DESIGN OF AN
UNDERGROUND SEASONAL THERMAL ENERGY STORAGE
FOR A RECREATIONAL HOUSE

A comparison between the BTES and the USTES

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Abstract

Due to the ongoing climate change, new energy efficient solutions with long-term effects are being sought, which should replace known energy systems with more efficient ones. This thesis arose from the occasion to find out whether the underground seasonal thermal energy storage, (USTES), is superior to the well-known borehole thermal energy storage (BTES) system. In this thesis, the energy balances and the different model structures are explained in a direct comparison in order to determine the more efficient system. The comparison is guided by three key questions, mostly related to the USTES system. These questions relate to: The amount of energy that can be stored, the amount of energy obtained from the storage and how the USTES has advantages over the BTES.

In order to create optimal conditions for a comparison, the same approximately 150 m2 recreational house located in northern Finland with two apartments and utility building is used for both models. IDA-ICE, an energy simulation software, is used to create a 3D energy simulation model of the house. A set-up is created for both systems, which is described in detail. Both of these systems are then simulated in order to answer the key questions and finally to demonstrate the advantages of the USTES system.

Both models are simulated over a period of one year in order to include summer- and wintertime in the total energy balance. The software IDA-ICE includes many factors, such as the location, the climate and the ground conditions, thus enables a very real simulation. The USTES model was additionally checked by an expert for IDA-ICE simulations.

The results of the simulation show that the USTES system requires less purchased energy compared to BTES. The USTES has a slightly greater overall energy consumption due to the additional components, but the amount of purchased energy (electricity) is 60% lower.

This knowledge is decisive for the further planning process of the house. On the other side, this could be an approach for further research in the optimization of the USTES system.

Keywords	energy efficiency, BTES, UTES, IDA-ICE, energy simulation, Finland
Pages	44 pages and appendices 3 pages

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I am very happy with the years I studied International Civil Engineering so far. My journey started at the University of Applied Science in Mainz, Germany and is now coming to an end with my bachelor thesis at the Häme University of Applied Sciences, Finland. It was a good to participate in the exchange possibility and move to Finland for a year. During my stay, I was able to get to know a lot of interesting people who, taught me a lot of new things about engineering and new personal perspectives on many topics. I would like to say thank you to all those who have supported me along my journey.

A special thank you goes to Jarmo Havula, it was a pleasure for me to get involved in your ongoing project. This offered me to relate my bachelor thesis to a real project, to advance this project and so the research on thermal energy storage.

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Jan Philipp von Schilgen
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Abbreviation list

AHU	Air handling unit
B2B	Brine to Brine
BTES	Borehole thermal energy storage
CAV	Constant Air Volume
CO2	Carbon dioxide
COP	Coefficient of performance
GSHP	Ground Source Heat Pump
HP	Heat pump
IDA-ICE	IDA Indoor Climate and Energy software
USTES	Underground seasonal thermal energy storage
VAV	Variable Air Volume

1 Introduction

1.1 Background and Topic

Due to the ongoing climate change, traditional ways of building are changing to adapt to the new climatic situation the world is facing. The construction sector is trying to find more efficient ways of building and is also developing more buildings with a low energy need. This is not only including the way of building, which can be optimised to reduce energy and water needs or to reduce CO2 emissions, it is the goal to reduce the energy consumption over the lifetime of the building to focus on more sustainable solutions. (BBC, n.b.)

The topic of this thesis "Design of an underground seasonal thermal energy storage for a recreational house" is a part of modern alternative ways of building, which may be more expensive to build, but are made to save money and energy over the lifetime of the building. The acknowledgement of these alternative ways is already existing but is currently still developing as the topic is getting more and more important due to increasing energy prices and an increasing global temperature. The important part of the modern alternatives is that they are more sustainable solutions which have the aim to improve the current state of impact on the nature and the climate with long-term effects.

1.2 Scope and Objectives

In this thesis, two thermal energy storages in a recreational house located in the northern part of Finland, are being compared under the topic of energy efficiency. The comparison is intended to provide new insights into the difference between the borehole thermal energy storage (BTES) and the underground seasonal thermal energy storage (USTES) and ultimately present the more efficient system.

The recreational house, which is currently in the planning phase, is getting analysed with the IDA-ICE 4.8 software. The software allows to recreate a 3D model of the planned house and offers the possibility to adjust the energy consumption in a lot of ways to create a model which is as close as possible to the real house and the real usage of components. For this, the two different thermal energy storage systems, the new alternative USTES and the traditional BTES, are being compared by their energy efficiency and other factors. The software will analyse both systems in a simulation over the period of one year. This includes all factors which can have an impact on the results (e.g., location, wind and materials). After the simulation and analysis of the data, it is possible to show the differences of both systems in their energy consumption, sustainability and their advantages.

Three main questions were selected to be answered about the USTES:

1. How much energy can be stored in the seasonal thermal energy storage?
2. How much of the stored energy can be used during the heating season?
3. How much advantage has the USTES compared to the traditional borehole system?

The goal of the comparison and analysis is to decide for the more efficient and sustainable energy storage system for the recreational house. The chosen system will be included in the further planning process of the project.

In order to further advance research on these systems and to obtain more precise data, there is the possibility of installing measuring devices during the construction process. These would enable a later comparison between the calculated data and the actual operational data.

2 Energy efficiency

The following paragraphs including a short introduction about the energy efficiency in the 2020s and the two energy thermal storage systems, which are getting used in the comparison in chapter 5.

2.1 Energy efficiency in the 2020s

As the topic of energy consumption and energy efficiency is getting more and more important in all sectors of life in the 2020s, so is the development of new energy systems in the building sector as well. Due to increasing energy prices it is more important to save energy costs, which could be solved by reducing the total energy consumption itself and by reducing especially the part of the purchased energy. Not only the COVID-19 pandemic, which started 2020, had a big impact on the building sector, the with it connected prices and markets (United Nations Environment Programme, 2020). The current geopolitical situation in Ukraine affects the energy markets dramatically because Russia stopped supplying parts of the European Union with gas and electricity (Xin, et al., 2022). Finland is one of the countries which Russia stopped supplying after a long time with gas and electricity. This long dependency makes it hard to find fast long-term solutions, to replace the gas and electricity demand. By reducing the energy consumption, more energy can be saved, which is not only a step forward to the climate neutrality targets, which Finland has set to

2035, it could be also a part of a solution to produce enough energy for Finland (Ministry of the Environment Finland, n.d.). Thermal energy storages are good solution to reduce the energy demand, which needs to be purchased additionally. This efficient energy saving systems do not only reduce the total energy costs, they are increasing the level of security of supply and also the energy efficiency level of the whole house (Letcher, et al., 2022, chapter 8.2.2). The goal by optimising known systems is to make them more affordable for private interested parties and finding new ways to increase the efficiency by adjusting components of the systems. These goals are part of the global decarbonisation which is focusing on the zero-carbon emissions building which should be achieved by 2050 (United Nations Environment Programme, 2020).

More detailed background information and reports about the energy efficiency in the 2020s related to Finland, can be found in the thesis “ENERGY SIMULATION OF SHEET METAL CENTER WITH IDA ICE SOFTWARE” (Nhung Nguyen, 2017, pp. 1-2).

2.2 Borehole Thermal Energy Storage (BTES)

One of the existing systems for reducing the energy consumption of buildings and optimising their energy efficiency is the BTES. The BTES consists of one or more boreholes which are around 50-200m deep. This borehole is filled with a U-pipe and grout which can help either in the winter with heating up the house or cooling it down in the summer. This system is connected to a ground source heat pump (GSHP), which pumps the liquid into the U-pipe and wins through the temperature differences form the heated or cooled liquid energy. The energy from the temperature difference is used to support the floor heating system to heat up the liquid to the needed temperature. It uses less energy as when the floor heating system must heat up the liquid by electric energy. (Skarphagen, 2019)

The ground temperature is over the year quite stable in this depth, aside from the air temperature outside (especially in Finland) (Kukkonen, 2000, p. 278). Therefore, the system has a constant heated or cooled liquid supply and is compared to solar collectors not depending on sunshine or warm air outside.

The BTES system is the most common system in this sector and is getting used for large industry buildings, factories and even for family houses. The versatility of this system is enabled by the opportunity of easily increasing the number of boreholes, which makes it even possible to build large fields of boreholes to adjust the energy efficiency of big industrial buildings.

2.3 Underground Seasonal Thermal Energy Storage (USTES)

The most recent system of energy storages is the USTES system, which may seem similar to the BTES because of its similar effects on the energy balance, has a crucial difference in its setup. The difference compared to the BTES is that the actual design is not a borehole, it is a thermal box or better even a whole thermal storage room. This room has to be located underneath or beside the building. But even if it is beside the building, it still must be below ground level to make use of the insulating properties from the surrounding soil, which cause a warmer temperature during winter. Furthermore, it is important that it is well insulated to keep the high temperature inside, so the heat loss is as small as possible. The thermal storage is filled up with a mixture consisting of sand, soil and gravel to further increase the capability of storing heat. Based on the chosen materials which it is filled up with, opens the opportunity of reaching different heat conductive values which can be optimized on the maximum temperature of the storage to achieve a reduction in heat loss. (Abdo, 2021)

In the form of a thermal storage, it will store energy as heat during the summer, which can be released during the winter when it is needed to support the floor heating system or domestic hot water (DHW) system. Next to this it can reduce the energy consumption of the whole house. The difference to the BTES is that the USTES is not able to help cooling down the house in the summer, without an external liquid loop outside the storage, as the heat is being already stored during this time and the release is exposed during summer.

The USTES system works in cooperation with a solar collector system which supplies the thermal storage with heat in the summer (Abdo, 2021). In the winter the solar collector system is switched off and the thermal storage is supplying through the HP heat to the heating system, as described above.

By this time (the 2020s), the use of USTES systems is not as famous especially when it comes to family houses. The more established system is the BTES system. The following comparison should display whether it would be more profitable to start using the USTES system in family houses than the before described BTES (chapter 2.2).

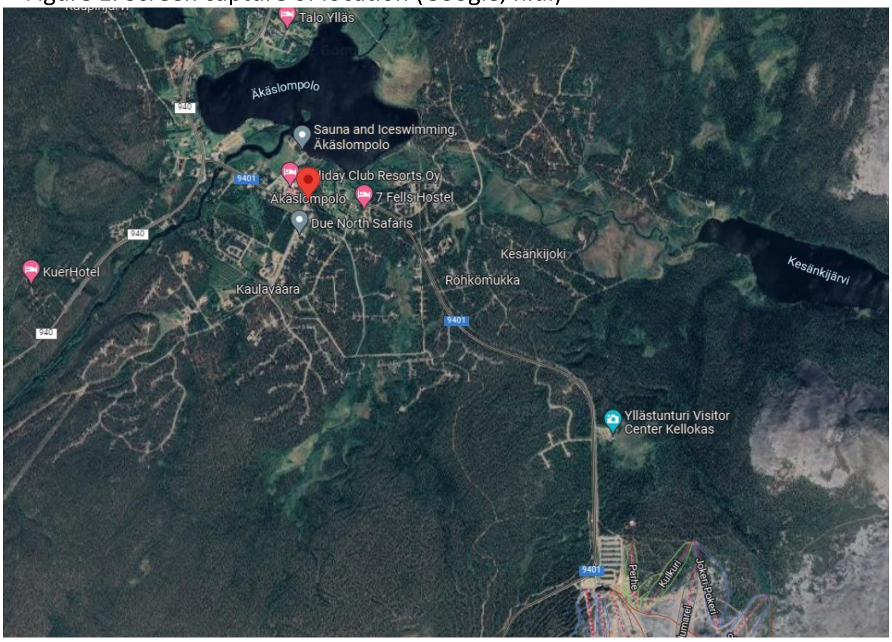
3 The project and the software

The following chapter presents the project to which the simulations and comparison relate to and also the IDA-ICE software, which is getting used to run these simulations.

3.1 The recreational house

The referred recreational house is currently in its planning phase, and it is set to start the building process in the middle of 2023. The location of the site is next to the town Äkäslompolo, Finland, which is about 50km away from Muonio, Finland. It is in a suburb area between the town and the countryside. The location of the recreational house is presented in the Figure 1. Because of needed privacy protection the accurate location will not be published in this thesis.

Figure 1. Screen capture of location (Google, n.d.)

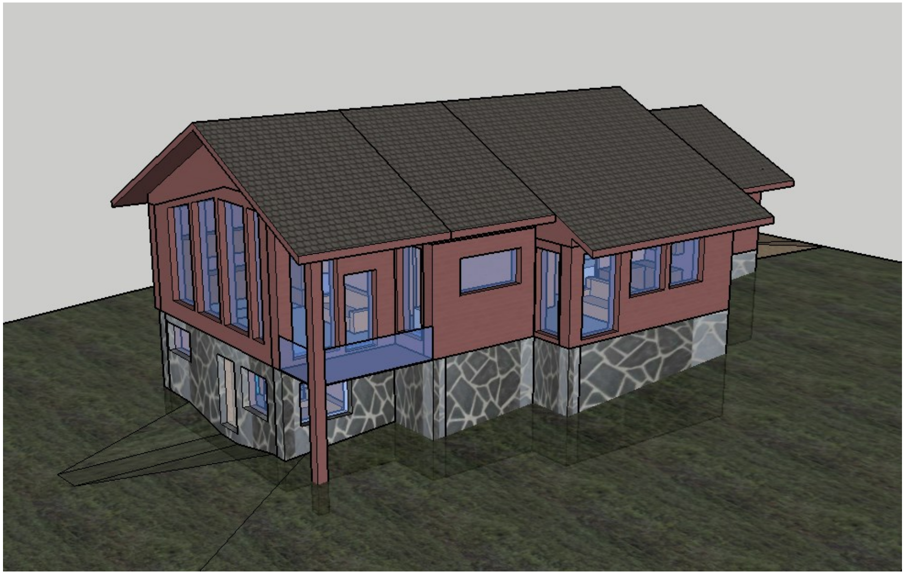


The house is planned with around 130 m^2 of two apartments and a 30 m^2 utility building, which are connected, on a plot size of around 1200 m^2. One of the apartments is for four persons and the other one for two, but it is also possible to increase the number of persons for each apartment by two, if needed. The 130 m^2 area is divided in two floors, one of them is half underground as the plot is not even. In the bottom floor is the basement, dressing room, shower and sauna located, but also the thermal storage in the later mentioned USTES system in chapter 5.2. On the first floor are the bathrooms, living rooms and bedrooms located. Separately is a utility room located on the first floor which is only accessible from the outside.

The plans were created based on the Finnish building rules and the European building code. All the used materials and structures are thus approved and their properties are better or at least the minimum of the Finnish requirements.

The 3D view of the building is presented in the Figure 2 (Havula, personal communication, 25.04.2022). Based on this model, the simplified 3D model for IDA-ICE was created, to simulate the energy consumption of the building, presented in chapter 5.

Figure 2. SketchUp 3D model



3.2 IDA-ICE

The IDA Indoor Climate and Energy software (IDA-ICE) is used to analyse and compare the two different systems of thermal energy storages in this project which are explained in chapter 5. The IDA-ICE version 4.8 is used for this project.

IDA-ICE is a software, which can simulate with the appropriate data like weather files, location files, materials and their properties, the design and a lot of more details about the energy and climate components of the house, the behaviour of the house over a period of more than a year. This gives the user the opportunity to change very small details about the components being used and it is possible to see the effects on the climate and energy behaviour of the house. (EQUA Simulation AB, n.d. -c)

The output data of the simulations contains for every created zone the highest and lowest temperature, humidity percentage, energy use and a lot more details. For the following comparison is the topic energy consumption and their components the most important one because IDA-ICE gives the user the opportunity to create energy producing components like solar collector, solar panels or wind turbines, which can have a major impact on the results. In the results after the simulation, it is possible to see the overall energy consumption and the purchased energy, which makes a comparison between different thermal energy storages possible.

IDA-ICE is one of the most well-known software on the market which allows the users to create quite simple and easy setups for small houses or even rooms. A lot of components are provided with default setups and easy control schemes. With these prerequisites, simple energy calculations can be made. (EQUA Simulation AB, n.d. -c)

For more advanced calculations or advanced schematic models, such as in the case of the example in chapter 5.2, there are no default setups available by now. But for this special cases IDA-ICE provides the option to use the advanced model, in which an individual setup of the house's components can be created. The advanced modelling is not as easy as the simple energy calculations because the model needs special connections between components without which it would not work and so run no simulation. For better illustration it is possible to compare the advanced modelling with a plug-in box in which each connection has to be provided with a transferring property and certain components need a special number of requirements without which they cannot work.

Further background information about energy simulations can be found in the thesis "Comparative analysis of energy simulation" (Iudin, 2018, p. 35).

4 IDA – ICE Setup

The following points in the chapter 4, if not mentioned differently, are the same for both designs in chapter 5.1 and 5.2 as only the different thermal energy storages are getting compared and the general setup of the systems are identical.

4.1 3D Model and Materials

The design of the 3D model was created with IDA-ICE, based on the previous shown SketchUp model. IDA-ICE provides for this an included 3D-modelling-software.

The first step of creating the 3D model was to insert the different ground floor areas, which have been used later on as the different zones. These different zones are needed to set up the AHUs and other needs like floor heating, special energy consumptions and occupancy, fitted precisely on the zones area. The ground floor areas have been chosen fitting to the shape of the house, most of them are including more than one room, these assumptions have been made to reduce the time of creating the 3D model as it does not affect the results of the comparison. For the same reason, the terrain of the property, which is not actually flat, was considered flat. The building class one/two-family houses was selected of the available options from IDA-ICE`s database.

Partition walls and crawl space were not built into the IDA-ICE 3D model for project-specific reasons, but since this assumption was made in both designs, it has no influence on the comparison. Due to this waiver, the energy consumption and ventilation rates are actually lower than in this model simulated.

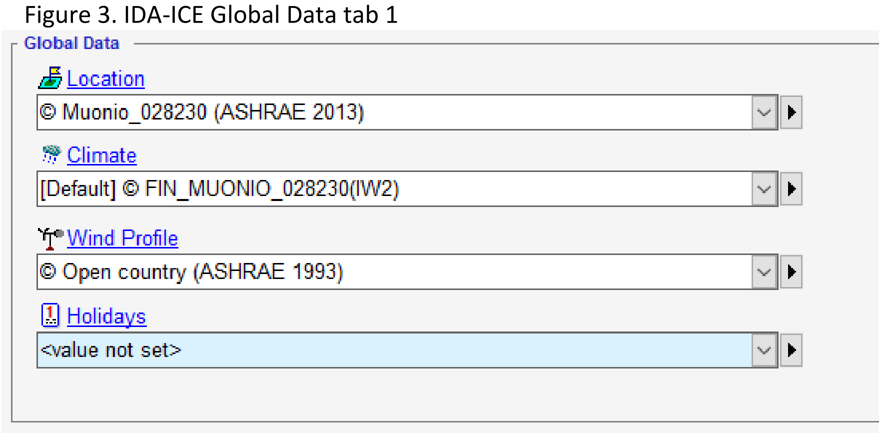
In the following table the materials and their specific U-values can be found. As IDA-ICE`s database does not include every material which was chosen in this project, similar materials with similar U-values and with almost the same thicknesses got chosen to provide a model which is as close as possible to the real building to get as accurate results in the simulations as possible. In Appendix 1 is the list of materials provided, based on which the materials in IDA-ICE were selected.

4.2 General setup

The setup of the general tab was the first step after creating the 3D model because it provides the basics IDA-ICE needs to set up the default settings. These default settings are based on the location of the building which can be chosen either from IDA-ICE`s database or external inserted, for example weather stations can provide this kind of weather-location files for those which are not by now in IDA-ICE`s database.

In this case the closest city, which is Muonio, is precise enough for the planned simulation and is also provided in the database from IDA-ICE. (EQUA simulation AB, n.d. -b) After adding the location file which includes common ground properties of this region and data about the ground temperature, the weather file from Muonio was added as well. The weather file gives information about the temperature over one year which got recorded from weather stations in this area over a long time. Next to this, it provides information about the wind direction, wind force and about the sun, how long it is shining and during which time of the year.

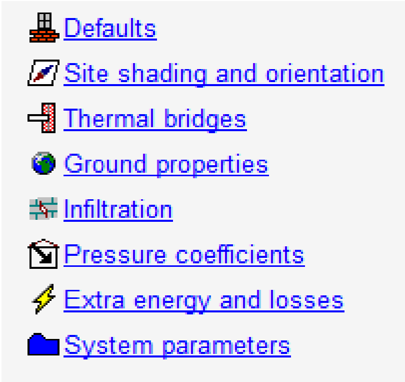
Figure 3. IDA-ICE Global Data tab 1



Once the location and weather file have been added, like in the picture above, it is possible to add holidays. For this project no holidays have been added as the purpose of the project is not a common residential house, it is getting used as a recreational house which is used by a special schedule (chapter 4.4).

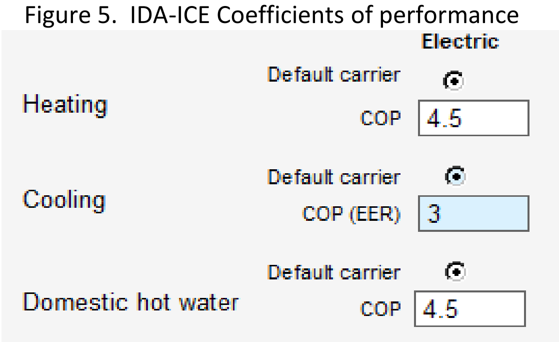
Before continuing with the individual zone setup, it is useful to enter the needed global data like shown in the following picture.

Figure 4. IDA-ICE Global Data tab 2



The tab default was explained before in chapter 4.1, under the name materials. But in addition to the materials the generator efficiency for standard plant and ideal heaters and coolers can be adjusted here. As heating, cooling and domestic hot water only runs on electricity the coefficient of performance (COP) was only set for the column for electric. Since this project is a new building and therefore only new high-quality devices are getting installed, the COP for heating was set to 4.5, for cooling to 3 and for DHW to 4.5 (Brennan, 2022).

Figure 5. IDA-ICE Coefficients of performance



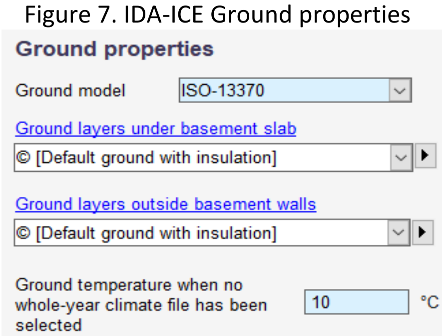
Site shading and orientation gives the user the possibility to set the north direction. Based on property plans the angle between the property direction and the north direction was calculated to 75.5°. This information is important for the simulation of the daylight, as later on the factor of the sun heating up the inside of the house, through windows, is taken into account of the energy consumption simulation.

All thermal bridges have been set to more than good because the house is getting build new and is fulfilling all Finnish guidelines and requirements. To make sure of this, all materials were therefore selected with consideration for optimal behaviour of the thermal bridges. The following picture shows on the right side the values with which IDA-ICE carries out the simulation.

Figure 6. IDA-ICE Thermal bridges simulation values

Since a location file and weather file were added beforehand, nothing needs to be changed under the ground properties tab because this data is automatically getting adopted by IDA-ICE.

Figure 7. IDA-ICE Ground properties



Except the tab for extra energy and losses were all other following ones left on default. In the tab extra energy and losses, the consumption of DHW was set to a 40L/per occupant and day for 8 persons. This value is based on a Finnish average water usage. (Ahmed et al., 2015) The consumption of the DHW is linked to the occupancy of the house by a schedule and thus only generates a consumption when the house is actually occupied. The schedules are discussed in more detail in chapter 4.4. The additional energy usage is different for the two systems (chapter 5.1 / 5.2) as the USTES system has more additional energy users. Only the sauna can be found in both systems as an extra energy user. The sauna has been added with an annual consumption of 3650kWh, this consumption has resulted from consultation about the frequency of use during the occupancy of the house.

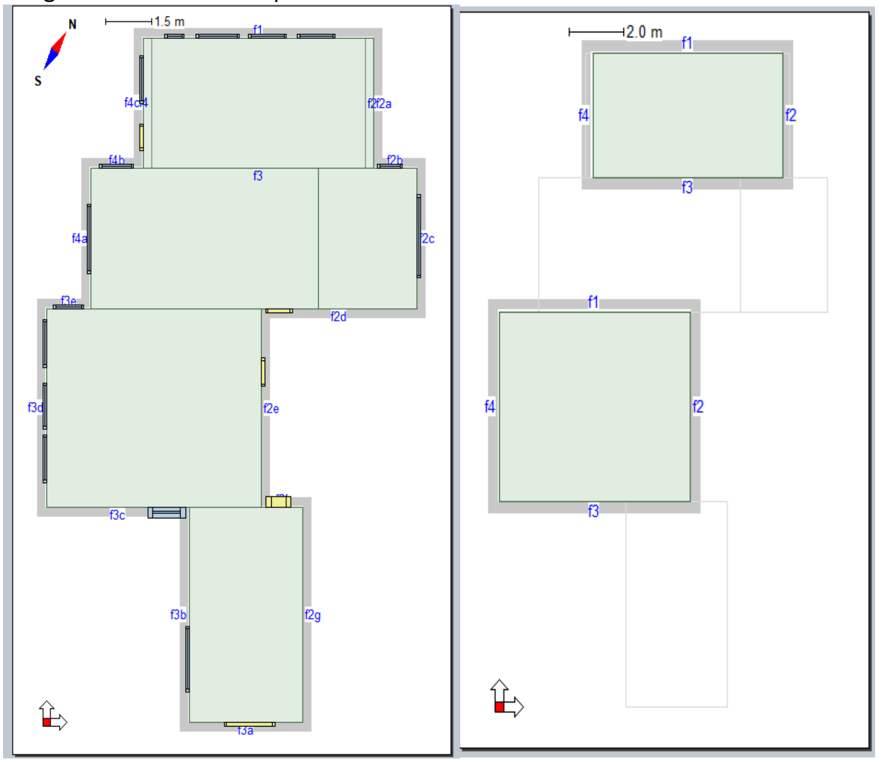
4.3 Zone setup

Once the general tab has been filled with all the needed information about the house and the location, it is needed to set up zones in the floor plans of the 3D model. The zoning helps later to adjust areas individually without changing the general setup and so other zones. It is good to set up first the general tab and then start with the specific zoning of areas, even if both is possible, this way it provides all the zones with the settings which have been made in general tab.

In “Appendix 3: Table of all zones (BTES)” and in “Appendix 4: Table of all zones (USTES)” a list is provided with the sizes, hights and more detailed information of the zones.

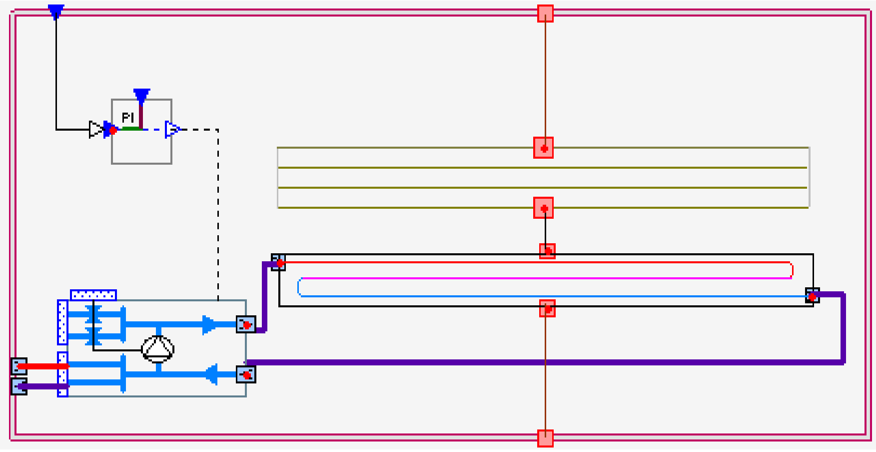
The areas for the zoning for this house have been chosen based on the shape of the floor area (building bodies), which gives enough leeway to make the appropriate adjustments for this project, as the priority is set to the comparison of the two thermal energy storages. The following picture shows the chosen zoning. On the left side is the ground floor level and on the right side is the basement which includes the sauna room and the USTES storage room (only in the design in chapter 5.2).

Figure 8. IDA-ICE Floor plans



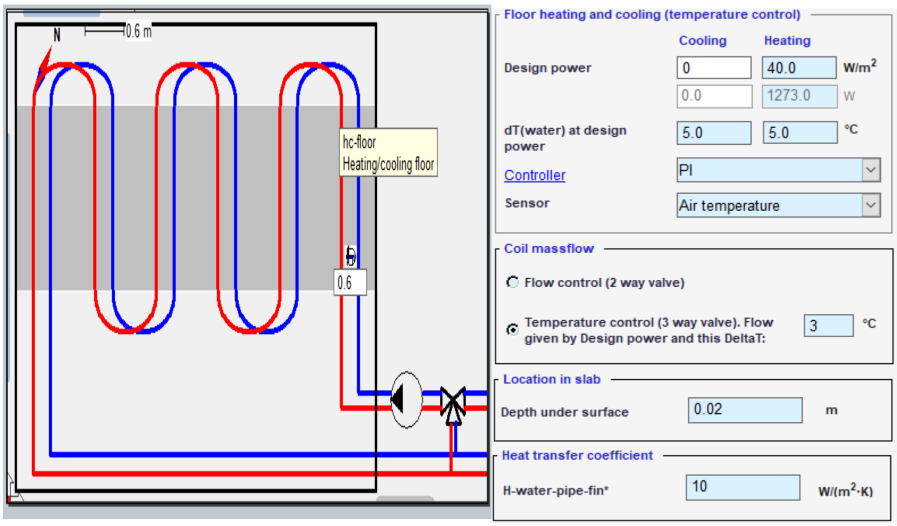
The created zones are heated with underfloor heating. The electronic underfloor heating that IDA-ICE proposes as a simplified component was not chosen for this purpose, but rather the underfloor heating with the hot and cold-water function from the schematic component structure. Since the cooling function is not to be installed in this project, it was removed from each zone in the schematic structure before creating the mathematical model which is needed for the final simulation.

Figure 9. IDA-ICE Advanced Floor heating Schematic



The geometry and setup, pictured in figure 10, was applied to all the different zones. The design power for heating was set to 40W/m2. The piping of the floor heating system was installed 0.02m under the surface.

Figure 10. IDA-ICE Floor heating geometry and setup



In the individual settings of the zones the right AHU (chapter 4.5) was chosen and the control system set to an Variable Air Volume (VAV) system which is connected to the indoor temperature. This system was preferred for energy saving reasons compared to the Constant Air Volume (CAV) system. (Pacific Northwest National Laboratory, n.d.)

Next to the control system, occupancy and light has to be set up in the individual settings. Except the zone of the utility room were all zones equipped with common light schedule and occupancy, as all the other rooms are considered as living space.

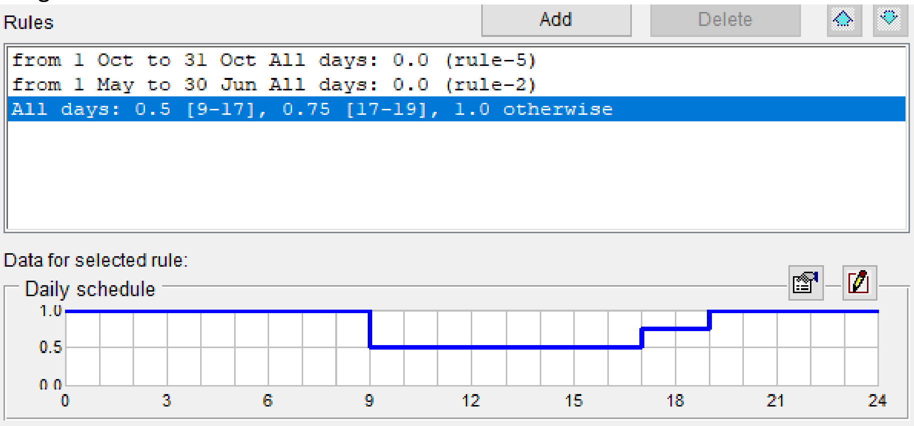
4.4 Schedules

IDA-ICE offers users the function of creating schedules. These schedules can be used in very simple situations, for example when scheduling holidays, or in more complex situation. This complex situation can be such as the plant model and its components itself or macro models, which can be either component groups or control units.

For this project, a schedule was created that controls the occupancy of the house, since the planned house is a recreational house and is therefore used less often than a regular house.

Thus, as already mentioned above (chapter 4.2), the holiday function was not used. In order to control the occupancy of the house as realistically as possible, the occupancy for the months of May, June and October were set to zero, since the house is most likely not occupied in these months. In all other months, the occupancy was managed so that the house is 100% occupied between 7pm and 9am, 50% between 9am and 5pm and 75% between 5pm and 7pm. This schedule has been prepared to consider day trips and similar things that the occupied times are as close as possible to the real situation. The same schedule controls the lighting times.

Figure 11. IDA-ICE Schedule



To reduce the energy consumption of the house the before mentioned schedule is used to control the AHU and the plant in its providing ventilation rate and heat supply. During the times, the house is not occupied the temperatures do not have to be as precise as when it is, that means during the time it is occupied the set temperature is 21°C and during the non-occupied time to 15°C. The utility room is all the time set to a 10°C as the room is not considered as living space and rarely used.

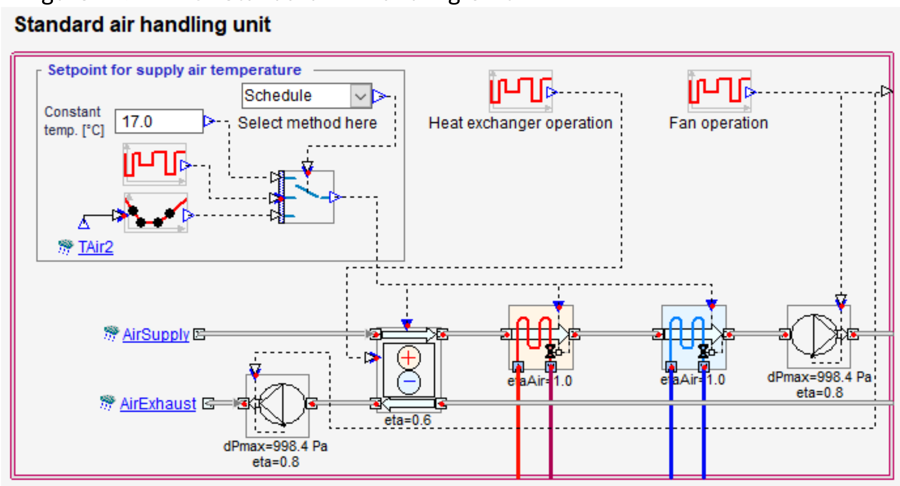
For the USTES system and the control of it more schedules are getting used which are further explained in the chapter 5.2.

4.5 AHUs

For the sake of simplicity, only in the IDA-ICE model two AHUs are getting used. In real it is possible to use one AHU and it is only needed to add special devices that can control one room (utility room) differently to avoid unnecessary energy consumption as this room has special needs and it is not connected to the rest of the house as it is only accessible from the outside. The room can be heated less than others but should not have a temperature less than 10°C. The control devices should be able to disconnect the room from the AHU as long the minimum and maximum of the temperature limit is not exceeded, and it should have as well a function for a manual handling, if for example some work is to do in the utility room.

The following picture shows the default setup of a standard AHU from IDA-ICE. The important component for a high energy efficiency is the heat exchanger which transfers a part of the heat of the outgoing air to the incoming air. (Schild, 2004) For this project the standard AHU was sufficient, as the heat exchanger is built into it and so it was used for both AHU`s.

Figure 12. IDA-ICE Standard Air Handling Unit



The supply air temperature for the living space is 17°C and for the utility room 10°C. The temperatures are only for the supply air and not the final room temperature as the other part of the final temperature is coming from the floor heating system.

4.6 Plant devices

The following devices are components for the two plant models, described in chapter 5.1 and 5.2. The ones mentioned below are for both designs the same, if not mentioned differently, and there are no differences in their control schemes.

Hot water tank

Adapted to the required amount of hot water for six to ten persons, which is 40L per person per day in this project, a size of $1m^3$ hot water tank was chosen. The hot water tank could have been smaller, but in order to fulfil a high demand of hot water during the evening caused from usage of the sauna, showers and other devices.

Cold water tank

The cold water tank is only theoretically included in this IDA-ICE project to round off the calculations and to give the system a value for the calculations and simulation. This means that the cold water tank will not be built into the real project, but will be built into the plant model with an almost infinite size to represent a cold water connection to the city's existing district supply system.

Top up heater

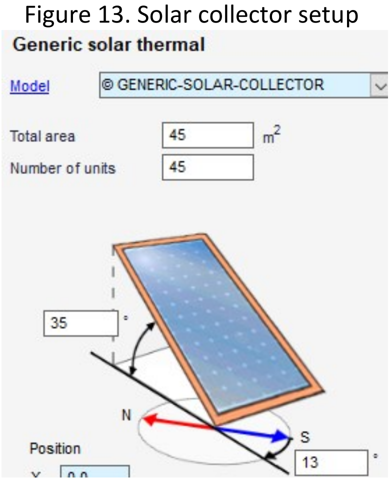
A top up heater had to be installed in the plant, it simulates the heating next to the thermal energy storages which are seen as the first source of heat and the top up heat as the second. This concept is to use the full available amount of heat, the thermal energy storages can provide. In the case the provided heat is not enough, the top heater, which works with electricity, is starting to support the system and heats the system to the needed temperature up. Later on, the from the top up heater consumed energy can be reflected in the results under purchased energy.

Solar collectors

Solar collectors were chosen only for the setup of the USTES system, as they are needed to heat up the thermal energy storage which makes them in this case indispensable for the design in chapter 5.2. For the design in chapter 5.1 solar collectors would be only used to support the DHW, which is non-essential to keep the BTES running. For this reason, the decision was made to not use them for the BTES system.

The solar collectors consist of an area of 45 m^2 in the USTES which are installed on the roof of the utility room. The solar collectors are installed with an angle of 17° from the roof pitch and an additional 35° from the angle in between the solar collector to the roof.

Figure 13. Solar collector setup



Heat pump

A brine-to-brine heat pump from IDA-ICE`s database was selected for both plant models. The B2B-HP-model was used in a similar situation before and has proven to be a good component for this kind of simulation with systems including thermal energy storages. (Nguyen-Ky, 2019, pp. 31-35)

5 The two different thermal energy storage systems

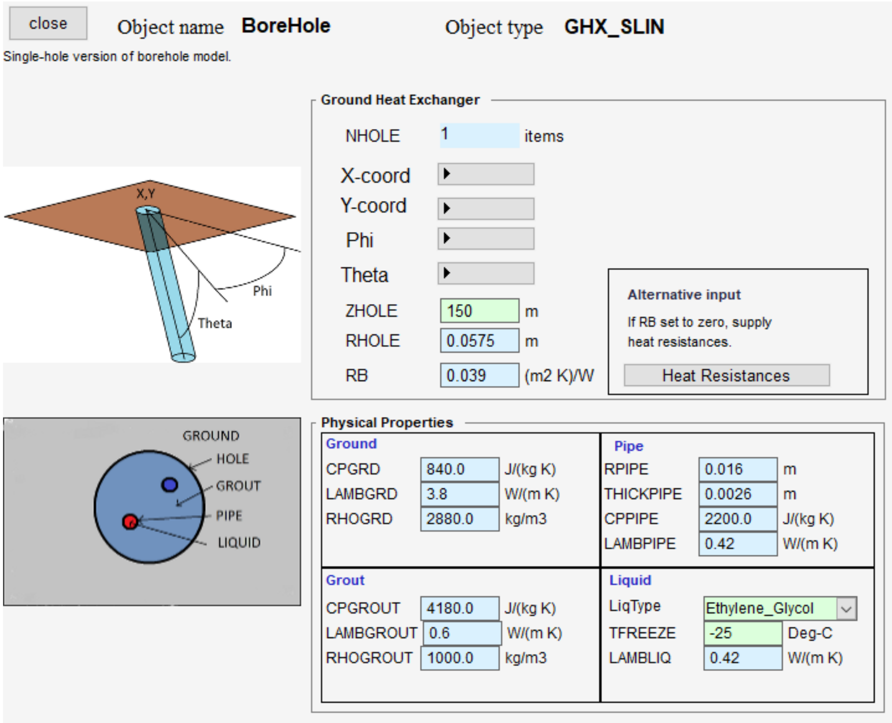
5.1 System 1 – BTES

The setup of the BTES is based on the available components from IDA-ICE, as they provide a simplified setup of the BTES for which normally no advanced model is needed. In this case the advanced model was only used to adjust a few settings to set up the same initial situation as for the USTES in chapter 5.2, more details about the changes in the advanced model can be found in the following paragraphs. (EQUA simulation AB, n.d. -a)

The information about the ground properties is provided from the location file (chapter 4.2), that means IDA-ICE fills out automatically the needed data with a pre setup which still can be edited if necessary.

The following picture shows the settings window for the borehole, in which the number of boreholes was set to 1 and the depth of the borehole to a 150m. The depth of the borehole, as shown below, was adjusted to find the optimal balance between efficiency and depth. This should prevent an unnecessarily high workload from drilling and so too high building-costs. The values for ground properties, pipe values, grout properties and the liquid properties were left on default as they are either the common average value or connected to location file. (Eswiasi, 2021)

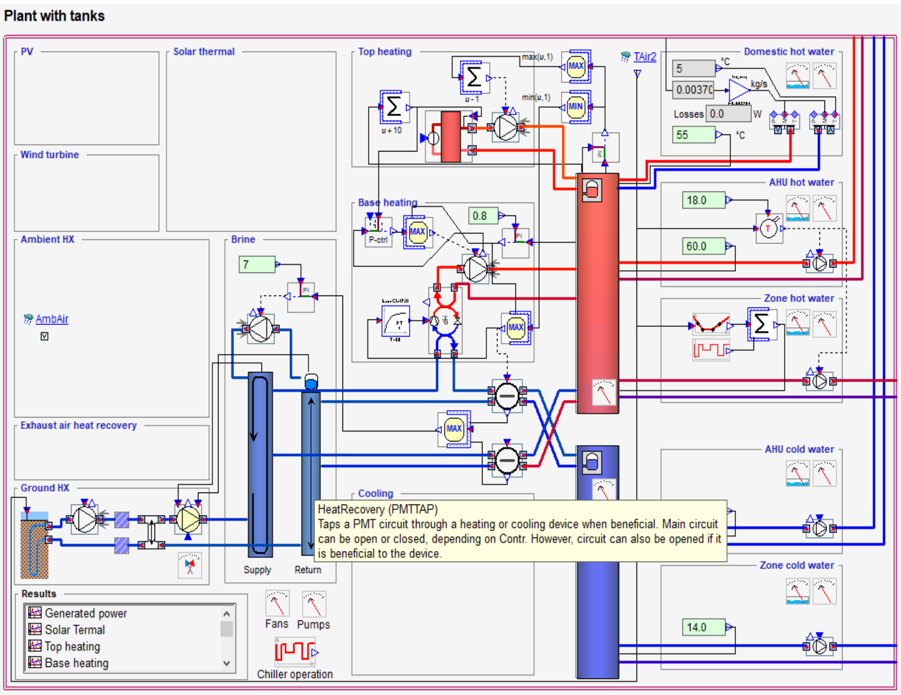
Figure 14. IDA-CIE Borehole settings



In order to optimise the depth of the borehole different pre-simulations have been made and it showed that a depth of 150m is the most efficient for the borehole. After 150m, the temperature in the ground does not increase as much anymore that the cost for drilling deeper would be worth it. The amount of kWh for 150m is around 12896.9kWh and for 250m it would just increase up to 13066.8 kWh. These results are over the average of this kind of borehole, as 5kW/d is the common result for up to 100m deep boreholes, for this case it is about 35kW/d (Reuss, n.d.).

The borehole heat is getting used on one side to support heating up the DHW and on the other side for the support of the floor heating system. If this project would make use from double floor piping (heating + cooling) it could support as well in summer by cooling down the liquid and so save energy which is needed to cool the system. This option is not used in this project as the location is in Lapland, Finland and the need of cooling devices is according to the low temperatures unnecessary.

Figure 15. IDA-ICE Plant setup BTES



5.2 System 2 – USTES

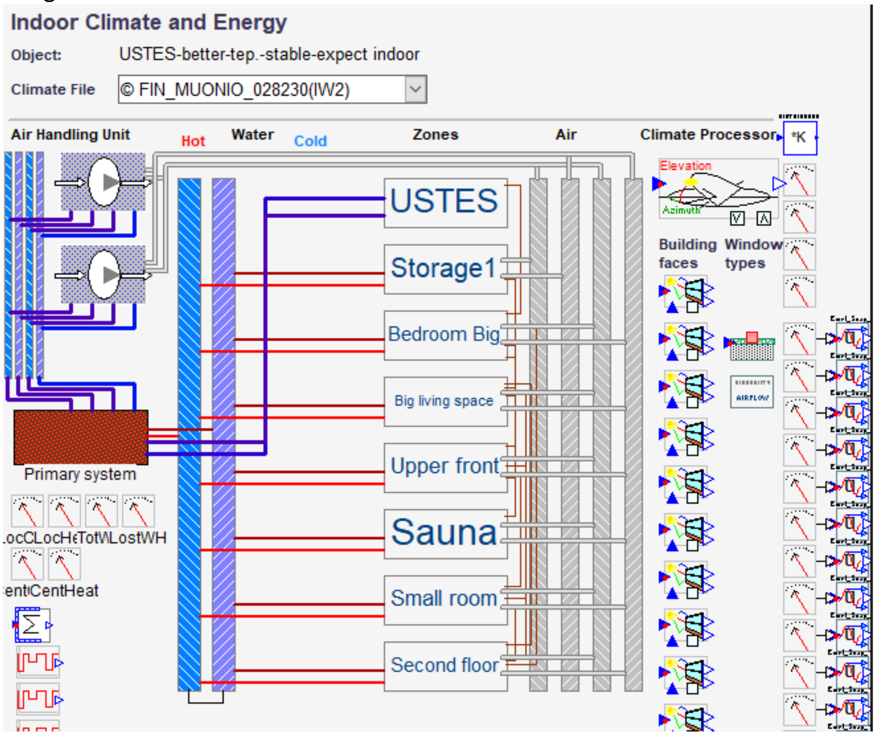
The design of the underground seasonal thermal energy storage (USTES) had to be designed in the advanced level of IDA-ICE where the user has the possibility to create an own model. This model is getting edited in a schematic tab which only pops up when the advanced level is getting used.

Before it is possible to create the advanced model the user must enter all settings from the chapters before, as most of them cannot be edited once the advanced model is built. This concerns especially all structural steps around the 3D model and the whole plant setup including the components. The components properties can only be edited later own through the schematic tab by finding the right component and using the outline or code tab. Attention is needed while editing the outline and code tab, as mentioned before each component has often many input and output connections and so the other affected components must be adjusted as well.

The general schematic tab is shown in the next picture. Through this tab all the different zones can relate to each other. This is the case, for example, when two or more zones touch structurally and share a wall, ceiling or floor. The connection is then used to pass on the generated data in the other room, such as wall and room temperature, to the directly connected zone and so enable their interaction.

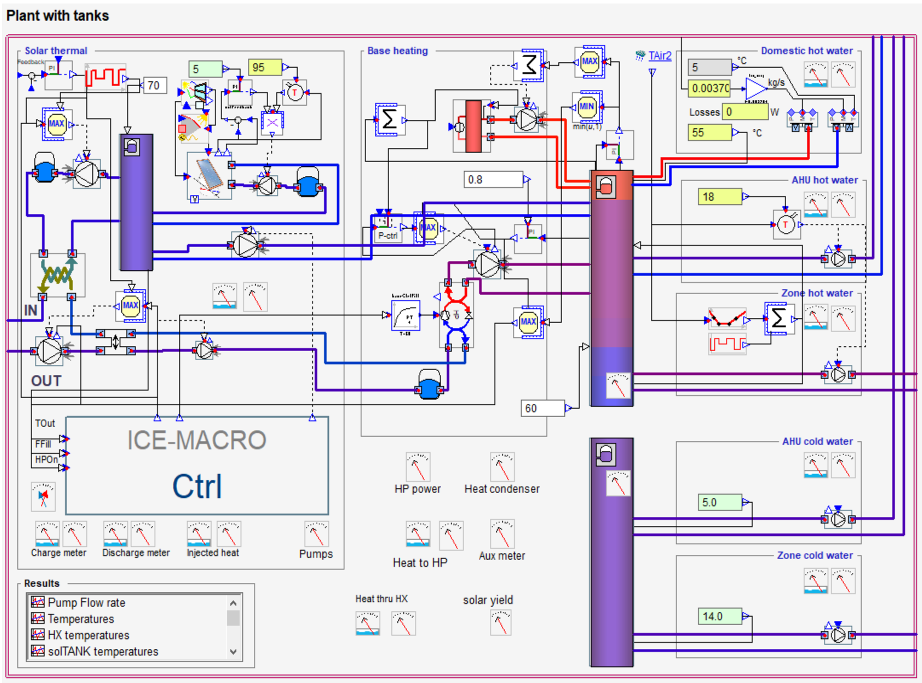
The primary system stands for the plant model which was built earlier with the chosen components in chapter 4.6. In this case the plant model had to be recreated as IDA-ICE does not provide a simplified USTES component by now, in the following paragraphs this is getting further explained. In the picture below only the connection between the USTES and the primary system had to be created. The connections between the zones and the hot water were automatically built as the floor heating system was selected earlier and so IDA-ICE was only connecting the two system. The same applies to the AHU systems as they have been adjusted earlier and the zones have been provided with the needed data, IDA-ICE is able to connect the pre-selected systems.

Figure 16. IDA-ICE Advanced mode



As previously mentioned, is the plant setup created by hand and not a simplified component of IDA-ICE`s database like the BTES system. This example of an USTES system was closely created based on the example of Sy Nguyen-Ky`s thesis. (Nguyen-Ky, 2019, pp. 30-35) The greatest difficulty, as mentioned several times before, was to set up the appropriate connections between the individual components as input and output values have to equal. For this purpose, many preliminary simulations were carried out in order to identify errors at an early stage and rectify them as quickly as possible. Another major difficulty was that the example of Sy Nguyen-Ky was adapted to small scale building and this project to an about 200 m2 large recreational house. In order to overcome this problem, each component was adapted to the new size of the USTES system. The following picture shows the whole plant model (primary system) including all the mayor components mentioned in chapter 4.5.

Figure 17. IDA-ICE Plant setup USTES

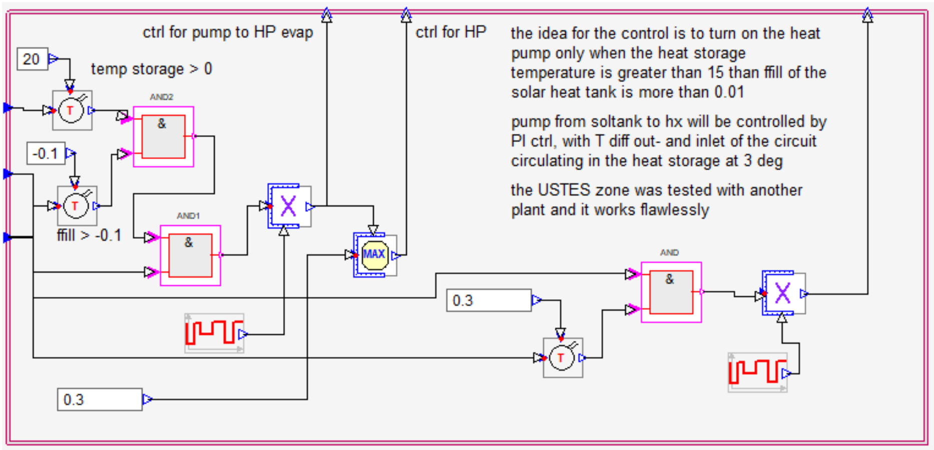


Apart from the already mentioned components is the solar collector system connected to a tank where the heated fluid is only getting released when the temperature gets higher than the temperature inside the USTES, which is getting explained in the following paragraphs, to avoid the problem of cooling the USTES down during for example cloudy days. The solar collector system is also linked to a schedule which is controlling the operation during winter and summer time so that the solar collector system is turned off during the period between 1st of November and the 31st of January because of the cold weather and possible snow on top of the solar collectors.

The released heated fluid heats up the circulating USTES fluid, through a heat exchanger. Once the USTES fluid is heated up, the fluid is going into the USTES which can be seen in the plant model on the left side at the IN sign. The USTES room was created as a room with an hight of 2.5m which is sized like the zone “bedroom big” but is located underneath it. The special feature of this room is that it is filled with a sand, gravel and earth mix which can be seen in the picture entitled "USTES piping solution". Only the pipes with the heated liquid are located next to the filling mixture in this room. These pipes ensure that the filling mix is getting heated up and that the room, thanks to its special insulation properties, stores this heat over the summer and can let it out in winter during the heating period.

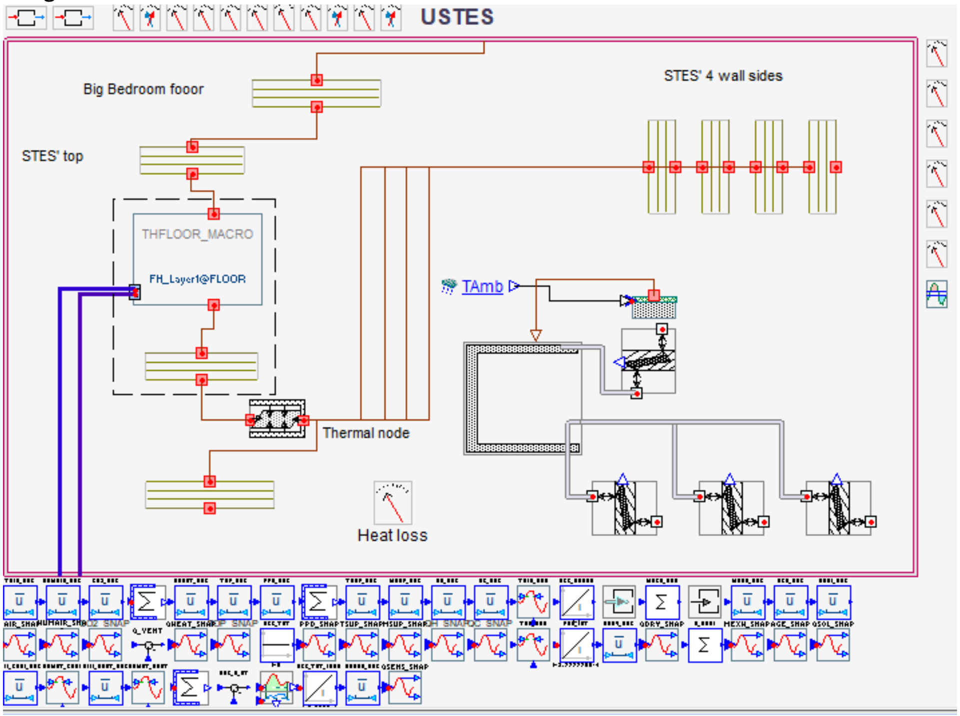
The following picture shows the so called "ICE-Macro" control tab which can also be seen in the plant model. This control tab is the general controller of the USTES system and its components. It includes if and else rules and sends via output connections the right parameters to the HP and the hot water tank, which controls the amount of heat getting released from the USTES and the operation of the top up heating to stabilize the hot water supply. (Nguyen-Ky, 2019, pp. 31-35)

Figure 18. IDA-ICE Plant Marco controler



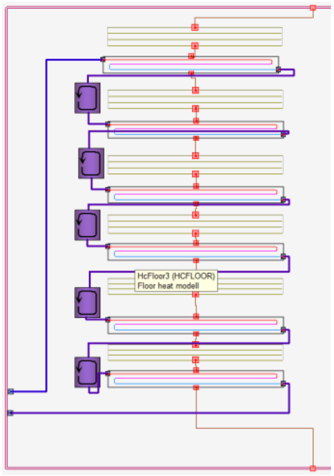
The picture "USTES zone model" is the classic tab of a zone setup, but the difference is in the "THFLOOR_Macro" model which was added to simulate the actual piping in the USTES room. The walls, floor and sealing, with their special insulation properties, have been disconnected from the old zone system which can be seen on the right side. Thus, it considers that the room does not have the common behaviour as other rooms and disconnect the inside of the USTES with IDA-ICE`s default behaviour settings. (Nguyen-Ky, 2019, p.33)

Figure 19. IDA-ICE USTES Zone model



As described in the previous paragraphs, the actual USTES room setup is in the next picture. It is symbolising the with the mixture filled room and its piping situation.

Figure 20. IDA-ICE USTES Piping solution



6 Simulation results

The simulation of both systems, described above, was carried out under the same conditions and pre-settings, this serves to create optimal conditions for the following comparison.

The simulation was carried out over a fixed period of one year. Start date is 03/01/2022 and end date is 02/28/2023. This period was chosen to create equal conditions for both systems, since the USTES system can only support heating if heat is also stored there. Therefore, it was necessary to start in March, as this is the start date of the USTES system to store heat (chapter 5.2).

In advance of the carried-out simulations, the setup of the USTES model was discussed with an expert in IDA-ICE simulations (Sy Nguyen-Ky). In his opinion, no adjustments that would significantly change the final results and so the discission between the systems, had to be made.

6.1 Results – BTES

The results of the simulation of the single borehole system consist of the following images. The first picture points out the total energy consumption of the described system in chapter 5.1. A total amount of 20935.0kWh is needed to heat up the house and supply all components with energy during the whole simulation period of 12 months. 9506.9kWh are needed for the zone heating, which is reflecting the floor heating system, 6791.2kWh are needed for DHW system and 4636.9kWh for the AHU system.

Figure 21. BTES total energy consumption

Building

Systems energy

	kWh
Zone heating	9506.9
Zone cooling	0.0
AHU heating	4636.9
AHU cooling	571.0
Dom. hot water	6791.2
Cooling	571.0
Heating	20935.0

The delivered energy for the BTES system has a total amount of 13599.8kWh, which is needed in addition of what the borehole and the heat exchanger can provide, to heat up the house during the winter. The total amount includes all components of the system which are consuming energy and which cannot only be supplied with the internal produced energy, as it is not enough.

Figure 22. BTES delivered energy

Delivered Energy

Meter	Total, kWh	Per m2, kWh/m2	Peak demand, kW
Lighting, facility	305.2	1.508	0.1569
HVAC aux	1904.7	9.412	3.047
Electric heating	297.0	1.468	1.959
Equipment, te...	4057.6	20.05	4.892
Heating, tenant	7035.3	34.77	2.823
CHP electricity	0.0	0.0	0.0
Total	13599.8	67.21	12.88

A monthly used energy table is provided from IDA-ICE to see the exactly used energy for zone heating in each month. It gives the possibility to find out the consumption peak in “moth 13” or the lowest in “month 6-8”. Next to this the total used energy amount is again provided like in the figure 21 but now it is possible to figure out the monthly breakdown.

Figure 23. BTES used energy

Used energy

kWh (sensible and latent)

Month	Zone heating	Zone cooling	AHU heating	AHU cooling	Dom. hot water
3	907.3	0.0	577.1	0.0	771.3
4	269.5	0.0	442.6	0.0	745.2
5	33.1	0.0	0.7	0.0	0.0
6	0.0	0.0	0.4	0.0	1.3
7	0.0	0.0	49.0	366.9	771.3
8	0.0	0.0	49.0	201.7	771.3
9	53.0	0.0	134.6	2.4	745.2
10	1352.0	0.0	1.0	0.0	0.0
11	1503.0	0.0	705.7	0.0	746.4
12	1823.0	0.0	935.8	0.0	771.3
13	1995.0	0.0	1013.0	0.0	771.3
14	1571.0	0.0	728.0	0.0	696.6
Total	9506.9	0.0	4636.9	571.0	6791.2

The utilized free energy expresses the amount of energy which can be saved due energy efficient systems, which are reducing the final needed energy amount. In this case the produced ground heat arises over an amount of 12896.9kWh and the AHU recovery with the heat exchanger over 8896.6kWh. The ground cold can take over a cooling load of 323.9kWh in the summer. Since all values are recorded monthly, maximum and minimum values can be identified very quickly.

Figure 24. BTES utilized free energy

Utilized free energy

kWh (sensible and latent)

Month	AHU heat recovery	AHU cold recovery	Plant heat recovery	Plant cold recovery	Solar heat	Ground heat	Ground cold
3	923.5	0.0				1440.0	0.0
4	966.6	0.0				961.5	0.0
5	0.0	0.0				51.8	0.0
6	16.0	0.0				21.6	0.0
7	857.4	-0.0				403.0	-207.1
8	585.5	-0.0				465.5	-116.8
9	634.8	-0.0				634.2	0.0
10	0.0	0.0				920.4	0.0
11	1119.8	0.0				1849.0	0.0
12	1342.1	0.0				2117.0	0.0
13	1364.3	0.0				2228.0	0.0
14	1086.7	0.0				1805.0	0.0
Total	8896.6	-0.0				12896.9	-323.9

6.2 Results – USTES

The results of the USTES simulation showed up differences to the previously executed BTES simulation. The total consumed energy of the complete system can be seen in the next figure. The heating of the whole house during the period of one year needs a total amount of 26742.9kWh of which most of it (17844.0kWh) can be related to the zone heating which can be considered as the floor heating system. The DHW system consumes during this period an amount of 5601.1kWh and the AHU system 3297.8kWh.

Figure 25. USTES total system energy consumption

Building

Systems energy

	kWh
Zone heating	17844.0
Zone cooling	0.0
AHU heating	3297.8
AHU cooling	0.114
Dom. hot water	5601.1
Cooling	0.114
Heating	26742.9

The delivered energy, which is the energy the system cannot provide by itself and has to be bought, includes an amount of 8144.6kWh and can be seen in the next figure. This includes all components of the system that cannot be operated with sufficient energy from the USTES and solar collector system.

Figure 26. USTES delivered energy

Delivered Energy

Meter	Total, kWh	Per m2, kWh/m2	Peak demand, kW
Valaistus, kiin...	306.1	1.512	0.1569
LVI sähkö	1582.2	7.817	2.496
Sähkölämmity...	5857.1	28.94	1.245
Laitteet, asukas	399.2	1.972	0.075
CHP tuotto	0.0	0.0	0.0
Total	8144.6	40.24	3.973

Translation:
Lighting
HVAC electricity
Electric heating
Equipment, tenant
CHP return

For the total consumed energy, IDA-ICE provides a table with a monthly consumption of the period of 12 months. This allows to see the difference in the consumption between summer and winter operation.

Figure 27. USTES used energy

Used energy

kWh (sensible and latent)

Month	Zone heating	Zone cooling	AHU heating	AHU cooling	Dom. hot water
3	2197.0	0.0	469.3	-0.0	472.7
4	1241.0	0.0	326.8	-0.0	527.7
5	977.0	0.0	0.7	-0.0	572.6
6	360.9	0.0	0.4	0.0	572.6
7	94.1	0.0	28.0	0.1	546.6
8	122.2	0.0	38.0	0.0	598.7
9	364.8	0.0	119.0	0.0	572.6
10	2308.0	0.0	1.0	0.0	529.2
11	2438.0	0.0	480.5	0.0	395.3
12	2588.0	0.0	615.7	0.0	315.7
13	2774.0	0.0	666.1	0.0	260.2
14	2379.0	0.0	552.3	0.0	237.2
Total	17844.0	0.0	3297.8	0.1	5601.1

The same kind of table is as well provided for the utilized free energy, which includes the AHU heat recovery of the heat exchanger and the solar collector system. As in the previous table, it is also possible to see the difference between summer and winter operations and the total amount of 12 months operating.

Figure 28. USTES utilized free energy

Utilized free energy

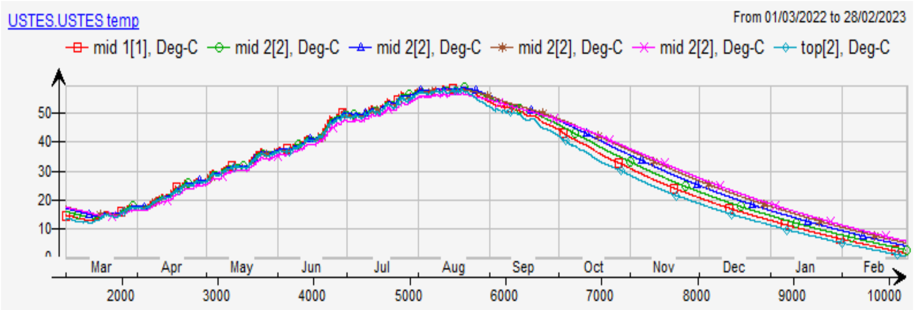
kWh (sensible and latent)

Month	AHU heat recovery	AHU cold recovery	Plant heat recovery	Plant cold recovery	Solar heat	Ground heat	Ground cold
3	644.1	0.0			681.7		
4	538.9	0.0			1502.0		
5	0.0	0.0			2076.0		
6	1.2	0.0			2154.0		
7	312.4	-0.0			1653.0		
8	309.2	-0.0			904.7		
9	369.2	-0.0			437.7		
10	0.0	0.0			131.2		
11	603.1	0.0			-0.0		
12	616.6	0.0			-0.1		
13	613.6	0.0			-0.1		
14	566.4	0.0			20.1		
Total	4574.9	-0.1			9560.1		

The following diagram is pointing out the recorded operating temperature inside the USTES. It is possible to read out for each moth the reached temperature and so the minimum and maximum.

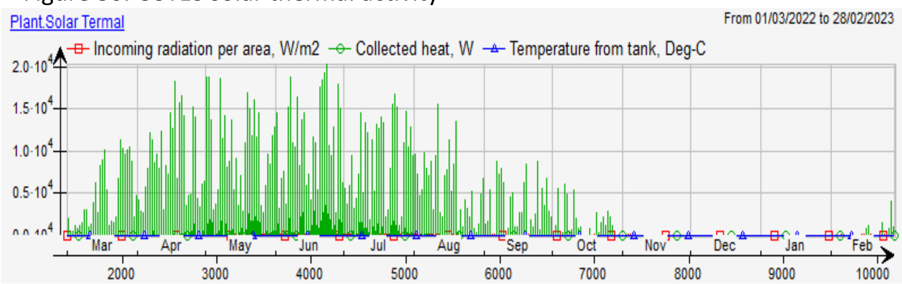
The different coloured lines are reflecting the different layers inside the USTES (chapter 5.2). The diagram is getting further analysed in chapter 6.2.1.

Figure 29. USTES - USTES recorded temperature



The diagram for the solar collector operation is reflecting the previously adjusted working period in the summer, as the diagram shows it is only operating between March and October. During this time it is providing, when needed, the whole heating system with heat or otherwise the USTES.

Figure 30. USTES solar thermal activity



6.2.1 How much energy can be stored?

According to the simulations carried out as described above, this question cannot be answered directly. Since the USTES system is not yet available as a simplified component in IDA-ICE, it cannot be directly resolved with a single value in the results. This is only possible because the USTES system has been provided with appropriate energy meters. It is therefore possible to deduct the delivered energy from the used energy and to attribute the difference in the remaining energy to the USTES system.

After the delivered energy has been deducted from the consumed energy, 18598.3kWh remain. This is the amount, the USTES system and its components can provide by themselves and so they are not taken into account to the delivered energy. According to the simulation results, 9560.1kWh of this is from the solar collector system. However, these 9560.1kWh form the solar collector system are not only suppling the USTES system. Since the solar collector system is also directly connected to the hot water tank and can also supply the whole heating system directly.

The maximum heat of the USTES is reaching a temperature of almost 60°C in all of his layers. This temperature is staring with a 15°C operative temperature in March 2022 and is reaching its peak in August 2022. Once it reached its peak the temperature decreases per month up to 15°C until it reaches February 2023, its all-time low. After February 2023 the solar collector system is starting its operation again and heat is getting stored again, so the temperature inside the USTES will not undergo the limit of 0°C.

6.2.2 How much energy can be used during the heating season?

As the results in figure 29 point out, the USTES system was successfully adjusted to the possible energy amount which it is able store during the summer. By end of February 2023 the thermal storage has released the whole amount of heat stored and is with all his layers in-between 0-10°C. This 0°C was set as the minimal temperature in the USTES to avoid problems like freezing fluid or filling mixture, as the unfreezing of any of these would cause condensation which can be problematic for the further use.

By increasing the size of thermal storage, the parameter which regulates the maximum of heat which can be released should be adjusted. These parameters are getting regulated in the previously described “Macro model” in chapter 5.2.

When thinking about increasing the size of the USTES, the connection between the size of the solar collectors, which are providing the heat and the with it connected maximum temperature in the USTES should be thought of. This is important as afterwards the maximal heat release has to be adjusted to not undergo the mentioned 0°C limit.

6.3 Comparison

In this comparison, as mentioned in chapter 1.2, the aim is to choose the more efficient system based on the lifetime of the building. Based on this question the most important value of the comparison is the delivered energy over the period of 12 month. As shown in the results in the chapter 6.1 and 6.2, the BTES system needs to its own produced energy an extra amount of 13599.8kWh. This is compared to the USTES system, which needs an extra of 8144.5kWh, a difference of 5455.3kWh per year. In percentage the USTES system needs only a 60% extra energy compared to the BTES system.

The COP of the whole system is calculated as follows: the Energy consumed divided by the purchased energy. According to this calculation the COP for the USTES system is 3.28 and for the BTES system 1.54. This points out, that USTES system has a more than twice better COP.

Figure 31. Comparison of supplied energy

Supplied Energy

Meter Energy

	USTES-afte		single-fam	
	kWh	kWh/m²	kWh	kWh/m²
Valaistus, kiinteistö	306	1.5		
LVI sähkö	1582	7.8		
Sähkölämmitys, kiinteistö	5857	28.9		
Lighting, facility			305	1.5
HVAC aux			1905	9.4
Electric heating			297	1.5
Total, Facility electric	7745	38.3	2507	12.4
Total	7745	38.3	2507	12.4
Laitteet, asukas	399	2.0		
Equipment, tenant			4058	20.1
Heating, tenant			7035	34.8
Total, Tenant electric	399	2.0	11093	54.8
CHP tuotto	0	0.0		
CHP electricity			0	0.0
Total, Produced electric	0	0.0	0	0.0
Grand total	8144	40.2	13600	67.2

To build the USTES system might be more expensive at the start, as more groundwork, foundation and material is needed. But because of the saved amount of 5455.3kWh per year it could be seen as a good investment. Calculated with 0.08€ per 1kWh (which is only the Finnish average price per kWh according to Eurostat statistics and is not including delivery or other charges (Eurostat, 2022)), it would be a minimum of 436.5€ per year which could be saved compared to the BTES system. When taking into account that energy prices are rising over time, especially due to the pandemic effects and the ongoing political tensions, it is not improbable that in the coming years the amount saved through energy savings will be increasing even more (Nordea, 2022).

When reviewing the results of the total used energy amounts, clearly the BTES is consuming less energy. This can be explained for the following reasons, firstly because of more components, like pumps measurement devices and similar components, are built into the USTES system which increases the total used energy. Next to this, the energy losses of the USTES are higher, as the thermal storage creates more areas which are in touch with the ground and so cause higher energy losses. But due to the overall performance of the USTES system it still has a lower delivered energy amount than the BTES system.

The total energy, for BTES, which still needs to be additional delivered has an amount of 67.2kWh/m2. For the USTES system the total amount is 40.2kWh/m2, which is 27kWh/m2 lower. Based on these values it possible to say that the energy efficiency of the USTES system is higher and will save over the lifetime of the building more energy and so more money as the common BTES system.

6.4 Proposal of improvements

During the process of the simulations, it was possible to see and analyse other information of the before compared models. This information is not significant enough for this comparison, which is the reason why it is not presented.

However, this information is pointing out that there are still some parts of the models which could be improved by adjusting certain values. The heat distribution system could be still improved to ensure the USTES system can provide fast enough needed energy during cold temperature fluctuations.

Another improvement could be the adjusting of the USTES room size, as the bigger the storage is, the lower the peak temperature is. This would have the impact that the with it connected heat losses could be lower, but the size of the solar collector area would have to be adjusted as more heat is needed heat up a bigger room.

7 Conclusion

In this thesis, two thermal energy storages in a recreational house located in the northern part of Finland, have been compared under the topic of energy efficiency. The comparison is intended to provide new insights into the difference between the BTES and the USTES system and ultimately present the more efficient system. To carry out this comparison, the software IDA-ICE was used, which is utilized to carry out energy calculations for houses of all kinds. The thesis guiding questions were posed in such a way that the results of the USTES system, which is the newer system of the two, covers the critical aspects of the comparison. The guiding questions were: How much energy can be stored in the seasonal thermal energy storage? How much of the stored energy can be used during the heating season? How much advantage has the USTES compared to the traditional borehole system?

In the comparison, a recreational house in Finland was taken as an example. Since this house is still in the planning stage, the simulation results will ultimately determine which system is going to be installed in the house. For this reason, the house was modelled in IDA-ICE in such a way, that only the thermal storage system makes the difference in order to enable an optimal comparison.

The thesis is following step by step the needed adjustments and setups, which have to be executed before it was possible to run the final simulations. The step-by-step instruction is especially important for the USTES system, as IDA-ICE does not have a simplified USTES component by now and in fact of that this system has been created by hand.

In conclusion, the results of the comparison point out that the USTES system is appliable to family houses and is compared under the thesis leading questions the more efficient system. With an amount of 40.2kWh/m2, the energy which needs to be purchased for the USTES system, is 27kWh/m2 lower than for the common BTES system. The final COP of the USTES system (3.28) is more than twice as good as the BTES COP (1.54), which clearly indicates the better performance and thus also the better efficiency of the USTES system. This knowledge about the comparison may increase interest in the USTES system and can drive more research into this energy storage. Also, by using this much more efficient system, the world can do some good, as this new type of thermal energy storage is a more sustainable solution and has therefore the aim to improve the current state of impact on the nature and the climate with long-term effects.

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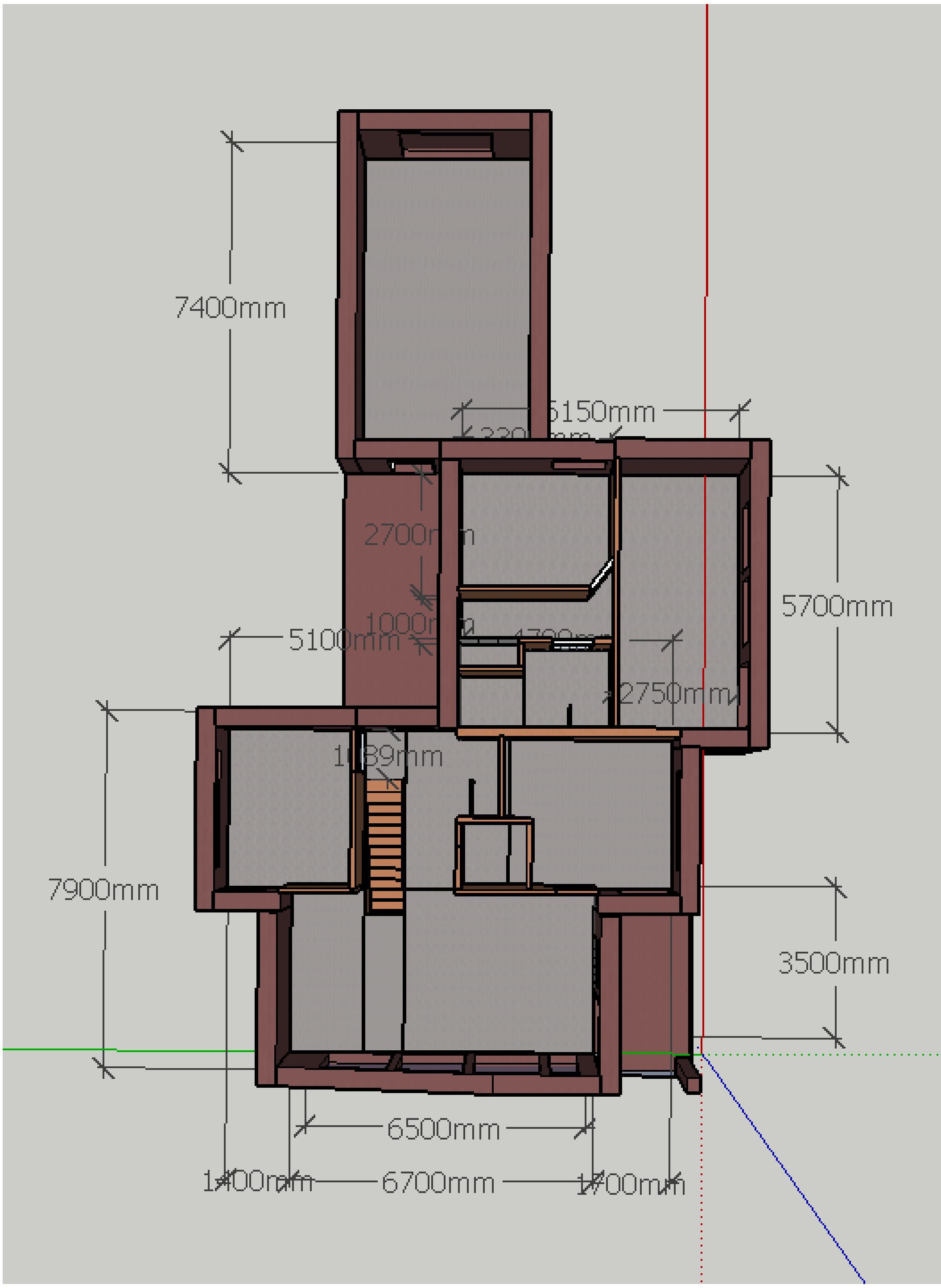
Appendix 1: Material list

Paroc solutions can be foudn from https://structureselector.paroc.com/

Elements	Layer/Material	Thicknes:	U-Value	U-Value(in all)	Note
External wall	Paroc: US-VF-10.11_04-2018.pdf			0.13	From Paroc document
Internal wall	Timber	28 mm		2.1	Estimation
	Gap/ timber st	48 mm			
	Timber	28 mm			
Internal floor	Floor covering (	10 mm		2.5	Estimation
	Thin insulatior	3 mm			
	Concrete	100 mm			
	Timber panels	12 mm			
Roof	Paroc: YP-PR-10.4_04-2018.pdf			0.07	From Paroc document
Basement wall	LECA LTH-420 blocks			0.13	From LECA document
Slap towards ground	Floor covering (	10 mm		0.13	Estimation
	Thin insulatior	3 mm			
	Concrete	100 mm			
	EPS	300 mm	0.04		
Windows (shading as layer?)				1.00	Estimation
External Doors				0.7	Estimation

Appendix 2: Floor plan (SketchUp)



Appendix 3: Table of all zones (BTES)

EQUA SIMULATION TECHNOLOGY GROUP		Systems Energy	
Project		**Building**	
		Model floor area	202.4 m²
Customer		Model volume	753.8 m³
Created by	Jan Philipp von Schilgen	Model ground area	144.8 m²
Location	Muonio_028230 (ASHRAE 2013)	Model envelope area	650.8 m²
Climate file	[Default]	Window/Envelope	6.2 %
Case	single-family-house-singleborehole-after-simulation	Average U-value	0.1676 W/(m² K)
Simulated	06/06/2022 19:10:41	Envelope area per Volume	0.8634 m²/m³

Name	Group	Floor height, m	Room height, m	Floor area, m2	Heat setp., °C	Cool setp., °C	AHU	System	Supply air, L/(s.m2)	Return air, L/(s.m2)	Occup., no./m2	Lights, W/m2	Lights, kWh/m2	Equipment, W/m2	Equipment, kWh/m2	Ext win. area, m2	Occup. schedule	Light schedule
Storage	Storage	0.0	2.6	24.42	10.0	25.0	Standa...	VAV, te...	7.0	7.0	0.0	0.819	0.2236	0.0	0.0	1.2		Sched...
Bedroom Big	House	0.0	2.6	42.7	21.0	25.0	Standa...	VAV, te...	7.0	7.0	0.1874	0.9368	1.726	0.0	0.0	11.22	Sched...	Sched...
Big living space	House	0.0	2.4	31.82	21.0	25.0	Standa...	VAV, te...	7.0	7.0	0.1433	1.1	2.027	0.0	0.0	4.74	Sched...	Sched...
Upper front	House	0.0	2.6	30.0	21.0	25.0	Standa...	VAV, te...	7.0	7.0	0.09999	1.0	1.843	0.0	0.0	19.86	Sched...	Sched...
Sauna	Sauna	-3.15	3.15	27.84	21.0	25.0	Standa...	VAV, te...	7.0	7.0	0.1	0.898	0.4903	0.0	0.0	0.0	Sched...	Sched...
Small room	House	0.0	2.6	13.76	21.0	25.0	Standa...	VAV, te...	7.0	7.0	0.0722	1.09	2.009	5.451	29.02	3.02	Sched...	Sched...
Second floor	House	2.4	3.0	31.82	21.0	25.0	Standa...	VAV, te...	7.0	7.0	0.1	1.1	2.027	0.0	0.0	0.0	Sched...	Sched...
Total/m2									7.0	7.0	0.1113	0.9884	1.506	0.3707	1.973	6.407		

Appendix 4: Table of all zones (USTES)

EQUA SIMULATION TECHNOLOGY GROUP		Systems Energy	
Project		**Building**	
		Model floor area	202.4 m²
Customer	HAMK	Model volume	863.2 m³
Created by	Jan Philipp von Schilgen	Model ground area	144.2 m²
Location	Muonio_028230 (ASHRAE 2013)	Model envelope area	731.9 m²
Climate file	FIN_MUONIO_028230(IW2)	Window/Envelope	5.5 %
Case	USTES-after-simulation	Average U-value	0.1588 W/(m² K)
Simulated	06/06/2022 17:33:00	Envelope area per Volume	0.8479 m²/m³

Name	Group	Floor height, m	Room height, m	Floor area, m2	Heat setp., °C	Cool setp., °C	AHU	System	Supply air, L/(s.m2)	Return air, L/(s.m2)	Occup., no./m2	Lights, W/m2	Lights, kWh/m2	Equipment, W/m2	Equipment, kWh/m2	Ext win. area, m2	Occup. schedule	Light schedule
USTES	0	-2.5	2.5	42.7	21.0	25.0	No cen...	n.a.	n.a.	n.a.	0.0	0.0	0.0	0.0	0.0	0.0		
Storage1	Storage	0.0	2.6	24.84	10.0	25.0	Standa...	VAV, te...	7.0	7.0	0.0	0.8052	0.2198	0.0	0.0	1.2		Sched...
Bedroom Big	House	0.0	2.6	43.24	21.0	25.0	Standa...	VAV, te...	7.0	7.0	0.185	0.9251	1.705	0.0	0.0	11.22	Sched...	Sched...
Big living space	House	0.0	2.4	32.63	21.0	25.0	Standa...	VAV, te...	7.0	7.0	0.1397	1.073	1.977	0.0	0.0	4.74	Sched...	Sched...
Upper front	House	0.0	2.6	30.39	21.0	25.0	Standa...	VAV, te...	7.0	7.0	0.09873	0.9872	1.819	0.0	0.0	19.86	Sched...	Sched...
Sauna	Sauna	-3.15	3.15	27.84	21.0	25.0	Standa...	VAV, te...	7.0	7.0	0.1	0.898	0.4903	0.0	0.0	0.0	Sched...	Sched...
Small room	House	0.0	2.6	14.09	21.0	25.0	Standa...	VAV, te...	7.0	7.0	0.07051	1.065	1.962	5.323	28.34	3.02	Sched...	Sched...
Second floor	House	2.4	3.0	32.67	21.0	25.0	Standa...	VAV, te...	7.0	7.0	0.0974	1.071	1.974	0.0	0.0	0.0	Sched...	Sched...
Total/m2									7.0	7.0	0.09065	0.8052	1.227	0.3019	1.608	5.297		