ENERGY MODELLING AND SIMULATION OF A PUBLIC BUILDING

The Solvik kindergarten study case

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Abstract

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This dissertation has the purpose of finding an alternative heating system for the Solvik kindergarten to the current one: natural gas boiler. Natural gas is considered an inconvenient fuel for the current geopolitical situation, in which natural gas supplies to Finland have been cut since 20th May 2022.
Furthermore, natural gas is not found to be a suitable energy source as it is discussed in the European and national carbon neutrality programmes. An alternative to the existing boiler is proposed, more specifically the other suggested option is district heating.

The material, such as Excel data and building drawings, was provided by the city of Hämeenlinna. The utilized software to carry out the simulation is IDA-ICE (4.8).
The thesis does not include timetable, profitability calculations, nor cost calculation. The modelled created in the software IDA-ICE was geometrically simplified, future simulations may be based on an accurate representation on the building to obtain more precise results, and other heating systems may be investigated.

Keywords Energy efficiency, IDA-ICE software, natural gas boiler, district heating.

Pages 39 pages and appendix 1 page.

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1 Introduction

This first chapter serves as an introduction to the topic of energy efficiency measures. The focus is on the European annual report and the objectives Finland has set to achieve the goal of carbon neutrality.

1.1 Energy usage in EU and Finland

Every year the European Union releases a report concerning the energy consumptions across its borders, and it is important to acknowledge what has changed in sight of the common objective: climate neutrality by 2050. Especially the last decade, from 2010 to 2020, has seen important decisions being made to act against climate change, pollution, biodiversity loss and the drainage of natural resources. When looking at the annual report, it is important to keep in mind what has happened in that time frame. During the last two years the Covid-19 crisis together with the climate change have challenged the Member States and a sharp spike of electricity and gas prices has been observed. The price raise was caused by a higher global demand for gas, as the economic recovery has started with a mismatch between demand and supply. (European Commission, 2021)

To reach the goal of climate neutrality by 2050, the European Union has adopted the European Climate Law, which is supported for instance by the package called "Delivering the European Green Deal". This package enshrines several proposals in the economic field building on the earlier 2030 goal, by setting new objectives for a reduction of greenhouse gas (GHG) emissions and for energy efficiency. Regarding the construction sector, it is important to focus on the Renovation Wave Strategy, boosted by several developments such as the "Next Generation EU", which proposes that the building renovation industry improves energy and resource efficiency. It has been proposed to introduce a 3% annual renovation of the total amount of public buildings, to make the public sector play a leading role, and to revise the energy factors. In fact, a revision of the Energy Performance of Buildings Directive (also known as EPBD) has been planned and it would include the introduction of minimum energy performance standards. (European Commission, 2021)

In order to achieve the European objectives regarding the building energy usage, Finland has developed minimum energy performance requirements for new and existing buildings.

The requirements, as stated in the Finnish National Building Code Land Use and Building Act (132/1999) (Haakana, Laitila & Forssell, 2016, p. 7), are:

1. The minimum annual efficiency of heat recovery must be at least 45%.

2. The maximum specific fan power (SFP) of a mechanical supply and exhaust system is 2.0 kW/(m^3/s).

3. The maximum specific fan power (SFP) of a mechanical exhaust air system is 1.0 kW/(m^3/s).

4. The maximum specific fan power (SFP) of an AC system is 2.5 kW/(m^3/s).

5. The efficiency of heating systems must be improved where possible when the related equipment and systems are renewed.

Cities in Finland have developed their own programs to reach the common goal, and the city of Hämeenlinna finalized its own in 2019. The city program will be investigated further in the chapter 2.2.

1.2 Objectives and limitations

The thesis presents an energy simulation of the Solvik kindergarten, a public school owned by the city of Hämeenlinna. The reasons why this study case was selected are its heating system, the natural gas boiler, and the high annual energy consumptions. More details about the study case will be provided in the chapter 3.2.

The focus will be mainly on the simulation process and results, accompanied by a background theory to support the thesis and provide the reader with enough knowledge to fully understand the topic.

The purpose of the research is to understand how the heating system impacts the energy efficiency of the building.

The thesis will focus on the following research questions:

- How have the energy efficiency regulations evolved in the last three decades?
- What are the reasons energy efficiency is so crucial in the 21st century?
- How do the regulations effect the efficiency of a building built in the 1990s?

This thesis does not take into account information regarding timetable, cost calculations, nor profitability of the new heating system.

1.3 Research framework

The thesis is divided into four chapters.

The first part of the thesis, starting from Chapter 2, has the purpose of providing a background theory in support of the simulation. More specifically, the evolution of the production of energy in Finland will be explained and shown through graphics, followed by an insight into the average building consumptions for edifices built in the decades between 1950 and 2019. Next, the European plans on the reduction of the emissions is explained in more detail, with a focus on the Finnish strategy and goals and how the city of Hämeenlinna has decided to implement in practice the measures.

The thesis is supported by an explanation of how the heating system operates, with a closer look at the natural gas situation in the current geopolitical context. This part is particularly crucial in understanding in depth the need of a heating system renovation for the Solvik kindergarten. The first chapter concludes with a description of a natural gas boiler and how it carries and distributes the heat in a building.

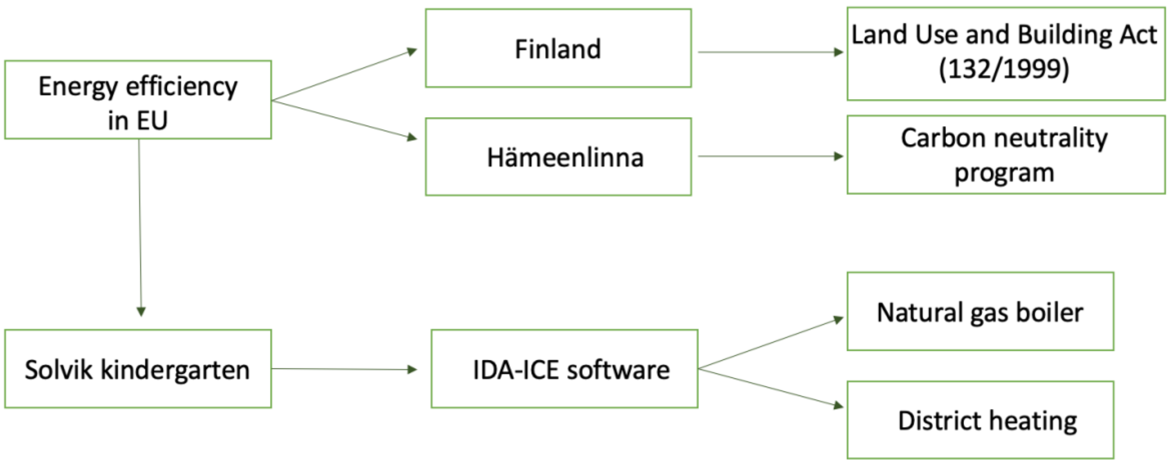
The second part presents the utilized software, IDA-ICE, to carry out the simulation of the energy consumptions of the building. IDA-ICE is introduced to the reader in a dedicated chapter.

A deeper insight into the study case is presented in chapter 3.2. The location of the building, its size and volumes are provided together with the structural types and their U-values. The structural types and the location of the building are crucial factors for the energy simulations. Finally, a closer examination of the electricity and energy consumption is

conducted to understand how the building is used and when, supported by Excel graphs based on the real consumptions of the building during the past year.
In the third part, the results obtained from the first model are compared with the real consumptions retrieved from the Excel files provided by the city of Hämeenlinna. This part is supported by an explanation describing the differences between the two results.
In this chapter, the alternative heating system, district heating, is simulated in the software and the results will be analysed.
In the conclusions, some suggestions regarding future modelling analyses are given, together with some considerations on how to make the model more accurate.

The following flowchart, Table 1, has the purpose to summarize the information given in the thesis.

Table 1. Flowchart with the thesis main points.



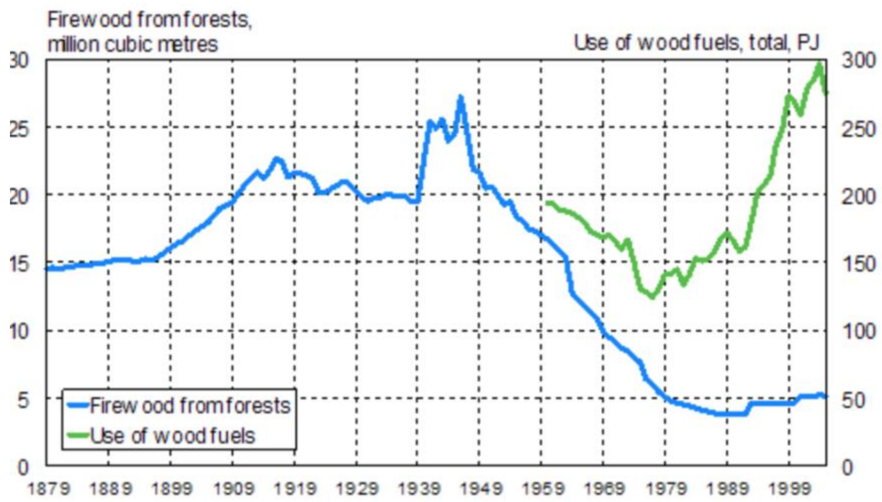
2 Energy efficiency of buildings

This chapter will discuss in depth the production and usage of energy in Finland during the previous century. The Hämeenlinna carbon neutral program, which can be found in the Appendix 1 of the thesis, is also introduced to the reader. The second chapter also includes a dedicated subchapter about heating systems, with a focus on the natural gas boiler. The last subchapter closes the thesis section with a close look at natural gas and its production.

2.1 Background theory

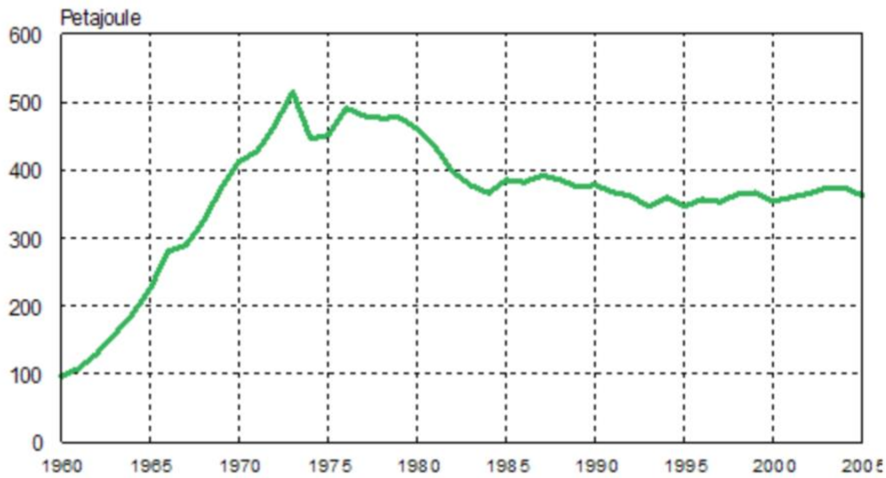
Before moving onto of how the decision on energy efficiency measures were taken, it is necessary to give an historical introduction to the use of energy in Finland. Following the independence from Russia, firewood was the main source of energy production. The use of wood fuels decreased until 1990, but afterwards it started to grow again. One of the reasons for this growing trend could be that wood based fuels are the main source of renewable energy in Finland. In 2019, the total consumption of wood fuels was reported to be 105TWh. This growth has been based especially on the increased use of forest industry by-products and wood residues (Ministry of Agriculture and Forestry of Finland, 2021, p. 15).

Figure 1. Firewood production and usage of wood fuels (source Energy Statistics).



For what concerns fossil fuel – especially oil, natural gas, and coal – usage, sharp rise has been seen in the years between 1960 and 1973, reaching in the latter year the highest peak. (Statistics Finland, 2007).

Figure 2. Oil consumption in Finland (source Energy Statistics)



Natural gas has been imported to Finland since 1974, when the Soviet Union opened a pipeline. Natural gas and coal are used in the industrial sector to produce heat and energy. (Statistics Finland, 2007)

Coal has been utilized in the large-scale production of thermal heat after the energy crisis in the 1970s.

Regarding the production of electricity, until the 1960s hydropower was the main source of production. The Imatra hydropower plant was the most sizeable and energy producing in Europe. However, starting from 1960s the production shifted in favour of the combined heat and power plants (CHP), which were able to produce both electricity and energy. (Statistics Finland, 2007)

Nuclear power plants started to be built in the late 1970s, which allowed the incrementation of the electricity production, and by the end of the decade even the most remote towns and villages in Finland were finally connected to the grid. Starting from the 1990s, wind turbines got erected in Finland, even though the production has become more substantial after 2010. Solar capacity has also recently become considerable after the prices of solar panels dropped. From 2015 to 2020 the production increased from 10 MW to 300MW, but the production is still less than 1% of the total energy demand in Finland.

2.2 Energy efficiency measures

The energy efficiency of a non-residential building is indicated by the average energy consumption for heating and the energy classes. Finland saw an energy crisis in the 1970s, which contributed to improving the energy efficiency of the existing buildings as well as the new ones. Year 1976 marks an important milestone in the field of energy performance of buildings of all purposes (residential, commercial, and public ones) by setting the first U-value requirements (Kauppinen, 2017). In the following table, the values of the average energy consumptions between 1970s and 2019 are inputted.

Table 2. Average heating consumption for non-residential building in different decades (Long-term renovation strategy, 2020–2050).

Decade	**-1959**	**1960-69**	**1970-79**	**1980-89**	**1990-99**	**2000-09**	**2010-19**	**Unit of measurement**
Avg energy consumption	190	165	195	175	170	105	95	kWh/m^2

In Finland, the rise in the energy price has been dealt with some measures imposed by the Sanna Marin's Government. These measures are especially directed at transportation, agriculture, and households. The Government has chosen a guaranteed model to promote the investment in the improvement of the energy efficiency of a building, such as the renewal of the heating systems in favour of the utilization of renewable sources (Valtioneuvosto, 2022).

In particular, the city of Hämeenlinna has worked on a carbon neutrality program since January 2019. The program was finished in December 2019 and approved by the city government in January 2020. According to the Carbon Neutrality report, the city will have to cut the emissions by at least 80% per capita between the years 2010 and 2035, and the remaining 20% of the emissions will be reduced or offset. (Hämeenlinna Kaupunki, 2020)

Regarding building emissions, the city government has found two ways to significantly reduce them. The current share of district heating emissions is estimated to be 15.9%, however the investment in a new biomass powered boiler will contribute to an increase of renewable energy production and a drop in the district heating factor. It was already the previous prime minister's wish, Antti Rinne, to cut completely separate heating systems by 2030s. These systems, for instance oil or natural gas boilers, account up to 12.6% of the total emissions (Finnish Government, 2019, p. 35).

In the first page of the "Listing of Measures", *Toimenpidelistaus* (Appendix 1), the main focus is on the energy, more specifically the use of renewable energies, energy efficiency and energy counselling for the dwelling inhabitants and users. The city has set the goal by 2025 of investigating, for all those buildings which are producing heating on site using natural gas, the possibility of replacing it with biogas.

2.3 Heating system

In Finland, the built environment is responsible for a significant share of energy consumption and greenhouse gas emissions. Municipalities can influence the consumption and energy efficiency of the heating systems through the planning of their own new and renovated buildings. The municipalities are bound to the Decree of the Ministry of the Environment on improving the energy efficiency of a building in repair and alteration work (4/2013, 2/2017). The most common heating methods for residential and service buildings are district heating, wood, and electric heating. However, oil is still used outside the agglomerations, and smaller buildings may be heated by electricity. (Motiva, 2020)

A heating system is a way to heat domestic water and maintain temperatures of an indoor space at a desired level, which is achieved by transforming energy in a heat generator. The obtained heat is stored and then it is transferred to the desired space. The energy transformation process can be either happening on site, like in the case of the Solvik kindergarten, or be generated in a different location from where it is then distributed. In either case the transformation happens in the heat generator, where the heat energy source is converted. Some examples of heat sources are wood, oil, natural gas, geothermal heat, and district heat, whereas the generators can be wood or gas burning boilers, geothermal pumps or district heat exchangers. In the case of electric heating systems, electricity is transformed into heat in the electrical resistor of the heating equipment. (Motiva, 2017)

The produced heat is kept mostly in hot water in the storage heater on in the structures of a building. Heat is transferred to the place where it is needed through a heat distribution system and finally released. Heat flows through water or air which is moved in the pipes or channels of the distribution system. The release of the heat is an essential part of the process and it can be done through radiators, floor heating pipes or cables, electric heaters, or air ducts.

The heating system is adjusted in accordance with the outside temperatures and the thermal stress of the edifice, in order to maintain a constant indoor temperature. A thermostat is an instrument that regulates the temperature of the liquid entering the network as a response to a changing outdoor temperature.

When choosing a heating system, it is important to pay attention to the following selection criteria (Motiva, 2020):

1. Environmental impact (CO_2 and particulate emissions);

2. Fuel prices (future price developments);

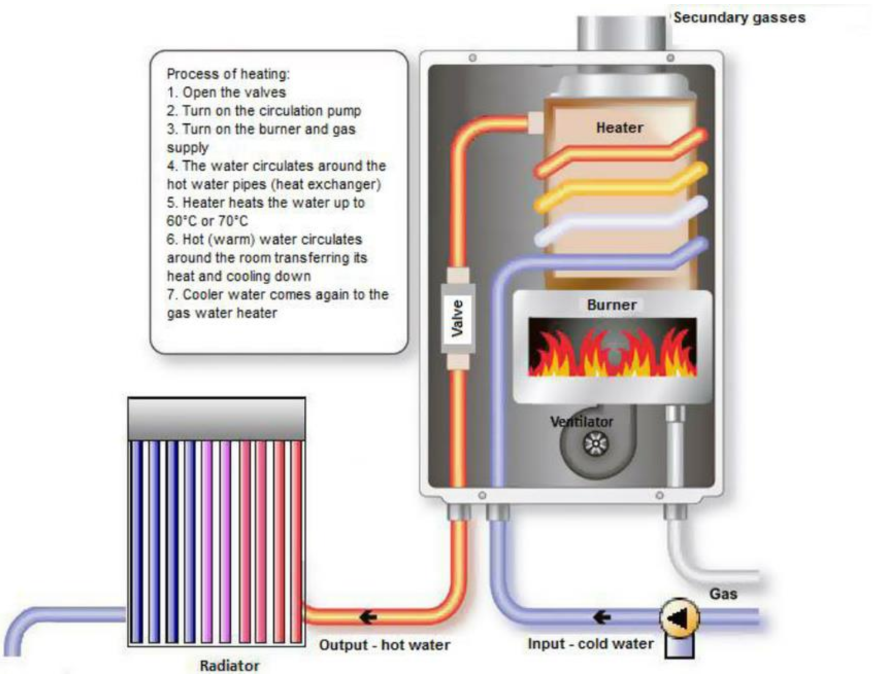
3. Operating and investment costs;

4. Reliability of the system;

5. Space requirements.

Currently, the Solvik kindergarten is heated up with a gas boiler, and a brief explanation on how a gas boiler works is reported as follows.

Figure 3. Configuration of a gas boiler and the heating process (Dajic, 2015).



The thermostat sends the signal to the boiler, the gas it then allowed to enter the burner and it is ignited by the pilot light. The gas flows through a small pipe filled with holes so that it simulates a flame. The flame warms up the heater, around which is wrapped a pipe containing cold water. The hot water is then distributed through piping and radiators. The water, that has lost much of the heat, goes back to the boiler, usually helped by an electric pump, where it is warmed up again (Motiva, 2022).

2.4 Natural gas production and geopolitical situation

Natural gas is a naturally occurring gas mixture consisting of methane, other alkanes, and it may also contain small amounts of carbon dioxide, nitrogen, hydrogen sulphite, or helium (Natgas, 2013).

Finland has no natural gas production, the gas is therefore imported from other countries. The natural gas in Finland is mostly used by large and medium-size industries and energy companies that transform it into heat and electricity. It is imported in two ways, by ships or by pipeline. Most of the natural gas is imported from Russia, and it is delivered through a pipeline located in Imatra, from where the gas is then sent into the Finnish distribution network. There is another pipeline that connects Estonia and Finland, and the gas is originally from Lithuania. According to statistics, in 2021 Finland used 25TWh of pipeline gas, 10 TWh of which from Estonia and the remaining amount from Russia. This trend seems to be in accordance with what is reported in the following table (Energiavirasto, n.d.).

Figure 4. Energy import in Finland in 2020 (source Finnish Customs/Foreign Trade Statistics).

Energy imports in 2020*

	Unit	Russia	Sweden	Norway	Other countries	Total Amount	Total Value mil. €
Coal and coal products	1000 t	1 333	0	0	1 333	**2 665**	**258**
Natural gas	mil. m^3	1 500	–	–	750	**2 249**	**349**
Oil and petroleum products [1)]	1000 t	11 509	1 746	1 828	2 091	**17 174**	**5 148**
Peat	1000 t	29	4	–	4	**38**	**1**
Wood fuels [2)]	1000 t	241	123	–	148	**512**	**30**
Nuclear fuel	tU	21	.	–	35	**56**	**84**
Electricity	TWh	3	19	0	0	**22**	**625**
Value	**€ mil.**	**3 461**	**1 293**	**590**	**1 198**		**6 543**

The natural gas price has also been increasing in the last 5 years, more precisely a price growth of 175.43% is reported in last year only (Trading Economics, 2022). The all-time high was reached on the 7th of March 2022, touching 345€ per MWh. This price growth was caused by a market response following the Covid-19 pandemic and more recently the Russian invasion of Ukraine. (Valtioneuvosto, 2022)

Due to the current geopolitical situation, the European Union has adopted five packages of sanctions towards Russia as a response to the unprovoked and unprecedented military attack against Ukraine. These measures were meant to weaken the Kremlin’s ability to finance the war and to impose economic and political costs on the Russia’s political elite. More specifically, the measures are targeting financial, trade, energy, transport, technology and defence sectors and they are currently extended until 31st July 2022 (European Council, 2022). These measures were progressively introduced since 2014, as a response of several political actions Russia took.

Even though natural gas in Finland accounts up to 5-6% of the total energy usage, it is an important component of the energy production. The Finnish government reunited on 7th April 2022 to discuss the matter of gas import from Russia, and the solution found is to lease a large amount of LNG (liquified natural gas) in cooperation with Estonia. This solution was found to be the quickest way to interrupt the import of gas through pipelines from Russia (Valtioneuvosto, 2022). This solution is outdated, since Russia starting from the 20th May 2022 has interrupted the natural gas supplies to Finland. The reason was that Finland did not agree to pay the fuel in rubles, as requested by the other country. Gasgrid Finland Oy has signed a 10-year agreement with the US company Excelerate Energy Inc. for an LNG terminal ship. The LNG terminal ship will secure gas supplies for Finland's industry. (Ministry of Economic Affairs and Employment, 2022).

Although natural gas boilers have an efficiency of around 94-95% (Vakkilainen, 2017) due to the aforementioned reason it is best to replace them with a different type of heating system. Furthermore, the city of Hämeenlinna had already planned in 2019 to replace all the natural gas boiler with biogas.

The Vanaja power plant, located in Hämeenlinna, has been upgraded with a new biomass fired K6 boiler. The fuel utilized is mostly wood based, including sawdust, bark, and other forest residues. This will bring the percentage of renewable fuels used by the factory up to 90%, making Hämeenlinna the first large city in the country to provide almost carbon neutral heat to the population (Lehtinen, 2021).

3 Methodology

This chapter includes detailed information regarding the used software, IDA-ICE, and the building. In the last part, the modelling assumptions are explained thoroughly.

3.1 IDA-ICE software

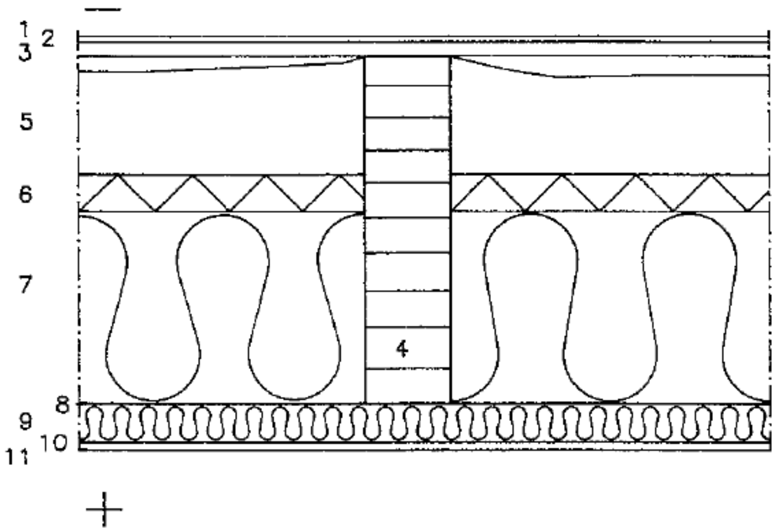
Any kind of building is a complex system, in which all the diverse energy phenomena are linked to each other. When analysing how a building behaves, building simulation software are the most used tools. Building simulation is a multidiscipline field, including physics, mathematics, material science, biophysics, and human behavioural, environmental, and computational sciences. (Khan, 2021) It is important to keep in mind that this software is not able to provide an exact prediction of the real building consumptions as, in fact, it is also up to the occupants and how they use the building.

IDA-Indoor Climate and Energy (IDA-ICE), developed by EQUA – a Swedish company -, is a simulation software to analyse the dynamic study of an indoor space. It was initially released in 1998 and has been upgraded in the years, and the current newest version is 4.8. The software can simulate indoor air quality, thermal comfort, CO_2 and moisture calculation and the energy consumption of the building (EQUA Simulation AB, 2002).

3.2 Study case description

The Solvik kindergarten was built in 1993. The building is a public kindergarten, owned by the city of Hämeenlinna, located in Onkitie 4, in Hämeenlinna. The structure has a floor area of 846 m^2 and a volume of 3262 m^3.
The kindergarten structure is insulated timber frame for the walls and the roof, and the floor is a concrete slab on the ground. In this chapter, more details will be provided regarding the structural types for roof, outside and inside walls, and floors.
The roof is flat in some areas and sloped in other, therefore two different types of roofs are used, however, in both cases the frame is made of wood and the U-value is equivalent.
YP1 type, or “yläpohja” 1, is used for the mono-pitch roof.

Figure 5. Structural type YP1.



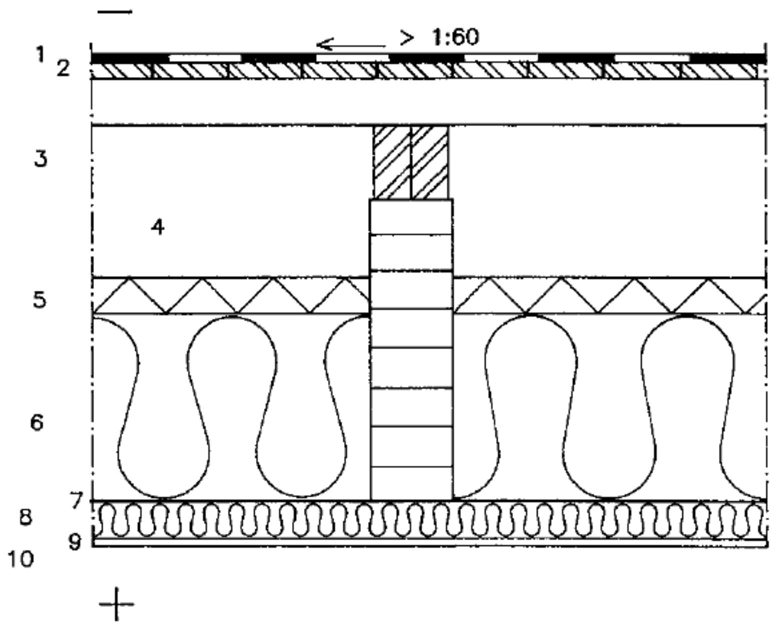
It consists, in order, of:

1. Seamed metal sheet
2. Wood purlins 25x100 c/c 100/150
3. Membrane
4. Wood rafter 115x495 c/c 900
5. Ventilation gap
6. Hard mineral wool 50mm
7. Plastic membrane
8. Wood frame 50x50 c/c 300 + mineral wool
9. Gypsum board
10. Surface finishing material according to design

U-value: 0.16 W/m^{2}K

YP2, used for the flat roof, has a similar structure to the YP1, with the exception of the bitumen used as a finish.

Figure 6. Structural type YP2.



Starting from the outside, the structure is made as follows:

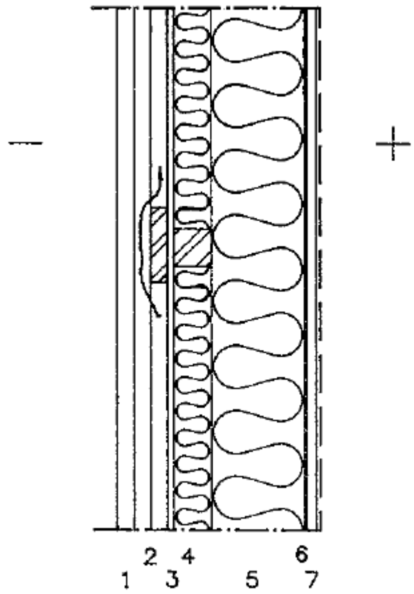
1. Waterproof, class B, point and seam joints with bitumen B 95/35
2. Wood roof sheeting
3. Wood rafter 115x405 c/c 900 + purlin 50x100 c/c 900
4. Ventilation gap
5. Hard mineral wool 50mm
6. Mineral wool 250mm
7. Plastic membrane
8. Wood frame 50x50 c/c 300 + mineral wool
9. Gypsum board
10. Surface finishing material according to design

U-value: 0.16 W/m^2K

The two different outer wall structures differ for the total thickness, however, the U-value was found to be the same.

US1, or “ulkoseinä” 1, will be analysed first.

Figure 7. Structural type US1.



From the outer part to the inner part, the structure is made of:

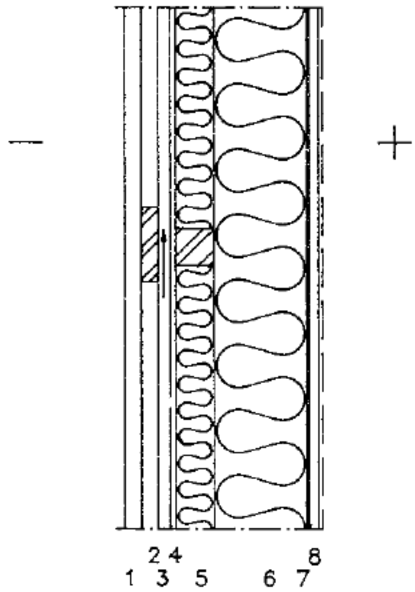
1. Vertical panelling 23x72 + 20x97
2. Ventilation gap + wood frame 22x100 c/c 600
3. Weatherproof plastic membrane, TS 9 9mm
4. Mineral wool + horizontal frame 50x50 c/c 600
5. Mineral wool 125mm
6. Vapour membrane
7. Gypsum board 13mm

Surface finish according to design

U-value: 0.27 W/m^{2}K

The second type of outer wall was found to be used in the upper part of the façade, for instance above the openings designated as windows.

Figure 8. Structural type US2.



The structural components of US2 are:

1. Vertical panelling 18x95, class A
2. Wood frame 22x100 c/c 600
3. Ventilation gap 15mm
4. Weatherproof plastic membrane, TS 9 9mm
5. Mineral wool + horizontal frame 50x50 c/c 600
6. Wood frame 125x50 c/c 600 + mineral wool 125mm
7. Vapour membrane
8. Gypsum board 13mm

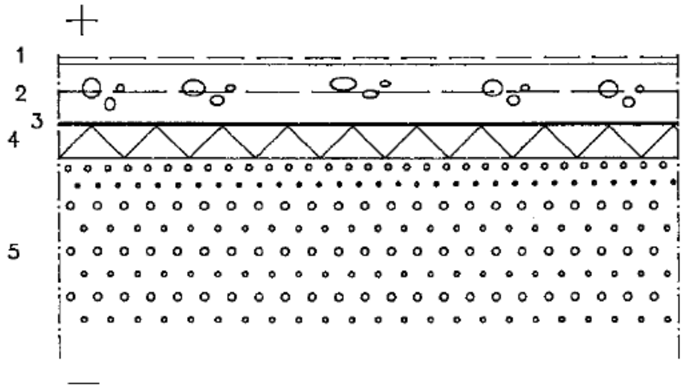
Surface finish according to design

U-value: 0.27 W/m^2K

Regarding the base floor, it is generally a concrete slab on ground.

The first analysed type of floor is AP1, or “alapohja” 1.

Figure 9. Structural type AP1.



The structures from the top to the bottom are:

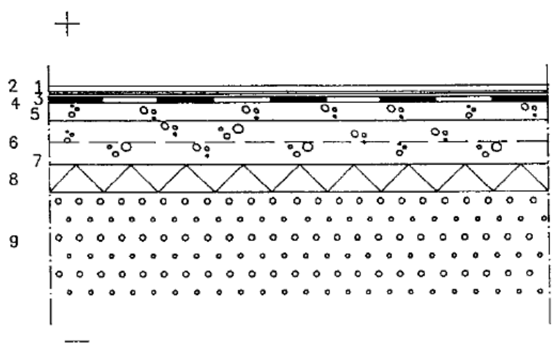
1. Surface material and finish in accordance with design
2. Reinforced concrete slab class A-4-30, #5-150 B500K
3. Capillary moisture barrier
4. Polystyrene insulation board 50mm
5. Compacted ground (90%)

U-value: 0.28 W/m^{2}K in the outer edges

U-value: 0.26 W/m^{2}K in the inner zones

Next is the AP2, which is used the wet areas of the building.

Figure 10. Structural type AP2.



From the top of the structure to the bottom:

1. Surface material and finish in accordance with design
2. Sealing mortar

3. Adhesion bridge
4. Waterproofing (up to the walls >50mm)
5. Concrete slab
6. Reinforced concrete slab class C-4-30, reinforcements #5-150
7. Capillary moisture barrier
8. Polystyrene insulation board 50mm
9. Compacted ground (90%)

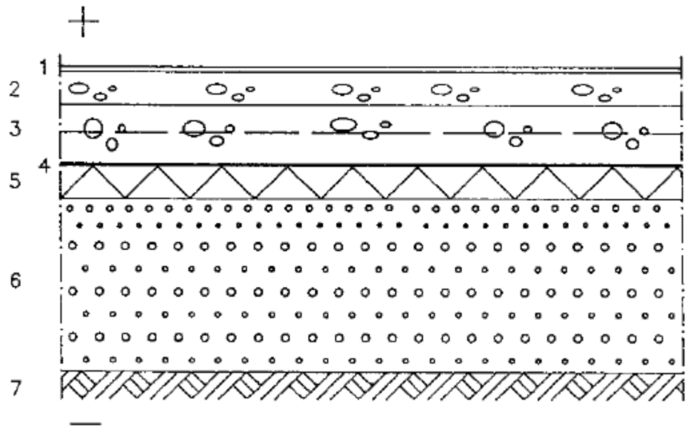
In the areas in which a floor sewer is present, the slope must be 1:50-1:100.

U-value: 0.28 W/m^2K in the outer edges

U-value: 0.27 W/m^2K in the inner zones

Finally, the “alapohja” 3 type is described.

Figure 11. Structural type AP3.



The structure is made as follows:

1. Plastic carpet in accordance with design
2. Levelling concrete slab 50mm
3. Reinforced concrete slab class C-4-30, reinforcements #5-150 B500K
4. Capillary moisture barrier
5. Polystyrene insulation board 50mm (density >20kg/m^3)
6. Machine pressed sand 300mm
7. Basic soil

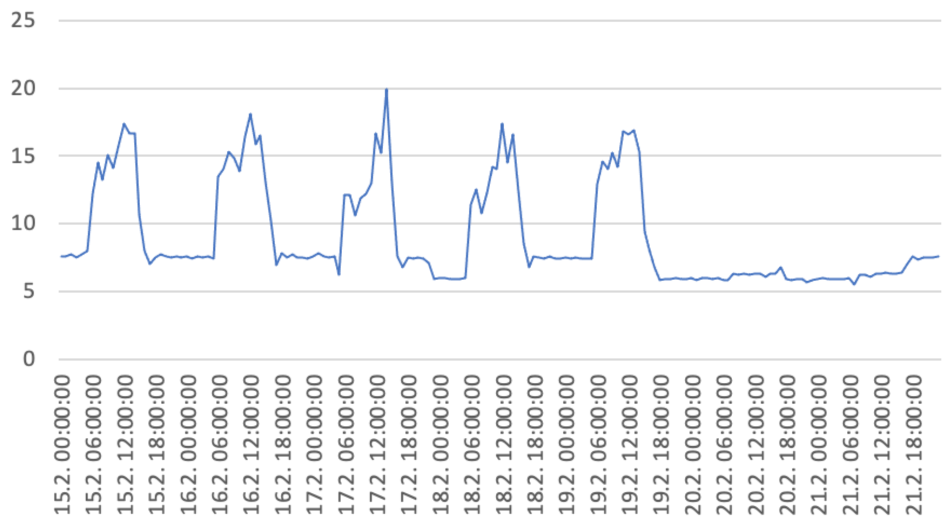
The building has a natural gas heating system, and it is not equipped with a heat recovery unit, which results in higher energy consumptions. This unit, also called heat exchanger, has the purpose of recovering the energy, by transferring the heat of the extracted air to the air that is driven outside. Some of the benefits of having one installed in the building are (Airtècnics, n.d.):

1. Better climate control;
2. Energy efficiency improvement;
3. Energy saving.

Figure 12. Location of the boiler room in the Solvik kindergarten.

When looking at the electricity consumption information from the year 2021, provided in an Excel file by the city of Hämeenlinna, it appears that during the weekends the building is not used. During the weekdays in the winter season, the hours reporting the highest electricity consumptions are between 6:00 and 16:00, whereas in the month of May the electricity was mostly used between 6:00 and 14:00. The following Excel graph, Figure 11, shows the electricity consumption data for a typical winter week.

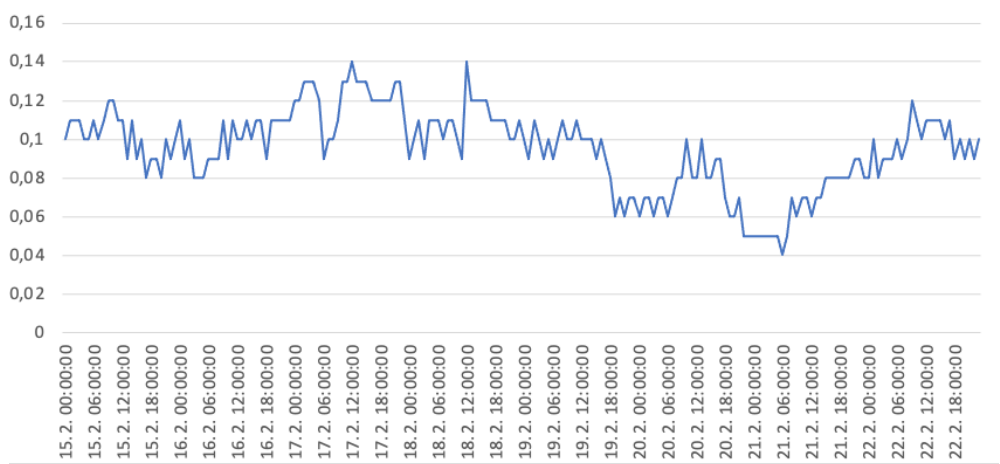
Figure 13. Electricity consumption during an example winter week.



The total yearly consumption of electricity accounted up to 68250.7kWh, which data was also provided in the Excel file.

Regarding the usage of natural gas, it appears that during the wintertime the kindergarten was naturally always warmed up, with the higher values in the consumptions usually between 5:00 and 16:00 in the winter months. During the warmer months the consumptions dropped significantly, and the levels maintained quite constant during day and night-time. In the following graph plotted in Excel on the base of the natural gas consumption, an example winter week is shown.

Figure 14. Natural gas consumption during winter.



In 2021, more specifically between 1st January 2021 and 1st January 2022, the kindergarten used 446.19 MWh of natural gas. This information was retrieved from an Excel file that was sent by the energy expert of the city of Hämeenlinna.

In the next chapter, the reader will be provided information regarding the assumptions made when producing the model for the kindergarten.

3.3 Assumptions

In this chapter, information regarding the assumptions made when creating the IDA-ICE model for the building in question are described.

The building model produced in IDA-ICE was simplified to facilitate the simulation process, however, the number of windows on the façades, floor area and volume of the building were kept the same.

As a comparison, the two floor plans, original and modelled in IDA-ICE, are inserted as follows.

Figure 15. Original floor plan of the Solvik kindergarten.

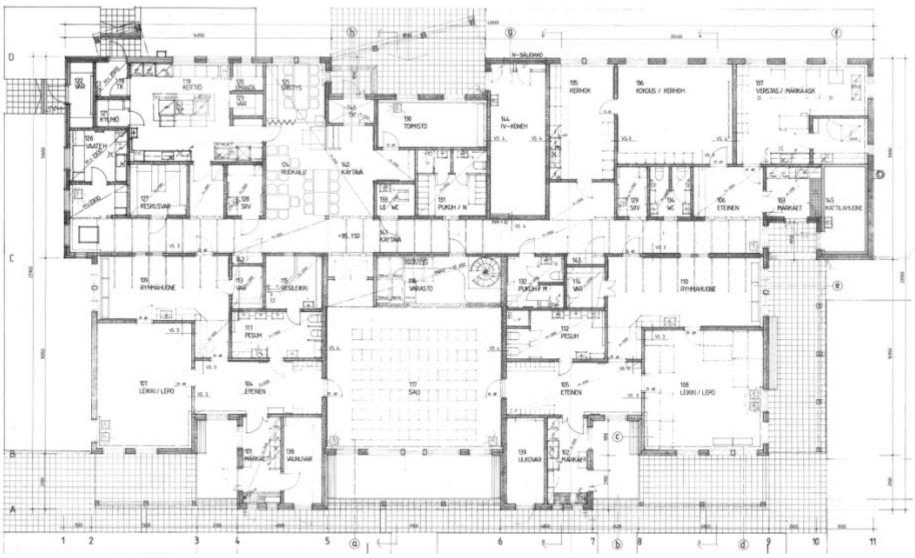


Figure 16. Floor plan of the Solvik kindergarten modelled in IDA-ICE.

The height of the building varies, as it can be seen from Figure 18, in accordance with the roof shape. The author simplified the model to a flat roof, and the height was calculated as an average between the different values. In the two following images, Figure 17 and 18, it is possible to see the difference between the roof profiles.

Figure 17. Section C-C of the Solvik kindergarten.

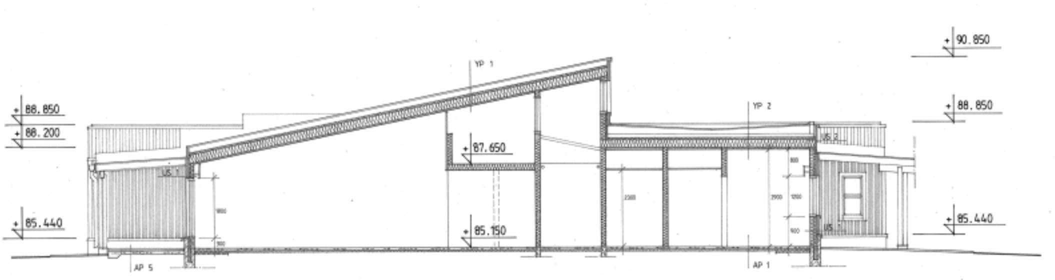
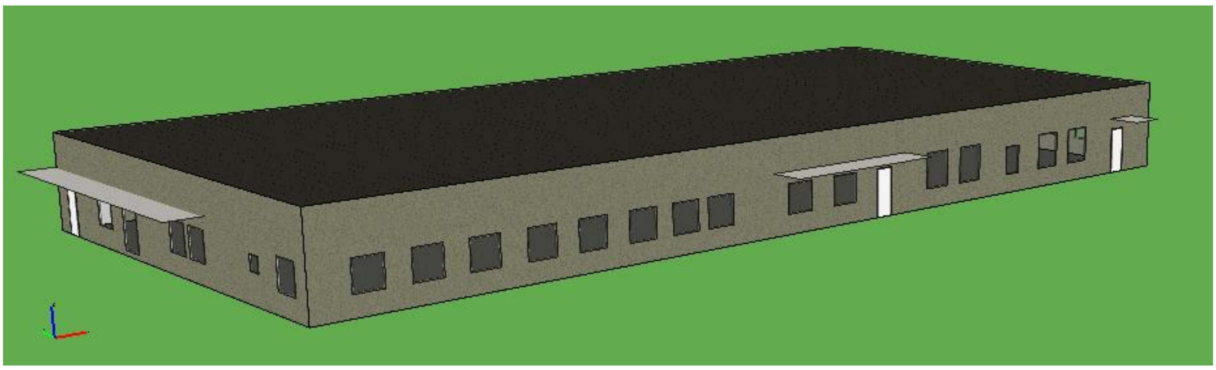


Figure 18. 3D image of the Solvik kindergarten model.



The structural types were also reduced from several per part of the structure to only one. The reason for this was to facilitate the model creation, nonetheless, this alteration should not have any consequence on the final result, since the U-values were found to be very similar, if not equivalent, in most cases. In the following table, the utilized U-values are input.

Table 3. U-values for the three main structural components.

Structure	**U-value (W/m²K)**
Roof (YP)	0.15
Outside wall (US)	0.27
Base floor (AP)	0.27

The windows are the original ones installed in the building when it was erected. They are triple glazed, wood framed windows, which U-value was estimated to be 2.0 W/m²K, in accordance to the model found in the IDA-ICE database and an estimation based on the following Table 3. (Ministry of the Environment, 2012) The outside doors were given a U-value of 1.4 W/m²K in accordance with the same table as the windows.

Table 4. U-values for building components (source Ministry of the Environment, 2012)

t	**Building permit pending in year**								
	–1969	**1969–**	**1976–**	**1978–**	**1985–**	**10/2003–**	**2008–**	**2010–**	**2012–**
Heated spaces									
External wall	0.81	0.81	0.40	0.35	0.28	0.25	0.24	0.17	0.17
Ground-supported floor	0.47	0.47	0.40	0.40	0.36	0.25	0.24	0.16	0.16
Floor with crawl space	0.47	0.47	0.40	0.40	0.40	0.20	0.20	0.17	0.17
Floor butting against out-door air	0.35	0.35	0.35	0.29	0.22	0.16	0.16	0.09	0.09
Roof	0.47	0.47	0.35	0.29	0.22	0.16	0.15	0.09	0.09
Door	2.2	2.2	1.4	1.4	1.4	1.4	1.4	1.0	1.0
Window	2.8	2.8	2.1	2.1	2.1	1.4	1.4	1.0	1.0

The global data is explained to the reader. The building location was chosen to be Helsinki-Vantaa since the exact location could not be found on the Finnish database available for the program. Helsinki-Vantaa was in fact found to be the most comparable one with Hämeenlinna.

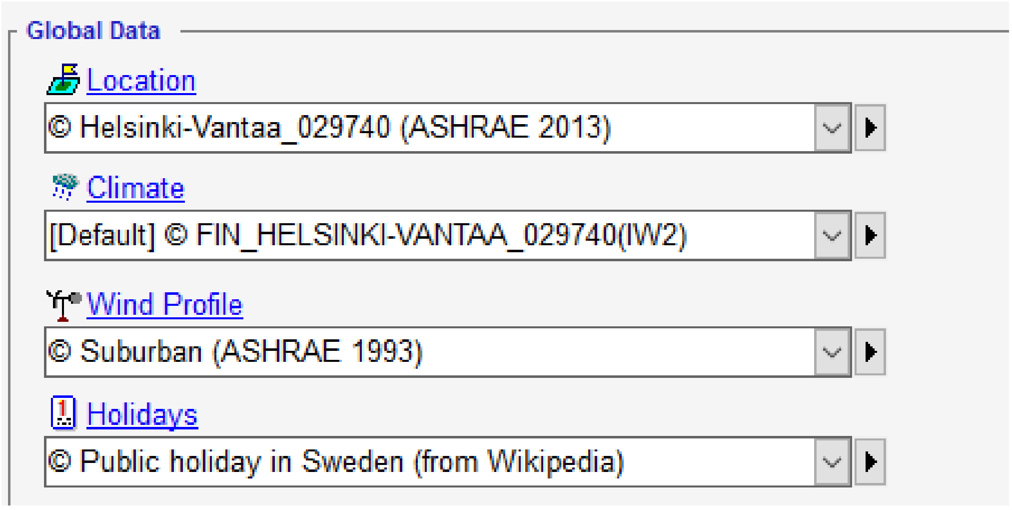
The climate selected is the Helsinki-Vantaa, and this choice was made for the analogous reason as the previous case. The wind profile is also a key value to be set, since it influences, together with the pressure coefficients, the infiltration. The pressure coefficients are automatically set by IDA-ICE when selecting the building level of exposure to the wind. In the case of the kindergarten, the profile “sheltered” was selected due to the thick concentration of trees around three of the façades, as it can be seen from the image taken from Google Maps.

Figure 19. Satellite image of the Solvik kindergarten showing the surroundings (source Google Maps).

Lastly, the Holidays were set to be the public holidays in Sweden, since this choice was the only available one that could be retrieved from the database.

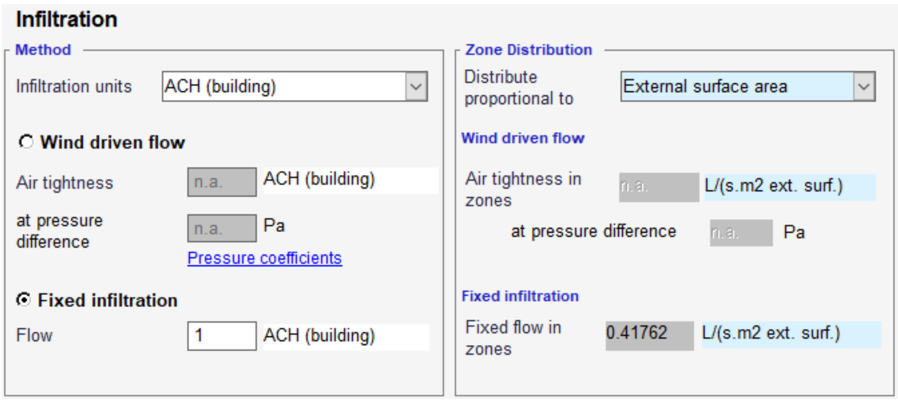
The following image, Figure 20, is a screenshot taken from IDA-ICE and it has the purpose to epitomize what has been described above.

Figure 20. Global data input in the IDA-ICE model.



For what concerns the infiltration, the value was based on the air change per hour, since the calculation of q_{50} were not feasible. The calculation of the q_{50} is based on the envelope area, which in the simplified model was too approximative to return any meaningful value.
The value 1 corresponds to a poor level, which is considered a good estimation for the building in question.

Figure 21. Infiltration values inputted in IDA-ICE.



Concerning extra energy and losses, the data input in the software was retrieved from Table 4 of the D3 National Building Code of Finland (Land Use and Building Act (132/1999)). According to the table, the specific consumption of domestic hot water (DHW) is 188dm^3/(m^2 a), and the heating energy is 11 kWh/(m^2 a).

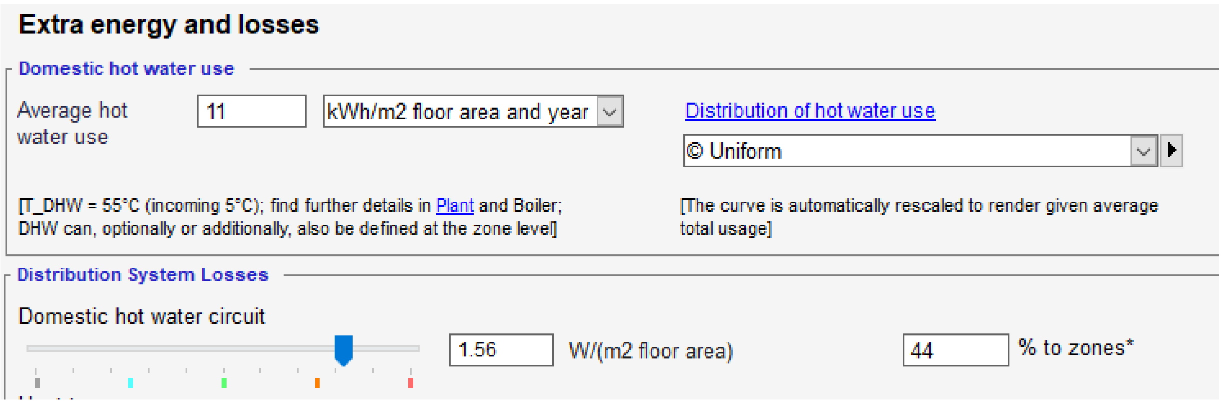
Figure 22. Specific consumption of domestic hot water and its corresponding net heating energy need per heated net area (source D3 National Building Code of Finland).

Type of building	Specific consumption of DHW dm³/(m² a)	Heating energy kWh/(m² a)
Separate small house and terraced and linked houses	600	35
Residential building block	685	40
Residential housing block, measurement of water per flat [1)]	582	34
Office building	103	6
Commercial building	68	4
Commercial accommodation building	685	40
School building and day care centre	188	11
Gym, large	343	20
Hospital	515	30

[1)] The measurement of water per flat must be made for both cold and for hot water.

The data collected from the National Code is inputted in the software as it is shown in the following picture, Figure 23. It was estimated by the author that the efficiency of the distribution circuit is poor. The assumption was based on the building age of the kindergarten and the fact that no renovation has been done.

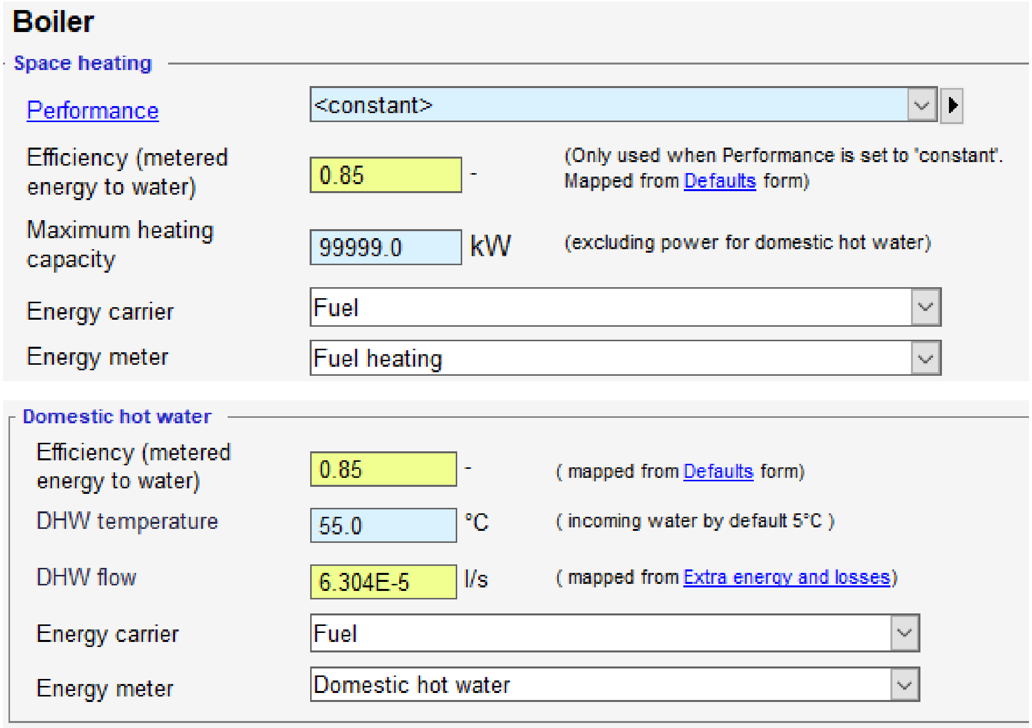
Figure 23. Hot water usage in IDA-ICE model.



The natural gas boiler was replaced in 2017, however more information about the model was not provided. The data input in the software is therefore an estimation. The fuel-to-steam is usually the value considered to be the true input/output value (Bathia, n.d.). The value input in the case of the Solvik kindergarten is 85%, or 0.85, for both space heating and domestic hot water.

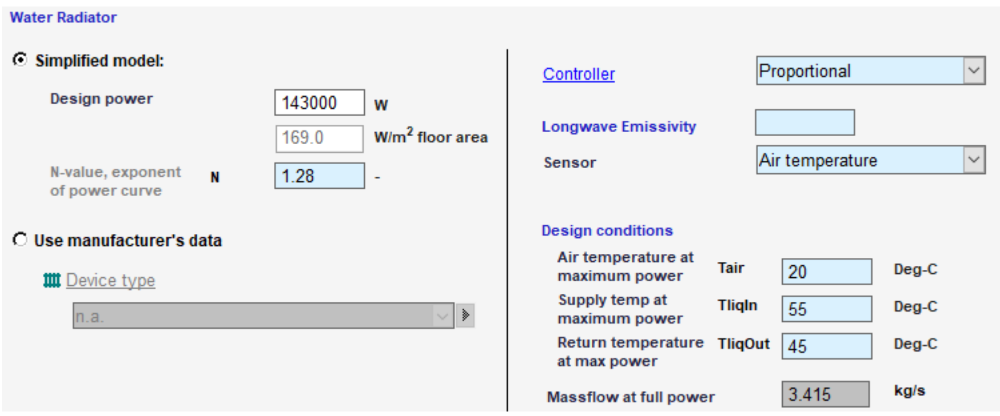
The Maximum heating capacity input value is the maximum supported by the software, which means the building will produce all the energy that it needs to maintain the indoor temperature at a desired level, in this case 21°C.

Figure 24. Boiler data for heating and DHW systems in IDA-ICE.



The heat generated by the natural gas boiler is distributed through water radiators. The information regarding the water radiators could not be retrieved, therefore they were modelled using estimations based on Table 1, which can be found in chapter 2.2. The design power, 143000 W, was calculated by the software on the base of average energy consumption for non-residential buildings built in the 1990s.

Figure 25. Water radiator data in IDA-ICE.



Regarding the internal gains of this structure, the author considered Light and Occupant variables. The Light variable is based on the value reported in the Table 3 of the Energy Efficiency of Buildings (Land Use and Building Act (132/1999)), which is reported as follows.

Figure 26. Standard use of buildings and internal thermal loads to be used per heated net area. (D3 National Building Code of Finland)

Type of building	Period of use hours	h/24h	d/7d	Degree of use -	Lighting W/m²	Devices W/m²	Persons[a] W/m²	Density of persons m²/person
Separate small house and terraced and linked house	00:00-24:00	24	7	0.6	8[b,c]	3	2	43
Residential building block	00:00-24:00	24	7	0.6	11[b,c]	4	3	28
Office building	07:30-18:30	11	5	0.65	12[c]	12	5	17
Commercial building	08:00-21:00	13	6	1	19[c]	1	2	43
Commercial accommodation building	00:00-24:00	24	7	0.3	14[c]	4	4	21
School building and day care centre	08:00-16:00	8	5	0.6	18[c]	8	14	5
Gym, large	08:00-22:00	14	7	0.5	12[c]	0	5	17
Hospital	00:00-24:00	24	7	0.6	9[c]	9	8	11

The inputted values are 18 W/m^2 for lightning and 8 W/m^2 for other devices.
In the next chapter, the results of the simulation with the data inputted will be given, together with an explanation.

4 Results and discussion

In this chapter, a comparison of the simulated date with the real consumption data will be provided.
Finally, the author will provide the modelling information inputted for the creation of the district heating system, together with the results for energy and electricity consumptions.

4.1 Comparison with real consumptions data

The simulation carried out with IDA-ICE has given results which are slightly different from the consumption data retrieved from the Excel files provided by the city of Hämeenlinna.
In the following table, Table 4, the real and modelled results are displayed.

Table 5. Real and modelled energy and electricity consumptions.

	Real building	**Modelled building**
Natural gas consumption (MWh)	446.19	387.527
Electricity consumption (kWh)	68250.7	64668

Some differences in the results were expected, since the software is not able to simulate how the building is used.

In addition to this, the building was simplified in its geometry, and also many assumptions were made, due to the lack of real data. The simplification in the geometry mostly affects the fuel heating results. The shape of the Solvik kindergarten plan is quite complex, with many corners which is where heat is lost. The roof shape was also changed, and the height of the building was estimated as an average between the different heights. The simplified model together with the values based on assumptions are the main reason why the real and virtual results differ.

In any case, the results obtained are still valid indicators of the building performance.

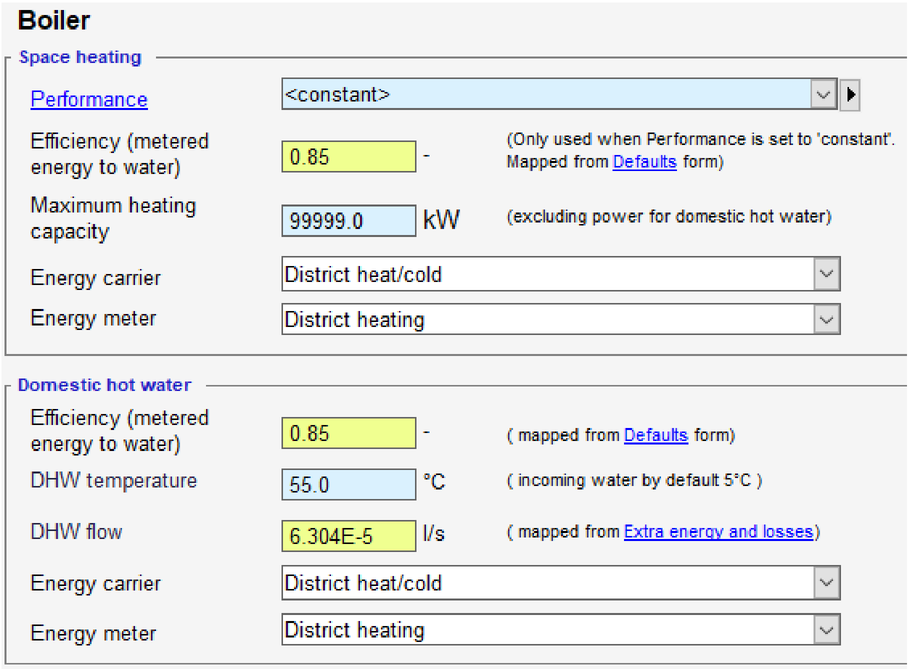
In the next subchapter, the alternative to the natural gas boiler will be explained in details.

4.2 District heating modelling and simulation parameters in IDA-ICE

The model for the district heating system alternative was slightly modified, in this subchapter all the new inputs will be explained and shown through images captured from the IDA-ICE software.

Firstly, the settings regarding the plant system are discussed. In IDA-ICE to model the heating system is necessary to set the energy carrier for space heating and domestic hot water as district heat/cold, and the energy meter as district heating.

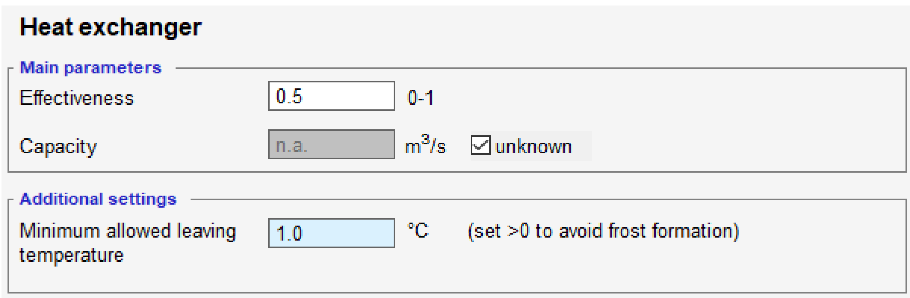
Figure 27. Boiler settings for the district heating model.



The efficiencies for space heating and domestic hot water were based on an estimation for district heating plants (Pöyry Energy, 2009).

Regarding the air handling unit, the major modification was adding a heat recovery system, with an efficiency of 50%. This addition will help reducing the heating energy consumptions.

Figure 28. Heat exchanger parameters.



The results obtained for the district heating consumption is 296 MW, which is considerably lower than the previous result and the effective energy consumption.

5 Conclusions

The last three decades have seen a tightening of the measures concerning the energy efficiency of buildings, in order to achieve more performing edifices. The goal of the measures is to reduce the impact buildings have on the environment by minimizing the energy usage, which reflects also in a maintenance cost reduction and the users will therefore save money. The newest legislation concerning the energy efficiency of existing buildings can be implemented in three different ways, which will lead – in the long run – to the same energy savings. The three different approaches are (Haakana, Laitila, Forssell, 2018, p.9):

1. energy efficiency requirements for each building element;
2. energy consumption requirements for a building by building type; or
3. E-value requirements of a building by building type.

It was found that the most cost-effective measures relate to ventilation and lighting (Kauppinen, 2017, p. 28). In the simulation, the heat recovery was added in the district heating model, however the lighting was left as in the original model.
The modelled kindergarten was geometrically simplified and many inputted values were obtained from the D3 National Building Code of Finland and/or the Annex to the memorandum on improving the energy performance of buildings undergoing renovation or alteration.
For future simulations, it would be relevant to verify the energy consumption value after changing the windows and doors with better U- and g-values. In addition to this, the radiators should be updated to a newer model, together with the heating system and the hot water pipes. The electric system should be checked, too.
Regarding the model itself, to get more precise results, it would be ideal to produce a more accurate representation of the building. Height, length, roof shape and floor plan should be adjusted to be the same as the real ones.
Furthermore, the model should have more than one single zone. This modification will give a better insight of the usage of the air handling unit and the heating system. Rooms with

different purposes are kept at different temperatures, and the ventilation requirements also vary by room.

To obtain more specific information, such as the effective air tightness, a visit on site would have added more precise data to input into the software.

To conclude the thesis, when renovating a public building, the life expectancy of the building should be evaluated, so that the renovation measures to be adopted will be profitable.

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Appendix 1: Carbon neutrality program Hämeenlinna

Toimenpidelistaus - Hiilineutraali Hämeenlinna

Teema	Alateema	Toimenpide	Vastuutaho	Mahdollinen yhteistyötaho	Käynnissä / Suunnitteilla / Myöhempi ajankohta	Vaikutukset	Kustannukset	Muu resurssitarve	Tavoitevuosi
Asuminen ja kiinteistöt	Energiatehokkuus	KETS 2017-2025-kaudelle liittyminen Tavoitteellinen energiansäästö 7,5 % -Toimenpideohjelman laatiminen ja toteuttaminen, -konserniyhtiöt liittyvät itsenäisesti VAETSiin tai tulevat mukaan KETSiin	Kaupunkirakenne, konserniyhtiöt		Käynnnissä		Kustannusvaikutus	Työaika	2025
Asuminen ja kiinteistöt	Energiatehokkuus	KETS 2025-> tavoitteiden nostaminen 10 %	Kaupunkirakenne, konserniyhtiöt		Myöhempi ajankohta		Kustannusvaikutus	Työaika	2030-2035
Asuminen ja kiinteistöt	Energiatehokkuus	Katuvalojen uusiminen ledeiksi investointimäärärahojen puitteissa	Kaupunkirakenne		Käynnnissä	Turvallisuus, saneerausvelan pienentäminen, valaistuksen laatu	Kustannusvaikutus, takaisinmaksuaika		2020-2030
Asuminen ja kiinteistöt	Uusiutuva energia	Nostetaan uusiutuvan sähkön osuus kahden seuraavan sopimuskauden aikana 100 %:iin kaupungin kiinteistöissä nykyisestä 20 %:sta.	Hankintapalvelut, kaupunkirakenne		Suunnitteilla		Kustannusvaikutus		2025
Asuminen ja kiinteistöt	Uusiutuva energia	Muutetaan kaupungin kohteissa olevat öljylämmityskohteet uusiutuvaan energiaan 2025 mennessä kaupungin ja yhtiöiden kiinteistöissä (toteutetaan peruskorjauksen yhteydessä)	Kaupunkirakenne		Käynnissä		Mahdollinen kustannusvaikutus, takaisinmaksu		2025
Asuminen ja kiinteistöt	Asukkaiden ja yritysten energianeuvonta	Asukkaita ohjataan luopumaan öljystä vuoteen 2030 mennessä; Käydään öljylämmityskohteet yksityiskohtaisesti läpi viranomaistoimin vuoden 2025 loppuun mennessä	Kaupunkirakenne	Pelastuslaitos	Myöhempi ajankohta	Pohjavesien suojelu	Mahdollinen kustannusvaikutus	Työaika	2025-2030
Asuminen ja kiinteistöt	Asukkaiden ja yritysten energianeuvonta	Selvitetään kaasulämmityskohteiden mahdollisuuksia korvata maakaasua biokaasulla	Kaupunkirakenne		Suunnitteilla		Kertakustannus		2025
Asuminen ja kiinteistöt	Asukkaiden ja yritysten energianeuvonta	Kehitetään energianeuvontaa yhteistyössä eri toimijoiden kesken: jaetaan tietoa eri energiaratkaisuista ja vaihtoehtoisista tavoista investoida energiaremonttiin, tehdään energiakatselmuksia	Kaupunkirakenne	yritykset, strategia	Suunnitteilla	Asukastyytyväisys kasvaa	Kustannusvaikutus	Vaatii resurssin	2021
Asuminen ja kiinteistöt	Asukkaiden ja yritysten energianeuvonta	Mahdollistetaan energiaremonttien yhteiskilpailutuksia esimerkiksi rakentamalla digitaalinen kilpailutusalusta	Kaupunkirakenne, Konsernipalvelut, ekosysteemit	HAMK	Myöhempi ajankohta	Asukastyytyväisys kasvaa, Houkuttavuus kasvaa	Kertakustannus	Työaika, Osaamista ei ole	2022
Asuminen ja kiinteistöt	Asukkaiden ja yritysten energianeuvonta	Jatketaan aluerakentamiskohteissa ympäristöystävällisien energiamuotojen edistämistä (kaukolämpö, maalämpö ja muut lämpöpumput)	Kaupunkirakenne	Loimua Oy	Käynnnissä		ei	ei	2020