Tampereen ammattikorkeakoulu

RENOVATION STRATEGIES FOR THE ENERGY CONSUMPTION OF A 1954 SINGLE-FAMILY HOUSE USING IDA-ICE.

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Opinnäytetyö 48 sivua, joista liitteitä 2 sivua
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Opinnäytetyössä tutkittiin vuona 1954 rakennetun pientalon energiankulutusta. Työssä luotiin kalibroitu malli rakennuksen todellisesta energiankulutuksesta ja vertailtiin mallia neljän vaihtoehtoisen tekniikan kanssa, joita voidaan käyttää rakennuksen peruskorjauksessa energiankulutuksen vähentämiseksi.

Työssä käytettiin rakennussimulointiohjelma IDA-ICE:ta. Käytiin läpi esimerkkejä Motivan energianlaskelmasta, ympäristöministeriön määräyksistä rakennuksen energiansäästön määrittämiseksi sekä Asumisen rahoitus- ja kehittämiskeskuksen neuvontaa.

Työn tuloksena selvisi, että kunnostusstrategioiden yhdistelmä vähensi energiankulutusta. Alkuperäinen energiankulutus oli 158 kWh/m^2 vuodessa. Peruskorjauksen jälkeen energiankulutus oli 38 kWh/m^2 vuodessa, kun käytettiin parametrien yhdistelmää. Rakennuksen vaipan U-arvojen parantaminen sekä aurinkopaneeleilla varustetun maalämpöpumpun asennus oli paras vaihtoehto energiankulutuksen vähentämiseen. Tällä yhdistelmällä energian loppukäyttöä voitaisiin vähentää noin 76 %.

Asiasanat: pientalo, energiakorjaus, energialaskenta, energiakulutus, IDA-ICE, U-arvot

ABSTRACT

Tampereen ammattikorkeakoulu
Tampere University of Applied Sciences
Degree Programme in Building Services Engineering
HVAC Systems

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Renovation Strategies for the Energy Consumption of a 1954 Single-Family House Using IDA-ICE.

Bachelor's thesis 48 pages, appendices 2 pages
June 2023

This study was conducted to fulfill the requirements of the owner of an old single-family house to study sustainability practices for implementing energy renovation strategies. The owner's objective was to renovate instead of building a new project. The focus was to make the building more energy efficient, creating a sustainable environment less vulnerable to climate changes.

In this study an energy model of an existing building was created and validated using a calibration method. The calibration process was necessary to achieve a reliable and valid model that was used to calculate energy consumption. The calibrated energy model was utilized to evaluate the energy consumption of a single-family house build in 1954 and study different alternatives applied in the renovation of the building to reduce energy consumption.

The goal was to improve the energy performance of the calibrated model using energy strategy combinations which were based on the following parameters: improved insulation, improved infiltration rates, an air-to-water heat pump retrofit, ground-source heat pumps with solar photovoltaic panels and a mechanical supply and exhaust ventilation with a heat recovery system.

The energy consumption of the entire building was calculated using IDA-ICE, an energy simulation program. Additionally, source materials such as Motiva's energy calculations examples, the regulations of the Ministry of the Environment to determine the building's energy savings, and documents published by Rakennustieto and the Housing Finance and Development Center of Finland were used.

According to the results, using a combination of renovation strategies reduced energy consumption. The base case building energy consumption was 158 kWh/m^2 year. After the renovations, the energy consumption was 38 kWh/m^2 per year. Improvements in the U-values and the installation of a geothermal heat pump with solar panels was the best option for reducing energy consumption. Using this combination, it could be possible to reduce the final energy use by approximately 76%.

Key words: residential houses, energy -renovation, -consumption, -calculation, IDA-ICE. U-values

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SPECIAL GLOSSARY AND TERMS

TAMK	Tampere University of Applied Sciences.
op	credit
Energy simulation	Creation of the building model to simulate its energy use prediction. Energy simulation enables us to estimate the performance of a building and compare different strategies to design and optimize the heating, ventilation, and air conditioning systems in the buildings. (ASHRAE Handbook – Fundamentals, Chapter 19.)
Calibration	The process of adjusting a model so the deviation with the real energy measurements agrees with the simulated model.
Rakennustieto	Finland’s leading database provider of information related to the environment and construction industry.
MOTIVA	A Finnish institution that provides information, training materials and promotes services regarding sustainable use of energy and materials.
ARA	Housing Finance and Development Center of Finland. It operates as part of the Finnish Ministry of the Environment. It provides grants to fund the renovation of buildings.
IDA-ICE	The Indoor Climate and Energy is a simulation software that calculates the building energy efficiency. It is used to model the building’s systems and control devices to predict energy consumption and thermal comfort. (EQUA Simulation).

ABBREVIATIONS

Q_{space}	Space heating, considers heat losses by conduction, infiltration, ventilation, make- up air
$Q_{conduction}$	Conduction heat losses throughout the building envelope. kWh/year.
$Q_{airleakage}$	Heat energy used to heat the outdoor air that flows into the building throughout cracks in the building envelope, windows, doors, vents, etc. (ASHRAE Handbook – Fundamentals, Chapter 16)
$Q_{ventilation}$	Heat energy used to heat the supply air that is mechanically introduced to the space kWh/ year.
$Q_{make-up\ air}$	Heat energy used to heat the supply air entering a natural ventilated building, kWh/ year.
q_{v}	Volumetric flow rate of air into space, (m^3/h) (ASHRAE Handbook – Fundamentals, Chapter 16 Ventilation, and Infiltration.)
q_{50}	Envelope air leakage rate (infiltration) which indicates the building air tightness. It shows the volumetric rate per area of building envelope at 50 Pa, ($m^3/h\ m^2$).
$Q_{energy,leak}$	The energy consumption due to air infiltration KWh/year
$q_{flow,leak}$	The air flow due to infiltration (m^3/s)
x	coefficient, that depends on the type and number of floors in the building: 35 for one-floor, 24 for two-floor buildings, 20 for three- and four-floor buildings, and 15 for higher buildings.

1 INTRODUCTION

The work was conducted to fulfill the requirements of the owner of an old single-family house to study sustainability practices for implementing energy renovation strategies. The owner's objective was to renovate instead of building a new project. The focus was to make the building more energy efficient, creating a sustainable environment less vulnerable to climate changes.

Energy performance in buildings is related to aspects of the architecture, structural, and building services technology. Design solutions in those practices can optimize energy efficiency and reduce energy consumption.

Energy modeling tools can be used to predict energy consumption and evaluate optimal parameters in the energy renovation process. The modeling in the renovation project should pay attention to the available existing data to predict energy use. However, previous studies have shown that there is a big gap separating the measured and predicted energy consumption (Fonkaides, et al.). Further studies showed that the measured energy use could deviate from the simulated model by 3% to 28%. (Kurkinen et al.) and (Johansson). In some cases, the differences were more than 100% (De Wilde). Calibration is necessary to achieve a reliable and valid model that could be applied for the study of different alternatives to minimize energy consumption.

The aim of the research was to model an existing building and simulate its energy consumption. The model in the simulation software was based on a calibrated model that has captured with more accuracy the behavior of the referenced building. The model was considered calibrated when the deviation between measured and simulated energy consumption was less than 20%.

Additionally, the thesis analyzed energy renovation strategies that can have an impact on feasible energy efficiency measures. Technical solutions that are likely to be carried out when renovating an old building.

The renovation strategies studied in this thesis reduced the energy used to heat the spaces, decreased the infiltration energy through better insulation, Overall, the purchased annual energy was reduced.

According to the results, the discrepancy observed between the actual usage and predicted performance has a variation of 16%. The difference was due to the uncertainty of the sources in the data input. The sources of uncertainty originated from assumptions of the U-values, infiltration rates or system efficiencies factors that were not possible to determine on the job site. Additionally, uncertainties related to the randomness and variability of the weather data and occupancy input had an impact in the calibration (ASHRAE Handbook – Fundamentals, Chapter 19). Part of the parameters for the dynamic simulation were determined based on values taken from the Finnish standards related to energy efficiency in buildings.

The results show that integration of renovation measures can be used to reduce the energy consumption by 76% from the base case when the building envelope is renovated using lower U-values, improving the airtightness and the geothermal heat pump in addition to photovoltaic panels systems was the best energy efficient alternative.

2 METHODOLOGY

The study has been done in the following phases:

- As first step the review of Finnish building codes literature and the collection of available information of the building were performed. This data included an interview with the owner, old drawings review, collection of the measured consumption data. In the case that, data was not available from the job site, this study considered data provided by the Finnish National Building Code - Energy efficiency of buildings, Motiva, ARA or Rakennustieto.

- The architectural model was created in Revit and exported as an IFC file to IDA-ICE. (The exported file was a simplified version of the architectural model.)

- The simulation model was created and calibrated in IDA ICE. In this step the building geometry and zoning were defined, the U-values for the building envelope and the energy requirements were determined.

- Energy efficiency measures and savings: Optimal renovation solutions were applied to the renovation strategies in the calibrated energy model. Parameters for energy optimization were modeled for four cases.

- The results of the simulations predicted the energy consumption in the building and were studied to compare the alternatives.

3 BASE CASE BUILDING

3.1 Building Description

The residential building is a single-family detached house built in 1954 in the city of Tampere, Finland. The front of the building faces southeast. There is a large area of glazing in the outside walls in all directions. (Figure 1). The building has two floors and a basement and approximately 264 m^2 of net heated area. The basement is not heated.

Details have been gathered by examining the building on site, during which photographs, and other relevant dimensions were taken and checked. The information gathered helped to create the 3D virtual model of the residence. In this way, it was assured that the drawings were up to date and that the dimensions were realistic.

The residence construction is based on a structural timber frame. The timber frame provides vertical load bearing as well as a base for attaching the wall components. The existing exterior walls are wood-framed with pine-wood sheathing at a 45° angle. (Figure 2).

The building is fitted with a gabled roof with sawdust insulated exterior walls and roof. A concrete slab as the intermediate floor (the structure between the basement and first floor).

The house utilizes natural gravity ventilation with mechanical exhaust from the kitchen and bathrooms. The outdoor air infiltrates the building through cracks in the building envelope, between windows and door frames.

Based on data given by the residents, the building has used a total of 28 m^3 of wood chips. The domestic hot water energy consumption in the building was 12000 kWh/year.

FIGURE 1. The reference residential building

3.2 Building envelope

There was not enough information to determine the U-values or the thermal bridges of the building's envelope from the site visit. For this study those values were based on information from the Finnish standard. (MOTIVA, Energiatodistusten laskentaohjeet 2018, Vanhojen alkuperäisiä suunnitteluarvoja) (Finlex. Ympäristöministeriö Energiatehokkuus, Liite 1 s.12).

FIGURE 2. Timber frame diagonal bracings.

3.2.1 Windows and doors

The windows are clear doubled glazed wooden frame with wooden sills. The height of the windows was under two meters. (Figure 3).

FIGURE 3. Original door and windows with inside shading.

4 INPUT DATA FOR ENERGY SIMULATION IN IDA-ICE

In this section, the input parameters involved in energy consumption calculations are described. The model creation and energy simulation in IDA-ICE will be discussed. In this section, the input data for the Base Case Scenario is going to be shown as it was input in IDA-ICE.

4.1 Weather Data

The weather data provides wind conditions, dry- wet- bulb as well as dew-point temperatures. Based on accumulated weather data, buildings can predict the impact in energy consumption. However, weather predictions are non-controllable elements affecting a building's energy performance and could have an impact in the calibration of the building energy model. (Gutierrez Gonzales, et al.)

The data used in the simulation was obtained from the Tampere/Pirkkala airport weather data set located 16 km southwest from the site. The city of Tampere has a subarctic climate. The winters are cold, the average temperature from December to February is below -3 º C.

4.2 Building Orientation

Building orientation is a key factor as it will allow the winter sun to enter the building and heat it up, thus reducing energy consumption. This capacity of the building to naturally heat and light a space reduces the amount of heat required for lighting and space heating.

4.3 Heating Plant

The building’s heating and domestic hot water are produced by a hot water tank. The tank is supported by a wood boiler connected to the water heater. The wood has been burned in the boiler during the year (Figure 4). The heating equipment is in the basement.

In the central heating system water is heated and distributed by a pipeline system to the distribution network (radiators). The radiators carry out the space heating supply/return temperature of 70/40 ºC, respectively. The efficiency of the heat distribution is 80% (Finlex. Ympäristöministeriö Energiatehokuus 1048 /2017, Annex 1 p.12).

The age of the water tank is not available, but it was estimated to be 60 years. The tank has a capacity of 4000 liters. The tank is totally covered by insulation. (Figure 4).

The setpoint temperature for heating and cooling of the occupied rooms are as follow:

Living room areas 20 /27 º C.
Bedrooms 18/ 27 ºC.
Storage spaces 17/ 27 ºC.
Basement areas are not heated.

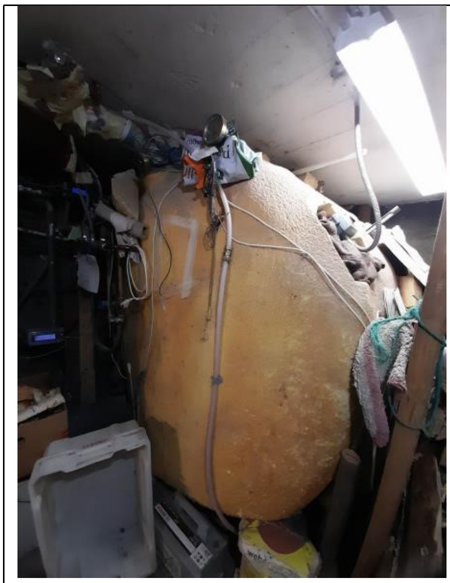


FIGURE 4. The building hot water tank covered by insulation.

FIGURE 5. The building wood boiler.

4.3.1 Space Heating

The space heating Q_{space} considers. conduction heat losses throughout the building envelope $Q_{conduction}$., air leakage $Q_{airleakage}$, ventilation energy $Q_{ventilation}$ and the heating of makeup air in the space $Q_{make-up\ air}$.

The heating energy is calculated using the equation (4.3.1.1)

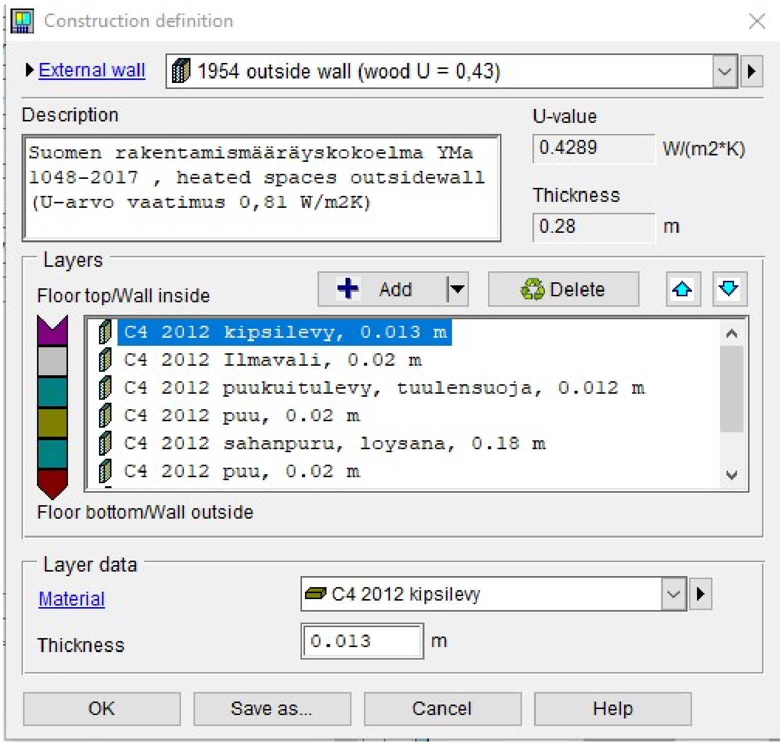
$$Q_{\mathrm{space}}(kWh) = Q_{\mathrm{conduction}} + Q_{\mathrm{airleakage}} + Q_{ventilation} + Q_{make-up\ air} \qquad (4.3.1.1)$$

4.4 Conduction - Thermal transmittance (U-values)

Conduction calculations include the heat losses of the building envelope U-values and the thermal bridges heat losses caused by the joints between the building components. In IDA-ICE the layer properties were updated to get the required U-values.

The gathered information was not enough to determine the U-values of the building's envelope or the thermal bridges. For this study the values were based on information from Standards or best practices recommendations. (MOTIVA, Energiatodistusten laskentaohjeet 2018, Vanhojen alkuperäisiä suunnitteluarvoja) (Finlex. Ympäristöministeriö Energiatehokkuus, Liite 1 s.12).

The Base Case U-values are shown in Attachment 1, Table 1, as they are used in the simulations. Figure 6 shows the U-values for an element of the building envelope input in IDA-ICE.



External wall: 1954 outside wall (wood U = 0,43)

Description:
Suomen rakentamismääräyskokoelma YMa 1048-2017 , heated spaces outsidewall (U-arvo vaatimus 0,81 W/m2K)

U-value: 0.4289 W/(m2*K)

Thickness: 0.28 m

```
C4 2012 kipsilevy, 0.013 m
C4 2012 Ilmavali, 0.02 m
C4 2012 puukuitulevy, tuulensuoja, 0.012 m
C4 2012 puu, 0.02 m
C4 2012 sahanpuru, loysana, 0.18 m
C4 2012 puu, 0.02 m
```

Material: C4 2012 kipsilevy

Thickness: 0.013 m

FIGURE 6 - Wall U-value definition in IDA ICE

4.5 Air leakage

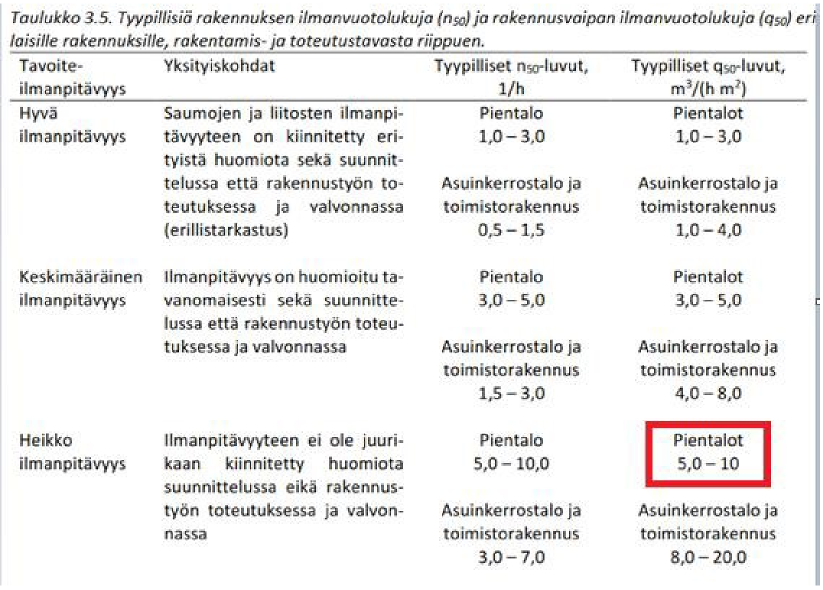
The infiltration rate expresses the air leakages that pass uncontrollably through the many openings or cracks in the building envelope. Poor airtightness of the envelope increases energy consumption. Regulations regarding air tightness on residential buildings aim to make the building envelope impermeable. An air-tight building can be achieved by sealing the openings and adding insulation to the building envelope.

The energy consumption due to air leakage is calculated using formula (4.8.1). The leakage air flow is calculated with formula (4.8.2). The airtightness of the building is expressed by the air leakage rate q_{50}.

$$Q_{energy,leak}(kWh) = \rho_i c_{pi} q_{flow,leak} (T_s - T_u)\Delta t / 1000 \tag{4.8.1}$$

$$q_{flow,leak} = \left(\frac{q_{50}}{x}\right) A_{envelope} \tag{4.8.2}$$

For q_{50} for the base case building was unknown. The values used in the IDA-simulation are based on data given in Table 3. of the energy efficiency regulation. (MOTIVA. Rakennuksen energiankulutuksen ja lämmitystehon tarpeen laskentaa, s. 22). Figure 7.



Taulukko 3.5. Tyypillisiä rakennuksen ilmanvuotolukuja (n_{50}) ja rakennusvaipan ilmanvuotolukuja (q_{50}) eri
laisille rakennuksille, rakentamis- ja toteutustavasta riippuen.

Tavoite-ilmanpitävyys	Yksityiskohdat	Tyypilliset n_{50}-luvut, 1/h	Tyypilliset q_{50}-luvut, $m^3/(h\ m^2)$
Hyvä ilmanpitävyys	Saumojen ja liitosten ilmanpitävyyteen on kiinnitetty erityistä huomiota sekä suunnittelussa että rakennustyön toteutuksessa ja valvonnassa (erillistarkastus)	Pientalo 1,0 – 3,0 Asuinkerrostalo ja toimistorakennus 0,5 – 1,5	Pientalot 1,0 – 3,0 Asuinkerrostalo ja toimistorakennus 1,0 – 4,0
Keskimääräinen ilmanpitävyys	Ilmanpitävyys on huomioitu tavanomaisesti sekä suunnittelussa että rakennustyön toteutuksessa ja valvonnassa	Pientalo 3,0 – 5,0 Asuinkerrostalo ja toimistorakennus 1,5 – 3,0	Pientalot 3,0 – 5,0 Asuinkerrostalo ja toimistorakennus 4,0 – 8,0
Heikko ilmanpitävyys	Ilmanpitävyyteen ei ole juurikaan kiinnitetty huomiota suunnittelussa eikä rakennustyön toteutuksessa ja valvonnassa	Pientalo 5,0 – 10,0 Asuinkerrostalo ja toimistorakennus 3,0 – 7,0	Pientalot 5,0 – 10 Asuinkerrostalo ja toimistorakennus 8,0 – 20,0

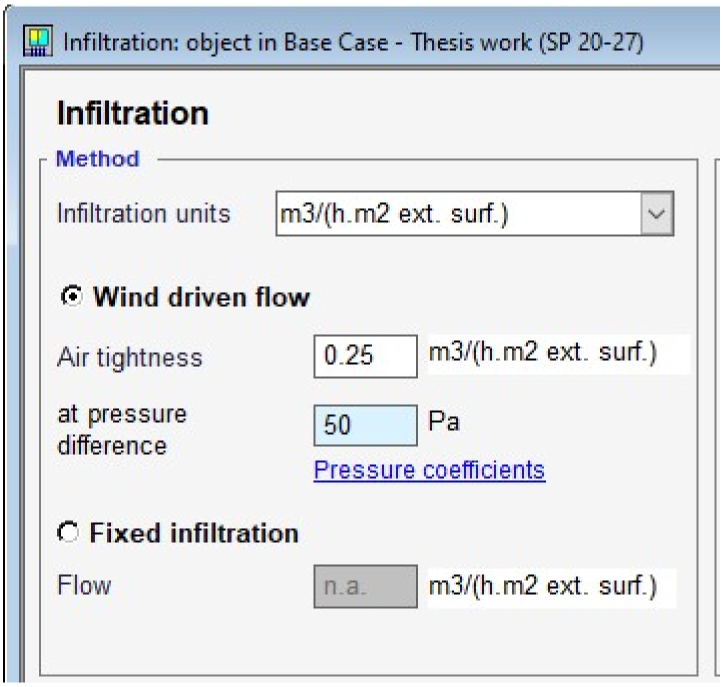
FIGURE 7. Air leakage rates for the building envelope (q_{50}) and air change rate per hour (n_{50}) numbers. (MOTIVA. Energiatehokkuus-Rakennuksen energiankulutuksen ja lämmitystehontarpeen laskenta, s. 22).

In the study, the q_{50} value used in the base case building corresponds to a poor air tightened residential house. The value was 6 $m^3/h\ m^2$. In IDA-ICE the infiltration rate was input with the units $m^3 / (h\ m^2)$. Figure 8.

The value of the air tightness in IDA-ICE is calculated with the formula 4.5.1 where x is a coefficient, that depends on the type and number of floors in the building: X is 35 for a one-floor building, 24 for two-floor building, 20 for three or four floors and 15 for higher buildings. (Ympäristöministeriön asetus 1010/2017, 17 §)

$$\frac{q_{50}}{x} = \frac{6}{24} = 0.25\ \mathrm{m}^3 / (\mathrm{h\ m}^2)\ A_{envelope} \tag{4.5.1}$$

In IDA-ICE wind driven flow was selected. As this option, automatically installs a leak in each external wall. (IDA-ICE Infiltration). Figure 8 also displays the input in IDA-ICE.



Infiltration: object in Base Case - Thesis work (SP 20-27)

Infiltration

Method

Infiltration units: m3/(h.m2 ext. surf.)

● **Wind driven flow**

Air tightness: 0.25 m3/(h.m2 ext. surf.)

at pressure difference: 50 Pa

Pressure coefficients

○ **Fixed infiltration**

Flow: n.a. m3/(h.m2 ext. surf.)

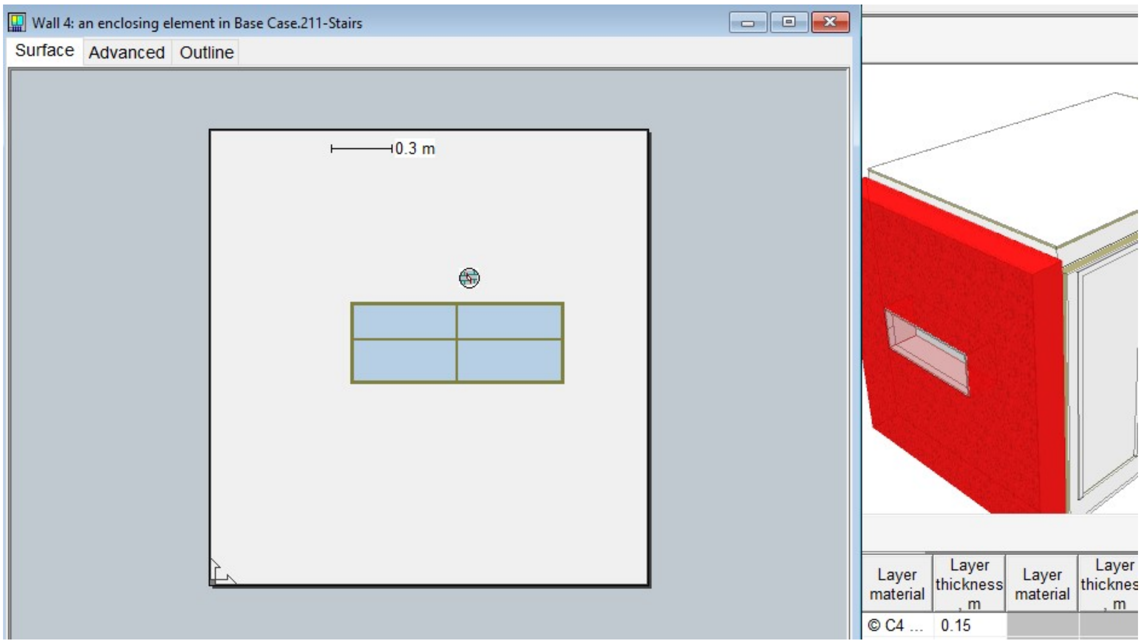
FIGURE 8. Infiltration rate – IDA – ICE

4.6 Make-up air

Gravity or natural ventilation is produced when natural forces such the influence of wind characteristics and temperature differences from the outdoor and indoor air temperatures occur.

In this type of system, the outdoor air enters the spaces as a replace or “make up” air through leaks in the outside walls, windows, and doors. The exhaust air leaves the building through the chimney (stack effect) due to gravity.

In IDA-ICE the air leakage is installed in the exterior walls (Figure 9). The chimneys are installed on the rooms that exhaust air such as the kitchen, closets and wc. (Figure 10)



Layer material	Layer thickness, m	Layer material	Layer thicknes, m
© C4 ...	0.15		

FIGURE 9. Gravity ventilation leak representation in IDA-ICE.

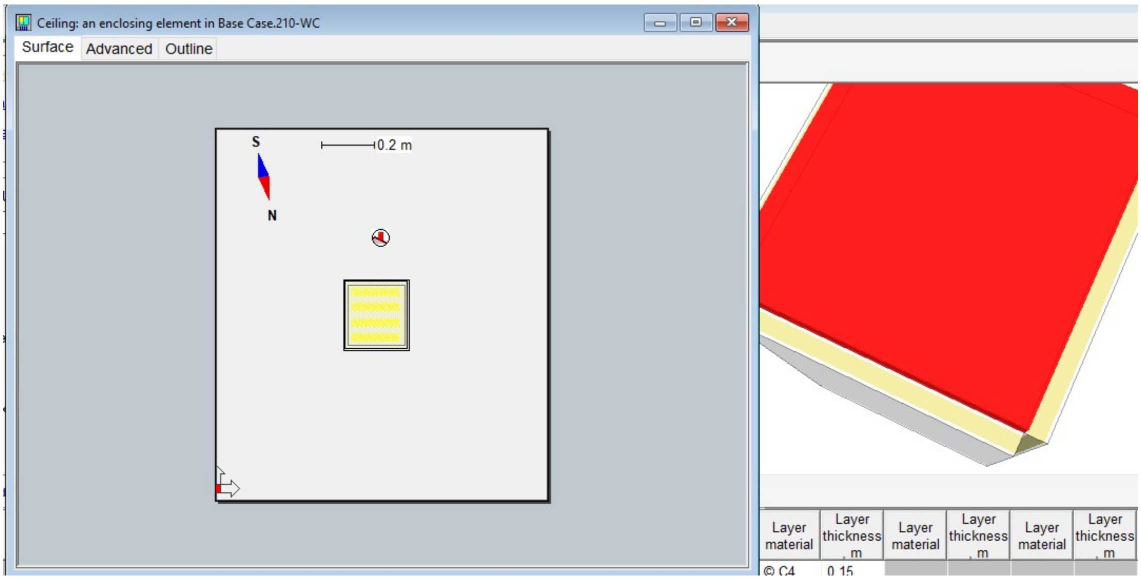


FIGURE 10. Gravity ventilation exhaust air path representation in IDA-ICE.

4.7 Domestic water Heating

A major percentage of the energy used for heating a residential building is utilized for the heating of Domestic Hot Water (DHW). The DHW energy consumption is formed in the water heater.

4.8 Heat gains

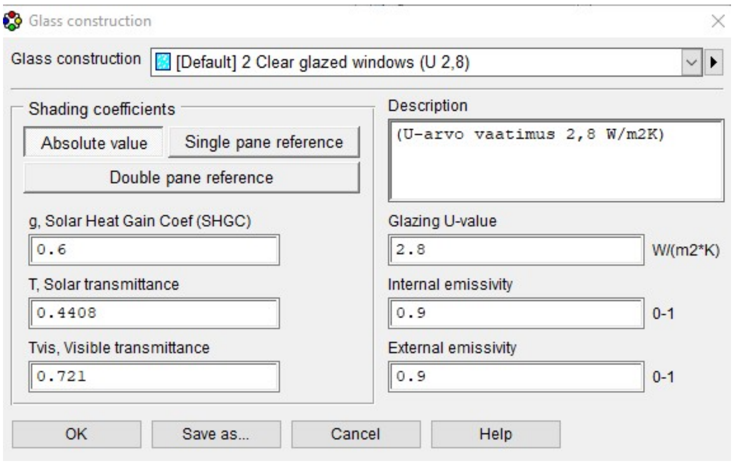
The internal heat gains include the heat that is produced by the people that live in the house, the lights, appliances, and the equipment.

There were four people living in the house. The activity level of the occupants was 1.2 MET. The occupancy schedule was determined by the standards as present at the residence 24/7. (Ympäristöministeriön asetus 1010/2017, 11 §)

The equipment input is 4,5 W/m^2. The lighting input is and 6,5 W/m^2. The equipment is used 60 % and lighting 10 % of the time from Monday to Sunday.

4.9 Solar radiation energy

In IDA-ICE, windows definition is shown in Figure 11.



Glass construction: [Default] 2 Clear glazed windows (U 2,8)

Description: (U-arvo vaatimus 2,8 W/m2K)

g, Solar Heat Gain Coef (SHGC): 0.6

T, Solar transmittance: 0.4408

Tvis, Visible transmittance: 0.721

Glazing U-value: 2.8 W/(m2*K)

Internal emissivity: 0.9 0-1

External emissivity: 0.9 0-1

FIGURE 11. Glass construction definition in IDA-ICE

5 STRATEGIES FOR IMPROVING THE ENERGY EFFICIENCY

In this section a brief review of the common Finnish energy renovation measures for single-family houses are presented. The tips provided will be considered, as they apply to improving the building's energy efficiency.

Improvements that can be implemented take into consideration the renovation of more than one parameter. Alternative strategies for the energy renovation considered improvements of building envelope U-values, reduction of the infiltration rate to make the building tighter, lowered temperatures for supply/return water in the heating system, consider a balanced mechanical ventilation system with heat recovery, an air-to water source- or ground source- heat pump and solar photovoltaic panels.

5.1 Heating Plant

In Finland, residential buildings account for 20% of the total energy consumption, 2/3 of that total is used to heat the spaces in the building. (Statistics Finland. 2020) (Figure 12)

Improving the heating systems' quality has a significant impact on energy consumption in the building and thus on the environment. MOTIVA guidelines present different alternatives that affect energy efficiency. (MOTIVA, Pientalon lämmitysjärjestelmät) (MOTIVA, Tips for energy renovation and purchases.).

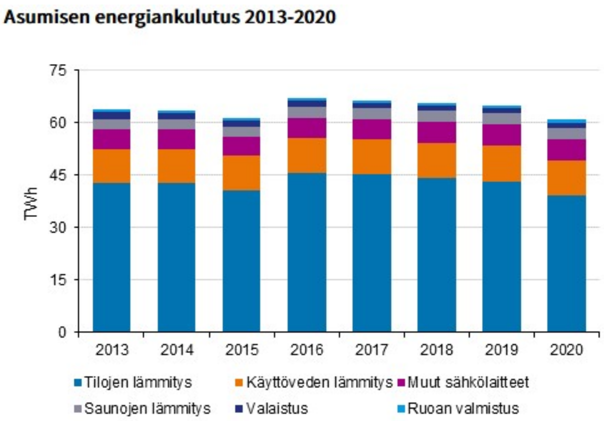
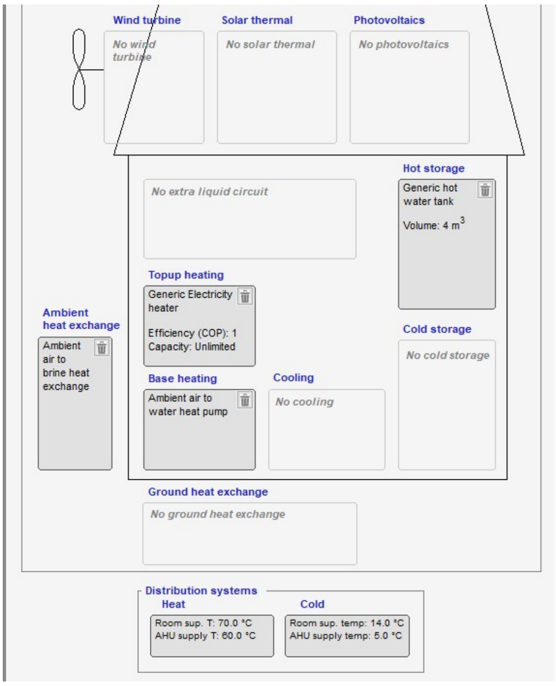


Figure 12. Residential energy consumption 2013-2020 (Statistics Finland. 2020).

The heating plant was modeled after IDA-ICE by using the ESBO plant. The default values provided by IDA-ICE were used to simulate the alternatives Cases. Figure 13. shows the general tab of the plant to define the air to water heat pump.



Wind turbine
No wind turbine

Solar thermal
No solar thermal

Photovoltaics
No photovoltaics

No extra liquid circuit

Hot storage
Generic hot water tank
Volume: 4 m^3

Topup heating
Generic Electricity heater
Efficiency (COP): 1
Capacity: Unlimited

Ambient heat exchange
Ambient air to brine heat exchange

Cold storage
No cold storage

Base heating
Ambient air to water heat pump

Cooling
No cooling

Ground heat exchange
No ground heat exchange

Distribution systems
Heat
Room sup. T: 70.0 °C
AHU supply T: 60.0 °C
Cold
Room sup. temp: 14.0 °C
AHU supply temp: 5.0 °C

FIGURE 13. The heating plant with an air-to-water heat pump defined in IDA-ICE

The next sections describe the energy renovation strategies that have been considered based on the referenced guidelines.

5.1.1 Radiators supply/return temperature

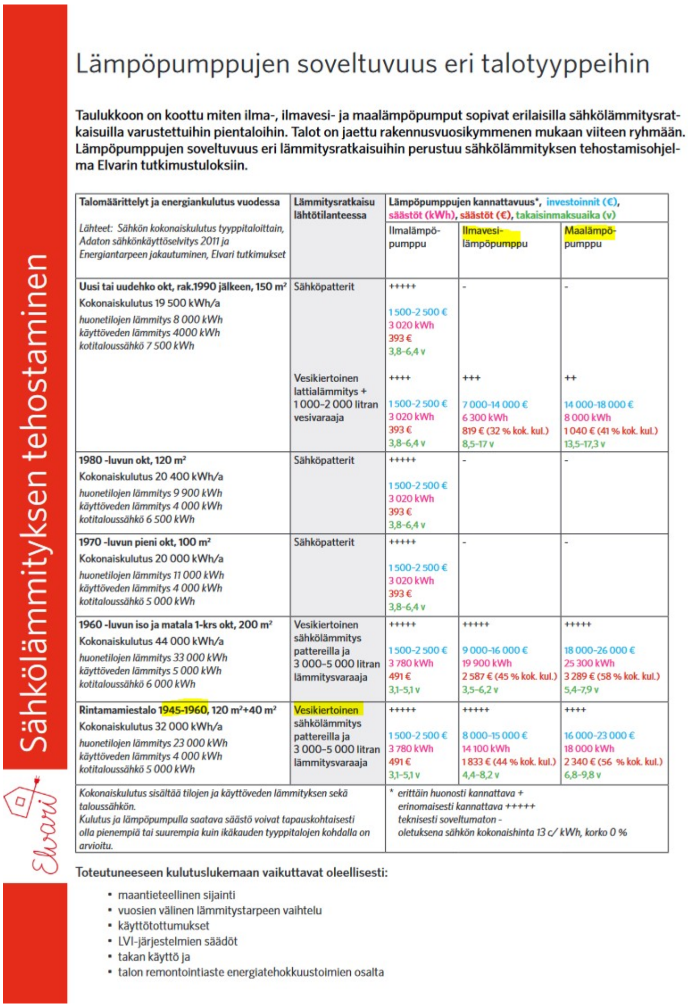
For the heat distribution a basic renovation strategy is to reduce the temperature of the supply/return water in the hydronic system. The radiator networks in the Base Case building were sized for a temperature difference of 70/40 °C. As a strategy to improve efficiency, the temperature difference has been lowered to 45/35 °C.

5.1.2 Heat pump (HP)

A HP transfers heat to control the room temperature. The condenser and evaporator components transfer the heat/cool using a refrigerant as the transfer agent. The compressor uses electricity to operate.

A HP has specific features that make it a suitable choice for a more efficient and sustainable renovation project. It uses refrigerants that have lower GWP (low global warming potential). Furthermore, the amount of energy that is produced is more than the electricity it uses. The efficiency of the heat pump is measured by the coefficient of performance (COP) which measures the amount of energy the heat pump produces for every kilowatt of electricity.

Motiva presents a table where it specifies the suitability of HP alternatives for diverse types of older houses. (MOTIVA; Suitability of heat pump for different house types). Figure 14. Suitable heat pump alternatives for the hydronic system simulated in this study are an air-to-water and a ground source heat pump.



Sähkölämmityksen tehostaminen

Elvari

Lämpöpumppujen soveltuvuus eri talotyyppeihin

Taulukkoon on koottu miten ilma-, ilmavesi- ja maalämpöpumput sopivat erilaisilla sähkölämmitysratkaisuilla varustettuihin pientaloihin. Talot on jaettu rakennusvuosikymmenen mukaan viiteen ryhmään. Lämpöpumppujen soveltuvuus eri lämmitysratkaisuihin perustuu sähkölämmityksen tehostamisohjelma Elvarin tutkimustuloksiin.

Talomäärittelyt ja energiankulutus vuodessa *Lähteet: Sähkön kokonaiskulutus tyyppitaloittain, Adaton sähkönkäyttöselvitys 2011 ja Energiantarpeen jakautuminen, Elvari tutkimukset*	**Lämmitysratkaisu lähtötilanteessa**	**Lämpöpumppujen kannattavuus*, investoinnit (€), säästöt (kWh), säästöt (€), takaisinmaksuaika (v)** Ilmalämpöpumppu	Ilmavesilämpöpumppu	Maalämpöpumppu
Uusi tai uudehko okt, rak.1990 jälkeen, 150 m² Kokonaiskulutus 19 500 kWh/a *huonetilojen lämmitys 8 000 kWh* *käyttöveden lämmitys 4000 kWh* *kotitaloussähkö 7 500 kWh*	Sähköpatterit	+++++ 1 500–2 500 € 3 020 kWh 393 € 3,8–6,4 v	-	-
	Vesikiertoinen lattialämmitys + 1 000–2 000 litran vesivaraaja	++++ 1 500–2 500 € 3 020 kWh 393 € 3,8–6,4 v	+++ 7 000–14 000 € 6 300 kWh 819 € (32 % kok. kul.) 8,5–17 v	++ 14 000–18 000 € 8 000 kWh 1 040 € (41 % kok. kul.) 13,5–17,3 v
1980 -luvun okt, 120 m² Kokonaiskulutus 20 400 kWh/a *huonetilojen lämmitys 9 900 kWh* *käyttöveden lämmitys 4 000 kWh* *kotitaloussähkö 6 500 kWh*	Sähköpatterit	+++++ 1 500–2 500 € 3 020 kWh 393 € 3,8–6,4 v	-	-
1970 -luvun pieni okt, 100 m² Kokonaiskulutus 20 000 kWh/a *huonetilojen lämmitys 11 000 kWh* *käyttöveden lämmitys 4 000 kWh* *kotitaloussähkö 5 000 kWh*	Sähköpatterit	+++++ 1 500–2 500 € 3 020 kWh 393 € 3,8–6,4 v	-	-
1960 -luvun iso ja matala 1-krs okt, 200 m² Kokonaiskulutus 44 000 kWh/a *huonetilojen lämmitys 33 000 kWh* *käyttöveden lämmitys 5 000 kWh* *kotitaloussähkö 6 000 kWh*	Vesikiertoinen sähkölämmitys pattereilla ja 3 000–5 000 litran lämmitysvaraaja	+++++ 1 500–2 500 € 3 780 kWh 491 € 3,1–5,1 v	+++++ 9 000–16 000 € 19 900 kWh 2 587 € (45 % kok. kul.) 3,5–6,2 v	+++++ 18 000–26 000 € 25 300 kWh 3 289 € (58 % kok. kul.) 5,4–7,9 v
Rintamamiestalo 1945-1960, 120 m²+40 m² Kokonaiskulutus 32 000 kWh/a *huonetilojen lämmitys 23 000 kWh* *käyttöveden lämmitys 4 000 kWh* *kotitaloussähkö 5 000 kWh*	Vesikiertoinen sähkölämmitys pattereilla ja 3 000–5 000 litran lämmitysvaraaja	+++++ 1 500–2 500 € 3 780 kWh 491 € 3,1–5,1 v	+++++ 8 000–15 000 € 14 100 kWh 1 833 € (44 % kok. kul.) 4,4–8,2 v	++++ 16 000–23 000 € 18 000 kWh 2 340 € (56 % kok. kul.) 6,8–9,8 v
Kokonaiskulutus sisältää tilojen ja käyttöveden lämmityksen sekä taloussähkön. *Kulutus ja lämpöpumpulla saatava säästö voivat tapauskohtaisesti olla pienempiä tai suurempia kuin ikäkauden tyyppitalojen kohdalla on arvioitu.*		* *erittäin huonosti kannattava +* *erinomaisesti kannattava +++++* *teknisesti soveltumaton -* *oletuksena sähkön kokonaishinta 13 c/ kWh, korko 0 %*		

Toteutuneeseen kulutuslukemaan vaikuttavat oleellisesti:

- maantieteellinen sijainti
- vuosien välinen lämmitystarpeen vaihtelu
- käyttötottumukset
- LVI-järjestelmien säädöt
- takan käyttö ja
- talon remontointiaste energiatehokkuustoimien osalta

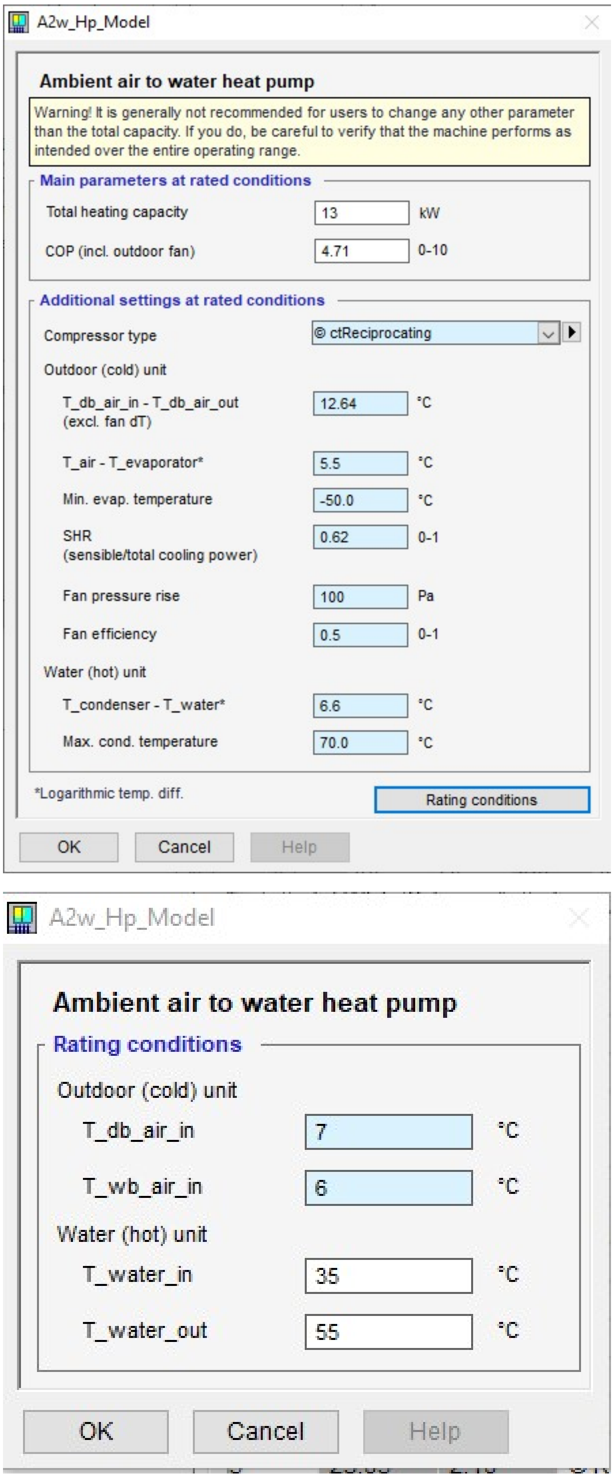
Figure 14. Suitability of Heat Pumps for different types of houses. (MOTIVA, Increasing the efficiency of electric heating.)

5.1.3 Air-to- water heat pump

The air to water heat pump transfers the energy from the outdoor air to the water radiators, floor heating systems and DHW systems.

The heat pump heating output was measured as 13 kW. In IDA-ICE the input parameters of the compressor rating conditions for the supply dry bulb temperature are 7 °C and for the wet bulb temperature is 6 °C. The supply and return temperatures of condenser are 35/55 °C. The COP of the air-to-water heat pump value is 4,71.

The air to water heat pump used in the simulation is an CCT ECOAIR 614M (CTC). In IDA-ICE the input data of the HP is shown in Figure 15



Ambient air to water heat pump

Warning! It is generally not recommended for users to change any other parameter than the total capacity. If you do, be careful to verify that the machine performs as intended over the entire operating range.

Main parameters at rated conditions

Total heating capacity 13 kW

COP (incl. outdoor fan) 4.71 0-10

Additional settings at rated conditions

Compressor type © ctReciprocating

Outdoor (cold) unit

T_db_air_in - T_db_air_out (excl. fan dT) 12.64 °C

T_air - T_evaporator* 5.5 °C

Min. evap. temperature -50.0 °C

SHR (sensible/total cooling power) 0.62 0-1

Fan pressure rise 100 Pa

Fan efficiency 0.5 0-1

Water (hot) unit

T_condenser - T_water* 6.6 °C

Max. cond. temperature 70.0 °C

*Logarithmic temp. diff.

Ambient air to water heat pump

Rating conditions

Outdoor (cold) unit

T_db_air_in 7 °C

T_wb_air_in 6 °C

Water (hot) unit

T_water_in 35 °C

T_water_out 55 °C

FIGURE 15. IDA-ICE input of the rated conditions for the air-to-water heat pump.

5.2 Renewable Energy

One of the goals of the European Unions and Finland for renovation projects is, to integrate renewable energy systems that can be obtained on site. This assumption will improve the energy performance and help reduce CO2 emissions in the building, especially for heating systems. (European Commission, A Renovation Wave for Europe). MOTIVA also addressed key measures to increase renewable energy to improve energy efficiency.

To aim for this goal, two sources of renewable energy were studied in this work: photovoltaic solar energy and a geothermal heat pump. The energy that comes from natural resources which are replenished naturally and that regenerates constantly.

5.2.1 Geothermal Heat pump and Solar PV panels

Geothermal heat is solar energy stored in the ground. The compressor helps the heat pump to transfer the ground thermal energy to the hydronic radiators and the DHW systems. “On average, about 2/3 of the heat produced by geothermal heat pump is renewable energy taken from the soil and 1/3 is produced by electricity”. (Toppinen, Joni 2016).

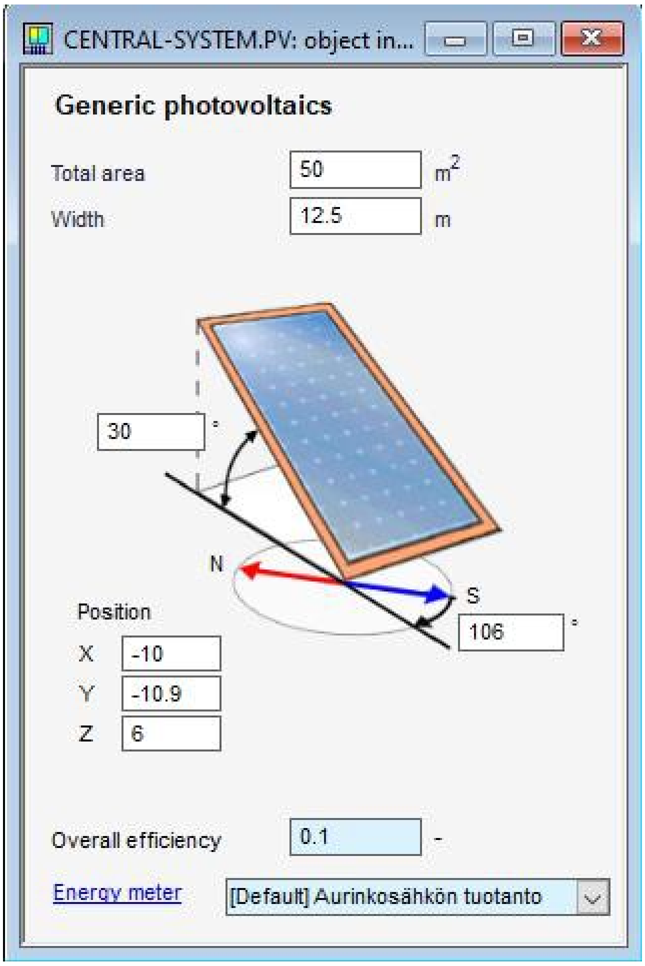
The source of energy was a borehole. In IDA-ICE the single-hole borehole was used, and the length was 150 m, and the heating output was 13 kW, the COP value was 4,85 (NIBE S1255).

Solar or photovoltaic (PV) panels change the energy from the sun into electrical energy. PV is a renewable power generation where the potential for solar energy could be beneficial to abate the use of electricity. Another benefit of using PV panels is that the excess electricity produced on site could be sold to the grid.

The factors considered for PV calculations are the panel tilt and azimuth. The tilt describes the angle between the PV panel and the horizontal plane. The azimuth is the direction that the PV panel face is facing. The maximum energy generation is produced when the panels are facing south and the range of the tilt could be between 30 -60 º. (Vesikukka Sari, 2022). The roof's slopes face the southwest and southeast direction, the panels were located southwest. They were positioned in the southwest orientation as the building’s entrance faces that direction. PV panels can be used for residential houses, regardless of the type of roof.

The power of the PV was designed to be 10 KW and the area was 50 m^2. The efficiency factor was 10% and the direction was southwest 106 º. The slope direction and the area of the solar panels were defined in IDA-ICE as shown in Figure 16.

In this study PV Astronergy panesl were selected. The panel's maximum power is 410 watts. The measurements are 1722 x 1134 x 30 mm, with a total area of Area 1,95 m^2 per panel. (Nordsolar verkokauppa, Astronergy).



CENTRAL-SYSTEM.PV: object in...

Generic photovoltaics

Total area: 50 m^2

Width: 12.5 m

30 °

Position

X: -10

Y: -10.9

Z: 6

106 °

Overall efficiency: 0.1 -

Energy meter: [Default] Aurinkosähkön tuotanto

FIGURE 16. IDA-ICE Solar PV input data.

5.3 Ventilation systems

Ventilation is the introduction of outside air into the building and distribution of the air inside the building. Mechanical ventilation was considered as the envelope renovation will create a tighter building. This method will provide an adequate amount of outdoor air.

One of the potential energy savings from the ventilation systems relates to heat recovery. The heat from the exhaust air can be transferred to the supply air, reducing the need for energy demand for heating the supply air. (Korpela Tuija, et al, 2022). When renovating a building, at least 45% heat must be recovered from the ventilation exhaust. (Ympäristöministeriön asetus 4/13. 2017)

This study considered a balanced ventilation with heat recovery system. The set-point temperature of the supply air is constant at 17 °C, electric reheat coil (for heating the supply air). A cooling coil is not considered.

5.3.1 Dimensioning of air flow rates

The ventilation rates were sized according to the Finnish Association of HVAC Societies (FINVAC) guidelines (Figure 17). The supply air flows are in the occupied rooms and exhaust air in dirty rooms, toilets, and kitchen. The FINVAC guide specifies the minimum requirements of air flow for residential houses' design. (FINVAC)

- “The outdoor air flow rate calculated over the whole floor surface area must be at least 0,35 $dm^3/s, m^2$”.
- “The outdoor air flow rate for the entire building is at least 18 dm^3/s”.
- “Each residential room must have an outdoor flow rate of at least 8 dm^3/s. Bedrooms over 11 m^2 floor area must have outdoor airflow rate at least 12 dm^3/s”.

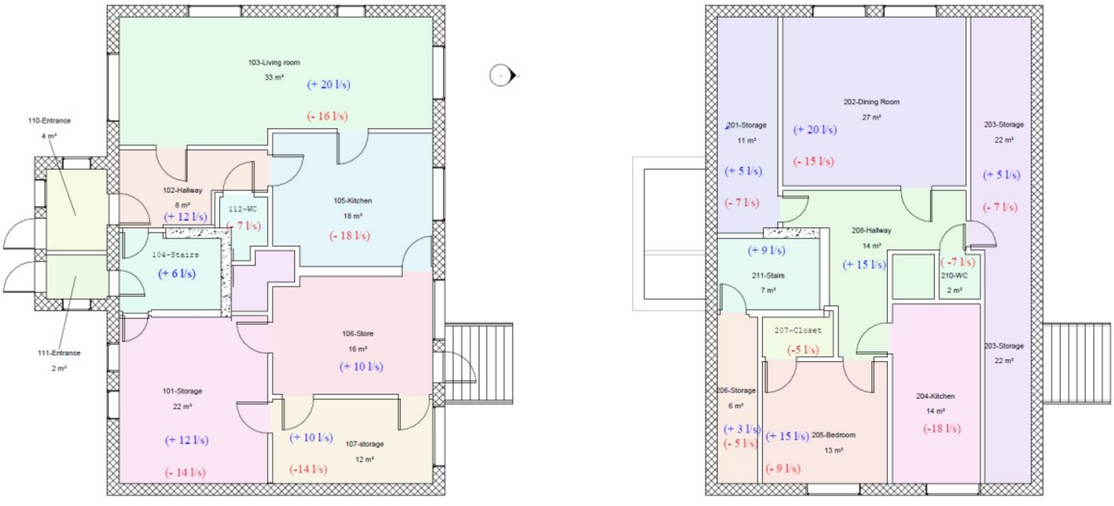
The design ventilation rate was 142 dm^3/s which satisfies the minimum requirement. For this study, the selected unit was the Vallox 145 MV, which is a unit

designed for large, detached houses and has an A+ energy rating. The heat recovery efficiency is 79%. The specific fan power is 1,33 kW/m^3/h. (Vallox)
The airflow rates considered for the renovation implementation are shown in Figure 18.

Taulukko 2. Asunnon tilojen normaalin käyttötilanteen ulkoilma- ja poistoilmavirrat.

Huonetila	**Ulkoilmavirta** dm^3/s	**Poistoilmavirta** dm^3/s	**Huomautus**
Suurin tai ainoa makuuhuone tai yli 11 m^2 makuuhuone	12		
Muut makuuhuoneet	8		
Muut asuinhuoneet kuten olohuone alle 22 m^2, ei kuitenkaan keittiö	8		Ulkoilma voidaan osittain korvata siirtoilmalla makuuhuoneesta.
Muut asuinhuoneet kuten olohuone yli 22 m^2, ei kuitenkaan keittiö	0,35 dm^3/s,m^2		Ulkoilma voidaan osittain korvata siirtoilmalla makuuhuoneesta.
Keittiötila, keittiö, keittokomero, saarekekeittiö (KT)		8 (25)	Liesikuvun/keittiötilan ilmavirran tulee tehostustilanteessa olla vähintään 25 dm^3/s. Ulkoilman saannista tehostuksen aikana on huolehdittava. Ulkoilma voidaan korvata siirtoilmalla asuinhuoneesta
Kylpyhuone WC:llä tai ilman (KPH)		10	Ulkoilma voidaan korvata siirtoilmalla asuinhuoneesta.
Erillinen WC (WC)		7	Ulkoilma voidaan korvata siirtoilmalla asuinhuoneesta.
Vaatehuone (VH)		6	Ulkoilma voidaan korvata siirtoilmalla asuinhuoneesta.
Varasto		6	Ulkoilma voidaan korvata siirtoilmalla asuinhuoneesta.
Huoneistosauna (S)	6	6	
Kylpyhuoneesta erillään oleva kodinhoitohuone		8	Ulkoilma voidaan korvata siirtoilmalla asuinhuoneesta.
Tekninen tila		3 3)	Mitoitetaan lämpökuorman mukaan, vähintään 3 dm^3/s.

FIGURE 17. Residential Buildings minimum ventilation rates (FINVAC, Table 2 page 6).



① 01 - 1st Floor - Supply/Exh
1 : 50

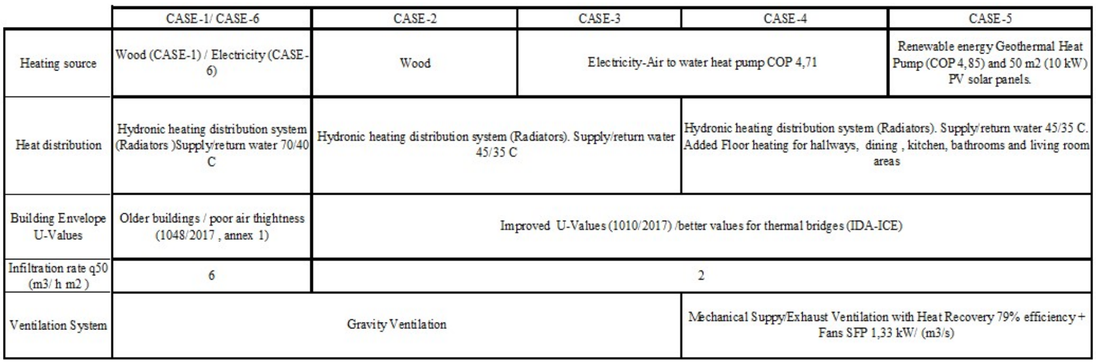
② 02 - 2nd Floor- Supply/Exh
1 : 50

FIGURE 18. Dimensioned supply and exhaust air flow rates

6 CASES STUDIES FOR THE RENOVATION IMPROVEMENTS

Once the characteristics of the reference buildings were defined, the simulation model parameters were selected. A series of case studies were set, in which optimal parameters were evaluated to improve the energy efficiency of the building. Table 1. summarizes the parameters that will be incorporated into the renovation design of the building for CASES 1 through 4.

TABLE 1. Alternative energy saving strategies for Case 1 through 6.



	CASE-1/ CASE-6	CASE-2	CASE-3	CASE-4	CASE-5
Heating source	Wood (CASE-1) / Electricity (CASE-6)	Wood	Electricity-Air to water heat pump COP 4,71		Renewable energy Geothermal Heat Pump (COP 4,85) and 50 m2 (10 kW) PV solar panels.
Heat distribution	Hydronic heating distribution system (Radiators)Supply/return water 70/40 C	Hydronic heating distribution system (Radiators). Supply/return water 45/35 C		Hydronic heating distribution system (Radiators). Supply/return water 45/35 C. Added Floor heating for hallways, dining , kitchen, bathrooms and living room areas	
Building Envelope U-Values	Older buildings / poor air thightness (1048/2017 , annex 1)	Improved U-Values (1010/2017) /better values for thermal bridges (IDA-ICE)			
Infiltration rate q50 (m3/ h m2)	6	2			
Ventilation System	Gravity Ventilation			Mechanical Suppy/Exhaust Ventilation with Heat Recovery 79% efficiency + Fans SFP 1,33 kW/ (m3/s)	

7 ARCHITECTURAL MODEL - REVIT

A simplified architectural model was created in Revit 2022. Modifications were made to the original Architectural model to improve the expected results of the Energy Model. Figure 19

The Revit BIM Model was imported to IDA-ICE using the IFC (Industry Foundation classes). Figure 20 shows the modeled building in IDA-ICE.

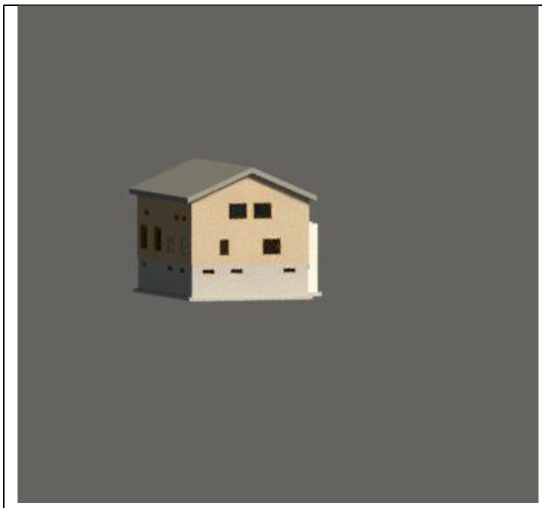


FIGURE 19. The building geometry in REVIT

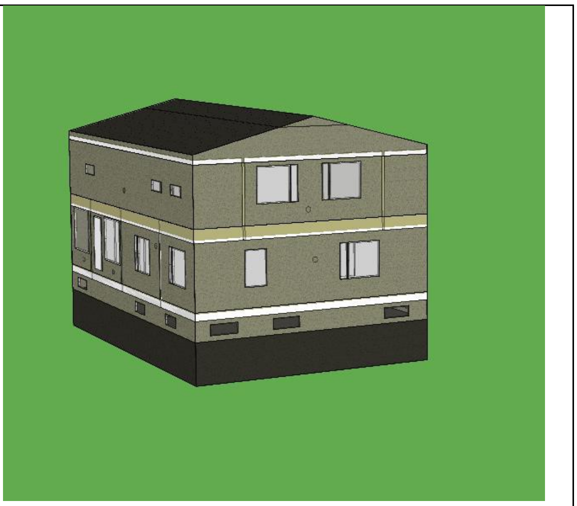


FIGURE 20. The building geometry in IDA ICE

8 SIMULATION MODEL (IDA-ICE)

IDA Indoor Climate and Energy (EQUA) is a building simulation software of energy consumption. It models the building, its systems and controllers ensuring optimal energy performance.

“IDA ICE is a whole year dynamic simulation software that can study the energy requirements for the building as well as the indoor climate of individual zones”. (EQUA)

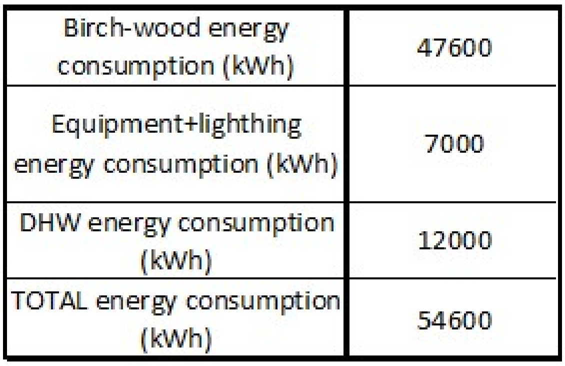
The IFC file created in Revit architectural was imported to IDA-ICE to perform the energy simulations. The supported objects and properties imported to IDA-ICE were the building geometry and space names.

9 RESULTS

In this section the results of the calculations are presented as the final metered energy. The outcome includes energy utilized in electricity, DHW and the energy used in the heating of spaces. The measured energy consumption data gathered is shown in Table 2.

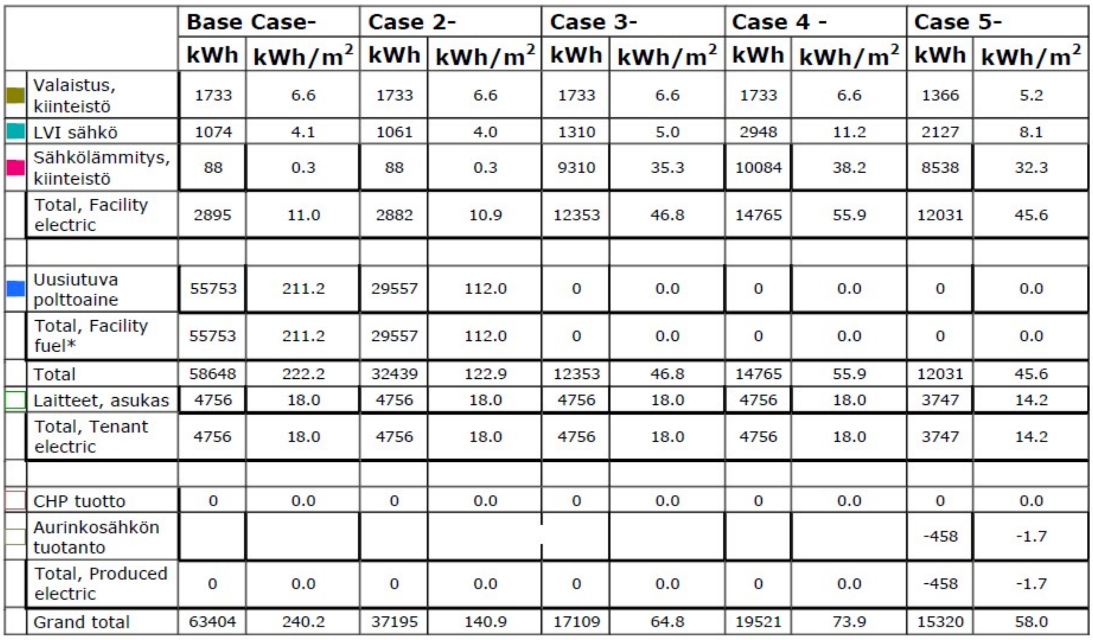
The simulated results implemented in the renovation of the old building are shown in Table 3.

TABLE 2. Measured Energy consumption.

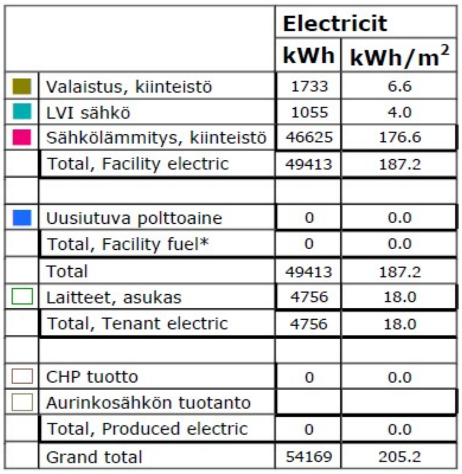


Birch-wood energy consumption (kWh)	47600
Equipment+lighthing energy consumption (kWh)	7000
DHW energy consumption (kWh)	12000
TOTAL energy consumption (kWh)	54600

TABLE 3. Calculated Energy consumption for the cases simulated in IDA-ICE.



		Base Case-		Case 2-		Case 3-		Case 4 -		Case 5-	
		kWh	kWh/m^2	kWh	kWh/m^2	kWh	kWh/m^2	kWh	kWh/m^2	kWh	kWh/m^2
■	Valaistus, kiinteistö	1733	6.6	1733	6.6	1733	6.6	1733	6.6	1366	5.2
■	LVI sähkö	1074	4.1	1061	4.0	1310	5.0	2948	11.2	2127	8.1
■	Sähkölämmitys, kiinteistö	88	0.3	88	0.3	9310	35.3	10084	38.2	8538	32.3
	Total, Facility electric	2895	11.0	2882	10.9	12353	46.8	14765	55.9	12031	45.6
■	Uusiutuva polttoaine	55753	211.2	29557	112.0	0	0.0	0	0.0	0	0.0
	Total, Facility fuel*	55753	211.2	29557	112.0	0	0.0	0	0.0	0	0.0
	Total	58648	222.2	32439	122.9	12353	46.8	14765	55.9	12031	45.6
□	Laitteet, asukas	4756	18.0	4756	18.0	4756	18.0	4756	18.0	3747	14.2
	Total, Tenant electric	4756	18.0	4756	18.0	4756	18.0	4756	18.0	3747	14.2
□	CHP tuotto	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
□	Aurinkosähkön tuotanto									-458	-1.7
	Total, Produced electric	0	0.0	0	0.0	0	0.0	0	0.0	-458	-1.7
	Grand total	63404	240.2	37195	140.9	17109	64.8	19521	73.9	15320	58.0



		Electricit	
		kWh	kWh/m^2
■	Valaistus, kiinteistö	1733	6.6
■	LVI sähkö	1055	4.0
■	Sähkölämmitys, kiinteistö	46625	176.6
	Total, Facility electric	49413	187.2
■	Uusiutuva polttoaine	0	0.0
	Total, Facility fuel*	0	0.0
	Total	49413	187.2
□	Laitteet, asukas	4756	18.0
	Total, Tenant electric	4756	18.0
□	CHP tuotto	0	0.0
□	Aurinkosähkön tuotanto		
	Total, Produced electric	0	0.0
	Grand total	54169	205.2

The measured annual energy consumption of the Base Case (Case-1) building was based on the consumption of wood utilized to heat the spaces, DHW and the consumption of electricity for equipment and lighting. The building consumed a total of 47.6 MWh of wood fuel in a year. The measured total heating energy consumption of the Base Case building was 54.6 MWh.

For the Base Case, the predicted energy consumption for the heating systems was 63 MWh. The wood consumption was 55,8 MWh a year (211.2 kWh/m^2 year). The measured electricity energy consumption for lighting, heating equipment and auxiliary heating equipment needed to heat the building was 11 kWh/m^2 a. The discrepancy observed between the actual usage and predicted performance has a variation of 16%.

The energy consumption for CASE-2 was reduced to 37 MWh improving the U-values, reducing the infiltration rate, and reducing the hydronic systems radiators supply/return temperature. The total energy consumption after the renovation was 141 kWh/m^2. The energy need for heating was 112 kWh/m^2. The predicted electricity energy consumption was around 11 kWh/m^2 a.

For (CASE-3) , replacing the wood furnace with an air- to- water heat pump with a COP of 4,71 reduced the energy consumption to 17 MWh (64.8 kWh/m^2), the electric energy used for heating the space, DHW and lighting, was 46.8 kWh/m^2.

Regarding CASE 4, the effect of the ventilation system with supply/exhaust air flow and heat recovery with an efficiency of 79%, reduced the energy consumption from Case 1 to 19.5 MWh (73.9 kWh/m^2). The electric energy consumption increased from CASE 3 by 9 kWh/m2.

Using an integration of a geothermal heat pumps and solar panels the consumption of energy is 15.3 MWh for the year (58.0 kWh/m^2). Using this alternative, the consumption is reduced from the Base Case-Electricity by 147 kWh/m^2. The Solar power electrical energy generation sold to the grid was 1.7 kWh/m^2 .

10 CONCLUSION AND DISCUSSIONS

There is a potential for saving the energy consumption in the Base Case building, implementing common renovation strategies provided by the Finnish regulations regarding energy consumption. The cost effectiveness of the systems has been omitted at this point.

The aim of this thesis was to create an acceptable predicted model of an old residential house and simulate its energy consumption by assessing different alternatives to achieve an optimal energy performance. A calibration between the measured energy consumption and a predicted model was implemented before studying the different alternatives.

The model was calibrated when the deviation between measured and simulated energy consumption was less than 20%. The discrepancy observed between the actual usage and predicted performance had a variation of 16 %. The difference is due to the uncertainty of the sources in the data input. The sources of uncertainty originated from assumptions of the U-values, infiltration rates or system efficiencies factors that were not possible to determine on the job site. Part of the parameters input in the dynamic simulation were determined based on values taken from the Finnish standards and best practice methods found in the review of previous studies. The outdoor weather conditions also had an impact in the calibration (Gutiérrez González, et al. 2021).

Additionally, in the natural ventilated building the outdoor air flows that enter the building are unknown, this also could be one of the reasons for the deviation between the measured and predicted energy consumption.

The results from the four alternatives simulated for the Base Case building show a reduction of energy consumption by 41-76% when energy implementation in the renovation is considered (Table 3).

Renovations implementing the upgrades of (CASE-2) improve the final energy consumption by 41 %.

Using the alternative of an air-to water heat pump (Case 3), as a replacement of the wood burner, reduced the energy consumption for heating the spaces by 73%. This alternative has a significant effect on the total purchased energy.

Replacing natural ventilation with a controlled supply/extract ventilation with heat recovery (CASE 4), decreased the energy consumption from CASE 1 by 69%. This points out that a gravity ventilated building takes more energy as the system is not equipped with a heat recovery that will retrieve the heat from the indoor air before it is extracted.

However, the energy consumption in CASE 4 increased by 14% from CASE 3. The increased energy consumption depends on the ventilation fans in addition to the heat pumps electric usage. In a supply/extract ventilation system the air flows have been designed according to the regulation requirements which are higher than air flows for a natural ventilated system. (Ekstrom Tomas, et al). When the outdoor air is provided by mechanical ventilation according to the design specifications, electric energy use increases as fans are utilized to bring the outdoor air to the spaces.

Renovations implementing CASE 5 reduced energy consumption by 76% from CASE 1. The geothermal heat pump significantly reduced the heating energy from electric heating, and as a renewable and clean energy source, geothermal heat could be a sustainable choice.

In the case of PV panels, the building absorbs most of the electricity produced by the PV panels (10 KW) and just 1,7 kWh of electric energy is sold to the grid. The availability of solar panels does not bring a significant improvement in energy efficiency as the house is not oriented directly to the south. The twenty-five PV panels will be an expensive investment compared to the savings that the panels will produce.

Energy consumption in the renovation of an old building can be reduced by a set of measures included. A standalone renovation is not enough to achieve an energy efficient building. A combination of parameters is the most efficient way to approach the best results.

Energy decisions in energy renovation are diverse. They are influenced by a wide range of factors. It is important to focus on what is the goal.

Regarding the time put into the energy modeling, it is important to realize that the model takes significant work to get results that are logical.

When the outdoor air is provided by mechanical ventilation according to the design specifications, electric energy use increases as fans are utilized to bring the air to the spaces.

11 FUTURE WORK

The extent of the thesis was focused on reducing energy consumption by analyzing various strategies that are common in the renovation of a single-family home.

The time used to study the topics, implement the simulations, and write this document, was a constraint to explore additional details that arose during this work.

Future studies could analyze the impact of climate change using a Life-Cycle Assessment approach. Life cycle costings could also be studied to determine the total cost of the systems over their life cycle.

Regarding the heating plant, ventilation and DHW system, IDA-ICE Advance level provides a platform for parametric analysis of building renovation measurements. Modeling the systems' components behavior to further reduce the consumption and lower the CO_2 emissions could be studied next.

Lastly, consider a data-driven approach and the benefits of electricity demand response changing the time of electricity use from peak hours to low-cost electricity prices. IDA-ICE could be used to study the effect of the demand response on the energy efficiency when real time data of the systems behavior are measured.

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ATTACHMENTS

Attachment 1. Input Data

The input data for the base case and improvement strategies are shown in the tables below. default values given in the Finnish standards have been used when there was no information available.

Table 1 throughout T able 5, summarize the input data for the studied cases.

Table 1 – Building Envelope U-values

Building Envelope	**U-Values (W/m^2. º C)**				
	Base Case	Case-2	Case-3	Case-4	Case-5
Outside Wall	0,43	0,17			
Roof	0,47	0,09			
Floor	0,47	0,17			
Windows	2,80	1,0			
Doors	2,20	1,00			

Table 2 – Building Envelope Infiltration rates

Building envelope Infiltration rates		**(m^3/ (h m^2)**				
		Base Case	Case-2	Case-3	Case-4	Case-5
q_{50}	m^3 / (h m^2)	6	2	2	2	2

Table 3 – Heating Systems

HEATING SYSTEMS	Base Case	Case-2	Case-3	Case-4	Case-5
Heat production	Wood-Electricity backup	Wood-Electricity backup	Air water source heat pump	Air water source heat pump	Geothermal heating + PV panels
Heat Distribution systems	Hydronic radiators	Hydronic radiators	Hydronic radiators/floor heating	Hydronic radiators/floor heating	Hydronic radiators/floor heating
Supply/Return design temperature °C	70/40	45/35	45/35 (radiators)		

Table 4 – Ventilation Systems

	Base Case	Case-2	Case-3	Case-4	Case-5
Ventilation System	Natural Ventilation			Supply and exhaust ventilation with heat recovery	
Heat recovery efficiency	-			79%	

Table 5 – Fans

		Base Case	Case-2	Case-3	Case-4	Case-5
Supply Fan SFP	**Kw/(m^3/S)**	-		1.0		
Exhaust Fan SFP	**Kw/(m^3/S)**			0.33		
Supply air Temp Setpoint	**C**			17		