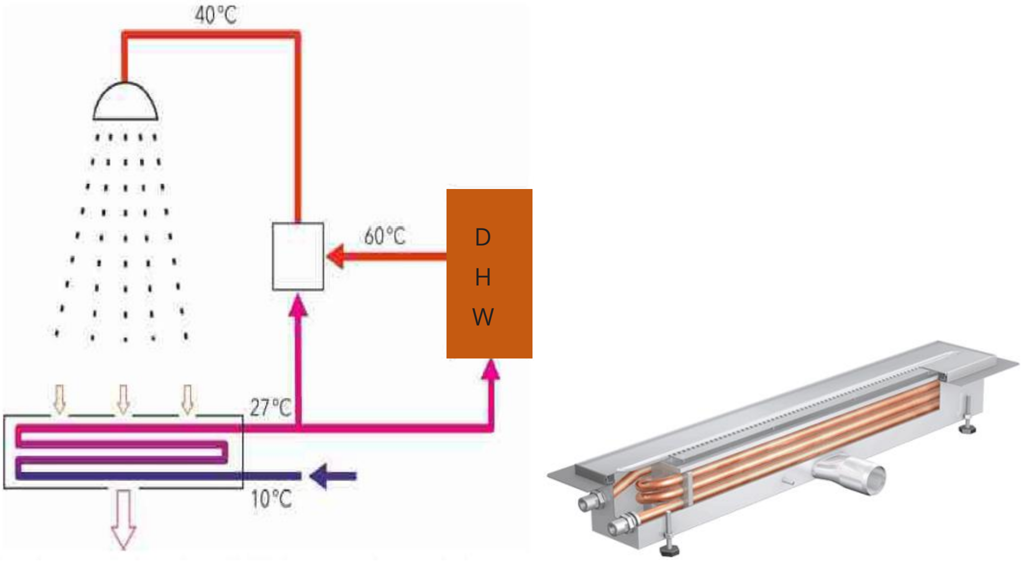


Figure 34: Principle of shower with heat recovery – prices 1200 € (Thomas Oberholz 2021)

Recommendation for the INDU-ZERO project:

Since the system itself is already expensive and the installation is additional to this costly and difficult, there is the need for a complete finished shower cabin, featuring a water saving showerhead, a shower water heat recovery. A mass production of this shower cabin will probably significantly lower the costs for these systems and the shower cabin could be used as an additional option, if the bathroom is supposed to be renewed within the renovation, too. So, a finished shower, featuring all the heat saving mechanisms is a real market gap or if this product should already exist, then it is an idea, that will be in a growing market.

Regarding the savings of the DHW-preparation of the shower head and the heat recovery, there will be significant savings on the energy balance of a shower. If the flow is reduced from 12 to 7 liters per minute and the heat recovery rate of the shower lied at 35 %, then only 38 % of the original consumption is necessary. Considering, that the heat can be supplied with heat pumps, with a S_COP of 3, the electric energy demand for the showers will shrink to 12,6 %, what means, that 8 People will then need as much energy for their showers as one person needed before. This value, however, has a theoretical character in comparison to the demands, that are calculated in the PHPP-tool. The values of the PHPP-tool have already a very sufficient character, so that the real reduction of the use is caused by the heat recovery system of the shower and especially the use of the heat pump.

Strategy: Cash equivalent values of systems if they are newly built

Some renovations in very old houses will require an exchange of the existing system, since the pipes might be too old to run for another 20 years. The following chapter is an approach to value systems when they need to be renewed. The following numbers are taken from a study made for the passive house institute in Germany. The values, however, represent the cost of the systems when they are newly built. Within a renovation, costs might significantly vary from the calculations done within the study.

For the calculation, a reference building near Frankfurt on the Main with 160 m^2 was regarded and for the cash equivalents, the study assumed an annual inflation rate of 1 % and an annual interest rate of 2,5 %. (Krick Benjamin 2017).

Direct space heating with electricity

In the diagram below a central ventilation register with an electric air heater was compared to an electric area heating system, that can be affixed to the ceiling. If a central ventilation system with a heat exchanger does already exist, it should be extremely easy to add the heating register. If, however, no ventilation system exists, a decentralized ventilation will probably be the best solution in many cases, because most of the buildings were planned with a ventilation and light-concept, that is based on the use of windows, so that the central solution is extremely hard to afterward build into the house. In such a case, it appears extremely easy to use infrared panels since the difficulty level of the affixation of the panels equals to affixing a large lamp. Regarding the costs of electricity and the INDU-ZERO standard with <15 kWh/(m2*a) and an electricity price of 0,3 Euros, the energy costs will be at 4,50 Euro per square meter and year or at 540 Euros per year for a terraced house with 120 square meters of living area. The invest into the heat panels, however, is as low as less than 100 Euros per room and the comfort level of this solution is very high. In comparison to replacing the entire heating system, this solution is definitively considerable.

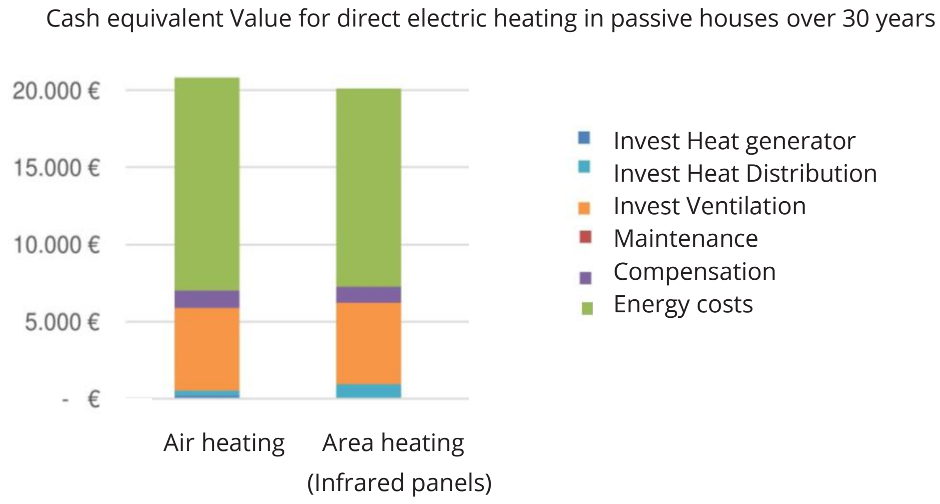


Figure 35: Cash equivalent values of direct heating systems after 30 years (Krick Benjamin 2017)

Space heating with heat pump technology

The figure below shows a comparison of cash equivalent values of different heating systems. The first system in the diagram below uses one split heating device (air-air heat pump or climate system) with 12 year of operating life expectancy. Looking at the number of rooms, it appears surprising that one device for heat generation might already be enough. However, there is an ongoing test with only one split device as a single heat source in houses, which has so far showed satisfying results, if the ground plan had the right design for this solution (Krick Benjamin 2017, S. 16). If there should be the need for more devices, the main advantage of the split devices is their low price, because they are produced large numbers. Further, some devices also allow a multi split system, which means, that one heat pump outside can supply two or three heat distributors inside. Apart from this, these split climate devices also allow cooling in the summertime. For the pricing, it is already possible to buy devices with 2,1 kWh of heat output for less than 1.000 €. A heat output of 2,1 kWh is for passive houses with a heating load of less than 10 W/m^2 enough to supply 210 m^2 of living area. Regarding their low price it is important to point out, that the low-priced systems can be very noisy at the inside and the outside, too. For staying under the permitted noise emissions outside and to have a higher comfort inside it will be necessary to find lower priced devices or to buy higher priced devices, that have less noise emissions. Looking at the installation, the system is easy to install, what makes it attractive for renovations that have no existing radiators or radiators, that need to be replaced. Apart from that, an installation of this system can also be quickly done, so that it is suitable for the INDU-ZERO project.

Looking area-heat-distribution-systems, it is clear, that the installation is very costly and not within the standard of INDU-ZERO. The installation comes with too much work within the building. For people, who want a solution that aims at the most possible comfort, this solution is good, and it could be added as an extra. If such a system, however, is already present and must be renewed, then the best solution would be to rethink the heating concept. So, if a different solution is accepted it would then be best to switch to air heating with split devices or install direct electric infrared heating panels.

Going back to the air heating with a centralized heat exchanger, it is possible to use a heat pump instead of an electric register. The invest in the heat pump will be higher, so that the price for a new installation will stay the same, however, the system will be better for the primary energy consumption and be more resistant against rising electric-energy prices.

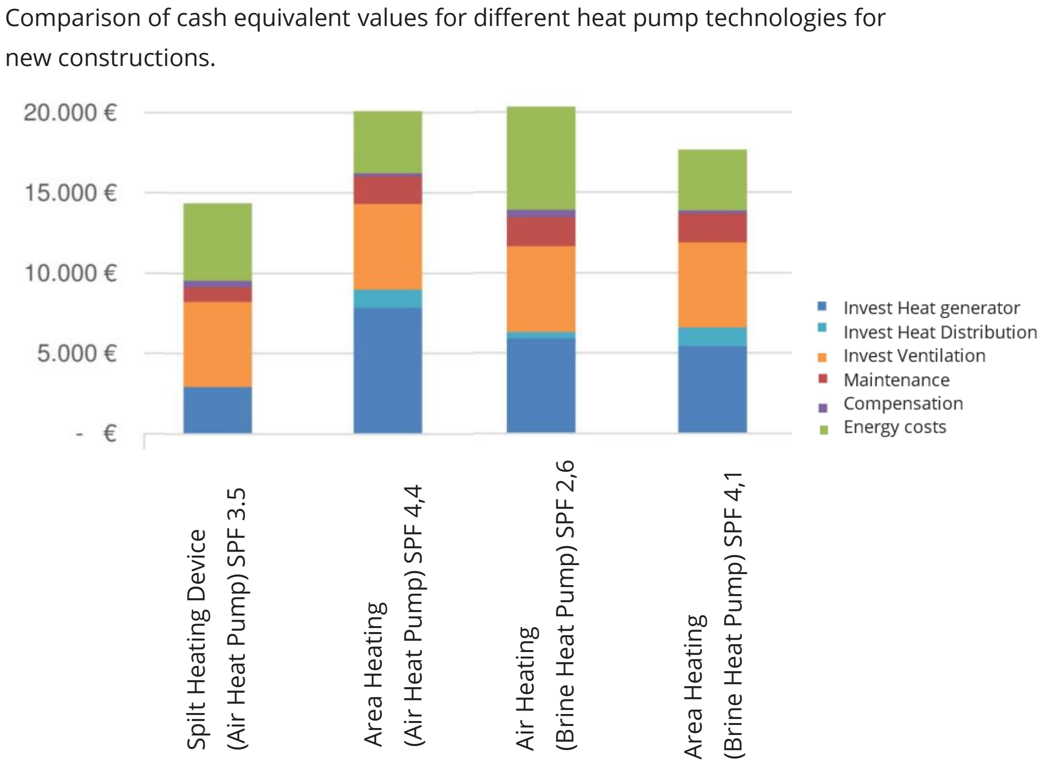


Figure 36: Heat supply concepts of passive houses – Cash equivalent value after 30 years of use (Krick Benjamin 2017, S. 18)

DHW preparation

Using a heat pump for preparing DHW will cause savings in most of the cases. The diagram below shows, that, a system that combines DHW preparation and space heating is cheaper two separate systems if the systems are newly build. Fur the calculation of the prices, when the system is newly built, the shower are already planned very sufficient, so that there are no further savings possible (Krick Benjamin 2017, S. 18). For methods, that used direct electric heating of the water with flow heaters it was assumed that the shower had a flow heater with 13 kW and the taps 3,5 kW. The result shows, that a direct electric solution comes over the years with similar costs like air-water heat pumps, if the direct electric heating is not combined with a shower heat recovery. Looking at the heat pump solutions, the heat pumps can help to reduce the consumption in the wintertime, which is good for the primary energy consumption but neutral to the costs. A beneficial side effect of the heat pumps will be, that a heat pump needs a heating storage, what allows to store energy and increase the own consumption.

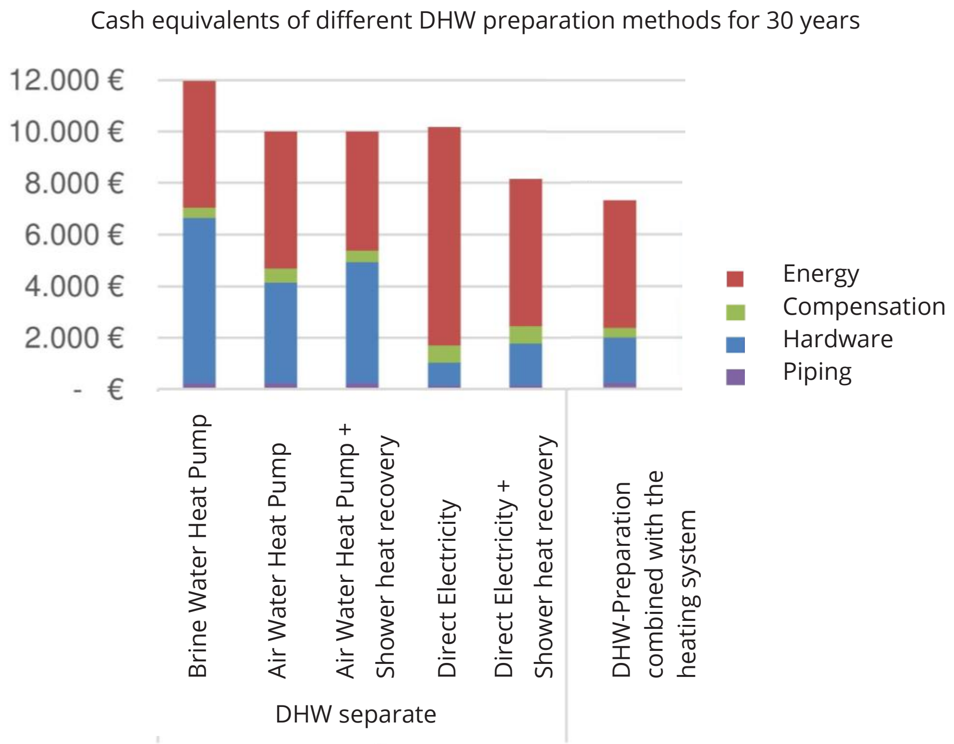


Figure 37: Krick Benjamin 03.2017 - Wärmeversorgungskonzepte in Niedrigenergie- und Passivhäusern.jpg (Krick Benjamin 2017, S. 22)

As a conclusion to this, it is best to have a central heating solution, that can generate DHW and supply heat for space heating at a low temperature level. If it is possible to install this solution, the solution would be the cheapest and also the solution, the solution with the lowest primary energy consumption and also the most grid friendly solution. (Krick Benjamin 2017, S. 21)

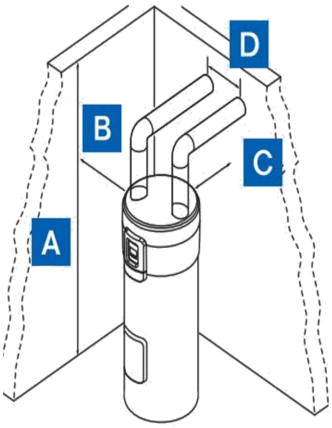


Figure 38: Ochsner Europa Mini Heat Pump for 1.700 Euros to continue using the heat storage if it was recently exchanged.

Figure 39: Exhaust Air/Air heat pump for DHW-preparation – price < 2.500 € and a COP of 2.9 at 7 °C – estimated at 2,35 for 0°C according to the rule of thumb by Viessmann (ManoMano). By choosing the right heat pump, the air inlet temperature is also important, because some heat pumps only operate until 5°C so that they work like booster heat pumps, that use a low temperature heat source for DHW preparation. The heat pump (second from the right side) is for example such a model, that needs warmer air – manufacturer Ochsner, price 1.800 €. (KlimaWorld 2021) At the right side is just the head of the heat pump, that can be bought for 1.600 Euros. It supplies hot water directly into an external heat storage(Ochsner Europa Mini IWPL 2021)

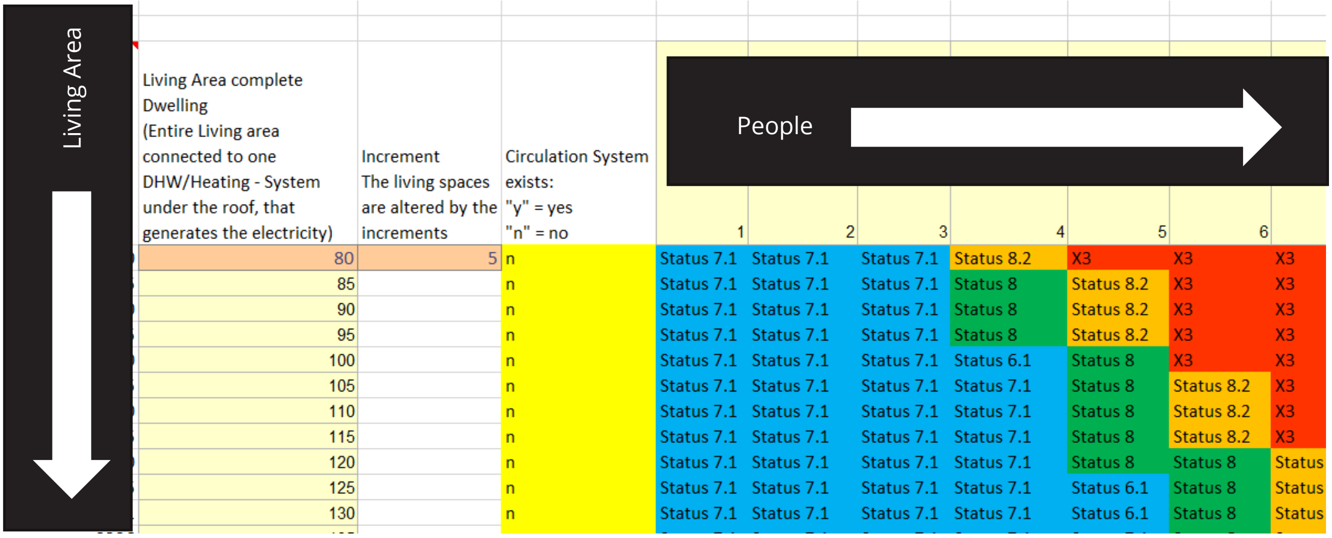
By looking at the conclusion over the entire chapter, the best economic values are achieved by the combination “Area heating systems with split devices + direct electric DHW with a shower heat recovery”. If the shower needs to be exchanged anyways, this solution will fortunately be possible within the Scope of INDU-ZERO. Further, this does also mean, that one of the most affordable solutions is applicable on one family houses with investment bottlenecks in the heating systems. This solution, however, might not bring the highest comfort level, so that the second-best solution would be the central heating solution with DHW preparation. For larger dwellings with multiple apartments, this chapter is not applicable, because the situation is completely different. In general, the matrix, presented in this work, might be the best help to choose the housing technology regarding the costs and the Net-Zero-aspect.

Matrix for choosing housing technologies

Up to this chapter many modern housing technologies have been discussed. A second part of this work was, to find a method to easily determine what measures it takes to make a house Net-Zero, or to quickly see whether the roof area of a dwelling is just too small to get it Net-Zero.

Since every dwelling has its own individual properties, regarding the different size, number of inhabitants, living area, habits of the inhabitants, inclination of the roof and DHW distribution system, the best approach appeared to create a matrix, that respects the different parameters of the building and that makes its calculation on the provided data. Since data can vary from country to country and year to year, the Matrix was implemented in an EXCEL-Sheet, because this environment would allow to alter all the parameters going into the calculations and to also adapt the formulas if new knowledge or problems turned up. Apart from this, an EXCEL based matrix can be integrated into the PHPP-Tool, so that the matrix can take the provided data from the PHPP-tool for its own calculations.

To do so, the matrix was designed in a way, that it regards the number of stories, since the solar gains stay the same on the roof, while the demand underneath the roof grows. Further, the matrix needed to regard the area and the people living inside. Since the number of people living inside and the area, that needs to be heated are characteristics, that can describe the consumption of a building very well, the two properties were used to form the outlines of the matrix. So, the matrix can be described as a people and living area matrix, just as it is shown in the picture below.



Living Area complete Dwelling (Entire Living area connected to one DHW/Heating - System under the roof, that generates the electricity)	Increment The living spaces are altered by the increments	Circulation System exists: "y" = yes "n" = no	1	2	3	4	5	6	
80	5	n	Status 7.1	Status 7.1	Status 7.1	Status 8.2	X3	X3	X3
85		n	Status 7.1	Status 7.1	Status 7.1	Status 8	Status 8.2	X3	X3
90		n	Status 7.1	Status 7.1	Status 7.1	Status 8	Status 8.2	X3	X3
95		n	Status 7.1	Status 7.1	Status 7.1	Status 8	Status 8.2	X3	X3
100		n	Status 7.1	Status 7.1	Status 7.1	Status 6.1	Status 8	X3	X3
105		n	Status 7.1	Status 7.1	Status 7.1	Status 7.1	Status 8	Status 8.2	X3
110		n	Status 7.1	Status 7.1	Status 7.1	Status 7.1	Status 8	Status 8.2	X3
115		n	Status 7.1	Status 7.1	Status 7.1	Status 7.1	Status 8	Status 8.2	X3
120		n	Status 7.1	Status 7.1	Status 7.1	Status 7.1	Status 8	Status 8	Status
125		n	Status 7.1	Status 7.1	Status 7.1	Status 7.1	Status 6.1	Status 8	Status
130		n	Status 7.1	Status 7.1	Status 7.1	Status 7.1	Status 6.1	Status 8	Status

Figure 40: The Matrix

In the head of the EXCEL-Sheet, several properties can be adapted. Since the explanations in the EXCEL-sheet might be not clear enough, they are more detailed explained here.

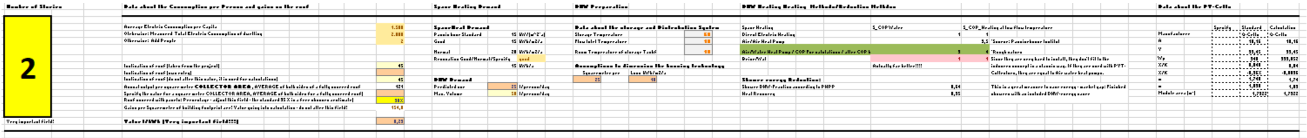
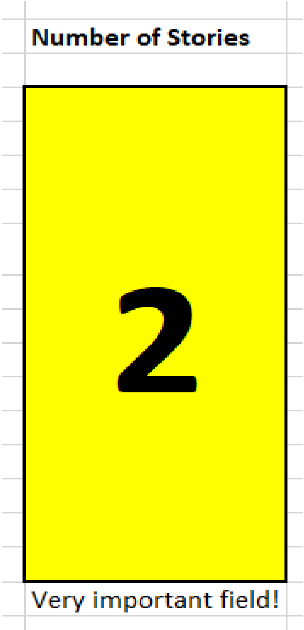


Figure 41: Head of the EXCEL-Sheet



Number of Stories

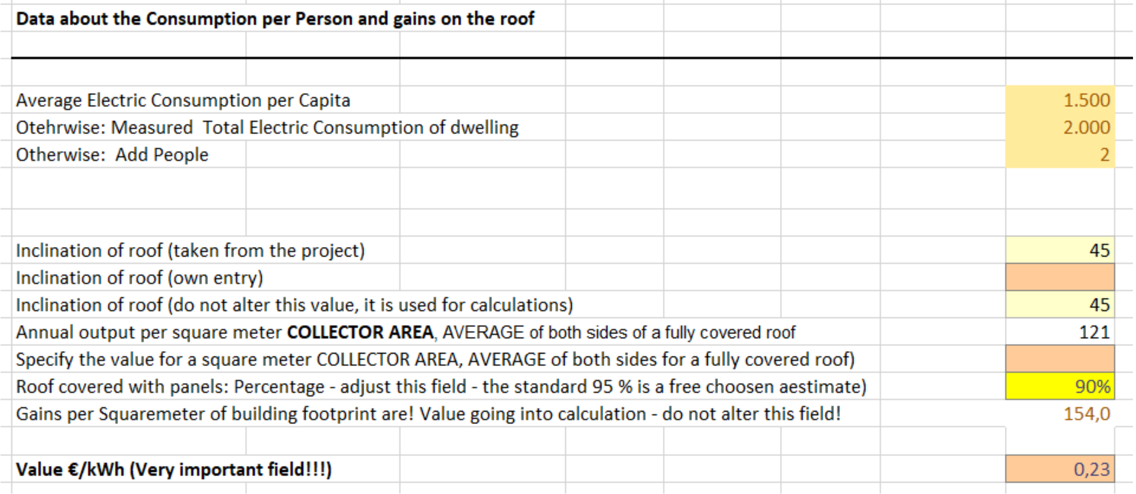
2

Very important field!

Figure 42: Number of stories

The number of stories is important for the calculations, since the solar gains on the roof are calculated regarding the number of stories. For this calculation it is assumed, that every house has a rectangular ground plan and the same height over all the stories, so that every square meter of the building footprint has a certain roofage area on top of it. With the provided inclination of the roof, the sheet calculates the actual roof area, that is needed to cover a square meter of building footprint. This area is then used to calculate the gains for the footprint of the entire building.

The next part of the head of the sheet deals with the data about the consumption per person and the gains on the roof.



Data about the Consumption per Person and gains on the roof	
Average Electric Consumption per Capita	1.500
Otehrwise: Measured Total Electric Consumption of dwelling	2.000
Otherwise: Add People	2
Inclination of roof (taken from the project)	45
Inclination of roof (own entry)	
Inclination of roof (do not alter this value, it is used for calculations)	45
Annual output per square meter **COLLECTOR AREA**, AVERAGE of both sides of a fully covered roof	121
Specify the value for a square meter COLLECTOR AREA, AVERAGE of both sides for a fully covered roof)	
Roof covered with panels: Percentage - adjust this field - the standard 95 % is a free choosen aestimate)	90%
Gains per Squaremeter of building footprint are! Value going into calculation - do not alter this field!	154,0
Value €/kWh (Very important field!!!)	0,23

Figure 43: Possibilities to Adapt data about the consumption

The average electric consumption per capita can be specified here. The value of 1.500 kWh/year is the default value, that is always used, if nothing else is specified. The value can be altered, when for example a measured total consumption is entered together with the number of people, that caused the consumption. If both, the number of people and the consumption are entered, then the consumption will be divided through the number of people, so that the Matrix will take this value as the new per capita consumption for the other lines, too. So, for a small dwelling with an extraordinary big number of people, which has also an electric consumption, that is much different from the average, the values in the matrix are only valid for the case.

The fields, that deal with the inclination of the roof allows the matrix to respect, that every roof is different. The matrix can get this information directly out of the provided data from the PHPP-Tool. Otherwise, the information about the inclination can be supplied at this point, too, if for example the roof will have a different inclination after the renovation.

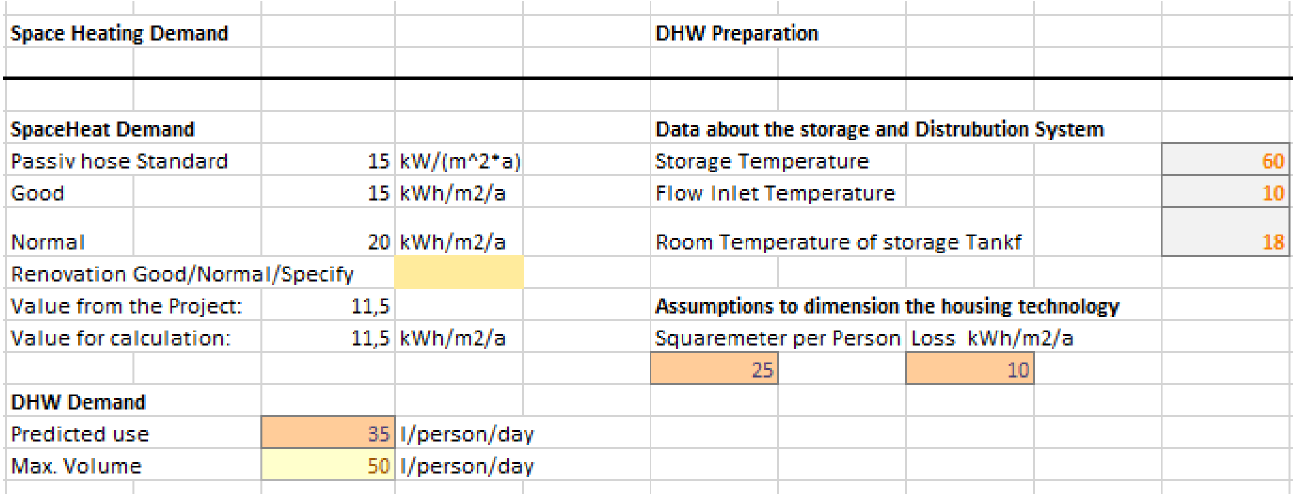
The annual output per square meter collector area on a gabled roof is a very important field, that is crucial for the calculations. The value represents the average solar gains, that arrive on one square meter of collector area. For this, the collector gains are calculated location and orientation of the house, which is described in PHPP-tool. The value is calculated by the PHPP-Tool for a ST-only collector, that is for example oriented to the North and a second collector that is oriented to the South. The average of the gains of the two collectors will then be the value, that is listed here – representing a square meter on a fully covered roof. The properties of the ST-only panel can also be specified in the head of the matrix at a different point, too. Further, the gains can also be manually entered if they are known better for example from the result of a simulation.

Since the roof cannot always be covered to a 100 %, because there will be in most cases a certain distance from the solar field to the edges of the roof or also a window, this value specifies, which fraction of the roof is fully covered with PV-panels. The gaps, between the panels, that are needed for mounting, are already regarded in the background. If the value is not known, it is smarter to use a low value, since it is better to have energy left, than need energy, that does not come from the roof. Regarding the fact, that many roofs protrude beyond the building footprint, a value greater than 100 % might be in some cases also possible.

One square meter of building footprint can have a larger roof area, when the inclination is regarded. This leads to a higher available amount of energy throughout the year. This value is used for the calculations, that the matrix does.

The value of a kilowatt hour can vary strongly, even within a country. Further, here could be discussed, whether a kilowatt hour has the value, that an end consumer pays or not, if there is excess energy left and the Net-Zero-Standard is reached. For most of the buildings with two stories, this should not be the question because most of the area-story-inhabitant-constellations do already need additional technology for reaching the Net-Zero standard. In front of the background, that electromobility is rising and that it might not be possible for a very long time anymore, to just simply spin the meter back in the summertime, entering the value of end-consumer prices appears justified here.

The next part of the head of the excel sheet deals with the space heating demand and the DHW-preparation.



Space Heating Demand			**DHW Preparation**		
SpaceHeat Demand			**Data about the storage and Distrubution System**		
Passiv hose Standard	15	kW/(m^2*a)	Storage Temperature		60
Good	15	kWh/m2/a	Flow Inlet Temperature		10
Normal	20	kWh/m2/a	Room Temperature of storage Tankf		18
Renovation Good/Normal/Specify					
Value from the Project:	11,5		**Assumptions to dimension the housing technology**		
Value for calculation:	11,5	kWh/m2/a	Squaremeter per Person	Loss kWh/m2/a	
			25	10	
DHW Demand					
Predicted use	35	l/person/day			
Max. Volume	50	l/person/day			

Figure 44: Providing information about the space heating demand and DHW preparation

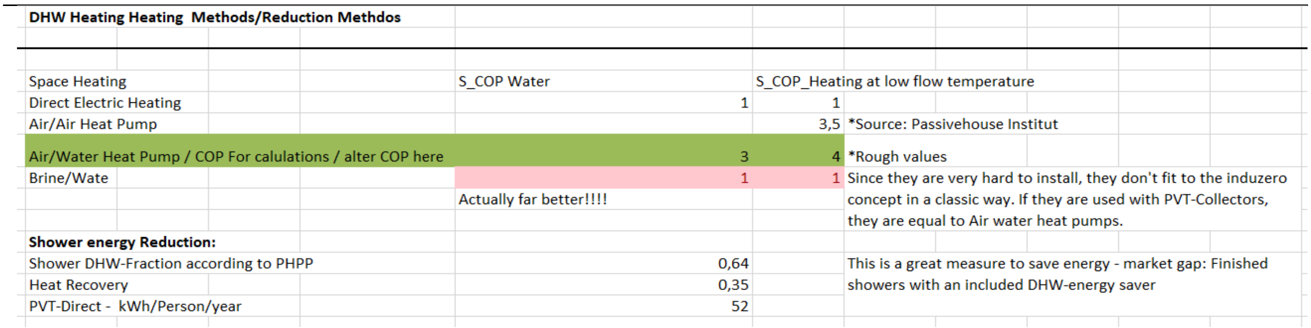
The space heating demand of INDU-ZERO houses is calculated in the PHPP-Tool. The value should be at around 15 kWh/(m^2*a) if the renovation achieved a good level. However, these low values might not always be reached, so that the values can be adapted by entering “good” or “normal” in the field, so that the space heating demand would be regarded in the Net-Zero calculation of the dwelling with 15 kWh/(m^2*a) or 20 kWh/(m^2*a). Instead of describing the status with words, the value can also be directly entered, if the value is known from a different source than the PHPP-Tool or if the value is supposed to have a more general character in a simulation. If nothing is entered in the field for the space heat demand, then the matrix uses the calculated value that comes from the PHPP-Tool, so that the heating load will fit to the specified project in the PHPP-tool.
The DHW-Demand can in some cases be crucial, whether a house can reach a Net-Zero status or not. The PHPP-tool assumes, that sufficient living people use 25 liters of water at a temperature of 60 °C every day. This predicted volume can be adjusted for future calculations, too, if it should turn out, that people do not adapt sufficient habits.
The maximum volume is a field for dimensioning the housing technologies. It is assumed, that the housing technologies must be dimensioned in a way, so that it is able to supply the inhabitants with 50 liters of water at a temperature of 60°C per day. That would allow everyone to use over 100 liters of

water on the tap per day. Since the heat pump comes with a small heat output power and the storage heat-up-time is long, this volume is also the volume, that will be used in the calculations for dimensioning the size of the storage tank.

For the DHW preparation it is important to calculate the storage losses. For this, the storage temperature and the temperature of the surrounding temperature must be known. Since it is assumed, that within the renovation not the most recent storage tanks are still further used, the loss calculation assumes the lowest energy efficiency class possible. The losses for the storage tank are important because they will always occur. If it turns out, that the direct electric heating would be more efficient at very small consumptions, the matrix finds this out and notifies the user, that a flow heater would lower the consumption.

Further the matrix is also designed in a way, that a DHW recirculation system can be respected, if it is already installed or planned. Single family homes and terraced houses usually have no DHW recirculation system, which is used to prevent the hot water between the storage tank and the tap from cooling by recirculating the DHW back in the heat storage through a loop. The losses, that result out of the circulation cannot be neglected, since they can be higher than the actual useful energy of the DHW preparation.

To estimate the losses there were sources, that said the annual loss lied at 10 kWh/m^2, which is a plausible value for the old piping systems, that are not renewed within the scope of an INDU-ZERO renovation. Since the housing technologies must be in some kind be prepared for these losses, the losses were calculated according to a fictional living area of 25 m^2 per person. The low value of 25 m^2 was used, because the heating losses were chosen for bad systems, and the value 25 m^2/person tends to fit better to large buildings, in which such systems are installed. These values are taken to dimension the housing technologies according to the number of people living inside the house. If the values are known better, because for example more research has been done for the object, then these values can be adjusted.



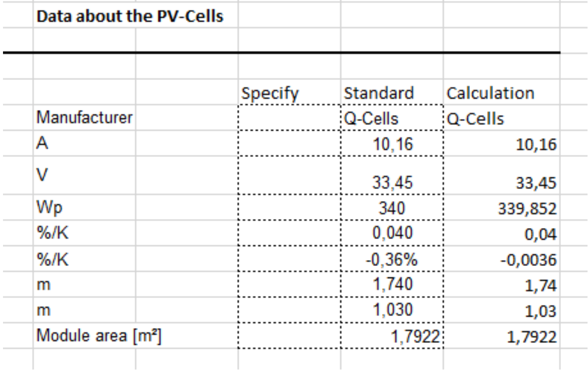
DHW Heating Heating Methods/Reduction Methdos			
Space Heating	S_COP Water	S_COP_Heating at low flow temperature	
Direct Electric Heating	1	1	
Air/Air Heat Pump		3,5	*Source: Passivehouse Institut
Air/Water Heat Pump / COP For calulations / alter COP here	3	4	*Rough values
Brine/Wate	1	1	Since they are very hard to install, they don't fit to the induzero concept in a classic way. If they are used with PVT-Collectors, they are equal to Air water heat pumps.
	Actually far better!!!!		
Shower energy Reduction:			
Shower DHW-Fraction according to PHPP	0,64		This is a great measure to save energy - market gap: Finished showers with an included DHW-energy saver
Heat Recovery	0,35		
PVT-Direct - kWh/Person/year	52		

Figure 45: DHW Heating and Reduction

At this place the S_COPs of different heat pump systems are presented. Since Air/Water heat pump systems are the easiest systems to install, their COP is used for every calculation involving a heat pump.

If a different heat pump technology is desired, then the values for the calculations can be altered in the green fields and the name of the technology can be overwritten. The COP values for the heat pumps are rough values only, which will probably fit to the reality since the values come from the federal association for heat pumps. They also provide a service to calculate the COP for the region according to the postal code an the climate, that is to expect there: https://www.waermepumpe.de/jazrechner/. If more information is known, then the COP will still depend on the flow temperature of the radiators and can be adapted.

The field shower energy reduction is in fact no active field – it is used to show, what consumption the DHW could have, if the shower water heat recovery is used after the renovation.



Data about the PV-Cells

	Specify	Standard	Calculation
Manufacturer		Q-Cells	Q-Cells
A		10,16	10,16
V		33,45	33,45
Wp		340	339,852
%/K		0,040	0,04
%/K		-0,36%	-0,0036
m		1,740	1,74
m		1,030	1,03
Module area [m²]		1,7922	1,7922

Figure 46: Adjusting parameters of solar panels

The data of the solar panels can also be adapted. The standard is a module from Q-Cells, which has a high efficiency. If other modules are used, their values can be entered here.

After the head of the EXCEL-Sheet, the first part of the body contains variables and solutions for further calculations.

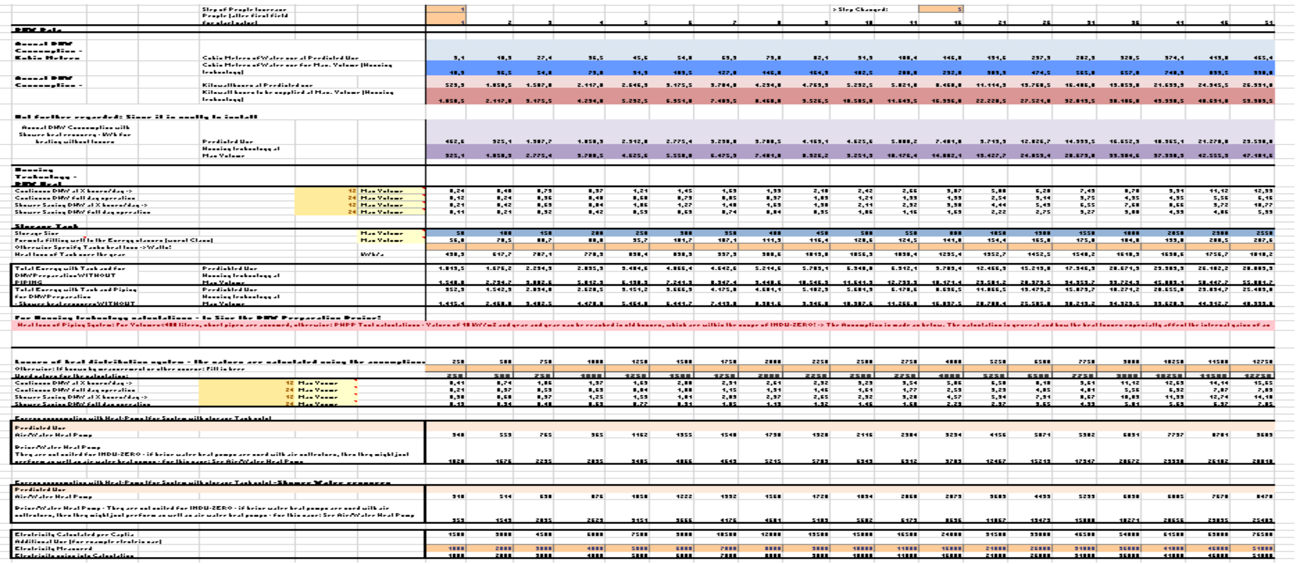
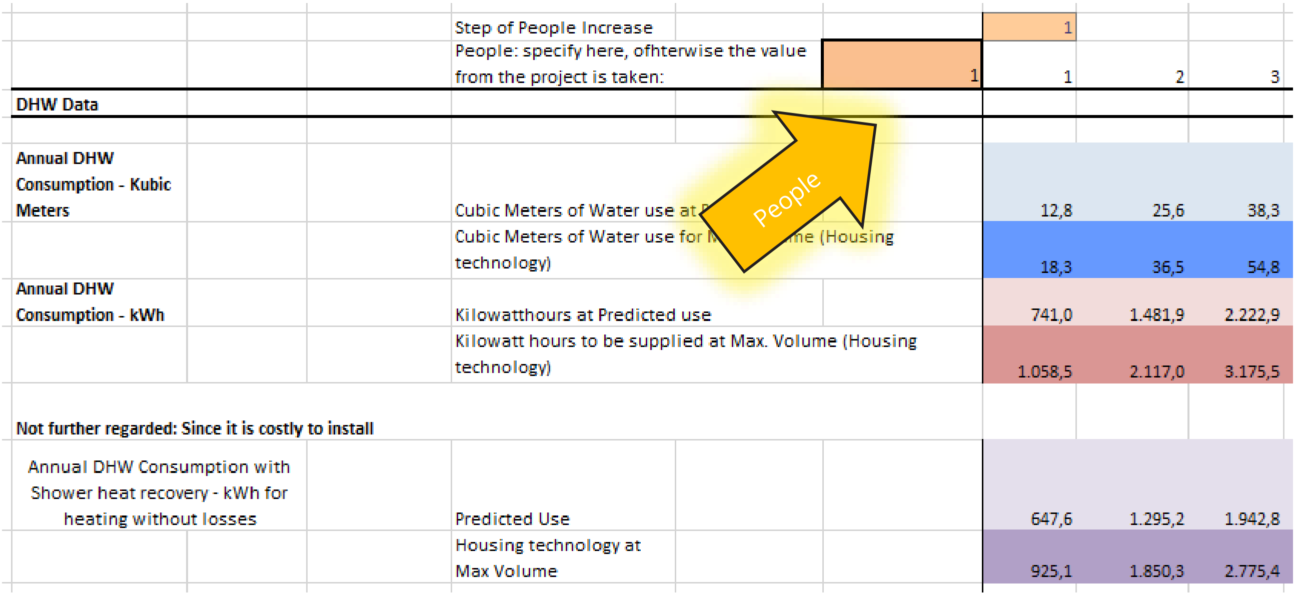


Figure 47: Body of the Matrix



	Step of People Increase		1		
	People: specify here, ofhterwise the value from the project is taken:	1	1	2	3
DHW Data					
Annual DHW Consumption - Kubic Meters	Cubic Meters of Water use at P		12,8	25,6	38,3
	Cubic Meters of Water use for M me (Housing technology)		18,3	36,5	54,8
Annual DHW Consumption - kWh	Kilowatthours at Predicted use		741,0	1.481,9	2.222,9
	Kilowatt hours to be supplied at Max. Volume (Housing technology)		1.058,5	2.117,0	3.175,5
Not further regarded: Since it is costly to install					
Annual DHW Consumption with Shower heat recovery - kWh for heating without losses	Predicted Use		647,6	1.295,2	1.942,8
	Housing technology at Max Volume		925,1	1.850,3	2.775,4

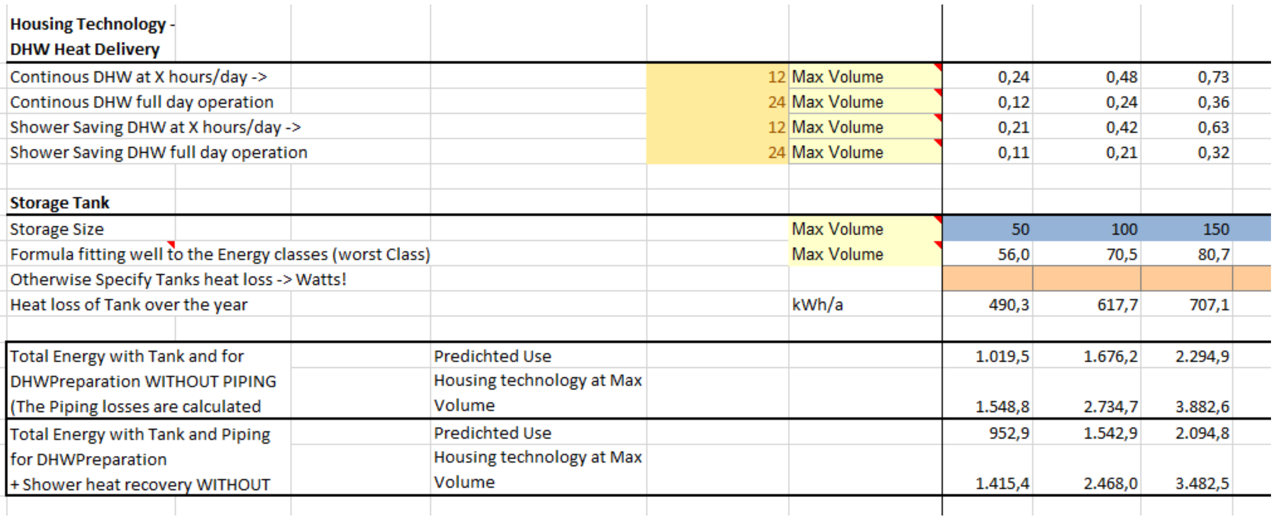
Figure 48: Adapting the Number of the People - Results for the DHW

At this place, the number of people can be adapted to any number. As a default, the matrix takes the number of people, that is connected to the object in the PHPP-tool. The increment value of the number of people can be altered here too. It is also possible and advised to use “half” people to check, whether the consumption is really close to the border of a Net-Zero home or not.

At first, the DHW consumption is calculated in cubic meters per year as an auxiliary value.

Then the kilowatt hours are calculated, using a standard temperature of 10 °C for water coming from the pipe. The Max value is the auxiliary value to dimension the size of the heat pump for the housing technology.

Since it is too costly to install, the shower heat recovery is not regarded any further. It is left here to show, what would be possible using this technology to have it as a teaser to install it, if bathrooms need to be renovated, too.



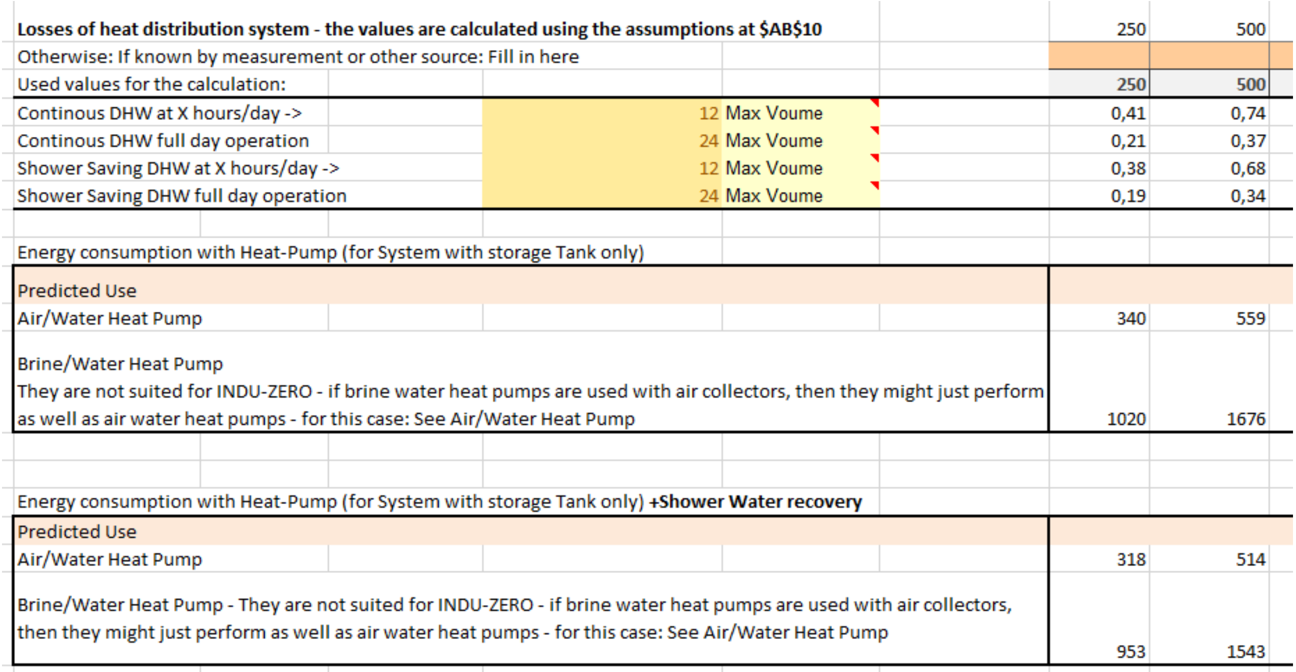
Housing Technology - DHW Heat Delivery						
Continous DHW at X hours/day ->		12	Max Volume	0,24	0,48	0,73
Continous DHW full day operation		24	Max Volume	0,12	0,24	0,36
Shower Saving DHW at X hours/day ->		12	Max Volume	0,21	0,42	0,63
Shower Saving DHW full day operation		24	Max Volume	0,11	0,21	0,32
Storage Tank						
Storage Size			Max Volume	50	100	150
Formula fitting well to the Energy classes (worst Class)			Max Volume	56,0	70,5	80,7
Otherwise Specify Tanks heat loss -> Watts!						
Heat loss of Tank over the year			kWh/a	490,3	617,7	707,1
Total Energy with Tank and for	Predichted Use			1.019,5	1.676,2	2.294,9
DHWPreparation WITHOUT PIPING (The Piping losses are calculated	Housing technology at Max Volume			1.548,8	2.734,7	3.882,6
Total Energy with Tank and Piping	Predichted Use			952,9	1.542,9	2.094,8
for DHWPreparation + Shower heat recovery WITHOUT	Housing technology at Max Volume			1.415,4	2.468,0	3.482,5

Figure 49: DHW Preparation - Storage Tank

Here the calculations are made to dimension the housing technologies. These technologies are used in the matrix, which serves for the calculation of the economics. Since the housing technologies need to be able to supply hot water also, when people are not living sufficient, they are calculated for the maximum volume specified in the head of the sheet. Sine heat pumps will probably be part of the load management in the future, and it might also be necessary to increase the own consumption in the future, too, it might be only possible to have the heat pump run for a certain number of hours per day. For this, the number of hours of operation per day can be specified. So, continuous operation means, that the heat pump will run throughout the day and the discontinuous operation means, that the heat pump only runs for 12 hours per day, just as in the example above. Considering the fact, that sufficient living is calculated with only half of the capacity of the housing technology and that the heat pump operates for 12 hours per day, the DHW-heat pump is then oversized by factor four.

The volume of the storage Tank is here calculated by the number of people and the maximal volume, that the housing technology is supposed to deliver per day. The heating losses of the tank are calculated with a formula that was empirically found and fits very well to the worst energy classes of the storage tanks. With the loss in watts, the losses over the year are calculated in kWh/a. If the values for the tank losses differ, they can also be specified by the user.

In the next step, the total energy is calculated, that is needed to supply the water and to compensate the storage losses. The piping losses are regarded at a different point. For the housing technologies, there are again the highest values calculated. The heat recovery for the shower remained at this point for information, too.

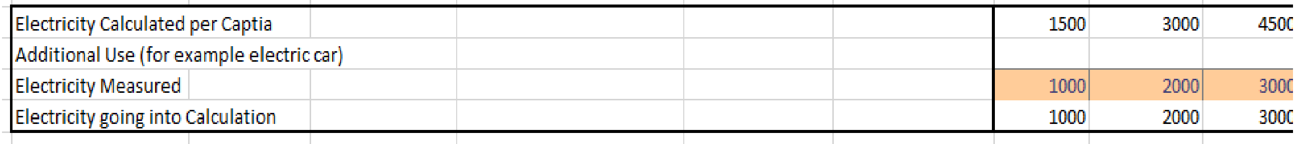


Losses of heat distribution system - the values are calculated using the assumptions at AB10			250	500
Otherwise: If known by measurement or other source: Fill in here				
Used values for the calculation:			250	500
Continous DHW at X hours/day ->	12	Max Voume	0,41	0,74
Continous DHW full day operation	24	Max Voume	0,21	0,37
Shower Saving DHW at X hours/day ->	12	Max Voume	0,38	0,68
Shower Saving DHW full day operation	24	Max Voume	0,19	0,34
Energy consumption with Heat-Pump (for System with storage Tank only)				
Predicted Use				
Air/Water Heat Pump			340	559
Brine/Water Heat Pump They are not suited for INDU-ZERO - if brine water heat pumps are used with air collectors, then they might just perform as well as air water heat pumps - for this case: See Air/Water Heat Pump			1020	1676
Energy consumption with Heat-Pump (for System with storage Tank only) **+Shower Water recovery**				
Predicted Use				
Air/Water Heat Pump			318	514
Brine/Water Heat Pump - They are not suited for INDU-ZERO - if brine water heat pumps are used with air collectors, then they might just perform as well as air water heat pumps - for this case: See Air/Water Heat Pump			953	1543

Figure 50: Losses of the heat distribution system and electric consumptions of heat pump solutions.

The next part allows to specify the losses of the heating system more precisely and allows a better dimensioning of the heat pumps. As in the case above, the possibility is regarded, that heat pumps might not be allowed to run continuously in the future, since they might be part of the load management. The shower heat recovery option is also described here, too.

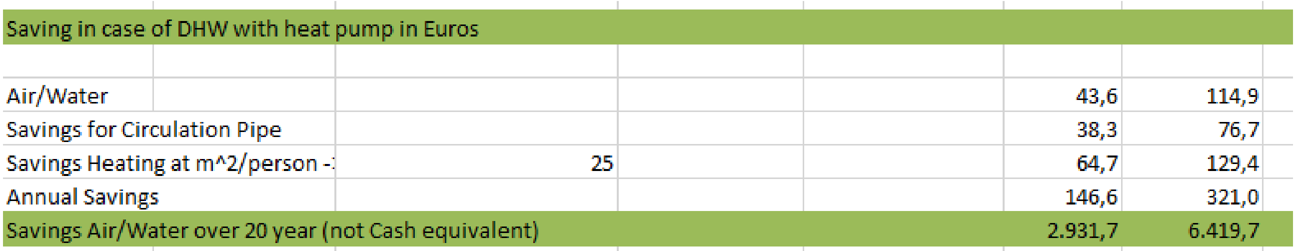
After this, the energy demand is calculated for the DHW supply with an air/water heat pump throughout the year. The seasonal performance factor for this be specified in the head of the EXCEL-sheet.



Electricity Calculated per Captia	1500	3000	4500
Additional Use (for example electric car)			
Electricity Measured	1000	2000	3000
Electricity going into Calculation	1000	2000	3000

Figure 51: Entering the electric consumption manually

The matrix also regards the electric consumption, that can be described here more detailed. If it is for example known, that only terraced houses are regarded, which are households with a maximum number of for example 8 people and the average consumption of the household sizes are known, then the values can be entered here manually, so that the consumption fits better to the known data. Further it is also possible here to regard other electric consumers like electric cars.



Saving in case of DHW with heat pump in Euros			
Air/Water		43,6	114,9
Savings for Circulation Pipe		38,3	76,7
Savings Heating at m^2/person -:	25	64,7	129,4
Annual Savings		146,6	321,0
Savings Air/Water over 20 year (not Cash equivalent)		2.931,7	6.419,7

Figure 52: Savings - An order of magnitude

Here the energy savings are provided to show an order of magnitude, how high the savings might be over the years. These values, however, are not very precise since the circulation pipe might alter the economics of the calculation if it is possible to replace it with a direct electric heater.

After this, the matrixes are placed in the excel sheet. Each of the matrixes has a different function, which is described below.

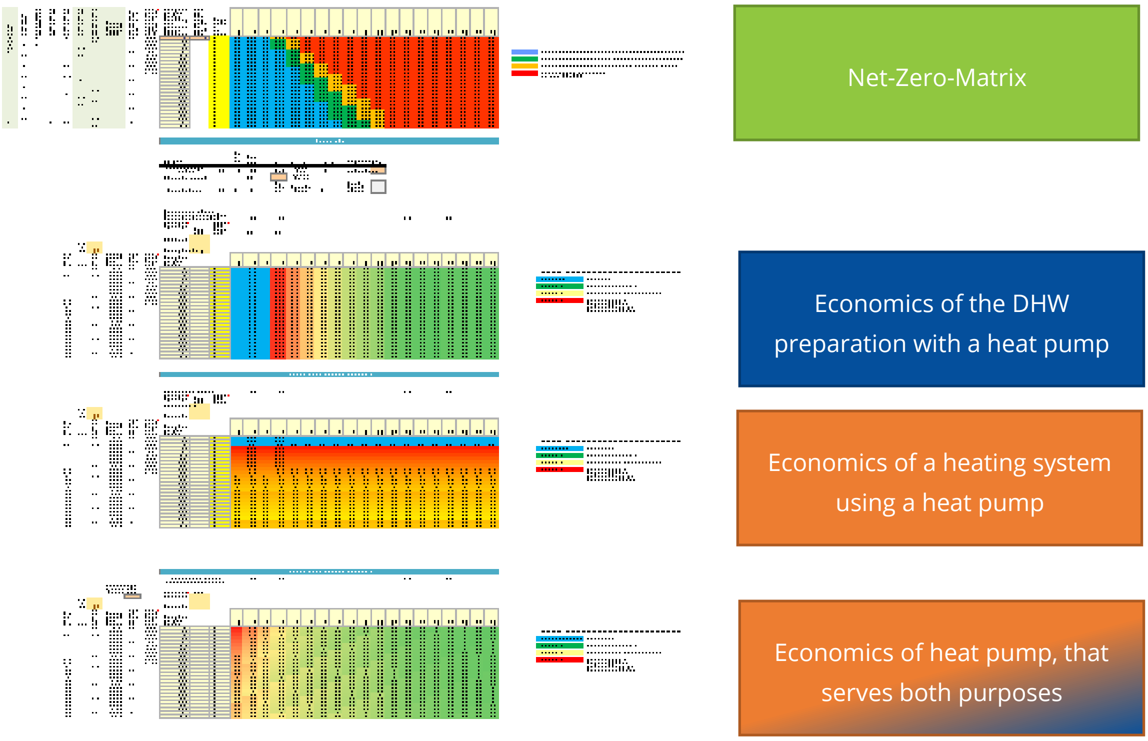
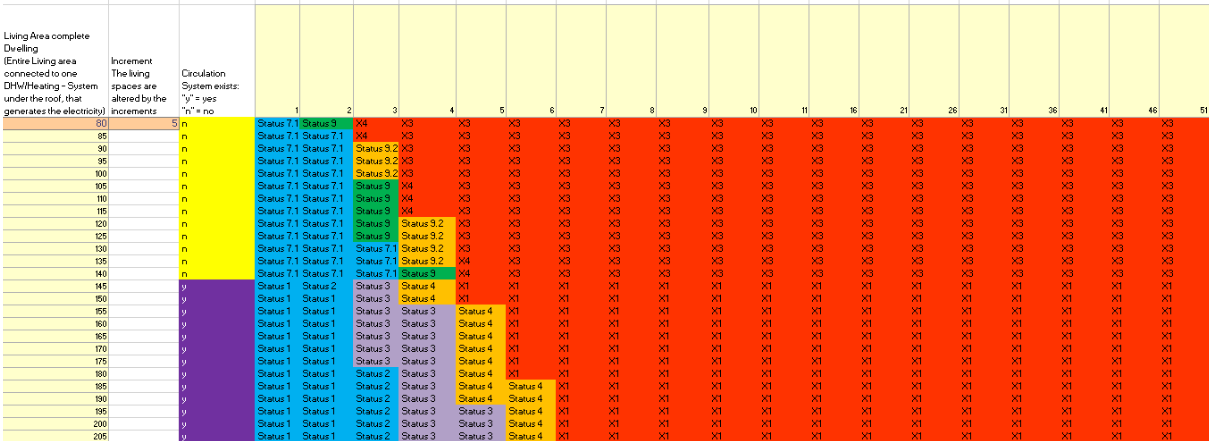


Figure 53: Overview of the matrixes and their main purpose

Net-Zero Matrix

Description

The figure below shows the net Zero-Matrix. The area, that is described at the side of the matrix counts for the entire dwelling and not for possible single apartments inside it.



Living Area complete Dwelling (Entire Living area connected to one DHW/Heating – System under the roof, that generates the electricity)	Increment The living spaces are altered by the increments	Circulation System exists: "y" = yes "n" = no	1	2	3	4	5	6	7	8	9	10	11	16	21	26	31	36	41	46	51
80	5	n	Status 7.1	Status 9	X4	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3
85		n	Status 7.1	Status 7.1	X4	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3
90		n	Status 7.1	Status 7.1	Status 9.2	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3
95		n	Status 7.1	Status 7.1	Status 9.2	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3
100		n	Status 7.1	Status 7.1	Status 9.2	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3
105		n	Status 7.1	Status 7.1	Status 9	X4	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3
110		n	Status 7.1	Status 7.1	Status 9	X4	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3
115		n	Status 7.1	Status 7.1	Status 9	X4	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3
120		n	Status 7.1	Status 7.1	Status 9	Status 9.2	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3
125		n	Status 7.1	Status 7.1	Status 9	Status 9.2	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3
130		n	Status 7.1	Status 7.1	Status 7.1	Status 9.2	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3
135		n	Status 7.1	Status 7.1	Status 7.1	Status 9.2	X4	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3
140		n	Status 7.1	Status 7.1	Status 7.1	Status 9	X4	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3
145		y	Status 1	Status 2	Status 3	Status 4	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1
150		y	Status 1	Status 1	Status 3	Status 4	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1
155		y	Status 1	Status 1	Status 3	Status 3	Status 4	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1
160		y	Status 1	Status 1	Status 3	Status 3	Status 4	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1
165		y	Status 1	Status 1	Status 3	Status 3	Status 4	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1
170		y	Status 1	Status 1	Status 3	Status 3	Status 4	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1
175		y	Status 1	Status 1	Status 3	Status 3	Status 4	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1
180		y	Status 1	Status 1	Status 2	Status 3	Status 4	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1
185		y	Status 1	Status 1	Status 2	Status 3	Status 4	Status 4	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1
190		y	Status 1	Status 1	Status 2	Status 3	Status 4	Status 4	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1
195		y	Status 1	Status 1	Status 2	Status 3	Status 3	Status 4	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1
200		y	Status 1	Status 1	Status 2	Status 3	Status 3	Status 4	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1
205		y	Status 1	Status 1	Status 2	Status 3	Status 3	Status 4	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1

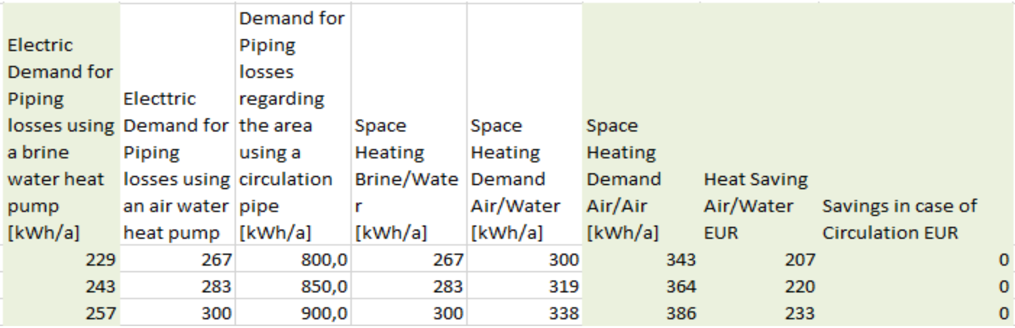
Figure 54: Net-Zero-Matrix

The different colors in the Matrix show, that different measures are necessary to get the house Net-Zero.

🟦	Home can become Net-Zero.	The status is important for further measures. A full electric supply of this home is possible.
🟩	Space heating heat pump required	A space heating heat pump is necessary to reach the Net-Zero-Standard
🟪	DHW heat pump required	A DHW heat pump is necessary to reach the Net-Zero-Standard
🟧	Two heat pumps are needed.	A DHW + space heating heat pump is necessary to reach the Net-Zero-Standard
🟥	Two heat pumps are needed, but the roof is still too small for a Net-Zero status.	In this case, the area of the roof is not large enough, so that the gains would be enough to cover the demand. Here are two heat pumps necessary to dramatically reduce costs, because a lot of energy must be bought otherwise. For this case it would also be good, to put up façade PV elements or use PVT-Panels.

Table 10: Color scheme of the matrix showing what measures are necessary to make the house Net-Zero.

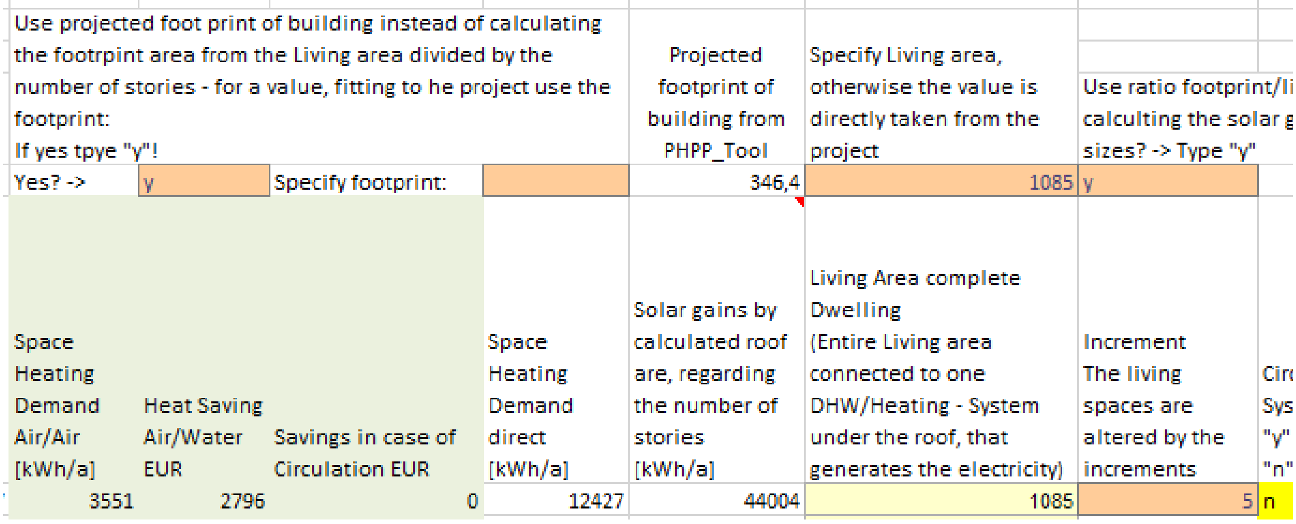
At the left-hand side of the Matrix, there are several information provided:



Electric Demand for Piping losses using a brine water heat pump [kWh/a]	Electtric Demand for Piping losses using an air water heat pump	Demand for Piping losses regarding the area using a circulation pipe [kWh/a]	Space Heating Brine/Water [kWh/a]	Space Heating Demand Air/Water [kWh/a]	Space Heating Demand Air/Air [kWh/a]	Heat Saving Air/Water EUR	Savings in case of Circulation EUR
229	267	800,0	267	300	343	207	0
243	283	850,0	283	319	364	220	0
257	300	900,0	300	338	386	233	0

Figure 55: Savings and consumptions regarding the space heating.

For the Net-Zero Matrix, there are on the left-hand side savings and consumptions described, that are supposed to give the user an overview, how high the consumptions are, what savings might be possible and what consumption other technologies would have. The “Savings in case of Circulation EUR” shows the savings, that the use of a heat pump can generate, if a recirculation system is installed and needs to be operated. If there is no recirculation system installed, a heat pump cannot reduce the consumption further, since the consumption is already at zero.



Use projected foot print of building instead of calculating the footrpint area from the Living area divided by the number of stories - for a value, fitting to he project use the footprint: If yes tpye "y"!				Projected footprint of building from PHPP_Tool	Specify Living area, otherwise the value is directly taken from the project	Use ratio footprint/li calculting the solar g sizes? -> Type "y"	
Yes? ->	y	Specify footprint:		346,4	1085	y	
Space Heating Demand Air/Air [kWh/a]	Heat Saving Air/Water EUR	Savings in case of Circulation EUR	Space Heating Demand direct [kWh/a]	Solar gains by calculated roof are, regarding the number of stories [kWh/a]	Living Area complete Dwelling (Entire Living area connected to one DHW/Heating - System under the roof, that generates the electricity)	Increment The living spaces are altered by the increments	Circ Sys "y" "n"
3551	2796	0	12427	44004	1085	5	n

Figure 56: Building footprint and other values to specify for the gains.

Here the space heating demand is calculated in kWh/a.

The solar gains can be calculated in two ways: If the building footprint is supposed to be used for the calculation, then it is important to type a “y” in the field, that asks to check, whether this is the case. Otherwise, the building footprint is calculated by dividing the living area by the number of the stories. With the building footprint, the gains are calculated using the average gains per square meter of footprint area from the head of the EXCEL-Sheet. The Footprint can also be specified if a different footprint area is supposed to be used. However, the solar gains will then for the other lines of the matrix not be adjusted to the larger living spaces anymore. To still have the lines with the solar gains adjusted to larger living spaces for theoretical uses, the formula for the solar gains also respects the ratio “footprint to living area”, for calculating the other gains. For this, it is important to type a “y” in the cell at the right-hand side of the figure above.

The living area can be altered here, just as the increment value to the next bigger living area. If no value is specified, then the matrix uses the values from the PHPP-tool.

If the dwelling has a recirculation pipe, then this can be specified here with a “y” or an “n”, if it does not have a recirculation system. Altering the letters here, will also alter the letters in the following matrixes below.

Working Principle of the Matrix

The Net-Zero-Matrix has an algorithm, that tries to find ways to effectively reduce the consumption until the home is Net-Zero. Further, even if the Net-Zero-Status has been reached, that Status describes, whether it is possible to make any further reductions or savings. In total, there are currently 34 statuses, that describe in what situation the dwelling is.

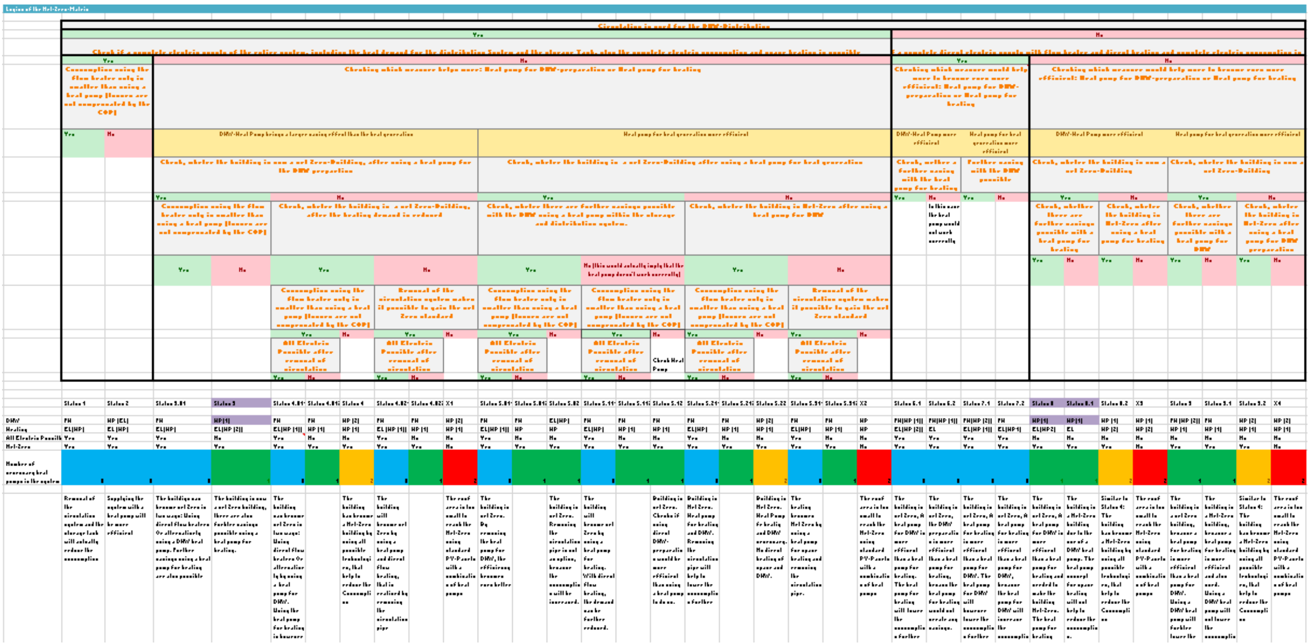
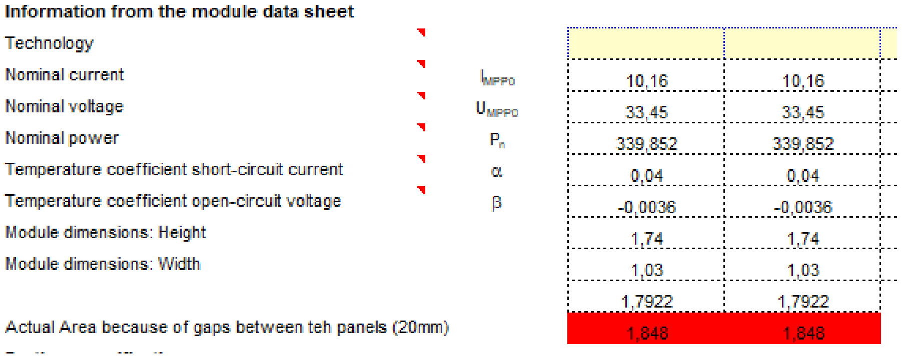


Figure 57: Logics of the Matrix

For having a close look at the logics and the different states, the description in the EXCEL-Sheet with the logic needs to be viewed. For houses with a recirculation system the matrix tests, whether it makes sense to remove the recirculation system and use direct flow heaters instead. This will however be in a normal house a very rare case.

Connections to the PHPP-Tool

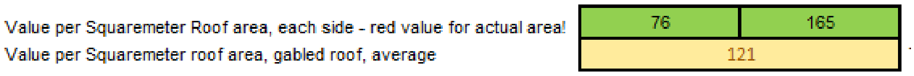
The Matrix has various connections to the PHPP-Tool. The number of inhabitants, the living area, the heating load, and the heating demand are taken from the Matrix directly. For the gains of the solar panels, the PV-Sheet of the Matrix was copied and renamed in "MatrixSupportPV-Power".



Information from the module data sheet			
Technology			
Nominal current	I_{MPP0}	10,16	10,16
Nominal voltage	U_{MPP0}	33,45	33,45
Nominal power	P_n	339,852	339,852
Temperature coefficient short-circuit current	α	0,04	0,04
Temperature coefficient open-circuit voltage	β	-0,0036	-0,0036
Module dimensions: Height		1,74	1,74
Module dimensions: Width		1,03	1,03
		1,7922	1,7922
Actual Area because of gaps between teh panels (20mm)		1,848	1,848

Figure 58: Entering the Values of the PV-Panels

Within this sheet, the values specified for the solar generators are passed on from the Matrix. The Area of the panel is enlarged by adding 20 Millimeters to the length and width during the calculation, because there are mostly gaps between the solar panels. If this is not the case, because the roof is built in a way, so that there are no gaps for the mounting, this needs to be altered, to get the slightly higher yield. Apart from this, it is also possible to add information about shading here and to specify the inverter efficiency.



Value per Squaremeter Roof area, each side - red value for actual area!	76	165
Value per Squaremeter roof area, gabled roof, average	121	

Figure 59: Calculation of the annual output of a square meter collector area.

Finally, the sheet takes the values from the calculated annual electric yields and forms the average out of it. The value is then the average gain per square meter collector area on a fully covered gabled roof per year.

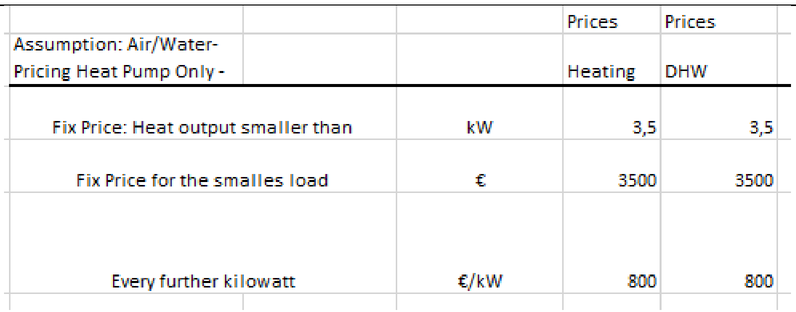
Economics Matrixes

To give a hint about the economics of a housing technology, the three economics matrixes were also programmed. The first economics matrix regards the case, when the space heating is done with a heat pump. The following colors were used to describe, whether the payback time is long or short, or whether a flow heater would be the better solution.

🟦	Flow heater	The use of a flow heater is recommended.
🟩	Heat pump	Heat pump with extremely short payback time < 3 years
🟨	Heat pump	Heat pump with payback time < 7 years
🟥	Heat pump	Heat pump with payback time between 7 – 15 years

Table 11: Color scheme of the economics matrixes

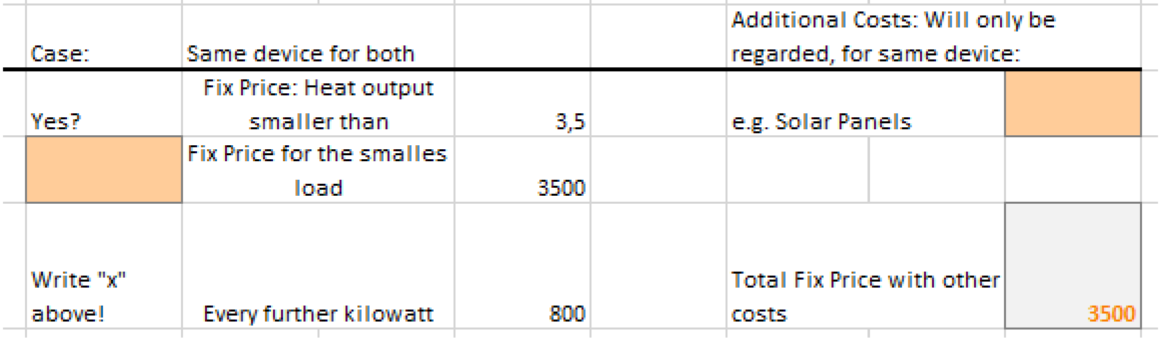
The Second economics matrix regards the case, when the DWH-Preparation is done with the heat pump only. The third matrix regards a combined solution of a heat pump, that can be used for DHW and heating. All Matrixes have further the possibility to combine the calculation of the amortization time of two separate devices. For adjusting the parameters that are going into the calculation for the economics, several values can be changed.



Assumption: Air/Water-Pricing Heat Pump Only -		Prices Heating	Prices DHW
Fix Price: Heat output smaller than	kW	3,5	3,5
Fix Price for the smalles load	€	3500	3500
Every further kilowatt	€/kW	800	800

Figure 60: Possible Values, that can be entered for the calculation of the economics.

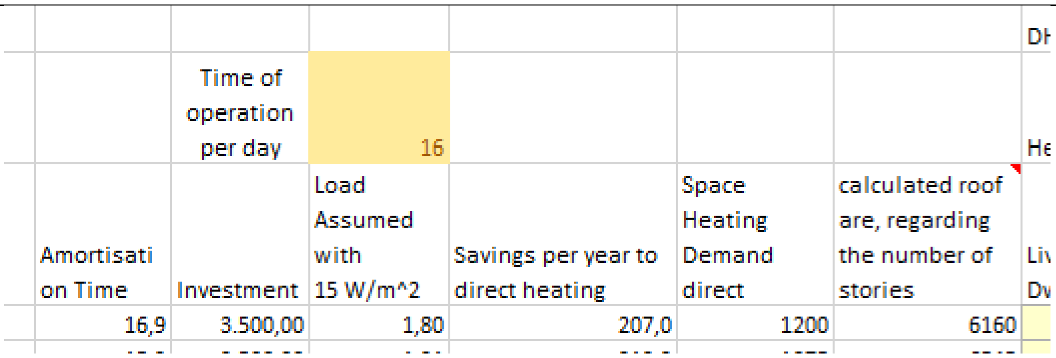
Here more information can be added if the pricing of the material components is known. The fix price for the smallest load could also be used to add the installation costs to the invest. The case, that larger heat pumps can cause less costs per kilowatt, is not regarded here.



Case:	Same device for both			Additional Costs: Will only be regarded, for same device:	
Yes?	Fix Price: Heat output smaller than	3,5		e.g. Solar Panels	
	Fix Price for the smalles load	3500			
Write "x" above!	Every further kilowatt	800		Total Fix Price with other costs	3500

Figure 61: Altering the values for combined heat pumps.

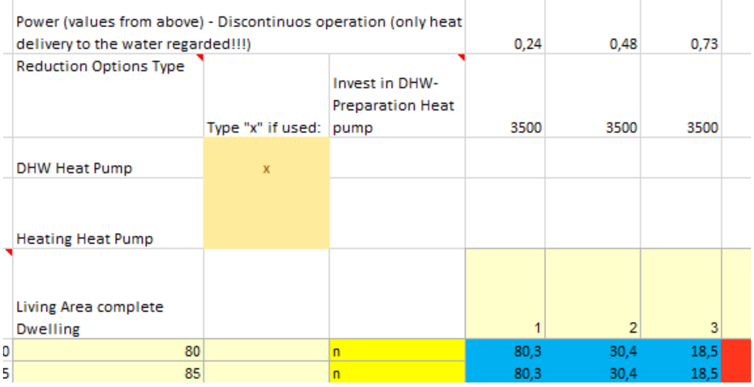
At this place it is possible to specify the prices for a combined device, that can supply energy for space heating and DHW preparation. Here it is also possible to specifically add costs to the combined system.



						D
	Time of operation per day	16				He
Amortisation Time	Investment	Load Assumed with 15 W/m^2	Savings per year to direct heating	Space Heating Demand direct	calculated roof are, regarding the number of stories	Li D
16,9	3.500,00	1,80	207,0	1200	6160	

Figure 62: Prices for the separate space heating solution.

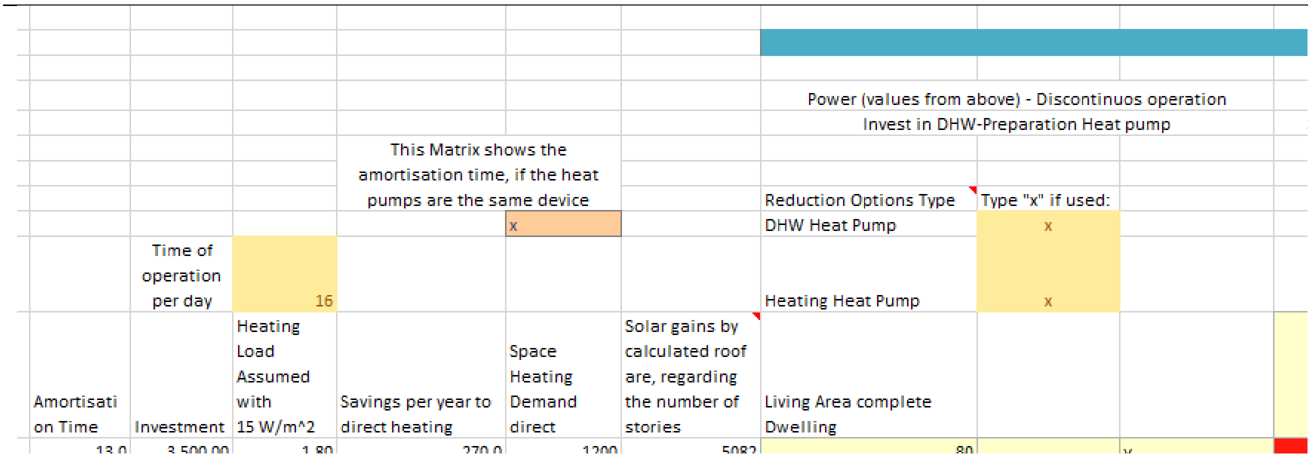
At the left-hand side it is in the case of the economics-matrixes possible to obtain more information about costs of a separate air/water heating system and to also set a time of operation per day if the heat pump should be part of the load management in the future. Further, there are also savings calculated, that a different heat pump solution can create. These values are presented for a comparison.



Power (values from above) - Discontinuos operation (only heat delivery to the water regarded!!!)			0,24	0,48	0,73
Reduction Options Type	Type "x" if used:	Invest in DHW-Preparation Heat pump	3500	3500	3500
DHW Heat Pump	x				
Heating Heat Pump					
Living Area complete Dwelling			1	2	3
80		n	80,3	30,4	18,5
85		n	80,3	30,4	18,5

Figure 63: Invest in DHW heat pumps.

Further, the invest in DHW-heat pumps is also calculated here. The values that is calculated here, however, actually differ from the reality, because the piping losses were regarded for a different area, than the apartment actually has. Since the DHW-heat pumps, however, are oversized anyways by factor four in the worst case, this should not have a too severe effect on the total economics anymore. Typing a “x” in the field “Heating Heat Pump”, would in this case lead to the calculation for an invest in both technologies as two separate devices. The advantage of having the two devices speared from each other in the matrix for the costs is, that it can be easily seen, what the better investment is. Especially if it is not necessary to take any other measures, because the Net-Zero-Standard is already reached. The problem with an oversupply of energy is, that the value of the electricity sinks significantly, so that the amortization time might be too long to pay out. For the environment however, an investment that lowers the primary energy consumption will always be beneficial.



						Power (values from above) - Discontinuos operation		
						Invest in DHW-Preparation Heat pump		
			This Matrix shows the amortisation time, if the heat pumps are the same device					
						Reduction Options Type	Type "x" if used:	
				x		DHW Heat Pump	x	
	Time of operation per day	16				Heating Heat Pump	x	
Amortisation Time	Investment	Heating Load Assumed with 15 W/m^2	Savings per year to direct heating	Space Heating Demand direct	Solar gains by calculated roof are, regarding the number of stories	Living Area complete Dwelling		

Figure 64: Last matrix offering to view the amortization time of a solution of a compact/combined heat pump

The last matrix offers the possibility to view the amortization time of a combined system. Combined systems tend to be cheaper, so that they should be used, if it is possible.

Summary

Looking at the original task, which was to find a solution that works without heat pumps, it can be concluded, that heat pumps will be necessary for most of the buildings to make these buildings Net-Zero. So, there will be heat pumps in the INDU-ZERO project.

By looking at the research on PVT-Collectors, which was another reason, why this work was written, it can be said, that PVT-Panels will for normal homes not help to significantly lower the reduction. If the solar gains are high enough to power the home with air/water heat pumps, then the PVT-solution will not pay back itself. If the roof area is in fact too small to supply the home with electricity, then it is fair to use for the calculation of the economics the end consumer price for every kilowatt hour. In this case, some very well insulated models will pay themselves back over the years by already only regarding the generation during the summertime. However, this calculation will only work, if it will be allowed to spin the meter back for the next 20 years. Since this will be difficult for the suppliers, because the renewables create other costs, it is to expect, that there will be a change of that system soon.

Looking at heat pump panels, there can be done further research, whether a heat pump panel can reduce the electric consumption of a heat pump since brine/water heat pumps work at a slightly higher efficiency. If the collector field is not further cooled than two degrees under the ambient temperature, then an air water heat pump would deliver less energy to the house, as a brine water heat pump. This, however, is in a magnitude of 15 % for the space heating and 6 % for the DHW preparation, what puts the total savings of a 4-person household in a 120 m2 building at less than 100 kilowatt hours per heating period, what is a value smaller than 40 euros. Of course, there are thermal gains in the summertime, too. However, it will be extremely hard to justify the significantly higher invest in the system with these little savings. Apart from this it will also help the least houses to become effectively Net-Zero, since the consumption is not significantly lower. Further, it will also be challenging for the heat pump panels to deal with snow, if they are put up in regions, where snowfall is to expect. A more reasonable solution for this, will be putting up PV-Panels on the façade. Looking at this, a PVT-solution should only be installed, if a quiet environment is absolutely desired by the person who makes the invest. If the person only desires quiet summers and accepts the low noise level of the heat pump during the wintertime, then a ST-only system would be the best option. ST-only solutions have a very high thermal yield, that allow to fully supply a home with DHW during the summertime without nearly making any noise. Apart from that, there will also be no or just a little performance loss on the total gains of the roof. A further interesting thing that needs more research regarding PVT is the purlin evaporator, that comes with the Tegnis roof.

Looking at the size of heat pumps in general, the most heat pumps are oversized, so that an INDU-ZERO heat pump should be developed, that fits ideally to the needs of renovated passive houses. This INDU-ZERO heat pump could for example then respect a PVT-Solution or a purlin evaporator, so that the heat pump is in fact noise emission free. In general, a combined device, that relies on the existing installations is within a renovation the potentially cheapest solution.

Looking at renovations with investment bottlenecks on the heating systems, air heating will be a good idea. For ventilation concepts, there should be done more research, whether it is possible to directly cut the heating channels into the panels and have a centralized ventilation unit, that can support air heating, too. For the DHW reduction, there should be a finished shower cabinet developed, that comes with a shower heat recovery and that can be used for the renovations of bathrooms easily.

Further, when it comes to separate DHW preparation, a compact unit, that can also work with the ambient air, appears as one of the cheapest and easiest to install solutions.

Looking at the second part of the work, in which the matrix was developed, the conclusion can be made, that the matrix is a powerful tool to support planners by choosing the right technology concept. Further it is a good way to determine, whether is possible at all to make a home Net-Zero by only using PV-Panels on the entire roof. Apart from that, it is useful for the planners to see, whether their installation will pay out quickly or whether it takes multiple years. A further development of the matrix could use more data from the PHPP-Tool or there could even be a VBA-Script, that chooses components from a list and tries to find the best solution for every house by trying out all components in a smart way. Since this solution would be in EXCEL, it would be easy to export the solution to other computer programs, that can for example order components or start production processes automatically.

Declaration of academic honesty

I hereby declare that I cited all the used information correctly and that I have never supplied this work to a different university for a different academic course. I worked diligent according to my best knowledge and conscience.

Michael Bäuerle

Michael Bäuerle

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