Sustainable energetic solutions for cruise terminal buildings in Northern Climate

01.11.2017

GREEN CRUISE PORT is an INTERREG V B project, part-financed by the European Union (European Regional Development Fund and European Neighbourhood and Partnership Instrument).

Cruise Terminal of Old City Harbour

Port of Tallinn

Sustainable energetic solutions for cruise terminal buildings in Northern Climate

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November 1, 2017
Tallinn

Interreg Baltic Sea Region
EUROPEAN UNION
EUROPEAN REGIONAL DEVELOPMENT FUND
GREEN CRUISE PORT

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TABLE OF CONTENTS

ANNEX 1 Comparison of Energy Performance Indicators (EnPI) of Different Solutions
ANNEX 2 Comparison of Actual Consumption, CO_2 Emissions and Economic Profitability of Different Solutions

1. Introduction

The purpose of this study is to analyze the possibility of implementing sustainable solutions at the cruise terminal built by Port of Tallinn. Climatic factors and the seasonal use of the cruise terminal have to be taken into account for technical solutions. In order to present and compare possible solutions, similar projects in Estonia and the Nordic countries shall be studied, and the conceptual solutions of nearly zero energy buildings and the authors' expertise of energy efficiency shall be applied.

2. Summary

The purpose of this study was to analyze the possibility of employing sustainable solutions at the cruise terminal built by Port of Tallinn.

The study analyzed the general nature of sustainability in Estonia and examined energy policy affecting the construction of the cruise terminal, and similar projects in Estonia and the Nordic countries. Based on the aforementioned analysis and the authors' expertise, possible solutions meeting the criteria of sustainability (Annexes 1 and 2) and descriptions of proposed solutions (Chapter 5) were drawn up.

According to the study of green certification carried out by Tallinn University of Technology in 2015, at Estonian climatic location **the three main factors of a sustainable building are indoor climate, energy efficiency and location** (see Chapter 4.1 for more details), which were also taken into account herein in developing the solutions of the terminal (except location).

Compared to the construction of a regular public building, it is important to point out several specific features regarding the cruise terminal in question:

1) **The building is used irregularly**, which requires the indoor climate systems to respond promptly to changes and have low overhead costs;
2) **A unique architectural solution.** Large proportion of glass facades presents a challenge for controlling indoor climate. Using the surrounding area of the building as an open area for people complicates the positioning of utilities (e.g. chiller's liquid coolers);
3) Due to **maritime climate** the outside temperature is slightly higher in the autumn and lower in the spring compared to inland areas, which affects the energy use of the building. Greater effect of wind in the area complicates using external curtains on the glass facade of the building, however, it can be utilized to generate wind energy;
4) In consideration of the national requirements for energy performance (see Chapter 4.2.3 for details), it is necessary to design the building according to the requirements of **nearly zero energy buildings**, i.e. the energy performance indicator (EnPI) should not be greater than 130 kWh/(m^2y) (in Annex 1 the EnPIs of solutions meeting the criterion are listed in bold).

Based on the study, the most important proposals for constructing the cruise terminal of Port of Tallinn are the following:

1) **Sustainable solutions are feasible in view of the building's life cycle.** The profitability analysis presented in Annex 2 indicates that present values of the solutions differ less than 10 % in 20 years from the most conservative solution (solution 1);
2) **The effect that the choice of the exterior facade of the building and the thermal conductivity of the envelope would have, would not be as important as the proportion and the type of glass facade** (see Chapter 5.2 for details). The authors of the study find that in order to ensure reasonable indoor climate and optimal energy consumption, the proportion of glass panels would have to be reduced at least by 30 % on the eastern, western and southern sides, and antisolar glass (SF 0.3) would have to be used on those facades;
3) **It is recommended to use seawater source heat pumps for the supply of heating and cooling.** This solution requires greater initial investment compared to the alternative of district heating and local cooling station, and as it is an innovative solution, it is technically more complicated; however, it is a better solution in the context of sustainability. District heating would be a better option in case it would be possible to combine it with district cooling (not in the scope of this

study);

4) In order to control the **indoor climate** in an irregularly used building, it is feasible to implement a demand-controlled (controlled based on CO_2 and temperature) VAV-type ventilation system with a recirculation function, which could also be used for quick heating and cooling of rooms (so-called additional heating and cooling). It is feasible to ensure base heating and cooling with units located in the room (in case of a sea water source heat pump underfloor heating and cooling is preferred; in case of district heating and compressor cooling radiators and convection heaters could be considered);
5) To use energy-efficient **controllable general lighting that is based on LED technology**. To ensure sustainability, it is recommended to use the solutions of well-known manufactures;
6) It is recommended to use **local electricity generation** (for example PV panels covered in the study). Although it is technically possible to achieve the level of nearly zero energy without such a production unit, using green energy in such a sustainable structure is important today already for the sake of an image. In addition, the 70kW solar panel examined in the study has a remarkable influence on the reduction of the building's CO_2 emission (see Annex 2 for details).

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3. General

3.1 General Overview of the Building

In essence, the cruise terminal forms a whole together with the promenade park that will be established to the northwest pier. Such a complete conception should enable to transform the port area that is currently closed to the public into an open and attractive part of the city.

The total length of the architectural object, part of which is the terminal, is about 800m. It is planned to build footpaths alternating with green areas throughout the whole length of the object (such a footpath would also run through the plane of the first floor).

The building is oblong and in large part has a glass facade. The building is characterized by two protruding areas covered by a gabled roof (one a terminal area, the other a cafe plane). In the architectural project, the gabled roof of the terminal area is designed to include solar panels. The first floor plane on the seaside flank of the building is designed with a screen on top.

The area and volume of the building are mainly made up of the terminal zone (including the check-in area, security, passport control, etc.), in addition, the building has a cafe, a lounge, commercial space, and smaller ancillary spaces.

3.2 Primary Data of the Study

The following documents have been used as the primary data of the study:

- Primary assignment for designing engineered parts for the Cruise Terminal of Old City Harbour of Port of Tallinn (March 2017);
- Salto AB OÜ Work no. 090-17 “Cruise Terminal of Old City Harbour”;
- Various field-specific standards, legal acts, studies and information on the reference buildings.

The building’s energy use and possible technical systems depend largely on its utilization and users. In the analysis of solutions, two different utilization profiles have been used:

- The typical utilization of the building, which is necessary to attest the building’s compliance with national minimum requirements for energy performance (including requirements indicating the class of energy performance certificate);
- The actual utilization of the building is necessary for forecasting the building’s actual energy use in the future;

The utilization profiles and the parameters required to ensure a uniform indoor climate have been presented.

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SOLUTION		Utilization mode of the building					Indoor climate of the building			
		Time of utilization, h/d[1]	Level of utilization	Lighting, W/m²	Facilities W/m²	Personnel, W/m²	Temperature min °C	Temperature max °C	Relative air humidity, %	Volume of airflow l/(sm²)
EnPI[2]	Commercial building and Terminal	14 / 7	0.55	20	1	5	18	25	-	2/0.15
Actual	Cruise season April 1 - September 30	14 / 7	See Figure 3.2.1	10	1	Max 1000	18	25	-	2/0.15
	Period October 1 - March 31	5/2	See Figure 3.2.1	10	1	Max 1000	10	-	-	2/0.15

Table 3.2.1 Utilization mode of the building and key parameters required for indoor climate

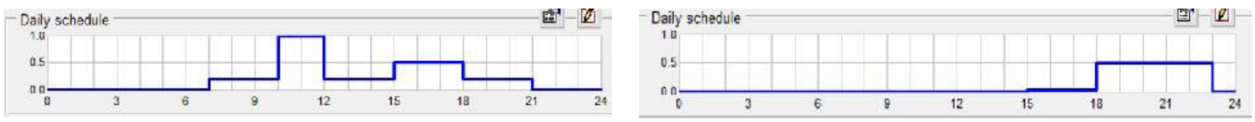

Figure 3.2.1 Actual utilization profile of the building. Cruise season from April 1 to September 30, Monday to Sunday (left); off-season from October 1 to March 31, Friday to Saturday (right).

3.3 Methodology of the study

The study is based on earlier field-specific studies and researches, in addition it relies on solutions that have been tried and tested in practice (also by the authors). The feedback and experience of reference buildings had an important role of devising the solutions.

The authors have not included all possible technical solutions in the analysis, instead, based on their own long-term expertise in the field, they have selected the solutions that qualify the best in terms of technical and economic criteria. Different variations have been analyzed particularly in view of sustainability (including energy performance and indoor climate) and economic expediency. The effect of energy use has been analyzed and compared using the simulation software IDA Indoor Climate and Energy 4.7 (see Chapter 3.3.11 for details).

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1 h – hours per day; d – days per week

2 EnPI – the calculation of energy performance indicator is based on regulation no. 55 “Minimum requirements for energy performance” and regulation no. 58 “Methodology for calculating energy performance of buildings” issued by the Minister of Economic Affairs and Infrastructure

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The assessment of the investments that the solutions of the cruise terminal require is based on the expertise of the authors and in part on the quotes of suppliers and contractors. The profitability of investment is assessed based on the method of net present value (hereinafter referred to as NPV). In net present value method all the revenues and costs related to the investment are taken into consideration, discounted back to the period of investment and compared to the cost of investment.

The profitability calculation is based on the following inputs:
1) the period of assessing profitability is 20 years,
2) the life cycle of systems is 20 years,
3) the discount rate is 8.1%,
4) the annual increase of energy prices is 4%,
5) the annual maintenance costs are 1.5% of the initial investment,
6) the price of district heating is 50 EUR/MWh,
7) the price of electricity is 85 EUR/MWh (connection to low voltage network).

In order to compare individual systems, relative values have been used, i.e. for the most common technical solution NPV is 1.0; net present values of other solutions have been noted as a ratio of that figure (e.g. 1.1 or 0.75). The prices and costs herein that have been expressed in monetary values do not include value added tax.

3.3.1 Simulation Model of the Building

The building's energy and indoor climate calculations are done by using the dynamic simulation software IDA Indoor Climate and Energy 4.7 developed by EQUA Simulation AB. The program has been validated and a comparative calculation has been performed based on the IEA BESTEST methodology. The calculation methodology used in the program is mainly based on the widespread standards and manuals of CEN (European Committee for Standardization) and ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers).

The outdoor climate data used in the energy calculations originates from Estonian base year climate data, which is based on the nationwide climate data from the period of 1970-2000 and has been drawn up in compliance with the Estonian standard EVS-EN ISO 15927-4:2005. The Estonian base year includes outdoor climate data (solar radiation, wind direction and speed, outdoor temperature, etc.) corresponding to 8 760 hours (i.e. 365 days).

The simulative calculations done for this report and the arising conclusions and results are subject to the primary data of the calculations and may vary depending on the following circumstances: base design, actual utilization profile, actual heat gain (various equipment, elevators, cafe, lighting, possible server room, etc.), actual room air temperature maintained in the building etc. Other possible energy consumers located on the premises (outdoor lighting, waste management, charging of electric vehicles, etc.) have not been taken into account in the calculations. Additionally, it has to be considered that the calculations are based on the Estonian base year and cannot be conveyed to the actual year, where short-term or long-term extreme weather conditions may occur. Should the aforementioned conditions change, it would be necessary to perform recurring calculations for adequate results.

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The primary data used in herein has been described in Chapter 3.2.

The simulation model has been divided into 10 different zones based on the purpose of rooms (Figure 3.3.1 and Figure 3.3.2).

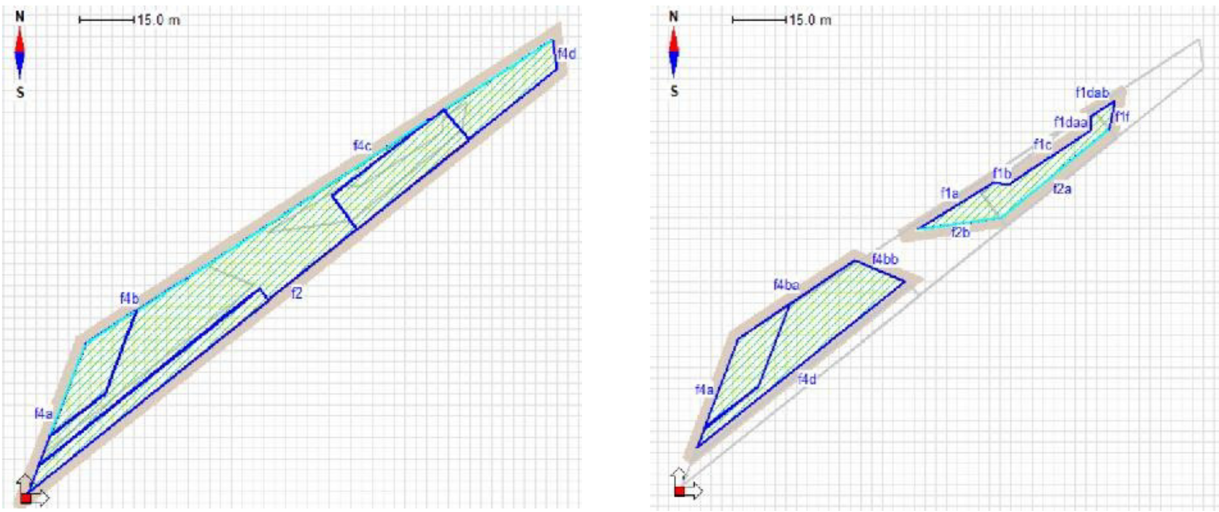

Figure 3.3.1 Zoning of the simulation model – plane 2.3m and 5.7m (left) and plane 9.1m (right).

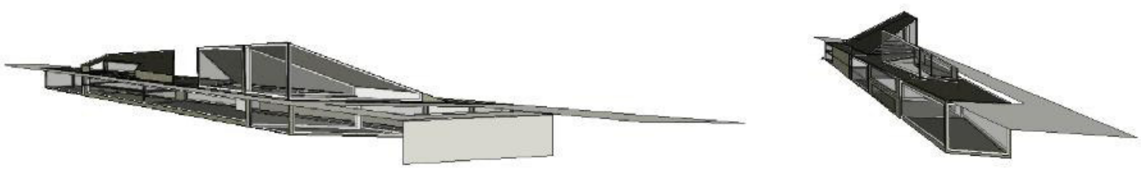

Figure 3.3.2 Simulation model in 3D

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4. Sustainable Cruise Terminal

4.1 General nature of sustainability

As a result of broader energy policy (see chapter 4.2 for details) and the overall development of society sustainability has been started to be valued more and more. Implementing and using the concept of sustainability begun already in the 1960s[3], when the first methods for assessing sustainability were created. The specific methods of assessing the quality (sustainability) of buildings originate from the beginning of the 1990s, therefore, in broader perspective the history of their implementation in the real estate sector is not long, regardless of that, their development has been very rapid. Today there are more than 100 different methods of assessing the quality of buildings, developed on the initiatives of both state and private sectors.

Designing a sustainable building differs significantly from developing and designing a so-called regular building. In designing such a building its whole life cycle is in focus: from the idea to the demolition of the building. Therefore, it is necessary to assess all the aspects affecting the building and its surrounding environment throughout its life cycle. As the objectivity of such a comprehensive analysis depends to a large extent on the location of the specific building and many other related factors, using the international methods for evaluating the sustainability of buildings may not yield the most objective results. In some cases, Estonian buildings have been granted global green certificates, but it has been done primarily on the initiative of non-Estonian owners of these buildings, because such certification is valued on the international real estate market, and it facilitates selling the property and attracting large corporations as rental customers.

In 2015 Tallinn University of Technology carried out a study of green certification[4] with the objective to clarify scientifically the environmental, social and economic criteria and factors of assessing **sustainability** in Estonia.

During the course of the study criteria of a sustainable building were developed. The criteria were analyzed and compared with two of the world's most common certification systems LEED and BREAAM.

Based on the study, the factors influencing sustainability of a building the most in the Estonian climatic location are the following (see also Figure 4.1.1):
1) indoor climate of the building;
2) energy;
3) location.

3 Assessing the environmental effect of buildings, so-called "green certification" https://energiatalgud.ee/img_auth.php/d/db/Hoonete_keskkonnamoju_arvestamine_roheline_m%C3%A4rk.pdf

4 2015 standard of green certification http://rkas.ee/files/Rohem%C3%A4rgise_uuringu_kokkuv%C3%B5te_2015.pdf

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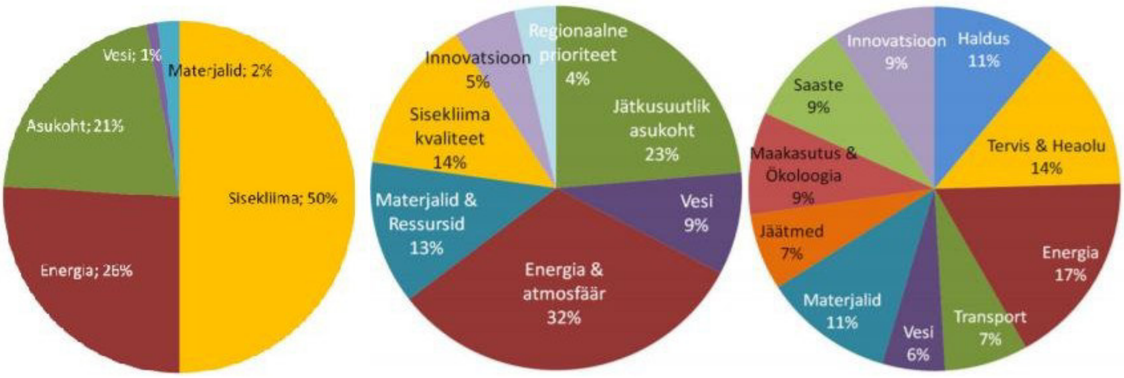

Figure 4.1.1 Division of Estonian Green Certificate categories resulting from their financial and environmental influence (left) compared to the categories of LEED (centre) and BREAAM (right) and their division. *Drawing no. 1: Water 1%, Materials 2%, Indoor climate 50%, Energy 26%, Location 21% / Drawing no. 2: Innovation 5%, Regional priority 4%, Sustainable location 23%, Water 9%, Energy and atmosphere 32%, Materials and resources 13%, Indoor climate quality 14% / Drawing no. 3: Innovation 9%, Administration 11%, Health and welfare 14%, Energy 17%, Transport 7%, Water 6%, Materials 11%, Waste 7%, Land use and ecology 9%, Pollution 9%*

Based on the above, the criteria of energy (energy efficiency) and indoor climate, which will be observed in the analysis of all versions of the building, have the greatest impact on the cruise terminal of the Port of Tallinn.

The location will not be addressed herein specifically. Important criteria for the location are: 1) proximity of public transport 2) proximity of services 3) transportation alternatives. In short it can be said that it is recommended to establish sustainable transport connections with different alternatives, i.e. to plan for bicycle rent on premises, connect it with bicycle paths, and build power outlets for the employees and visitors of the terminal to charge their electric vehicles.

When designing an energy efficient building, the most attention has to be paid on the technical systems of the prospective building and its "box", which has to take into account and be suitable for the climatic conditions of its location. The pyramid on Figure 4.1.2 indicates an approximate order of choices needed to be made during planning and designing and their influence on energy efficiency and cost (in the figure energy efficiency has been shown on the horizontal axis as return on investment and cost has been shown on the vertical axis). The pyramid also reflects the best practice employed today in Riigi Kinnisvara AS (State Real Estate company). As seen from the figure, energy efficiency is greatly influenced by designing the building's volume, particularly in terms of its compactness and positioning on the lot, as well as by the area of the building's envelope, limiting the area of glass facades and windows is of particular importance. Failing on the lower level of the pyramid has an extensive effect on the overall cost of the building. The arrows of return on investment and cost next to the pyramid emphasize the relative inexpensiveness and great influence of decisions on lower levels compared to decisions on higher levels, the cost of which per saved kWh is significantly higher. For instance, mistakes relating to volumetric design cannot be effectively corrected by local production of renewable energy. In the case of a nearly zero energy building all stages of the pyramid have to be resolved effectively and judiciously (it is likely that the requirements of nearly zero-energy buildings have to be followed in the course of construction; see Chapter 4.2 for a more precise definition of a nearly zero-energy building and related energy policy).

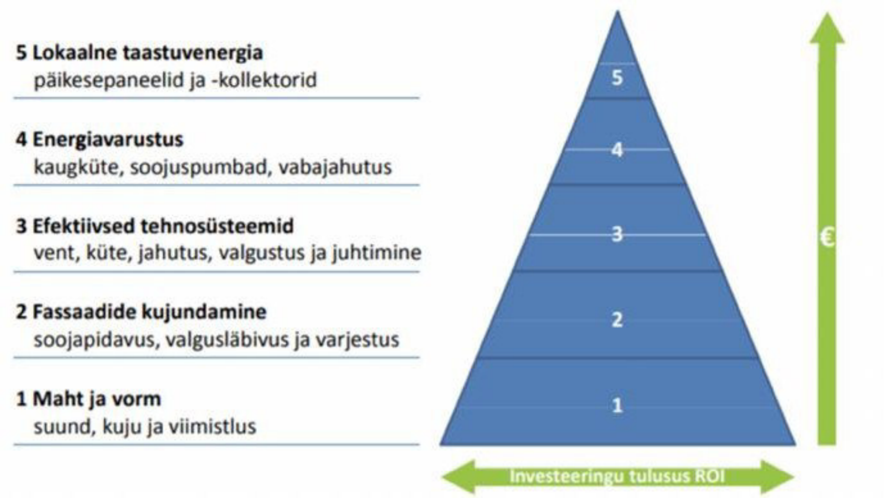

Figure 4.1.2 Pyramid of designing an energy efficient building[5]. *Drawing: 5 Local renewable energy – solar panels and collectors; 4 Energy supply – district heating, heat pumps, free cooling; 3 Effective technical systems – ventilation, heating, cooling, lighting and control; 2 Façade design – insulation, light transmittance, shielding; 1 Volume and form – direction, shape and finishing; RETURN ON INVESTMENT*

In the case of an energy efficient building, the customer, the architect and the engineer of special parts have to be open-minded and have to include an aspect of energy efficiency to the solution of the building's envelope, this means that in order to achieve the lowest maintenance costs and optimal result, it is necessary to consider local features of the specific building and not to rely too much on regular practices.

The indoor climate of the building will be addressed more thoroughly under the technical solutions of the building (Chapter 5).

4.2 Energy Policy

4.2.1 General Directions

In order to understand how local energy policy and in particular requirements and guidelines for energy performance and sustainability of buildings are shaped in our country, it is necessary to understand that Estonia as a member state of the European Union follows the union's uniform energy policy.
The foundation of long-term development in Europe is the strategy "Europe 2020", which enlists 3 principles of sustainable development:
1) smart economic growth,
2) sustainable economic growth,
3) inclusive economic growth.

In relation to sustainable economic growth the European Union has agreed upon a climate and energy package, which establishes the most important energy-related objectives for 2020, also known as the "20-20-20" objectives:
1) decreasing greenhouse gas emissions by 20% compared to the base year 1990,
2) increasing the proportion of renewable energy in final consumption to 20%,
3) improving energy efficiency by 20%.

5 Low and nearly zero energy buildings http://rkas.ee/files/Madal_ja_liginullenergiahooned.PDF

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In local context, the aforementioned energy-related objectives are part of competitiveness plan called "Estonia 2020"[6]:
1) reducing the limit of greenhouse gas emissions by 11% (compared to 2005),
2) increasing the proportion of renewable energy in final consumption to 25%,
3) decreasing the final consumption of energy by 11% (i.e. in reality preserving the energy consumption levels of 2010).

Observing how Estonia has fulfilled the objectives in practice, the situation is quite positive. We have never exceeded the targets/limits of greenhouse gas emissions, an important role in this are played by facts that as an oil shale country our base level (2005) is quite high and in addition we have actively used the EUs possibilities of trading greenhouse gas emissions.

Preserving the base level of energy consumption at the level of 2010 (compared to the consumption forecast for 2020) is more attainable to us than the previous objective. In order to achieve the target primarily the funds of the European Union have been channelled to almost every sector (since the EUs period of structural funds is coming to an end, then currently the few remaining support schemes to the industrial sector are in process). At 2015, energy consumption in Estonia was 2.3% lower than the 2020 target.

We have already fulfilled the renewable energy objective at 2015: the share of renewable energy in final consumption was 28.6% back then. A sub-objective of the given objective was to increase the proportion of renewable energy in the final consumption of the transportation sector to 10%. Concerning the latter, Estonia has still a few more steps to go, which is why it is currently possible as an active support measure to receive resources for establishing biomethane filling stations, in addition, starting from new year it is possible to to apply for state aid for producing biomethane. Although the government has supported the suggestion of green activists to increase the share of renewable energy even more (to be precise, the new target is 50% of final consumption), then in reality the government has not yet passed the National Development Plan of the Energy Sector Until 2030[7], which would establish the above target (although they started composing it already in 2013).

4.2.2 Support Schemes

Simply put, the support schemes of the energy sector are divided into two: investment grants and production refunds. At present, we are examining the options that are related to local energy production; due to the exhaustion of EUs funding period 2014-2020 the state coordinated extensive investment grants have largely run out (in this area the above-mentioned industrial sector support is still active); investment grants can also be applied for from the European structural funds that are not directly associated with fulfilling the national energy objectives.

The following 100% local energy production methods can be implemented in the cruise terminal: energy production with solar panels and wind turbines. Resulting from the requirements for district heating areas and the concept of preliminary architectural design using, for example, a combined heat and power producer is not real. According to a support measure that is currently still in effect it is possible to

6 National Reform Programme "Estonia 2020". https://riigikantselei.ee/sites/default/files/elfinder/article_files/eesti2020_tekstiosa_2017-2020_istungile_27.04.17.pdf
7 Draft of National Development Plan of the Energy Sector Until 2030. https://www.mkm.ee/sites/default/files/enmak_2030_koos_elamumajanduse_lisaga.pdf

receive a grant of 53.7EUR/MWh for the production of renewable energy. As mentioned in the previous Chapter 4.2.1, the national renewable energy support has been exhausted, in addition, extensive subsidizing of renewable energy has increased the level of applicable technologies and the competence of people operating in the field to the so-called level of market maturity (see Figure 4.2.1). In the Estonian context, the market maturity line in the figure is, in the grand scheme of things, equal to the national objectives, thus there is no need to continue employing the same generous support scheme.

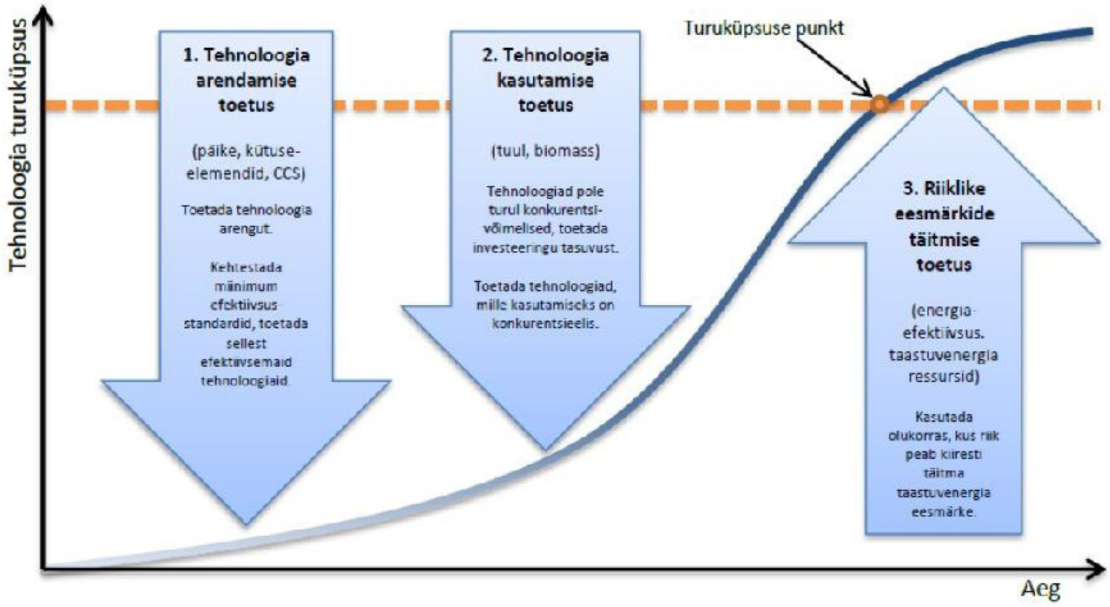

Figure 4.2.1 Foundations of changing subsidies for renewable energy. Source: WEC-Estonia

Drawing: The Marketability of Technology – Time; 1. Technology development support (sun, fuel cells, CCS). Support the development of technology. Establish minimum standards for efficiency, support technologies that are more efficient than this level. / 2.Technology use support (wind, biomass). Technologies are not competitive on the market, it is necessary to support the return on investment. Support technologies with competitive edge. / Market maturity point / 3. Support for achieving national objectives (energy efficiency, renewable energy resources). Use in a situation where the objectives of renewable energy must be quickly achieved.

A draft legislation amending the Electricity Market Act is presently in process; this would reform the current support scheme radically. The draft legislation prescribes that the current support scheme will expire as of July 1, 2018. The possible new scheme allows using the possibilities of quota trade (i.e. it will be possible to sell the statistics of energy produced from renewable sources to other member states that cannot meet their targets on their own). According to the initial plan, this trade would be coordinated by the state on the basis of underbidding. Since the new support scheme differs principally from similar support schemes of many other European countries and the Estonian government, regardless of its previous hasty plan, has not passed the amendment of the Electricity Market Act by today, then various market participants from the private sector are on a wait-and-see position and have, for the time being, stopped their large renewable energy projects until the amendment has been passed. Since the new support scheme accompanies a risk that the bulk of the amount will go to state-owned energy production, then it is possible that in certain situations support for other market participants will be non-existent or significantly lower than currently.

Based on the above, the authors of this study, for the sake of simplicity, will not take production refunds into account in evaluating economic profitability of the given cruise terminal.

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4.2.3 Energy Performance Requirements

Specific requirements for the energy performance of buildings are based on Directive 2010/31/EU of the European Parliament and of the Council[8], from where they have been transferred to Estonian legislation. Pursuant to the directive, the minimum requirements of energy performance[9] have been established in Estonia. The general purpose of the directive is to establish environmentally and economically sustainable requirements for buildings; such buildings are epitomized in the word **cost-optimal**. To put it simply, each new prospective building[10] has to be cost-optimal; to this end, the minimum requirement for energy performance has been equalized with that level. The directive's logic establishes that such cost-optimal level changes in time: today it has been equalled with a regular new structure (current energy performance certificate class C[11], the minimum requirement for energy performance), in the future, the level should be adjusted to match a low energy house (current energy performance certificate class B) and finally a nearly zero energy building (current energy performance certificate class A).

A **nearly zero energy building** (internationally also known as nZEB) is a building that has been built in accordance with the best possible construction practices using the technological solutions of energy efficiency and renewable energy, and the energy performance indicator of which in the case of a terminal would not exceed 130 kWh/(m2-y). An **energy performance indicator** is a specific use of energy, which reflects an integrated energy use for controlling indoor climate, heating of household water and utilizing appliances and other electrical equipment, and it is calculated per square meter of heated area of a building in its typical utilization.

Despite the fact that state legislation had established an objective that state buildings had to be at the level of nearly zero energy by 2019 and private sector buildings by 2021 (by then a building permit had to be issued), the Ministry of Economic Affairs and Communications has adopted the position of the European Commission that nearly zero energy buildings that are completed by the stated dates have to have the authorization for use.

In essence, this means that if constructing a larger than average building is reckoned to take two years, then all new private sector buildings will already have to be nearly zero energy buildings, and in public sector the same applies for buildings, the construction of which will commence at the latest in the first half

This position has created great opposition in the real estate and construction sectors, because on the one hand nearly zero energy buildings are not yet financially viable in our environment (i.e. competitive enough) and in addition there is no widespread expertise of constructing them (a few examples of nearly zero energy buildings that have been constructed on the initiative of the state have been listed in the references of this study). A positive trend is that the Ministry of Economic Affairs and Communications has confirmed that the State Real Estate Ltd. is already designing all new buildings as nearly zero energy buildings.

8 Directive 2010/31/EU of the European Parliament and of the Council on the energy performance of buildings. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:153:0013:0035:ET:PDF

9 Minimum requirements for energy performance. https://www.riigiteataja.ee/akt/128022017002?leiaKehtiv

10 The current chapter only covers energy performance requirements for new buildings (i.e major renovations have been excluded)

11 Format and procedure of issuance of energy performance certificates. https://www.riigiteataja.ee/akt/106052015002?leiaKehtiv

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Today the state is in a situation, where it is no longer possible to implement a smooth (read: moderate) transition to the standard of nearly zero energy buildings (as described in the first section of this chapter), which is why based on the current information it is necessary to match the minimum requirements for energy performance with the requirements of nearly zero energy buildings (i.e. energy performance indicator 130 kWh/(m2-y)) already in the first quarter of 2018. Before the Ministry of Economic Affairs and Communications passes the new requirements, it is necessary that Tallinn University of Technology, which is working on it actively, completes its research on the concept of nearly zero energy buildings and requirements therefore. Since the research has not been completed yet, it is currently not possible to present the official results, but on account of the expertise of the authors of this study (including the position of coordinator of energy performance at the Ministry of Economic Affairs and Communications) it is possible to draw the following initial conclusions:

1) The level of nearly zero energy buildings is likely to persist as the fundamental value. It is very likely that electricity conversion factor (a factor that takes into consideration the national energy targets and environmental factors, and with which the energy use of a building is multiplied) will be adjusted (read: increased), which means that in reality the level of nearly zero energy buildings (i.e. minimum requirements for energy performance) may increase. This, in turn, means that in the future achieving the near zero level without local renewable energy production will not be possible;
2) In all likelihood, the district heating conversion factor (the nature of the factor is similar to electricity conversion factor described in the previous clause) will be adjusted. The factor will be adjusted in such a way that it would be related to the fuel that is being used in boiler plants of the specific area (i.e. in case of fossil fuels the factor would be higher, in case of biofuels lower);
3) Probably exceptions for special buildings (traditional wooden buildings etc.) will be established in the requirements;
4) The methodology for calculating the energy performance of buildings will not be changed. Since the current methodology is extremely unfair for the irregularly used terminal that is the object of this study (i.e. it requires a substantial year-round utilization), then the calculated energy performance indicator will be highly "over-dimensioned";

Since the above amendment of minimum requirements for energy performance has not been passed at the time of drafting this study, then the nearly zero energy level (energy performance indicator may not exceed 130 kWh/(m2-y)) will be used as the target value for energy performance herein.

4.3 Special Characteristics of the Cruise Terminal

The cruise terminal cannot be directly compared to a residential building or a typical non-residential building (an educational building, an office building etc.). The primary differences between the cruise terminal in question and other buildings are listed below:

- **Irregular utilization of the building.** The intensity of the building's utilization is affected by cruise ships arriving during the cruise season, therefore the heat gain of the terminal can change rapidly by a large extent, and thus it is reasonable to consider controlling the indoor climate by air heating/cooling, which would allow to react promptly to such changes;
    - **The utilization of the building during an off-season is minimal**: the building is used and indoor climate control is needed only during a limited time period;
    - **The number of people inside the building varies greatly in time** – as a result, it is recommended to use demand-controlled ventilation (together with recirculation), in order to ensure necessary indoor air temperature at any given time;

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- **Influence of maritime climate.** Due to this the temperature is slightly higher in autumn and lower in spring compared to inland areas (affects primarily the energy use of the building);
    - **Greater effect of wind**, which might make it problematic to use external curtains to block solar radiation; however, the circumstances might be beneficial for generating energy locally using wind turbines.
- **Architectural solution.** Large proportion glass facades make it difficult to ensure proper indoor climate. Using the surrounding area of the building as an open area for people complicates the positioning of utilities (e.g. chiller's liquid coolers).

4.4 Examples of Sustainable Terminals

Reference buildings in Estonia and in Europe chosen by the authors are described below. Reference buildings have been divided into three groups: terminal buildings, nearly zero energy (nZEB) non-residential buildings, exemplary solutions of seawater source heat pump. The list is not exhaustive, for instance, in addition to the examples described herein, there are several regional examples of seawater source heating and cooling in Finland (district cooling in Tampere, etc.) that are worth analyzing in depth, in case it is decided in favour of this type of energy supply in developing the terminal.

4.4.1 Sustainable Terminal Buildings

- **Cruise terminal of Copenhagen** (new building)

Photo 4.4.1 Cruise terminal of Copenhagen (Source of the photo: the website of the architectural bureau: http://www.christensenco.dk/projekter/&p=34)

The cruise terminal of Copenhagen that has an architectural solution imitating sails has been built in 2014. The area of the complex consisting of three buildings is approximately 10 000m^2. In terms of construction, it is a rather simple building (a support structure of posts and beams made of cast-in-place concrete, a roof made of light materials, large glass facades. During an off-season the terminal is used for different cultural events, concerts and exhibitions.

Solar panels (PV panels) have been installed on the southern sides of the terminal. The buildings have a green roof that cleans the air, reduces the load of rainwater, and decreases the temperature of the roof.

In addition to the buildings, innovative solutions can be found elsewhere on the pier as well: for example docking ships can connect to the electric network on the ground (instead of operating the ship's generators), the pier has its own water processing system that is able to process the wastewater of 3 ships at the same time.

- **Leonardo da Vinci International Airport of Rome, Terminal T3** (renovated building)

Photo 4.4.2 Terminal T3 of International Airport of Rome (Source of the photo: http://www.sitalimpianti.it/en/news-and-media/872-opens-the-new-terminal-3-and-forepart-of-fiumicino.html).

Renovated and partially extended terminal T3 is one of the most important terminals in Italy, about 40 million passengers pass through it each year. The materials found in English are scarce and originates from a conference article (15th IEEE International Conference on Environment and Electrical Engineering, EEEIC12). The aim of the article was to carry out a case study about the possibility of nZEB based on the example of a terminal building.

The terminal was partially renovated and extended (the extension is shown on photo 4.4.2). Below is a brief overview of technical solutions that were used:

- ✓ Demand-controlled LED lighting;
- ✓ Demand-controlled ventilation with sub-heating/sub-cooling to control the climate of each zone/area the best;
- ✓ Heat supply of the building based on combined heat and power producer that serves the entire airport;
- ✓ PV panels on the roof;
- ✓ Glass facade that has low g-number (g=0.13) and thermal conductivity (U=1 W/m^{2}K);
- ✓ Absorption cooling;

12 https://sapienza.pure.elsevier.com/en/publications/sustainable-airports-and-nzeb-the-real-case-of-rome-international

- **Munich Airport, *New Satellite* Terminal**

Photo 4.4.3 Munich Airport, *New Satellite* Terminal (Source: www.munich-airport.com

The CO_2 emissions of the terminal that was opened in April 2016 are approximately 40% lower than the emissions of previous terminals of the airport. The facade of the building partially uses a special buffer zone that separates the exterior environment from the interior environment by a special glass facade ("a gap" of 4-5m), the glass allows the sunlight to enter, but keeps the heat outside. The heat and electricity of the building are produced by the airport's combined heat and power producer; in the summer it's the excessive heat is used to produce cold in the absorption cooler. Centrally automated LED lights are used in the terminal.

As an innovative solution, parking airplanes can use the building's heating and cooling system to control their inner climate.

- **Värta Terminal of the Port of Stockholm**

Photo 4.4.4 Värta Terminal of the Port of Stockholm. Source of the photo: marketing materials of architectural bureau C.F. Møller Värme

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The construction of 16 000 m^2 Värta terminal that was completed in 2016 is based on extremely high environmental and structural standards – the building has been accredited with the highest, gold class of Swedish green certificate Miljöbyggnad.

The terminal has been architecturally designed in a manner that it would extend the city, be an integral part of it, not collide with it as the traditional port structures do. To illustrate this, the oblong terminal has plenty of green areas, benches, viewpoints, outside cafes, etc. that would attract citizens regardless of whether they are planning a cruise or not.
Some examples of constructing an environment-friendly building: most of the construction materials were delivered to the site by ship, in order to reduce pollution and emissions into the environment (by using this method 6 700 tonnes of CO_2 was spared); all construction waste was sorted for recycling and only 0.3% of all waste was delivered to waste station; very high pollution standards were set for construction machines and equipment, etc.

The most significant technical features of the building:

- ✓ The energy consumption of the building is approximately 40% lower than other similar buildings in Sweden.
- ✓ Seawater is used for heating and cooling the premises and producing hot water. An open water system is used, where seawater is pumped to heat exchangers, from where the preheated water for room mesh runs into heat pump, which brings the energy carrier to the set temperature. As an original solution the cooling piping has been installed inside the structures.
- ✓ 400m^2 of PV solar panels have been installed on the roof of the terminal to generate electricity locally. The panels also function partly as the sunshades for the facade.
- ✓ Vacuum-type solar collectors are used for heating the premises and producing hot water during the winter.
- ✓ The building has a green roof that cleans the air, reduces the load of rainwater, and decreases the temperature of the roof. Similar green areas are situated around the building as well for the purposes of cleaning the air and rainwater (cleaned seawater is directed into the sea).
- ✓ Wind turbines are used to generate the electricity for the building and charge the batteries of employees' vehicles.
- ✓ On the terminal area outside lights with an autonomous power supply have been used (i.e. self-supplying lights that have built-in solar panels). Similar solutions can be seen more and more in Europe nowadays, for example in the lights of pedestrian crossings, in traffic lights, in advertising banners.

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4.4.2 Nearly Zero Energy Non-residential Buildings in Estonia

- **State Upper Secondary School of Põlva**

Photo 4.4.5 State Upper Secondary School of Põlva. Source of the photo: **www.innove.ee**

The first nearly zero energy building in Estonia. Class A energy performance indicator has been achieved with the following technical solutions:

Envelope of the building:			**Technical systems of the building:**	
Exterior wall:	0.11	W/m^2K	Heating supply:	district heating
Roof:	0.06	W/m^2K	Heating system:	radiator heating
Windows:	0.8	W/m^2K	Ventilation system:	CAV
g=	0.4		Cooling system:	None (external curtains)
			Lighting:	LED + demand-based control
Use of local renewable energy:				
PV panels on the roof:			36kW	

Table 4.4.1 State Upper Secondary School of Põlva

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- **Rakvere Smart House**

Photo 4.4.6 Rakvere Smart House. Source of the photo: www.rakveretarkmaja.ee

Rakvere Smart House is a multifunctional building that is partly an office and partly a test building, where it is possible to test various solutions of technical systems. The key parameters of a nearly zero energy building are the following:

Envelope of the building:			**Technical systems of the building:**	
Exterior wall:	0.07	W/m^2K	Heating supply:	district heating
Roof:	0.08	W/m^2K	Heating system:	radiator heating
Windows:	0.8	W/m^2K	Ventilation system:	VAV + CAV
g=	0.4		Cooling system:	High-temperature cooling using energy rods
			Lighting:	LED + demand-based control
Use of local renewable energy:				
PV panels on the roof:		33.8 kW		

Table 4.4.2 Rakvere Smart House

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- **Office Building Väike-Ameerika 1** (the so-called "Super-ministry")

Photo 4.4.7 Super-ministry office building. Source of the photo: www.err.ee

The principal technical data of the joint building of four ministries in Tallinn:

Envelope of the building:		**Technical systems of the building:**	
Exterior wall:	0.1 W/m^2K	Heating supply:	district heating + 100kW geothermal heat pump
Roof:	0.1 W/m^2K	Heating system:	4-piped chilled beam
Windows:	0.65 W/m^2K	Ventilation system:	CAV+VAV (conference)
g=	0.3	Cooling system:	chiller with cooling stack; chilled beams
		Lighting:	LED + demand-based control
Use of local renewable energy:			
PV panels on the roof:	40kW (currently not yet completed)		

Table 4.4.3 Suur-Ameerika 1, Tallinn

4.4.3 Seawater Source Heating and Cooling Solutions

- **Tallinn Seaplane Harbour**

Photo 4.4.8 A branch of Estonian Maritime Museum "Seaplane Harbour". Source of the photo: meremuuseum.ee/lennusadam/

Seaplane hangar with an envelope of reinforced concrete is an internationally important architectural and historical monument that is situated by the Tallinn Bay. The building has been included in this study as one of the few reference buildings in Estonia, where seawater source heat is used for controlling the indoor climate. The building has underfloor water heating and 400kW heat pump system that consists of 3 heat pumps. The heat pumps obtain the necessary heat energy from seawater. In the summer the sea functions as passive and active cooling. A so-called open loop system, where seawater is pumped through the heat exchanger, which has a fine filter equipped with automatic cleaning mode (particles caught by the filter are directed past the heat exchanger). On the secondary side of the heat exchanger there is an ethylene-glucose aqueous solution, which directs sea heat to heat pumps. In order to avoid the freezing of the heat exchanger, the system will be stopped, when the temperature of seawater drops below the potential freeze limit, in this case the building will be heated using an electric boiler.

The cooling schedule of the building is 7/12°C. In case of lower ambient air, higher temperature cooling is used, free cooling by seawater is to be used, if the temperature of seawater is up to 7°C (if the temperature of seawater rises above 7°C, cooling energy will be produced by compressors). According to the assessment of the maintenance staff and State Real Estate Ltd. (Riigi Kinnisvara AS), the annual coefficient of performance is approximately 3.5.

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- **District Heating and Cooling in Stockholm, Sweden (Värtan Ropsten Heat Pump Facility)**

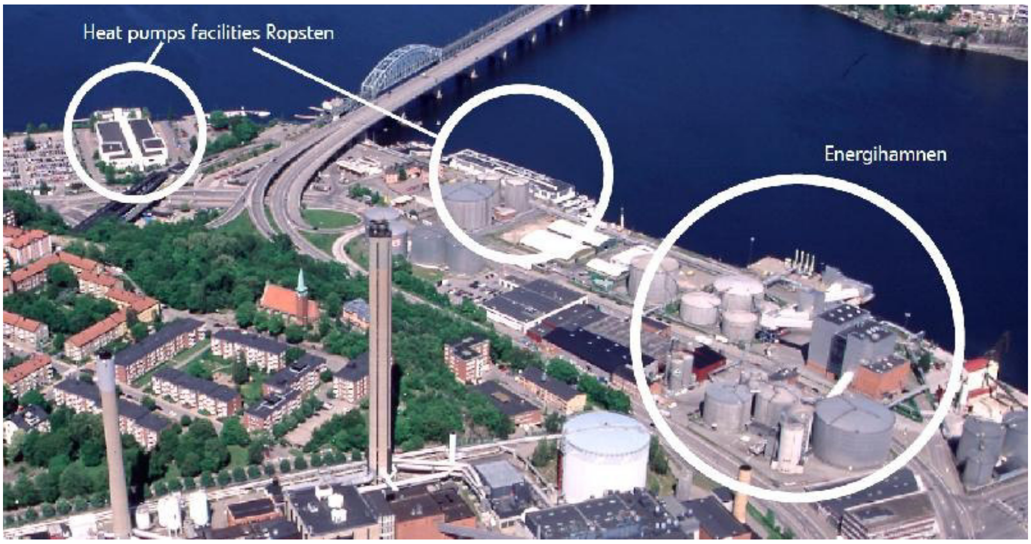

Figure 4.4.9 Ropsten heat pump facility for district heating of Stockholm (the photo shows liquid fuel terminal Energihamnen, which belongs to the owner of the district heating facility). Source of the photo: Public marketing material of AB Fortum Värme

One of the largest production units of district heating and cooling in Stockholm is Värtaverket located by the port. The unit consists of 4 district heating plants, 2 cooling plants, 2 combined heat and power plants (CHP) and the heat pump facility of Ropsten. The maximum capacities of Värtaverket are 1 755MW (heat), 389MW (electricity) and 125MW (cooling). The area of district heating and cooling of Stockholm managed by Fortum group is very unique in the world, because major investments in implementing environment-friendly solutions are being done constantly: the whole area of district heating would want to be climate neutral by year 2030.

There are in total 10 heat pumps with the total capacity of 256 MW in the Roptsen heat pump facility, which makes it the largest heat pump system in Europe. The facility uses an open loop system, which means that seawater is pumped into a reservoir tank, from where it is in turn pumped into a heat exchanger. The facility is used for the production of both heating and cooling water. The parameters of heat production are: evaporation temperature -3°C, condensation temperature +82°C, in/out temperatures of seawater +2,5-3°C/0.5 °C, temperature of supply/return of heating water +80°C/+57°C, steady operation 10-100%. For the production of cooling water both free cooling (pumping cold seawater into the district cooling system without using heat pumps) and heat pumps (in case the seawater is too warm in the summer, the water returning from the district cooling system is directed into the sea using heat pumps) is used. In the production of hot water, the annual average seasonal coefficient of power (SCOP) is 3.75-4.

- **District Cooling of Tartu**

Photo 4.4.10 District cooling plant of Tartu City Centre

The first district cooling plant in the Baltic States was opened in Tartu in 2016. The capacity of the district cooling plant is 13MW, and for the production of cooling energy it uses both traditional compressor-type chillers and the water of river Emajõgi. The temperature of cooling water that is transmitted to customers is 6°C (the maximum return temperature can be 16°C). The temperature of river water is approximately 5°C. It has been planned that from November to March it is possible to employ free cooling (this means that there will be only the cost of pumping, cooling compressors would not have to be utilized).

For the generation of electricity, the cooling plant has installed PV panels. The plant is also equipped with a heat pump that allows directing the excessive heat from cooling customers to district heating network.

- **Lappari Entertainment Centre, Tornio, Finland**

Photo 4.4.11 Lappari entertainment centre, Tornio, Finland

The entertainment centre built into the former Lapin Kulta factory of about 12 000m^2 includes an activity park, a restaurant, a fitness centre, a brewery, etc. At Lappari heating and cooling energy is produced by a so-called hybrid model: both geothermal energy (rods in the ground) and seawater energy is used. An open system is used to obtain energy from seawater, meaning that seawater is pumped into the heat exchanger, from where it is directed into the house; the solution is unique due to the fact that it uses Uponor's innovative patented plastic heat exchanger, which enables to obtain heat energy from water that has very low temperature (theoretically 0-1°C, in practice such extreme temperature levels are still being tested by the installer).

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4.5 General Criteria for Designing a Sustainable Terminal

Based on the Estonian study of green certificates[2], the energy policy of the state, the special characteristics of designing a cruise terminal and the experience of reference buildings, it can be stated that the primary criteria for designing a sustainable terminal are the following:

- Low class of energy performance certificate – a nearly zero energy building;
- Energy-efficient lighting (in order to reduce energy consumption and the need for cooling energy, since the building will be primarily used in the summer);
- Demand-controlled ventilation (the intensity of using the building varies greatly);
- Passive solar control (in designing the building's facades reducing the load of cooling and limiting solar radiation have to be considered);
- Local production of energy
- Due to the seasonality of cruise ships, the building has to be, in essence, multi-functional, allowing use it year-round.

5. Technical Solutions

5.1 General Concept

The shape of the building affects its use of energy. The more compact the building and the smaller the area of the envelope per volume unit, the lower the need of heat energy during the heating season. The cooling of the terminal during the summer is essential, since it is then, when it is primarily used, which means that it is important to reduce the passing of solar radiation into the interior. The compactness of the building would not have a significant effect during the cooling period; however, assuming that the ambient air is cooler during the night, then the compactness and an envelope with greater thermal conductivity will contribute to the cooling of the building. Therefore, the shortcomings of the architectural design lie in the large glass facades that are directly exposed to the sun, which makes it difficult to ensure the desired indoor climate in the surrounding rooms.

As the building together with the surrounding "extension of urban space" form an integrated concept, then this study presents options, which would maintain the architectural essence of the building, meaning that the primary focus is on analyzing the envelopes and technical systems.

5.2 General Construction Solutions

The analysis divided general construction criteria affecting the energy performance of the building into two:

1. **Envelope of the building**. Solutions exterior wall based on either a light (timber frame, sandwich panel, etc.) or a massive structure (reinforced concrete panel) were analyzed. The same value of thermal conductivity (U-value) was used in both solutions. To analyze the effect of thermal conductivity, also a version with lower thermal conductivity was presented (Figure 5.2.1).

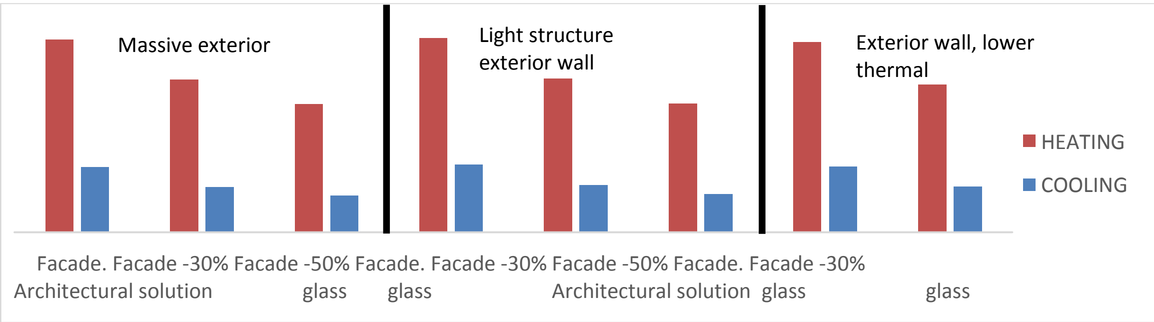

Figure 5.2.1 Comparison of terminal's envelopes.

The results can be generalized as follows:

- The massiveness of the exterior wall has a trivial effect on the energy performance indicator;
- The effect that solar control and the proportion of glass facade have is very important, therefore it is recommended to reduce the proportion of glass facade, to lower the energy use of the future building, facilitate indoor climate control and improve the national energy performance indicator;
- In modern solutions, the effect of the envelope's thermal conductivity does not affect the energy performance indicator or the energy needs of the building substantially (the effect is smaller than the effect of glass facade).

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2. **Doors and windows of the building (glass facade)**. The effect of doors and windows compared with the part of exterior wall that does not include them is great, which is why the specific influence of doors and windows was examined. The analysis compared insulating glass units (G=0.5), which are part of the regular construction practice, and anti solar glass panes (G=0.3). The solutions with high proportion of glass facades have difficulties ensuring a comfortable indoor climate, therefore the comparison included a setup with an external curtain that can be controlled with respect to the movement of the sun (i.e. when the sunlight falls on the facade, the curtain is automatically lowered) (Figure 5.2.2).

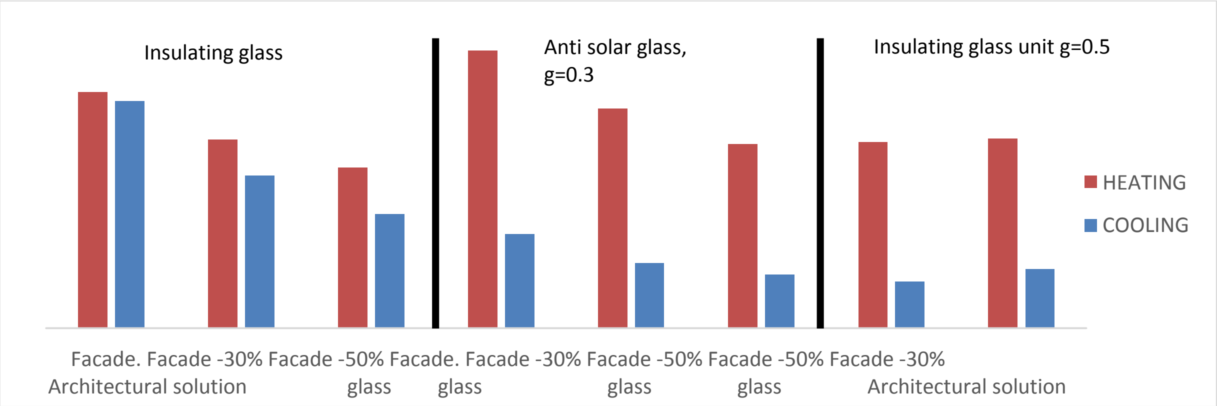

Figure 5.2.2 Effect of insulating glass units on the energy demand of the building.

The results can be generalized as follows:

- It is necessary to use anti solar glass or regular glass (G=0.5) together with external shades for solar radiation (e.g. external curtains or roller blinds integrated into the glass unit) on the eastern, southern and western sides;
- Lower proportion of glass facade will ensure lower energy consumption in controlling the indoor climate.

5.3 Heating and Cooling Supply

The registered immovable of the cruise terminal is located in the Tallinn district heating area[13], which is why alternative energy production solutions are limited. In district heating area consumers can also purchase heat energy converted from fuel free and renewable sources directly from its producers[14], in addition to the heat of district heating network; essentially this means that it is permitted to use the heat returned from the building's systems and produce energy from renewable sources like the sun, wind, earth and water on site. In case a heat pump solution is used, then it is assumed that the input energy originates from renewable sources as well: therefore it is necessary to use, for example, solar panels or wind turbines to produce energy on site or purchase green energy on balance. Green energy can be purchased from a traditional electricity vendor, who uses central Elektrilevi network, and from an energy vendor, who is operating the production facilities on the site, where the energy is consumed (but only in case the portfolio of the respective service provider includes production of renewable energy, which would enable them to issue green energy certificates for their customers' objects). In addition to legal restrictions, it is important for the network operator of district heating area to assess the economic feasibility of the project, and therefore it is possible

13 Boundaries of Tallinn district heating area, the conditions and policies for joining and departing the district heating

area, general requirements for quality of district heating, and network operator's duty of development https://www.riigiteataja.ee/akt/424052017005

14 District Heating Act https://www.riigiteataja.ee/akt/103032017012?leiaKehtiv

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that if the customer uses largely cost-effective energy sources, then the district heating company would not want to invest into the area only to support peak consumption.

In the light of the above, two possibilities of heating and cooling supply have been compared in herein:

1. **Heat supply on the basis of district heating**. Cooling supply will be satisfied with central chiller or local systems for direct evaporation, excessive heat will be directed into the ambient air or the sea;

2. **Heating and cooling supply using a seawater source heat pump** that will channel the excessive heat into the sea in the summer and will use the heat of the sea to heat the building during the heating period.

5.3.1 District heating and local cooling

The cruise terminal in question is located in the Tallinn district heating area. The port area is not a designated area of any network operator and therefore it is legally possible for an interested network operator to start operating in the area. The above means that it is possible to create an entirely new network servicing the port area, if any network operator is interested in such a long-term investment project (considering that network operators in Estonia have to coordinate their investments, costs and energy prices with the Estonian Competition Authority, it is often economically complicated to establish an entirely new network in this regulatory system). Since the heat pipes currently closest to the port area belong to the city centre network area of Utilitas Tallinn AS, then only from the perspective of heat energy they are the rational choice.

The heat of the city centre utility line of Utilitas Tallinn AS is provided by the company's Mustamäe boiler plant, Tallinn Power Plant and Iru Power Plant. In 2016, the share of heat produced from renewable fuels was 45%[15], which is why it is theoretically possible that the adjustment of the regulation of minimum requirements for energy performance by the Ministry of Economic Affairs and Communications in the beginning of 2018 will establish more favourable conditions for "green" district heating: meaning that the conversion factor will be lowered, which will improve the energy performance indicator of buildings or in certain cases the class of energy performance certificate (read more about the requirements for energy performance from Chapter 4.2.3). According to the standard terms of Utilitas Tallinn AS the maximum supply temperature is 105°C, which would allow the temperature schedule of approximately 75/55°C, but according to the 2016/2017 temperature schedule of Utilitas Tallinn AS the maximum supply temperature of network water was 122°C (at the outside temperature -22°C), which would allow even higher schedule (90/65°C).
The specific temperature schedule will be designed by the designer of the building's heating system.

Since currently there is no district cooling option in the area, it is necessary to solve the **cooling of the terminal** locally.

The most traditional and the most common method of producing cooling energy is a central chiller, which would use water as the carrier. The chiller's condenser will be cooled by dry-cooler, which would be located in the external environment. In view of the architectural concept (citizens visiting the area of the cruise terminal frequently), it may be necessary to use low-noise dry-coolers, which would increase the size and cost of the appliances significantly. It is advisable to use at least 35% mixture of water and ethylene glycol in the mesh between the dry-cooler and the chiller. Since there might be complications positioning the cruise terminal properly in architectural terms,

15 www.utilitas.ee

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then for comparison purposes we have included an option in the study, where excessive heat would be driven into the sea; the solution would allow to use the so-called free cooling (i.e. cold water would be collected from the sea and it would be directed past the chiller directly into storage tank). A great disadvantage of the latter is its economic feasibility, since the investment into the system is substantial (combining seawater source heating and cooling would be more rational, see Chapter 5.3.2 for details). The dry-cooler solution would not use free cooling, since climate control would in large part be executed using ventilation, which would already provide free cooling in terms of air (in case the ambient air temperature is sufficiently lower than the room air, then it is possible to drive it into the room and ensure the necessary climate at low cost).

It is recommended that the chiller would have a valid EUROVENT certificate. It would be practical to choose a chiller that would have a screw or a scroll compressor, in order to have step by step control of the machine and thus prolong its lifespan and reduce energy consumption, also several compressors ensure partial operation of the chiller, in case one of them would break down. The average cooling factor (ESEER) for the cooling period provided by the manufacturer has to be at least 5.0 (the actual annual average cooling factor at the location of the cruise terminal would have to be at least 4.0).

Depending on the solution of room equipment, usually a temperature schedule of 7/12°C is used in case of condensate systems and 14/17°C in case of condensate-free systems (e.g. in case of chilled beams).

Should the primary indoor climate control system be ventilation (as the authors of this study recommend; see Chapter 5.6 for details), then one of the possible options may be using **direct evaporator batteries**. In the event of this solution the system circulates a cooling agent (usually freon, but due to restrictions on polluting greenhouse gases in the European Union, from the standpoint of sustainability it would be reasonable to consider more environment-friendly cooling agents like CO_2). In such a system liquid cooling agent is guided from the condenser located in outside environment to the cooling battery of the ventilation device, where it evaporates (superheat phase: the heat is accumulated, until all the liquid has evaporated) and returns to the condenser, where it is cooled by a fan (subcooling phase: cooling agent is cooled until it turns entirely into gas). The layout of suitable internal components permits to use only one external component (similar to VRV/VRF solution); however, for the purpose of ensuring energy supply it is advisable to consider installing one external component per every internal component (should one of the external components malfunction, then it would not affect the entire cooling system of the building). This solution cannot be controlled as good as the traditional water cooling system mentioned earlier and the applicability and efficiency of the system is limited by the length of the pipes of its internal and external components (which might be essential for the cruise terminal); however, the greatest advantage of direct evaporator cooling is the low investment it requires.

	Advantages	Disadvantages
Central cooling	▪ The cooling medium in the system is safe for the environment and the users of the building ▪ The system is very reliable ▪ The system is easily adjustable and controllable ▪ Possible to use together with free cooling (more efficient) ▪ Easy to expand the system	▪ Requires greater initial investment compared to direct evaporator cooling system ▪ Maintenance costs are greater than for direct evaporator cooling system ▪ Placing dry-cooler into the external environment might be difficult (furthermore, the terminal area requires lower noise level from the equipment, i.e. larger external component)
Local direct evaporator cooling system	▪ Lower initial investment ▪ No problems related to leaking and condensates, which are inherent in water systems	▪ Not possible to use free cooling (lower efficiency) ▪ Difficult to expand the system ▪ Stricter requirements for greenhouse gas emissions in the European Union will increase the investments and maintenance costs

Table 5.3.1 Comparison of producing cooling energy

5.3.2 Seawater Source Heat Pump

The analysis of suitability of seawater source heat pump for the Port of Tallinn cruise terminal is based on reference solutions from Estonia and the Nordic countries (several of them have been described in Chapter 4.4 herein), professional literature[16] and the authors' practical experience with different heat pump solutions.

To put it simply, seawater source heat pump systems can be divided into two based on their method of obtaining energy:

1) **Closed loop system**. A system, where cold/heat carrier is in a closed pipe that has been installed to the bottom of the sea. In favourable conditions closed loop system may ensure higher coefficient of performance, but its disadvantages are high cost of installation and complicated detection of possible leaks in the future (in practice it is problematic and expensive).

16 The Preliminary Research of Sea Water District Heating and Cooling for Tallinn Coastal Area https://file.scirp.org/pdf/SGRE20120300011_19171139.pdf
Advances in Ground-Source Heat Pump Systems. Simon J. Rees. 2016
Field measurement and energy efficiency enhancement potential of a seawater source heat pump district heating system. Shu Haiwen Duanmu Lin Shi Jing Jia Xin Ren ZHiyong Yu Haiyang. 2015
The thermal performance of seawater-source heat pump systems in areas of severe cold during winter. Wandong Zheng, Tianzhen Ye, Shijun You, Huan Zhang. 2014

2) **Open loop system**. In open loop system the heat is obtained from the sea using a heat exchanger. In Estonia, similar system is used by Seaplane Harbour (see Chapter 4.4 for more detailed description of the reference).

Due to the fact that the traffic routes of ships make it difficult (and risky) to install a closed loop system i.e. sea heating mesh into the sea in the port area, it would be objective to consider an open loop system for the Port of Tallinn cruise terminal. *Note! Resulting from customer's request a solution of closed loop system has been added to the adjusted version of the report (see Annex 2, solution 13a for details). The added solution takes into consideration that the collector system will be installed approximately 10m deep under the cruise pier. Compared to the open loop system, the closed loop system would enable the system to operate with lower temperature of seawater and guide the seawater directly into heat pumps (without a heat exchanger in the middle), therefore the system's coefficient of performance is higher. However, constructing this system is more complicated and expensive, and it will be very difficult to detect and repair leaks of sea mesh during maintenance.*

In the case of an open loop system, a key factor is the choice of a heat exchanger. Although Swedish installers of seawater source heat pumps[16] have developed a heat exchanger, which should make it possible to obtain heat from 0°C seawater, the current practice shows that in heating mode it would be rational to consider channelling at least 2.5°C water to the heat exchanger. Assuming that the depth of the sea by the cruise terminal is 10-15m, we can see from the chart of seawater temperatures in the Gulf of Finland (Chart 5.3.2) that during the cruise season adequate average temperature is mostly guaranteed, but during the winter the water is considerably colder (since the chart displays average temperatures, then in reality there are periods with suitable water temperatures for seawater source heating also during the winter, for example, close by at the Seaplane Harbour an average temperature during winter months is 2°C[17]). **In case the Port of Tallinn decides to use seawater source heating in the cruise terminal, then the authors recommend to conduct precise measuring of seawater in the area** (optimal measuring period 1 year). When choosing a heat exchanger, it is important to observe that its construction would enable using seawater efficiently at the lowest possible temperature (e.g. a Finnish installer of seawater source heating that was consulted pointed out that in some solutions inside the heat exchanger supply pipe is too close to return pipe, as a result the return pipe will cool the supply pipe and reduce the overall efficiency of the system).

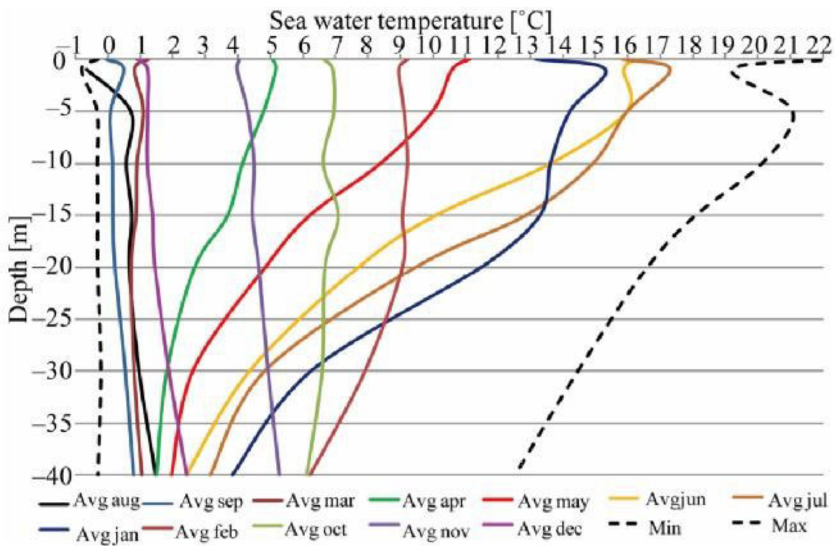

Chart 5.3.2 Seawater temperatures in the Gulf of Finland

17 Evaluation of applicability of surface water heating system in Estonian climatic conditions. Lii Vammus. 2015

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When designing an open loop into the sea, it is recommended in the area of the Port of Tallinn to place the supply pipe as far away from the shore as possible, in order to avoid larger debris getting caught in the pipe and to obtain warmer water during winter (Finnish experts of seawater source heating that were consulted during the study pointed out that in the Gulf of Finland the temperature of seawater is often lower by the pier than a few dozen or a few hundred meters away from it).

It is advisable to use heat pump solution for both heating and cooling. A less expensive and more common solution (that has also been considered in the analysis of solutions herein) enable using heating or cooling, i.e. heat carrying process is turned around within the same technical solution. In the world there have been a few pilot projects of hybrid heat pump solutions, which allow to heat and cool the building simultaneously.

To maximize the efficiency of this solution, it is advisable to also use free cooling (natural cooling in the terminology of sea water source heating solutions). In this case parallel to heat pumps a separate round of pumps together with a heat exchanger will be installed, which allow to cool the building in spring or autumn, when the temperature of seawater is low, without the heat pumps consuming of electricity. If the standard temperature mode of indoor cooling system is 7/12°C, then for free cooling it would be necessary to increase it by a few degrees, in order to increase the scope of application of “free of charge” cooling (the exact temperature schedule will be clear in the design phase).

In order to increase the coefficient of performance (COP) of heat pumps, it is advisable to design the heating of the building to a heating schedule that would be lower than regular (e.g. 60/40°C or even lower). Since during the winter season it is possible that the temperature of seawater will fall so low that the heat exchanger will not be able to obtain any heat from it, it is necessary to establish an alternative heat source for such cases. In the examined example of Maritime Museum (Chapter 4.4) electric heating was used. In case of high efficiency of seawater source heat pump (properly functioning system; the use of electric heating up to 5% of total heating), then due to minimum use of additional heating the purposeful choice would be electric heating. Should a wind turbine be constructed for the cruise terminal, if the wind speed and ambient temperature are suitable, it would be possible to use it for producing a portion of the electricity necessary for additional heating.

Based on the reference objects that were studied, professional literature and consulting with the Finnish constructors of district cooling, it is possible to achieve a seasonal coefficient of performance (SCOP) up to 4.0 for heating supply and a seasonal energy efficiency ratio (SEER) of approximately 5.0 for cooling supply.

It is possible to decrease higher investment expenses per unit for seawater source heat pumps, if the system is established for the entire area of the port[16].

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	Advantages	Disadvantages
District heating and local cooling	▪ Traditional solution; ▪ Lower risk of design and construction flaws; ▪ The solution would be more familiar for the maintenance staff;	▪ Lower efficiency; ▪ The positioning of external components of cooling devices on the facade or the roof of the building might be difficult
Seawater source heat pump for heating and cooling	▪ Ensures lower maintenance costs; ▪ Ensures a more sustainable outcome;	▪ Higher initial investment; ▪ A more modern solution, that might cause problems in design, construction and maintenance; ▪ Necessary to provide a reserve heating source for the winter (should the temperature of seawater be too low for pumping)

Table 5.3.3 District heating and local cooling compared to the solution of seawater source heat pump

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5.4 Heating

The comparison of different heat distribution systems of the building has been presented in table 5.4.1. For all described heat distribution systems, it has been taken into account, that in order to reduce vertical temperature gradient, ventilation fans (e.g. Frico ICF) will be used to reduce air stratification and direct the heat efficiently to service areas.

Table 5.4.1 Range of heat distribution systems

	Advantages	Disadvantages
Hot air heating	▪ Enables to heat up large rooms using air recirculation; ▪ Allows a flexible room program (depends on air distribution system).	▪ Requires a high temperature heat carrier; ▪ Difficult to surmount great waste of heat and might cause inconvenient blowing (in case of great waste of heat).
Radiator heating	▪ Effective heat distribution; ▪ Possible to use low temperature heat carrier (increases heating surface significantly); ▪ Prompt response in spring, when in the course of the day both cooling and heating are needed; ▪ If built in module system, changing the room program is flexible.	▪ Compared to convection heaters the radiated heat distribution is greater, which could cause discomfort, if the seat was located close to a radiator; ▪ Increased waste of heat through an exterior wall behind the radiator (the lower the heating schedule, the smaller the effect); ▪ From the standpoint of interior architecture the appearance is often not aesthetic enough.
Convection heating	▪ Effective heat distribution; ▪ Possible to use low temperature heat carrier (increases heating surface significantly); ▪ Prompt response in spring, when in the course of the day both cooling and heating are needed; ▪ Visually possible to install into floor channels.	▪ High initial investment; ▪ Increased waste of heat through an exterior wall behind the convection heater and through the floor under it.
Underfloor heating	▪ Effective heat distribution; ▪ The system is very flexible; ▪ Requires a low temperature heat carrier; ▪ Low initial investment; ▪ Ensures uniform internal temperature.	▪ Increased waste of heat through the floor; ▪ Slow response to abrupt change in waste of heat; ▪ When adding and attaching fixed equipment or installations to the floor later on, the outline and location of underfloor heating have to be taken into account.

It is possible to divide heat distribution systems into two:

- **Base heating**. The heating system, which ensures the temperature (e.g. +10°C, the precise temperature will be clear in the design phase) when the building is not used and during an off-season.
- **Peak heating**. The objective of peak heating is to ensure and adjust the desired room air temperature during using the building. The response time of peak heating has to be prompt.

	Advantages	**Disadvantages**
Base heating – underfloor / Peak heating – air	▪ Low initial investment; ▪ In the cooling period it is possible to use the same mesh for cooling; ▪ Visually invisible.	▪ When using the same mesh for cooling, it is not possible to cool one part of the room and heat the other.
Base heating – radiator or convector / Peak heating – air	▪ Ensures a more flexible climate control; ▪ Enables to dispose of heat gain better.	▪ Higher cost; ▪ Visually visible.

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5.5 Cooling

The comparison of cooling distribution systems of the building has been presented in table 5.5.1. Since utilization of the building is very volatile and heat gain primarily depends on the number of cruise passengers and arrivals, then the system has to be flexible and responsive.

Table 5.5.1 Range of cooling distribution systems

	Advantages	Disadvantages
Air conditioning	▪ Limited cooling capacity. In case of large cooling load, the exchange of air may cause draft; ▪ Air conditioning enables fresh air to reach service area; ▪ A flexible and responsive solution.	▪ May cause draft; ▪ Limited cooling load.
Convection cooling	▪ Large cooling capacity; ▪ Takes little space, flexible location; ▪ Responds quickly.	▪ Noisy ▪ Convector's fan consumes additional electricity; ▪ Draft (on high speed the movement of air causes discomfort), i.e. poor indoor climate; ▪ Controlling more inexpensive devices by automation of the building is limited. ▪ Expensive solution
Underfloor cooling	▪ If the mesh exists, it is possible use effectively high temperature cooling (free cooling with seawater); ▪ Uniform distribution; ▪ Invisible system.	▪ Difficult to control; ▪ Does not respond quickly to heat gain fluctuations.

Similarly to heat distribution, it is advisable to also implement cooling in two stages to ensure a user-friendly cooling system with a high degree of flexibility:

- **Base cooling**. Base cooling ensures the set temperature of room air. Cooling distribution system in the terminal building may operate using for example convectors or the mesh of underfloor heating. It is important to dimension the system to as high a temperature schedule as possible, so that passive seawater cooling can be used as much as possible.
- **Peak cooling**. Peak cooling ensures climate control in case of great fluctuations in free cooling. It is wise and advisable to ensure peak cooling using air (i.e. ventilation). In order to ensure room air temperature as energy-efficiently as possible, it is recommended to use recirculation of room air. In the beginning of cruise season, when the outside temperature is lower than room air temperature, it is possible to apply free cooling using ambient air.

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5.6 Ventilation

When designing a sustainable building, it is very important to control indoor climate as efficiently as possible, which is why minimal use of demand-based ventilation in the main zone of the terminal is advisable (the comparison of constant and demand-controlled air exchange has been presented in Table 5.6.1). The air exchange of the terminal building is quite vast and varies (depends on how many people are using the building).

Table 5.6.1 Comparison of constant and demand-controlled air exchange

	Advantages	**Disadvantages**
Constant air volume system (CAV)	▪ Compared to DCV-system it is easier to construct and adjust ▪ Compared to DCV-system its cost is lower	▪ Compared to DCV it is less flexible (service time, thermal and indoor climate parameters) ▪ Greater energy consumption (compared to DCV)
Demand-controlled ventilation system (DCV/VAV)	▪ In service an energy-efficient solution ▪ Flexible (service time, ensuring good thermal environment and air quality)	▪ Higher cost ▪ If the solution is not comprehensive, problems may arise during adjustment and use ▪ Adjusting elements may cause noise (it is necessary to pay attention to blocking it)

It is advisable to control the units of the terminal's demand-based ventilation (including fan speed) based on the content of carbon dioxide (CO_2) and room air temperature. If the ventilation is also used for heating or cooling the building, it is advisable to implement recirculation of air, which would also be controlled per room based on CO_2 (necessary to install CO_2 meters to critical rooms/zones).

The distribution of ventilation systems depending on the use of service areas is also important in the terminal. According to the room information that the authors of the study have, it is necessary to design ventilation systems to the following areas: terminal area, cafe/kitchen, commercial spaces, toilets, ancillary spaces.

When designing a ventilation system and controlling indoor climate, indoor air distribution has an important role. When deciding on the air distribution system and outlet types, it is important to consider, whether air is also used for controlling indoor temperature, i.e. whether it is used for heating and/or cooling the building. Generally, laminar air distribution is used in terminal buildings, due to low speed this ensures a good indoor climate, but taking into consideration the economic aspects of the terminal in question, we recommend using diffusers designed for public spaces instead of the expensive solution above. A solution using diffusers has been applied at Tallinn Airport: at sloping surfaces fresh air is directed to people's area with diffusers along the wall, which avoids intense air blowing at the service area.

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5.7 Automation

In a building, where there are higher expectations on sustainability, energy efficiency and indoor climate, it is recommended to build a central automation system. A central automation system enables to manage and monitor all technical systems, transmit alarms, and organize the cooperation of systems. In modern solutions it is not necessary to set up a local physical control centre (computer), instead, it is possible to use web controllers, which could be accessed remotely (i.e. over the Internet) using a computer or a smart device.

5.7.1 General Requirements

It is advisable to design the automation system based on the following standards:

- Standard EVS-EN 15232. Energy Performance of Buildings - Impact of Building Automation, Controls and Building Management.
- EN ISO 16484 "Building automation and control systems".
- EU directives 2004/108/EEC and 2006/95/EEC.

In order to increase the sustainability of the building, demand-controlled operation of climate systems and lighting should be used as extensively as possible, that is to say it is advisable to design the automation system in accordance with the standard EVS-EN 15232. In general, as regards controlling indoor climate and lighting, we recommend complying with Class A requirements. Class A automation provides for controlling indoor climate (and lighting) based on demand and restrains double consumption of energy (e.g. heating or cooling simultaneously).

It is recommended to resolve the automated processes of adjusting, managing and controlling the system/device by freely programmable microprocessor-system (Direct Digital Control-system (DDC)), which are represented by all types of controllers nowadays. The devices used must comply with EU directives in effect: electromagnetic compatibility directive 2004/108/EEC and low voltage directive 2006/95/EEC. Using freely programmable controllers enables maximum programming of demand-based control and monitoring programs to operate climate systems.

5.7.2 Automated Systems and Devices

We recommend integrating all the primary technical systems into the automation system:

- Ventilation devices
- Exhaust fans
- Heating system
- Heating unit/heat pumps
- Cooling station
- Local cooling equipment
- Air curtains
- Electrical system (including indoor and outdoor lighting)
- Other systems (elevators, UPS, emergency generator, and other special systems)
- Cost trackers (meters)
- Local units of renewable energy

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<u>**Cost Tracking by the Automation System**</u>

The automation system has to able to continuously monitor the consumption of electricity, heating and water, and alert in case of abnormal overruns. Minimum and maximum values shall be set for the meters and outside of this range the automation system will be alerted of irregular functioning of the system.

We recommend that all consumption meters of electricity, heating and water have impulse output or other output that would allow measuring consumption and would be compatible with the automation system (preferably M-bus or Modbus output). If the vendors of electricity, heat and water supply etc. do not allow using the outputs of their meters, it is advisable to use duplicate meters.

If possible, the following meters should be integrated into the automation system:

- Cold water (entire building)
- Thermal energy:
  - Entire building
  - Heating mesh
  - Mesh of heating coils
  - Mesh of air curtains
  - Hot water
- Electricity
  - Entire house
  - Cooling station/heat pump
  - Engines of large ventilation devices (consumption data through frequency converter)
  - Indoor lighting (general lighting)
  - Outdoor lighting
- Local production of energy

5.8 Lighting

Designing the entire building with LED-type lights would give the best possible technological and economic outcome. Referring to insufficient practice of changing the whole building to LED-type lights, it has been assumed in the analysis that LED lights are used as little as possible in all general areas.

5.8.1 General Information

Lighting manufacturers are obliged to present series of data on their websites, including the data about energy performance, which would facilitate the selection process. All lighting calculation applications allow calculate solution-specific annual energy consumption and its **LENI** value. LENI values of energy efficient solutions have been presented by area of activity in the standard EVS-EN 15193:2007 “Energy performance of buildings. Energy requirements for lighting”. Although several manufacturers may have products that are similar externally, their technical lighting parameters might not even come close to each other. In case of same lamps, the technical lighting parameters of a light depend on the material of its reflector or diffuser, its qualities of reflecting or passing light through, shape, and the positioning of lamps in relation to the reflector or diffuser. In a way the efficiency of a light is indicated by performance factor LOR, which is used to characterize the percentage of light flux that can be obtained from the light, because part of the light flux will remain unobtainable, this figure may be compared for lights with similar construction.

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5.8.2 Most Important Light Sources

Lighting of general areas

It is advisable to solve the lighting of general areas with lights based on LED-type light sources. The lights have to be zoned based on floors or some other zone of use. The lights will be integrated with the automation system, and they will be controlled by time program, and motion/occupancy sensors. Depending on the zone, the lights can be dimmed.

Outdoor lighting

It is recommended to use lower (height <=6m) post lights with LED-type light source (e.g. in parking area) and LED-type facade lights (e.g. projector lamps). The lights can be controlled by the automation system's time program and light intensity. For lighting outdoor areas it is recommended to use autonomous LED lights equipped with a solar panel and a battery (Figure 5.8.1).

Figure 5.8.1 Outdoor light equipped with a solar panel.

5.9 Local Energy Production

The definition of nearly zero energy buildings expects an excellent building, where solutions of renewable energy are used to produce energy (Chapter 4.2.3); therefore it can be said that local energy production is an integral part of the concept of nearly zero energy buildings. Nationally the use of renewable energy has been subsidized, see chapter 4.2.2 for more specific details about support schemes.

5.9.1 Wind Turbine

It is reasonable to implement the production of electricity by wind turbines in regions, where the annual average wind speed exceeds 3-4m/s (generally wind turbines do not function with wind less than 3m/s or more than 25-30 m/s). Based on literature and experience the estimated annual average wind speed in the area of port of Tallinn might be ~6m/s.
Before proceeding with the investment, it would be useful to measure wind speed over a certain period to be convinced that the investment is profitable.

There are small wind turbines with either horizontal or vertical axis. It would be more rational to prefer horizontal-axis wind turbines, the productivity and efficiency of which are significantly higher compared to vertical axis wind turbines.

5.9.2 Solar Panels

It is advisable to install solar panels on the southern pent for producing electricity (the analysis did not cover installing heat-producing solar collectors, since the need for electricity exceeds substantially the need for heat energy during the period, when producing heat energy with solar collectors would be possible). When deciding on solar panels (PV panels), it is important to choose the panels, for which the manufacturer would issue a 10 year warranty of the efficiency, in addition to the usual warranty. The panels have to be chosen based on dynamic calculations, in order to consider possible forming of shadows and other environmental aspects. Taking into consideration the maturity of solar panel technology and continuing trend of decreasing prices, it is possible to choose between a large number of manufacturers and installers in Estonia.

ANNEX 1 COMPARISON OF ENERGY PERFORMANCE INDICATORS (EnPI) OF DIFFERENT SOLUTIONS

SOLUTION	ENVELOPES									VENTILA-TION		HEAT SUPPLY		COLD SUPPLY			LIGHTING		EnPI	
	Exterior wall		Solar control of doors and windows		Proportion of glass facade*			Blinds between insulating glass unit (G=0.39)	External curtain (G=0.14)	System										
	Exterior wall U=0.17 and window U=1.0	Exterior wall U=0.13 and window U=0.9	Solar control glass (SF 0.3)	Regular glass (SF 0.5)	Archit ectural design	-50%	-30%			CAV	VAV	Seawater source heat pump	District heating	Seawater source heat pump + free cooling	Chiller (with dry cooler)	Chiller + free cooling (sea)	In accordance with legislation	LED	Without local renewable energy and energy	With local renewable energy (PV or wind turbine)**
1	X			X	X					X			X		X		X		227	197
2	X			X	X					X			X			X	X		223	193
3	X			X	X					X		X		X			X		203	173
4	X		X		X					X			X		X			X	175	145
5	X		X		X					X		X		X				X	146	116
6	X		X		X						X		X		X			X	148	118
7	X		X		X						X	X		X				X	122	92
8	X		X				X				X		X		X			X	135	105
9	X		X				X				X	X		X				X	114	83
10		X	X				X				X		X		X			X	133	103
11		X	X				X				X	X		X				X	113	83
12		X	X			X					X		X		X			X	125	95
13		X	X			X					X	X		X				X	107	77
14				X		X			X		X		X		X			X	119	89
15				X		X			X		X	X		X				X	104	74
16				X		X		X			X		X		X			X	120	90
17				X		X		X			X	X		X				X	105	75
18				X		X		X			X		X			X		X	120	90

*reducing the proportion of insulating glass unit means reducing glass surface particularly on the southern orientation (secondarily on the eastern and western orientation)

**70kW PV panels have been considered, annual production approximately 60MWh, and wind turbines of the same production (approximate diameter 11m)

ANNEX 2 COMPARISON OF ACTUAL CONSUMPTION, CO_2 EMISSIONS AND ECONOMIC PROFITABILITY OF DIFFERENT SOLUTIONS

The same energy consumers have been taken into account in the calculations of the actual consumption that have been used in the calculations of energy performance indicator (EnPI) set out by legislation, i.e. such energy consumers as outdoor lighting, charging of electric vehicles, outdoor heating, elevators, etc. have not been included

SOLUTION	ENVELOPES									VENTILATION		HEAT SUPPLY			COLD SUPPLY			LIGHTING		EnPI		CO_2 EMISSIONS, tons / y		NPV 20y ratio (in relation to solution 1)***
	Exterior wall		Solar control of doors and windows		Proportion of glass facade*			Blinds between insulating glass unit (G=0.39)	External curtain (G=0.14)	System														
	Exterior wall U=0.17 and window U=1.0	Exterior wall U=0.13 and window U=0.9	Solar control glass (SF 0.3)	Regular glass (SF0.5)	Architectural design	-50%	-30%			CAV	VAV	Seawater source heat pump (closed)	Seawater source heat pump (open)	District heating	Seawater source heat pump + free cooling	Chiller (with dry cooler)	Chiller + free cooling (sea)	In accordance with legislation	LED	Without local renewable energy and energy	With local renewable energy (PV or wind turbine)**	Without local renewable energy and energy	With local renewable energy (PV or wind turbine)**	
1	X			X	X					X				X		X		X		127	97	245	175	1.00
2	X			X	X					X				X			X	X		122	92	234	165	1.01
3	X			X	X					X			X		X			X		108	78	248	179	1.02
4	X		X		X					X				X		X			X	99	69	166	97	1.00
5	X		X		X					X			X		X				X	80	26	183	113	1.02
6	X		X		X						X			X		X			X	94	63	152	82	1.00
7	X		X		X						X		X		X				X	74	43	169	99	1.02
8	X		X				X				X			X		X			X	85	55	141	71	0.94
9	X		X				X				X		X		X				X	68	38	156	86	0.96
10		X	X				X				X			X		X			X	83	53	140	70	0.99
11		X	X				X				X		X		X				X	67	37	153	84	1.02
12		X	X			X					X			X		X			X	78	48	133	63	0.95
13		X	X			X					X		X		X				X	63	33	146	76	0.98
13a		X	X			X					X	X			X				X	62	32	143	73	1.02
14		X		X		X			X		X			X		X			X	72	42	126	56	0.97
15		X		X		X			X		X		X		X				X	60	29	137	68	1.00
16		X		X		X		X			X			X		X			X	74	44	129	59	0.99
17		X		X		X		X			X		X		X				X	61	31	140	70	1.03
18		X		X		X		X			X			X			X		X	73	43	129	59	1.01

*reducing the proportion of insulating glass unit means reducing glass surface particularly on the southern orientation (secondarily on the eastern and western orientation)

**70kW PV panels have been considered, annual production approximately 60MWh, and wind turbines of the same production (approximate diameter 11m)

***all investments in technical systems covered herein and changes in investments related to envelope elements in relation to solution 1 have been taken into account in the calculations o net present value / Production facilities of local renewable energy have not been taken into account in the calculation of net present value