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EXCESS

FleXible user-CEntric Energy poSitive houseS

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Abstract
This document is a report on advancing simulation-based energy performance assessment for optimal PEB design. Energy Models have been developed along this task for every EXCESS demo pilot to evaluate the energy performance with PEB purpose. Conclusions about building design optimization and their facilities as well as the optimization of control strategies are exhibited along this document.

Keywords
Positive Energy Building, Simulation, Energy Model, Simulation, Performance Assessment, Optimal Building Design, Control Strategy

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EXECUTIVE SUMMARY

The deliverable D2.6 "Report on advancing simulation-based energy performance assessment for optimal PEB design" describes the detailed developed models to simulate each Demo pilot in the context of the Work Package 2 "Technology and their Integration into PEBs". Furthermore, the main results about the energy performance assessment for optimal PEB design are presented. This deliverable comprises a direct outcome of the Task 2.6 "Advancing simulation-based energy performance assessment for optimal PEB design", which aims to:

- Develop energy simulation models addressing the particularities of each demo pilot.
- Analyze the obtained results simulations from each demo pilot with proposed technologies.
- Evaluation of PEB achievement simulation-based energy performance assessment.
- Set conclusions for enhancements.

Depending on the demo cases, different modelling and simulation software have been used to develop the energy models. Also, different types of stereotypes, variables and constraints have been considered in the energy simulation models. Indeed, some stereotypes[1] have been created of the developed technologies in the tasks, T2.1 (Energy harvesting building envelope elements), T2.2 (deep BH development), T2.3 (multisource HPs with high COP DHW) and T2.4 (Activating thermal and electrical flexibility in DH substations) and integrated in the Energy Models.

Moreover, the simulation models will be able to be further used for testing the Model Predicting Controls, performing also prediction analyses based on weather forecast and energy prices.

The main achievements of this task are the four developed energy models, as a powerful tool to evaluate the performance of buildings and their facilities for each demonstrator from a holistic modelling PEB scope.

With regard to the continued developments and with the information provided in this deliverable, some further research work could be undertaken to study and evaluate new control strategies and to improve the design to reach PEB level. It is expected that there is still room for improvement.

By the time being, one of the main conclusions from the study developed along this task is that the achievement of PEB standard, as defined in deliverable D1.1, is difficult to be fulfilled for the Finnish Pilot, but it could be reached in the Spanish Pilot and the Austrian Pilot with some enhancements. The Belgian Pilot has not been evaluated yet, because the required data for its energy model are not available yet (target spring 2021).

Finally, it is important to note that the thermal energy for user-comfort requirements, under assumptions considered is this study, has as much influence (or even a bit less in some demo pilot) as the rest of electrical energy consumptions of the building (artificial lighting, household appliances, electrical devices, electrical consumption in common zones). For this reason, it is concluded that the user-engagement will be a key point to reduce the overall building demand and achieve the PEB goal.

[1] Simple engineering representation of a system component considering main inputs to emulate real operations, including performance variations, and generating outputs.

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Glossary

Acronym	Full name
BEPS	Building Energy Performance Simulation
BH	Borehole
BIM	Building Information Modelling
BIPV	Building Integrated Photovoltaic
BTES	Boreholes Thermal Energy Storage
COP	Coefficient of Performance
DHW	Domestic Hot Water
EER	Energy Efficiency Ratio
EXCESS	FlEXible user-CEntric Energy poSitive houseS
FCU	Fan Coil Unit
GHX	Ground Heat Exchanger
GSHP	Ground Source Heat Pump
HP	Heat Pump
HVAC	Heating Ventilation and Air-conditioning
IAQ	Indoor Air Quality
MPC	Model Predictive Control
PEB(s)	Positive Energy Building(s)
PV	Photovoltaic
PV/T	Photovoltaic/ Thermal
SC	Space Cooling
SH	Space Heating
WP	Work Package

1 Introduction

1.1 Purpose of the document

This document is a report on advancing simulation-based energy performance assessment for optimal PEB design related to every Demo Pilot.

The linkages between Task 2.6 and the rest of WP(s) of EXCESS project are represented in the following scheme:

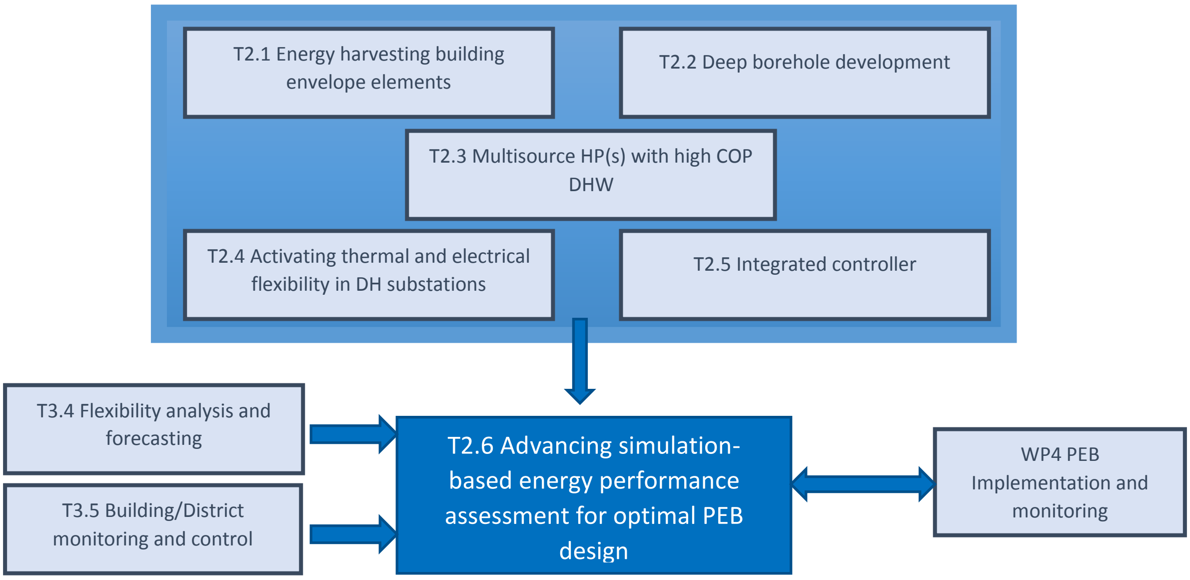

Figure 1-1: Task 2.6 and other EXCESS Tasks-Linkages. Source: EXCESS Project

Some of the outputs developed in the rest of Tasks of WP2 (Task 2.1, Task 2.2, Task 2.3 and Task 2.4) have been integrated as components (stereotypes) in some of the models developed in Task 2.6.

Besides, Task 2.6 and WP4 will exchange information to achieve the PEB optimal design for every Demo Pilot.

Indeed, WP4 will provide some inputs (mainly in existing buildings: Belgian and Austrian Demo) for the models developed in Task 2.6. Some outputs of Task 2.6 will be used in WP4 to design the PEB building (mainly in new buildings: Finnish and Spanish Demo).

Additionally, the outputs of the Task 3.4 (generation and demand forecasting) (planned to start in M14) and Task 3.5 (from Building/District monitoring and Control) (planned to start in M14) could be used to run the models developed in Task 2.6 to improve control strategies.

The partners contributing to this Task are AEE, VITO and VTT. CENER, apart from the leader of this Task, is the responsible partner for the Energy Model developed for Spanish Pilot.

On the other hand, VTT will be the partner responsible for the Energy Model developed for the Finnish Pilot, VITO for the Belgian Pilot and AEE for the Austrian Pilot.

1.2 Scope of the document

This document presents a detailed description about the particularities of the four Demo Pilots and the developed Energy Models for each one as well as their capabilities. Also, main results from the energy performance assessment are presented for each Demo. To conclude, the potential of improvement in both design and control, for every Pilot, to achieve the PEB objective (in accordance with Task 1.1) has been exhibited.

1.3 Structure of the document

The document is structured in six sections. The first section is an introductory section focused in the purpose, scope and structure of this document. The main body of the document is divided in four sections (Section 2-Section 5), one for each Demo Pilot. Finally, a set of conclusions is exhibited in the last section.

In order to address all the aspects relevant to the scope of Task 2.6, the present deliverable has been structured as follows:

- Section 1 introduces the work performed and the scope of this deliverable along with the deliverable's structure (authored by CENER).
- Section 2 provides a comprehensive documentation of the Finnish Demo Pilot (authored by VTT).
- Section 3 provides a comprehensive documentation of the Spanish Demo Pilot (authored by CENER).
- Section 4 provides a comprehensive documentation of the Austrian Demo Pilot (authored by AEE).
- Section 5 provides a comprehensive documentation of the Belgian Demo Pilot (authored by VITO).
- Finally, in section 6 the main conclusions of the work are reported (authored by CENER).

2 Case Study in Nordic Climate. Finland

2.1 Short Description of the Case Study

The Finnish demo case is situated in the South of Finland. Helsinki is the primate and most populous city of Finland. Located on the shore of the Gulf of Finland (60°10′15″N 024°56′15″E), it is the seat of the region of Uusimaa in southern Finland, and has a population of 656,229. The climate of Helsinki is generally cold, and the average temperature is 5.6 °C. The coldest temperature can be -25.9 °C and the highest temperature can be 32.8 °C [1].

The pre-design process of the demo case building started in spring 2020. In the first phase, preliminary architect plans were completed and the ideas of the heat generation with ground coupled (deep boreholes) heat pump as well as the electricity and heat generation with PVT panels existed. The first thing to get started was to access the heating, cooling and electrical load demands of the building. Several brainstorm sessions were carried out with the intention to lower the total energy demand of the building and its uses. At that time, a very simple energy calculation tool, e-pass[2], was utilized to picture the effect of various measures on the energy demand. After the first phase, the preliminary design phase started with detailed energy simulation both with the building and on the other hand with the energy generation system. The results presented in this report are from this deep analysis phase. The design will proceed to the construction design phase and to the start of the construction in spring 2021. The process is illustrated in Figure 2-1.

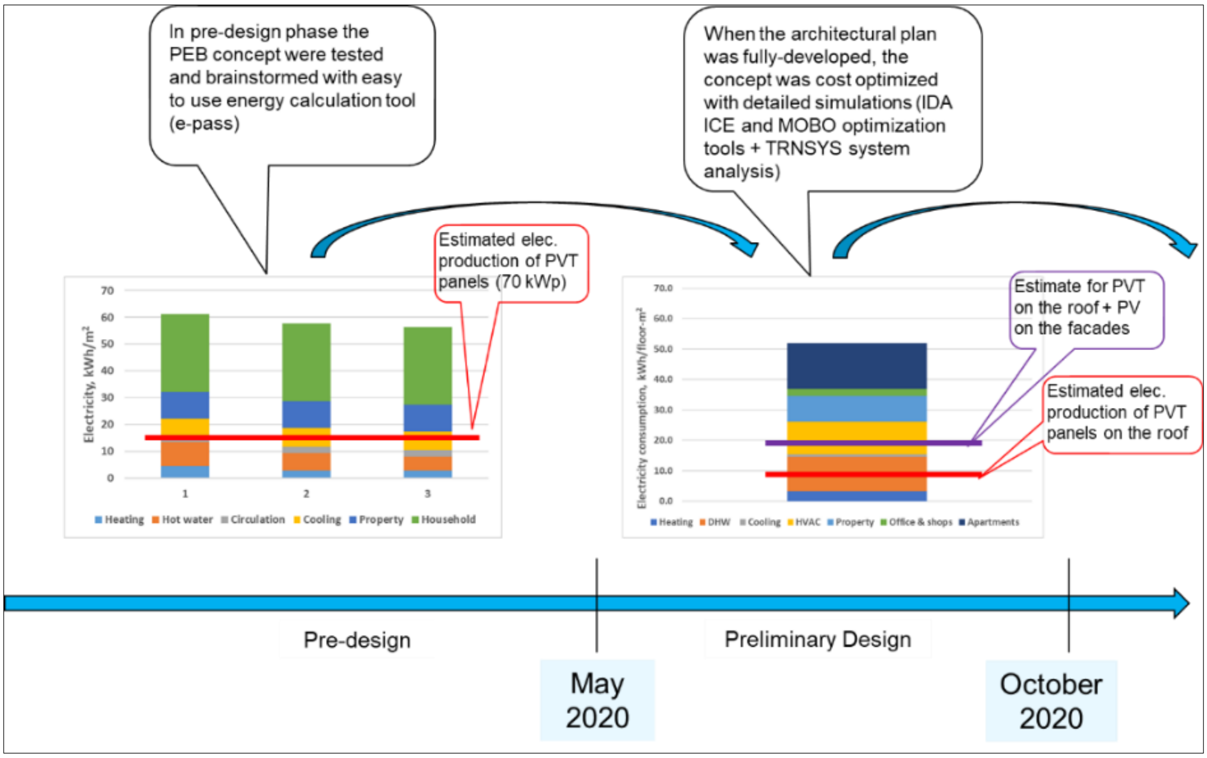

Figure 2-1: Building process timeline and used analysis methods. Source: VTT

[2] e-pass is a free web-based energy calculation tool for energy retrofit analysis of buildings developed by VTT in NewBee EU-project. http://cic.vtt.fi/epass/vtt/

It is clear, that although the demand has been managed to decrease from pre-design to preliminary design and at the same time designed PV production has been increased, it is challenging to make the building energy positive, notably if household electricity is included in the demand. The design process is still ongoing and possibilities to reduce the demand and increase the PV generation are being studied.

2.2 Climate Description

The simulations have been carried out using typical hourly weather data (TRY2012) for Helsinki. The heating design outdoor temperature for Helsinki is -26 °C and yearly mean outdoor air temperature is 5.6 °C. The very same weather data is used nationally when applying for building performance to prove that the building's design fulfils the building regulations and with the energy label calculations.

The hourly outdoor air temperature and solar radiation values are presented in Figure 2-2 and Figure 2-3 respectively for the whole year.

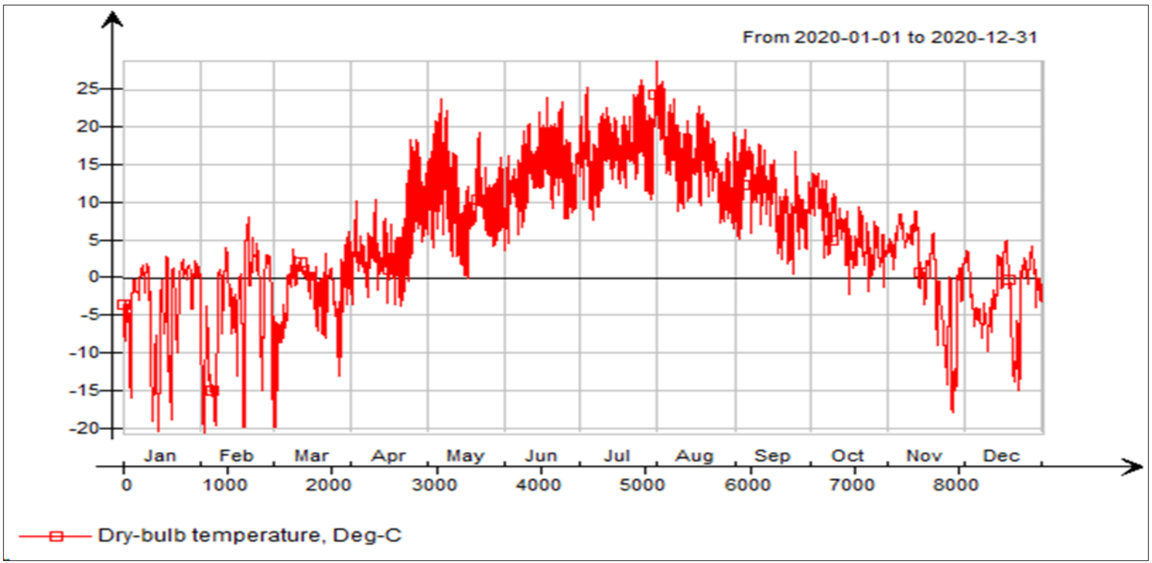

Figure 2-2: Outdoor air temperature of Helsinki (TRY2012). Source: [1].

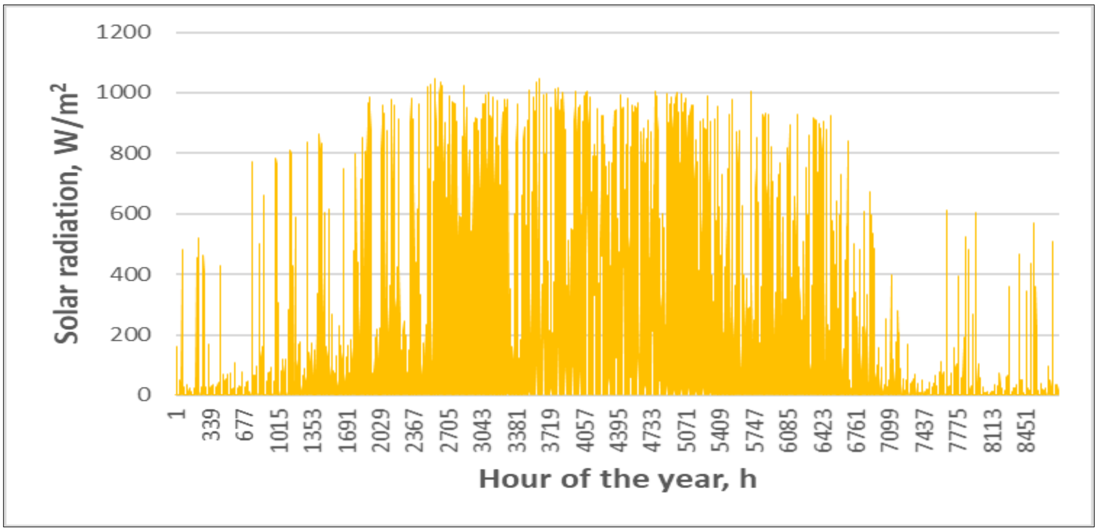

Figure 2-3: Total solar radiation (direct + diffuse) of Helsinki (TRY2012) on one year. Source: [1].

2.3 Building Description

It is planned to construct an apartment building in Kalasatama with about 51 apartments and a total heated area of around 4000 m^2. The Figure 2-4 shows the location of the building that would be constructed from 2021 onwards. It is planned to habitat the building by year 2023. It is a modern building located in the heart of the city, that has high energy efficiency and it will be integrated with renewable technology, energy storage and with user centric aspect included. With renewable technology and energy storage integrated within the building, it is expected that the building will have low emissions and will be self-sufficient. Moreover, it is expected to construct a building that also keeps user satisfaction, user interaction and user comfort at the core of the designing process.

Figure 2-4: The EXCESS project demo case building in Kalasatama region of Finland, Helsinki. Source: Sweco architects Oy, [2], [3].

Figure 2-5 shows the planned site location of the EXCESS project's building. It can be observed that the building is located close to the harbour and there is new ongoing construction in the vicinity.

Figure 2-5: The EXCESS project demo case building location and planned area in Kalasatama, Helsinki Source: Sweco architects Oy, [2], [3].

2.4 Energy System Description

The proposed energy system is shown in Figure 2-6 and it consists of the following main components:

- A roof mounted photovoltaic thermal hybrid collector (PVT) field.
- Building integrated photovoltaic panels (PV) on the building's south-west and west façade
- A buffer tank charged by the PVT.
- Borehole thermal energy storage (BTES) is in the energy centre at a centralized location. It is charged via the buffer tank if excess energy is available in the tank.
- A central heat pump (HP) is used to charge a hot tank by taking heat energy from the buffer tank or BTES during periods.
- Domestic hot water (DHW) and space heating (SH) is provided through this hot tank.
- A heat pump (HP) is also used to provide cooling via cold tank to the building. This is also used to charge the BTES by collecting the waste heat from the building.

2.5 Model Description

In the Finnish demo case of positive energy building (PEB), there are two main systems, one is the building and the second one is the energy system. As both of these systems are integrated together, there has to be a control that can maximize the performance of the energy system. The main framework and components of the energy systems are shown in Figure 2-6.

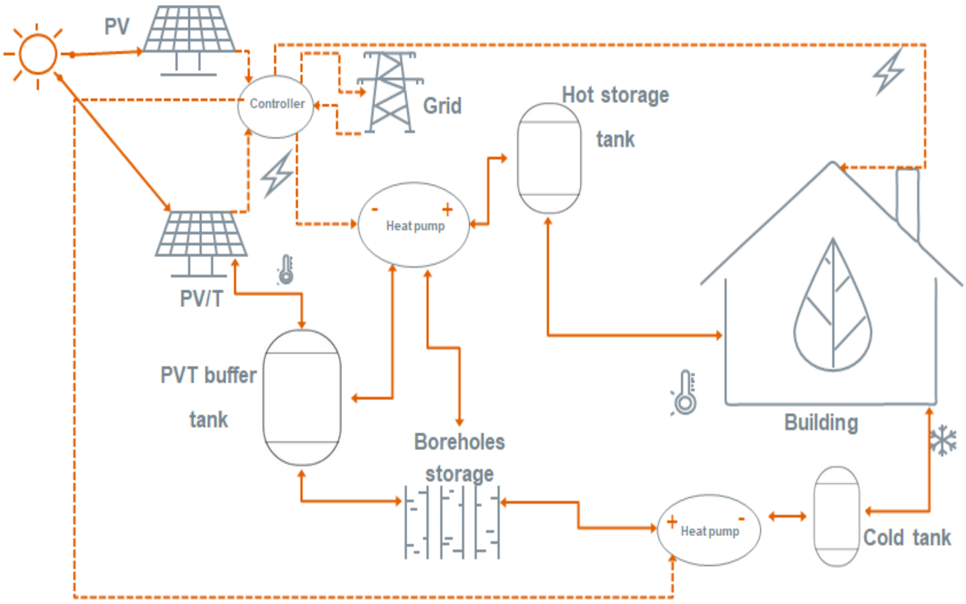

Figure 2-6: The energy system layout. Source: VTT

Two software are mainly used for the building simulation and for the energy system simulation. IDA-ICE is mainly used for the building simulations and to generate demand profiles. TRNSYS is mainly used for the energy system simulations. A short description about the two software is mentioned in section 2.5.1. The description of the building model is mentioned in section 2.5.2 and the description of the energy system model is mentioned in section 2.5.3

2.5.1 Short Description about the Software Used

Computer simulation is a method where a real life or hypothetical system is modelled to analyse the behaviour of the system. These models are generally created on the computer. The model allows predicting the behaviour of the system virtually. Simulation can be used in different contexts. It can be used to show the real effect on the system caused by alternative conditions. These models are created when the real-life system cannot be used because of the high costs, real life system is not available, or it may be dangerous [4]. Some of the main factors that can influence the simulations are valid data availability, key parameters, and schedules. Therefore, in a simulation environment many simplifications and assumptions are made. After this, the validation is carried out [5].

The designers use energy and building simulation software in order to analyse the technical and economic feasibility. The simulation software provides designers with a tool to estimate the performance and optimize the energy system and building with good accuracy. The simulations also allow designers to identify the important design parameters and variables that can influence the building's and energy system's performance. Ultimately, the simulation can support the designers to make decisions while developing a new or existing energy system and building [4]. The tools allow to model complex energy systems with minimum investment, as the designers do not have to construct a real system that can be expensive [6]. Designers can simulate and understand the behaviour of the building and energy system before their construction. In addition, the investments and operational costs of the systems during their life cycle can be estimated.

The local policy and regulations can also be used in the energy simulation to provide appropriate suggestions. Energy simulation software tools have been developed over the years. Now there are many energy simulation tools available with different complexity and response to different variables [4]. Three steps that have to be performed in all energy simulation software tools are: 1) model creation, 2) carry out the simulations and 3) analysis of the results. Different commercial simulation tools are available like IDA ICE, IES, Energy Plus and TRNSYS. These software tools have been used in various studies [7].

2.5.1.1 TRNSYS-Dynamic Simulation Software

TRNSYS stands for transient system simulation program. TRNSYS is an extensive and complete simulation software. Since 1975, this software has been under use [8]. TRNSYS provide the flexibility especially for the energy system simulation. It was developed in 1970s by the Solar Energy Lab, University of Wisconsin-Madison and Colorado State University, Solar Energy Applications Lab [8].It provides the platform as a solver where algebraic and differential equations are solved. The components are connected graphically in the simulation studio to create the systems. Complex systems can be built in TRNSYS as modular components and structures are provided by the software. These components may range from wind turbines to a multi-zone of a building complex. The components are configured through the graphical user interface known as TRNSYS Simulation Studio [9]. All the components are solved simultaneously at each time step. The time step may vary from an hour to 0.1 seconds. The library in the software tool allows the use of various components like, solar panels, photovoltaic panels, HVAC systems, cogeneration systems etc. It also provides different weather data. The simulation results can show performance of individual component or sub systems that can be selected from the simulation studio. Logical programming or simple equations can be written on open source code to accomplish system control strategies. TRNSYS also provide TRNEdit that is an editor for reading and writing TRNSYS input and outputs. TRNEdit can also perform parametric TRNSYS simulation and plot data [9, 8, 10]. In addition, this energy simulation tool allows the user to incorporate components developed in other software tools such as Matlab, Excel, VBA, etc.

2.5.1.2 IDA ICE- Indoor Climate and Energy software

The modular dynamic multi-zone building simulation tool, IDA Indoor Climate and Energy (IDA ICE), is a commercial program that was released around 1998. It can be used to study the thermal indoor climate of individual zones as well as the energy consumption of a building and its systems (heating, cooling, ventilation). The modular nature of IDA ICE makes it possible to write individual models extending its capabilities as needed by the individual users [11].

2.5.1.3 Comparison between TRNSYS and IDA ICE Software

Each software tool has certain characteristics and specific applications. In order to understand the features of IDA ICE and TRNSYS, Table 2-1 presents a summary of the features of each of the software tools presented above.

Table 2-1: Comparison of features of various simulation software tools. Source: [9].

Simulation characteristics	IDA ICE	TRNSYS
Simulation of loads	X	X
Iterative solution of nonlinear	X	X
Simultaneous selection of building systems	Limited	Manifold
Walls, windows, roof and floors	X	X
Solar analysis	X	X
Calculations of the building in general	X	X
Airflow via windows		X
Daylighting controls	User friendly	Less user friendly
Natural and mechanical ventilation	X	X
Window control	User friendly	Less user friendly
CAD software integration	X	
Photovoltaic panels	X	X
Management of electric power load	X	X
HVAC system	X	X
Controls	X	Easy
User interface	Better	Need understanding

Based on Table 2-1 above, the building model can be built in the IDA ICE simulation software and TRNSYS would be used for the energy system modelling and simulation. IDA ICE provides a user-friendly platform and graphics to build the complex building. TRNSYS provides an easy and flexible platform to integrate components and data. Moreover, the control strategy for various energy systems is easier in TRNSYS. Multi-objective optimization software can also be integrated with TRNSYS and IDA ICE.

2.5.2 Building Model Description

The simulated building along with the shading neighbouring buildings, as well as the floor layout of the 1st apartment floor is presented in Figure 2-7.

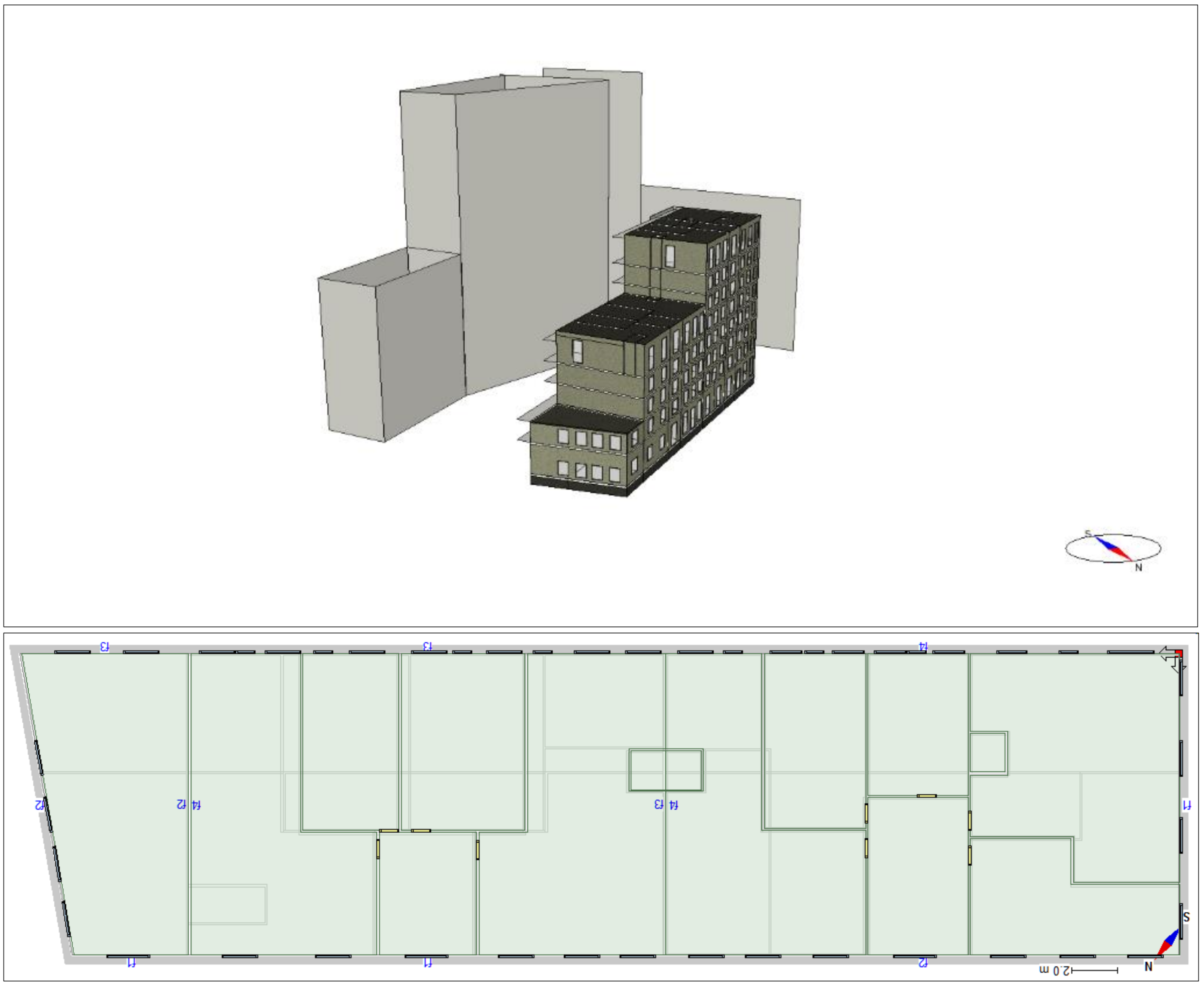

Figure 2-7: The simulated building with neighbouring buildings and the 1st apartment floor layout from IDA ICE simulation tool. Source: Sweco architects Oy

The building's demand profiles are generated using IDA-ICE which is later on integrated with the TRNSYS simulation model as an external text file.

2.5.2.1 Load Profiles (and User Behaviour)

The load profiles for lighting and appliances follow our national recommendations of the Finnish Association of HVAC societies (FINVAC) [12], tuned so that the yearly energy consumption equals the values given in our building regulations [13]. The profiles take into account daily and seasonal user behaviour, and are presented in Figure 2-8 and Figure 2-9.

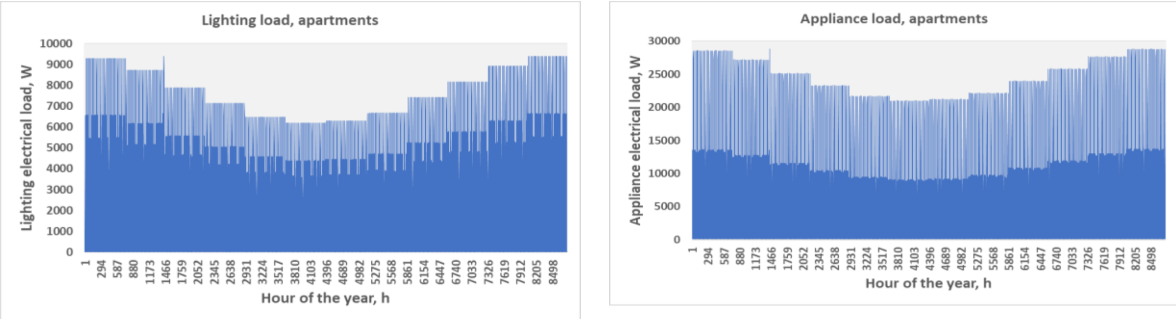

Figure 2-8: Apartment lighting and appliance hourly load profiles during one year. Source: [12], [13].

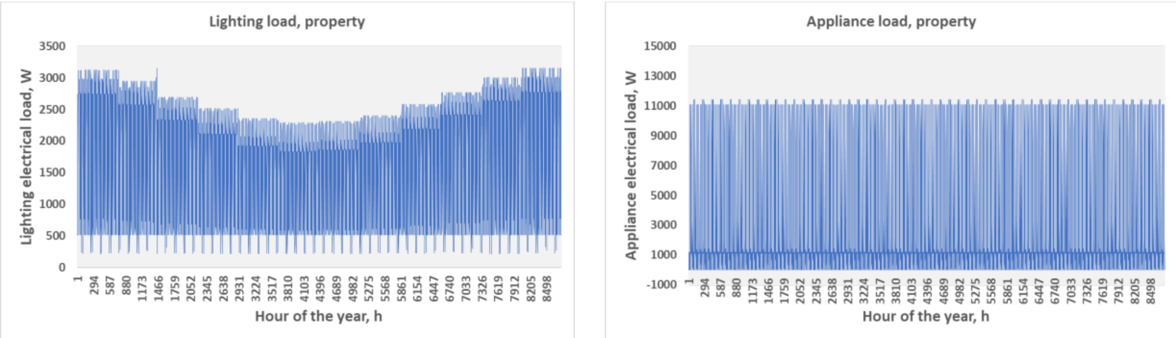

Figure 2-9: Property lighting and appliance hourly load profiles during one year. Source: [12], [13].

2.5.3 Energy Model Description

The main components of the energy systems are photovoltaic-thermal (PVT) panels, photovoltaic (PV), buffer tanks, hot and cold tanks, boreholes thermal energy storage (BTES), heat pumps (HP) and the electrical grid.

The building's main components are heat recovery units, ventilation, lighting, property loads, appliances, space heating, cooling and domestic hot water demands.

The control framework of the energy system is designed so that, PVT is cooled down by providing cold water from the buffer tank in order to maximize the electrical and thermal production from the PVT. When the buffer tank is charged at a certain level, the excess heat energy is dumped in the BTES. The HP takes the energy from the buffer tank or from the BTES to provide space heating and domestic hot water to the building at higher temperature. The cooling is provided to the building by using the HP, cold tank and ventilation unit. The heat from the building is recovered in the cold tank, where the heat pump takes the heat from the cold tank and dumps the heat energy in the BTES, rather than wasting the heat from the building.

The PVT is used to charge the buffer tank mainly if the buffer tank temperature is lower than 55 ºC, it is heated to 60 °C. The PVT pump is used when the solar radiation is above 700 kJ/hr.m^2 and the PVT flow is recirculated so that the buffer tank inlet temperature is higher than 20 °C to avoid cooling of the tank and to heat the working fluid (glycol mixture of 40%) before sending it to the buffer tank. The hot tank is used to provide the space heating (SH) and domestic hot water (DHW) to the building. If the hot tank temperature is lower than 60 °C, it is heated to 65 °C by the heat pump. The heat pump takes energy from the buffer tank or BTES at maximum 25 °C to avoid any technical issues. If the buffer tank temperature drops below 15 °C during the period when solar energy is not available, the heat pump takes energy from the BTES directly.

Any excess energy present in the buffer tank is transferred to the BTES when the buffer tank temperature is higher than 35 °C until the buffer tank temperature drops to 30 ºC. The working fluid here considered is a glycol mixture of 20%. Space heating is provided by passing the water through a heat exchanger that is connected to the hot tank. The space heating to the building is provided at a temperature that varies between 20 °C to 45 °C, depending on the outdoor temperature. It is slightly higher than the designed temperature in order to include the losses. The domestic hot water (DHW) is provided by passing the cold water through the hot tank via the heat exchanger [14]. The water is heated up to 58 °C before being supplied to the tap and this water is recirculated. There is also backup heating provided by a direct electric heater in case the system is not able to provide sufficient heat.

The space cooling is provided by the separate cooling tank, in a way that the space cooling tank temperature is kept at 10 °C; if the tank temperature increases to 16 °C the heat pump is used to cool the tank. The heat from the building is exchanged with the cooling tank to provide cooling to the building during summer. The waste heat from the building is used to charge the BTES through the heat pump to recirculate the waste heat in the system.

As mentioned in the previous section, Dynamic simulation software (TRNSYS) [15] is used for the simulations of the proposed energy system described above. This simulation software has been used and validated by Drake Landing Community, Canada for similar applications [16].

The TRNSYS simulation model as build in the simulation studio is shown in Figure 2-10. The simplified version was shown in Figure 2-6.

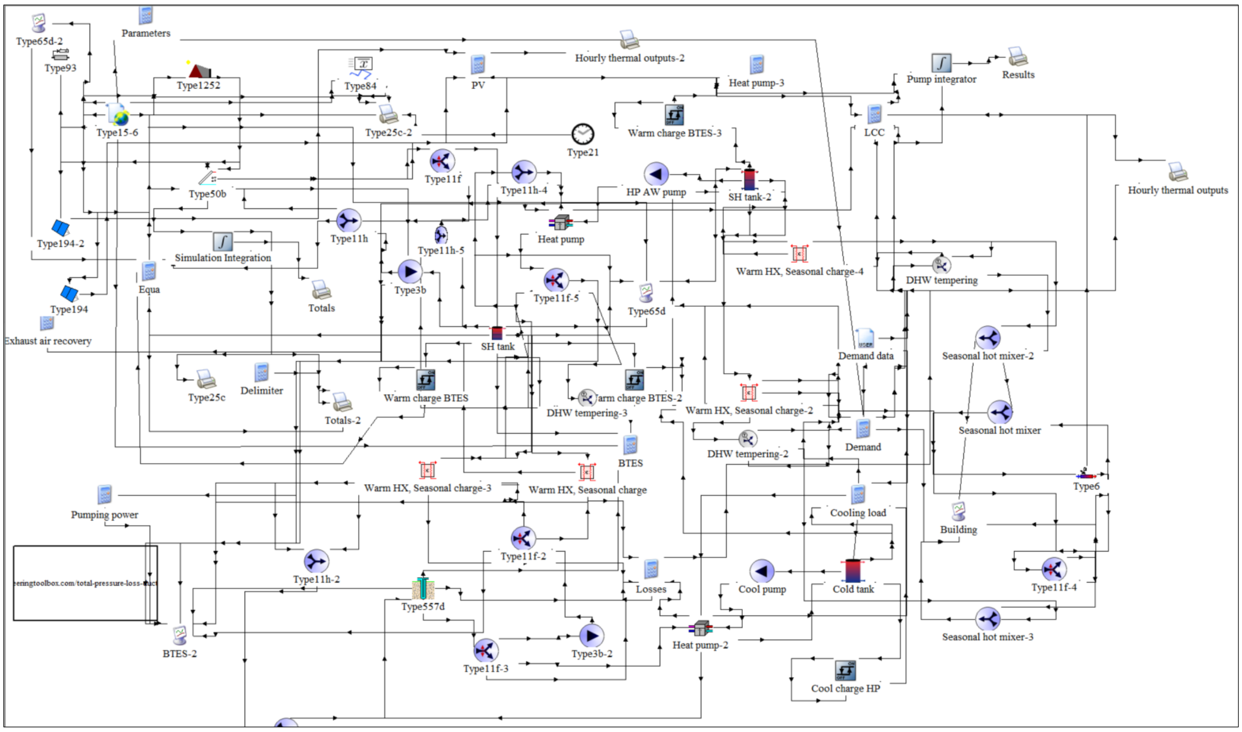

Figure 2-10: TRNSYS simulation model. Source: VTT [15].

TRNSYS modules are used for the modelling of photovoltaic-thermal (PVT) hybrid (Type 50b), shading (Type 1252), weather data (Type 15), short-term tanks (Type 534), pump (Type 3b) heat pump (Type 668), borehole thermal energy storage (BTES) (Type 557d) photovoltaic panels (Type

194), data reader (Type 9e), and output printers (Type 25c) [14]. For the weather profile, metronome data for Helsinki is used and TRNSYS Type 15 is used for weather input. Building demand profiles produced on IDA-ICE (for heating, cooling and electrical demands) are read in TRNSYS using the data reader TRNSYS Type 9e. TRNSYS modules for the controls of the pumps (Type 2b), heat pump (Type 2b), flow diverters (Type 11f), mixer (Type 11h) and temperature (Type 11b) are used. These are basic on/off and differential controllers that operate based on the temperature or certain rules as described in the section 2.5.3 of the report.

The main component's Types used in the TRNSYS and their description are shown in Table 2-2.

Table 2-2: Main components and Types used in the TRNSYS. Source: VTT

MAIN COMPONENTS (types)
Type 50b: PV-Thermal Collector
This component is used to estimate the heat and electrical energy produced by the PV-thermal collector connected at the roof of the EXCESS building.
Type 3b: Variable speed pump
This component is used to pump the fluid from different components such as PVT, heat pumps, tanks, etc. The fluid flow from the pump can vary based on the control signal.
Type1252: Surface Shading for Beam Radiation
This component has been used to evaluate the effect of shading in BIPV due to obstacles. At this stage, no obstacles have been included. It is expected that during the EXCESS monitoring period no other building will have been built close to the Demo building.
Type 668: Heat pump
This component allows to integrate the heat pump and its performance curve in the model.
Type 15: Weather data processor
This component allows to read the weather data for simulation. This weather data is then used to predict the PV-thermal and PV energy production.
Type 534: Cylindrical storage tank with immersed heat exchangers
This component is used to act as a stratified storage tank. It also allows multiple entry and exit ports for the fluid to flow. This component is used as buffer tank for the PVT, hot storage tank for the space heating and domestic hot water and also as cold storage tank for space cooling.
Type 557d: Boreholes thermal energy storage
This component is used to estimate the boreholes energy storage performance. In EXCESS project the coaxial boreholes are used to store heat energy from the PVT and from the waste heat.
Type 194: Photovoltaic
This component is used to estimate the electrical energy produced by the building integrated PV panels on the southwest and west façade of the EXCESS project building.
Type 9e: Data reader
This component is used to read the building's demand profiles. These profiles are generated using IDA-ICE simulations.
Type 2b: Differential controller
This component allows controlling the temperature of the tanks (set-points), on/off of the pumps, on/off of the heat pumps and charging /discharging control of the storages (set-points).
Type 11f: Controlled Flow diverters
This component is used to divert and/or divide the flow of fluid. It has one inlet and two outlets such that it can act as a three-way valve. They are used to control and divert the flow direction of the PVT working fluid, borehole fluid, heat pump working fluid, domestic hot water circulation etc.
Type 11b: Temperature tempering controller
This component is used to control the temperature of the space heating, domestic hot water and heat pump flow temperatures.

Type 11b: Tee Piece
This component is used to mix the fluid coming from two different streams into one stream.
Type 25c: Printers
This component prints and gives the output results in text files.
Type 65d: Online printers
This component provides the output results on the online plotter (on screen).

The main input files in the energy system simulation model are the building demand profiles (from IDA-ICE) and weather data that are provided in text format.

The output files are integrated results such as energy production, heat flows, electricity import and export values etc. The outputs results are also given in the text file, which is later post processed on excel.

The performance of the system is estimated by varying the design parameters of the energy system. The components that are used for the parametric study of the energy system simulations are shown in the Table 2-3.

Table 2-3: The variables used for the parametric study in the TRNSYS. Source: [15].

Component	Parametric values
Photovoltaic-thermal collector (m^2)	100, 200, 300, 400
Shading (m)	0, 45, 90
Photovoltaic-thermal collector (m^2-surface)	50 m^2 southwest 100 m^2 west façade 100 m^2 southwest 200 m^2 west façade
Buffer tank (m^3)	10, 20, 30, 40, 50
Borehole height ratio	1, 3, 5
Borehole density (BH(s)/m^2 BH area)	0.05, 0.10, 0.15

The main results of the building and energy system simulations are discussed in section 2.6.

2.6 Analysis and Results

This section is divided in two main parts. The IDA-ICE building simulation results and its analysis are shown in the sections 2.6.1-2.6.3. While the TRNSYS energy system results and their analysis are shown in the sections 2.6.4-2.6.8.

2.6.1 Building Heating Demand

The heating demand includes ventilation and space heating demands. Space heating will be based on low temperature floor heating and a ventilation heating coil will be designed to work also on low temperatures.

Both heat delivery systems will be designed to work on the same supply water temperature level (+35 °C at design conditions), which is why both loads have been summed as total heating load in Figure 2-11.

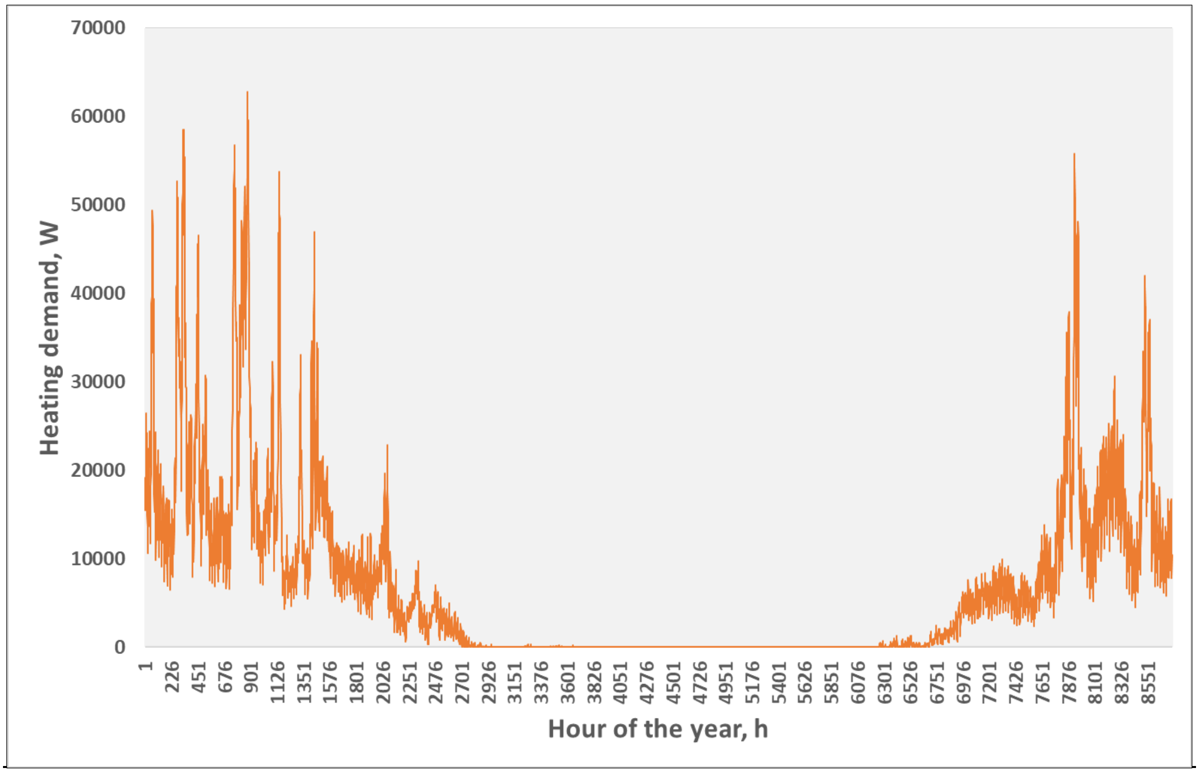

Figure 2-11: Hourly heating demand (ventilation + space heating) during one year. Source: VTT

Total yearly heating demand is 62 MWh which is converted to the electricity demand of the heat pump with an estimated COP = 4.5. Yearly electricity demand is thus 13.7 MWh as presented in Table 2-4.

The domestic hot water load consists of hot water demand and hot water circulation losses. The user behaviour has been taken into account in the daily profile i.e. there are daily two demand peaks, one in the morning and the second in the evening. Weekly load profile is presented in Figure 2-12.

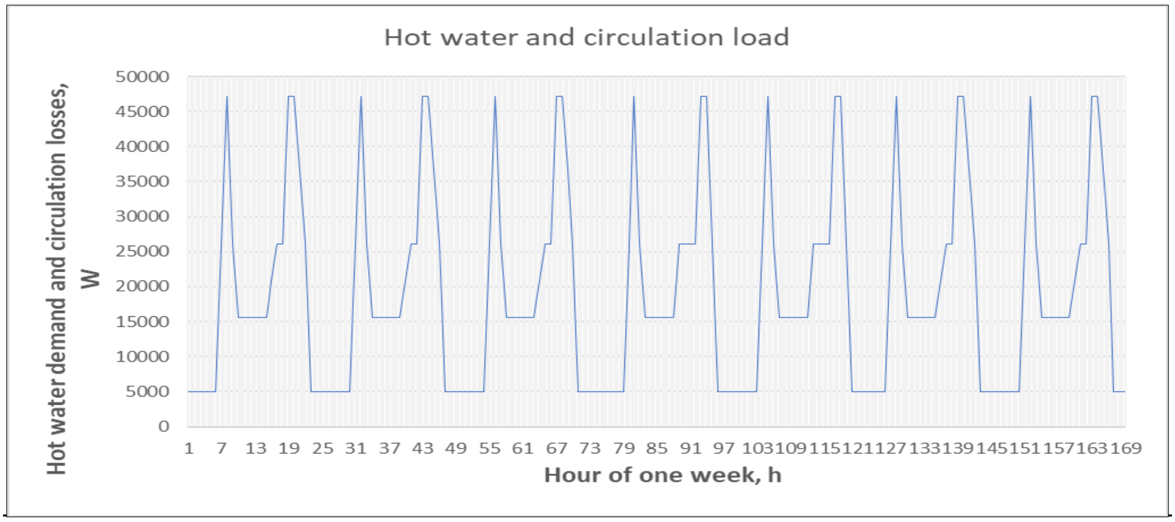

Figure 2-12: Weekly load profile of domestic hot water and circulation losses. Source: VTT

The yearly hot water demand is 124.7 MWh and circulation losses 43.9 MWh. The corresponding electricity demands of the heat pump are presented in Table 2-4 (31.2 MWh and 14.6 MWh). The coefficient of the performance (COP) of the ground source heat pump are estimated to be COP = 4.0 for hot water production and COP = 3.0 for the circulation losses. The high efficiencies are based on the new idea and design by SENERA and Gebwell to make hot water with ground source heat pump [17].

2.6.2 Building Cooling Demand

According to the simulations, it is not necessary to have a very expensive space cooling system. With passive cooling design of the windows (low g-value), it is enough to cool the supply air during summer- time to keep the room air temperatures below 27 °C, which is the critical limit for the cooling in the regulations. The cooling energy is also utilized to regenerate the boreholes like described in section 2.5

The hourly cooling demand of supply air of the air-handling unit (AHU) is presented in Figure 2-13.

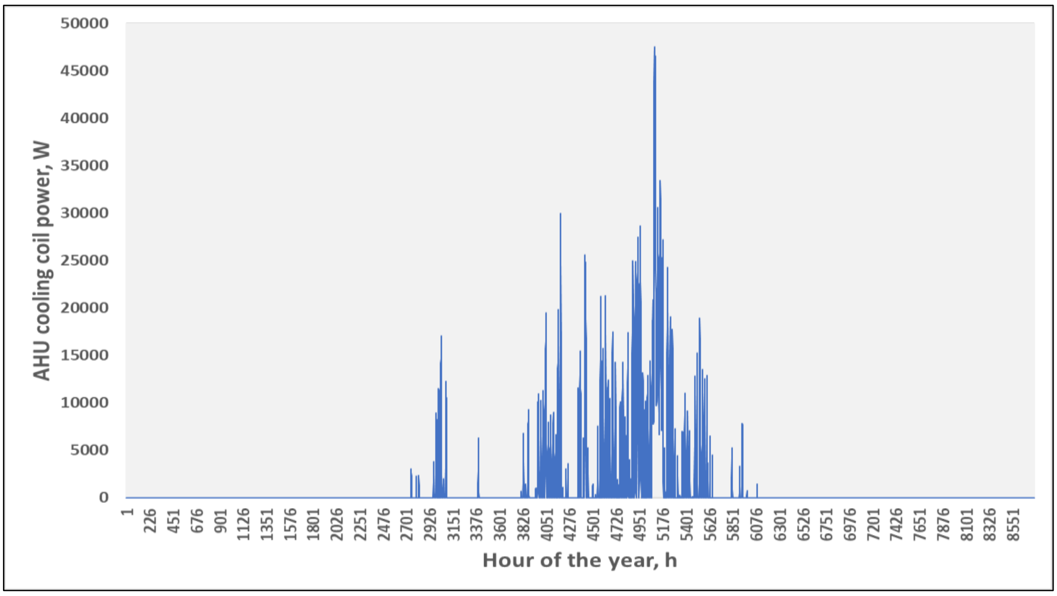

Figure 2-13: Hourly cooling demand of the air-handling unit (AHU) during one year. Source: VTT

Total yearly cooling demand is 9.4 MWh. The cooling energy will most probably be produced with the heat pump so this will slightly increase the electricity demand but this is marginal compared to other electricity loads (Table 2-4). The seasonal energy efficiency rate of cooling (SEER) was estimated to be SEER = 3.0 which gives a yearly cooling electricity demand of 3.1 MWh (Table 2-4). It was considered important to ensure the regeneration of the boreholes that is possible with the higher temperature level from heat pump condensers than straight from the cooling coil of the AHU.

2.6.3 Building Electrical Demand

Electrical demand consists of the property and apartment demands. The property demand includes HVAC (heat pump, fans, pumps, and auxiliary equipment), appliances (elevators, property laundry, and property sauna) and lighting of public spaces as shown in Table 2-4. The apartment demand includes appliances, lighting and apartment saunas as shown in Table 2-5.

Table 2-4: Yearly property electricity demand. Source: VTT

Subject	Yearly consumption, [MWh]	Yearly consumption per gross floor area [kWh/m^2]
Heating (space + air handling)	13.7	3.4
Domestic hot water	31.2	7.6
Domestic hot water circulation	14.6	3.6
Cooling	3.1	0.7
Fans	32.0	7.8
Floor heating auxiliaries	10.0	2.5
Domestic hot water circulation pump	2.0	0.5
Property sauna	14.0	3.4
Property laundry	3.5	0.9
Elevators	3.0	0.7
Office and shop appliances	3.0	0.7
Outdoor lighting	2.3	0.6
Property lighting	12.0	2.9
Property total	**144.7**	**35.5**

Table 2-5: Yearly apartment electricity demand. Source: VTT

Subject	Yearly consumption, [MWh]	Yearly consumption per gross floor area [kWh/m^2]
Appliance	43.7	10.7
Lighting	17.5	4.3
Apartment total	**61.2**	**15.0**

The total estimate for the yearly electricity consumption is 205.9 MWh including property and apartment electricity.

Electricity consumption is visualized in Figure 2-14 where consumptions are lumped. “Apartments” consists of appliance and lighting electricity consumptions. “Property” consists of elevators, property sauna, property laundry, property lighting and outdoor lighting. ”HVAC” includes supply and exhaust air fans, pumps and auxiliaries. “DHW” includes heat pump electricity for making domestic hot water (COP = 4.0) and circulation losses (COP = 3.0). “Heating” consists of space heating and supply air heating (for both COP = 4.5).

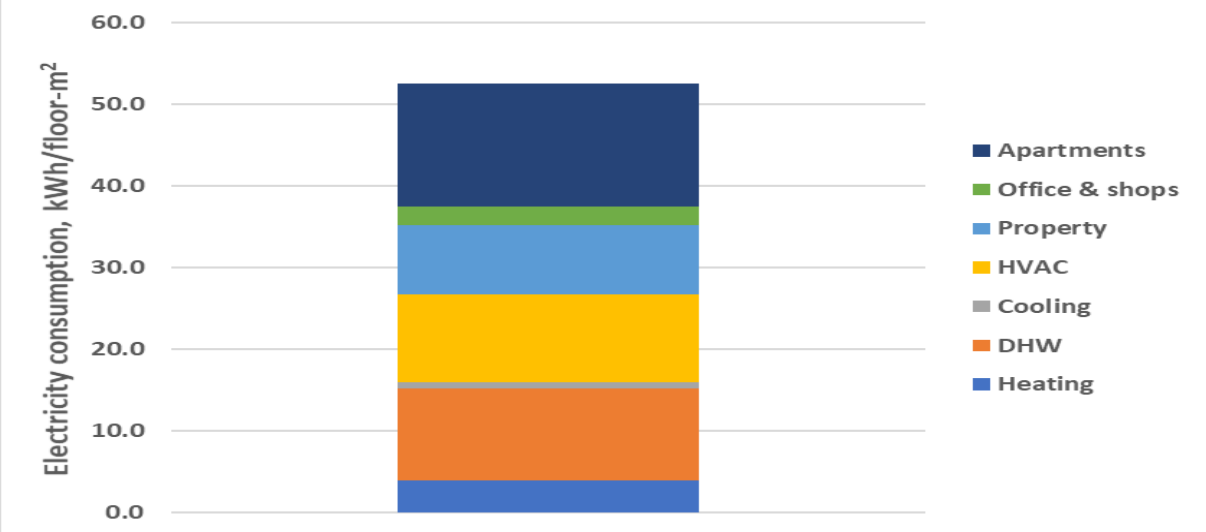

Figure 2-14: Total electricity consumption per heated gross floor area of the building. Source: VTT

2.6.4 Photovoltaic-Thermal Collector (PVT) Testing

The PVT's thermal performance for the DualSun model (300-310M – 60 – 3BBPN) [18] is shown in Figure 2-15. The x-axis shows the panel inlet temperature and the y-axis shows the thermal output of the panel in Watts. It is assumed that the flow rate of 200 lit/hr is used and the area of the panel is 1.635 m^2. The glycol mixture of 40% is used, that has the density of 1072 kg/m^3 and the specific heat capacity of 3.595 kJ/kg ^{o}C [19]. Furthermore, it is assumed that the irradiance is 1000 W/m^2 and the ambient temperature is 25 ^{o}C. It is observed that as the fluid inlet temperature or the panel's working fluid temperature increases the thermal performance of the PVT starts to decrease. On the other hand, when the fluid inlet temperature is low or close to zero, the thermal output of the panel is maximum i.e. around 1559 Watt (thermal).

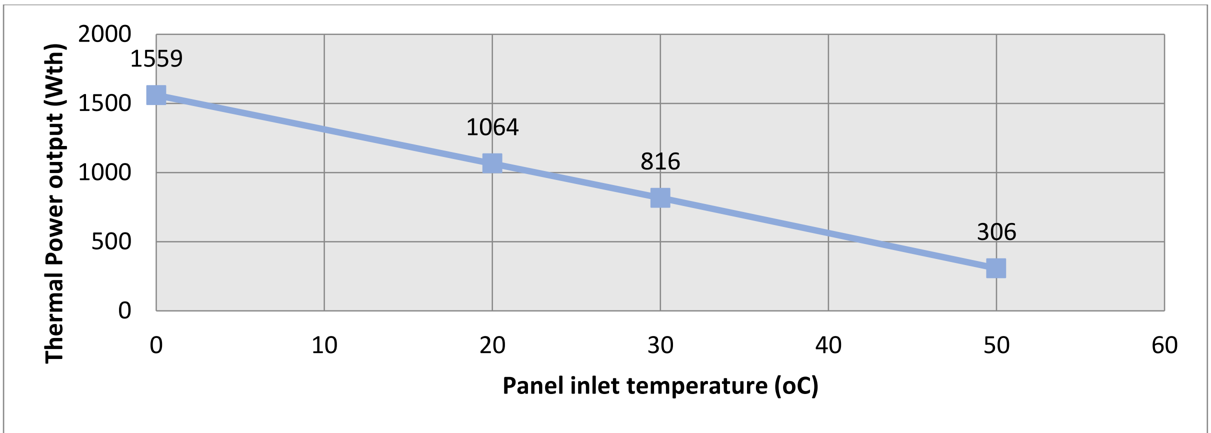

Figure 2-15: The thermal performance curve of the DualSun PVT model (300-310M – 60 – 3BBPN). Source: [18].

The pressure loss curve of the PVT panel is shown in Figure 2-16. It is for each panel that has an area of 1.635 m^2. The pressure drop increases when the flow rate increases in the panel.

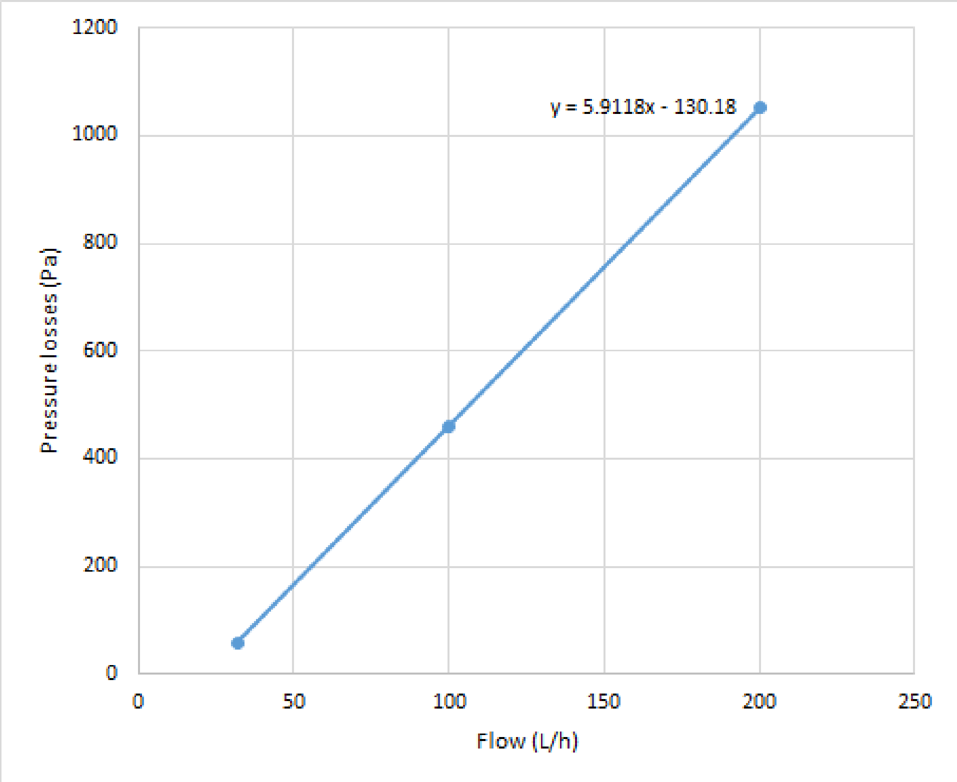

Figure 2-16: The pressure drop curve of the DualSun PVT model (300-310M – 60 – 3BBPN). Source: [18].

2.6.4.1 Without Electrical Load

The PVT panels used are based on the specification as mentioned in section 2.6.4 and in Table 2-6. The pressure drop is based on the equation as given in Figure 2-16 and the height of the building is assumed to be 45 m. It is assumed in all calculations that there is shading on the southern side of the demo building. The performance of the PVT is based on the curve as shown in Figure 2-15 for the thermal energy generation.

Table 2-6: PVT specification. Source: [18].

Simulation characteristics	**Value**
Maximum flowrate	630 kg/hr for 400 m^2
Working fluid	Glycol mixture 40%
Gross area of each panel	1.635 m^2
Heat loss coefficient (a1)	16.5 W/k.m^2
Heat loss coefficient (a2)	0
Optical efficiency	59.9 %
PV	Monocrystalline
Number of cells per module	60
Module efficiency	19.1%
Orientation	40^o slope, facing south

The performance of the energy system is shown in Figure 2-17, when property load such as common spaces appliances, HVAC equipment, sauna, laundry, office lighting, shops lighting, outdoor lighting, elevators and apartment loads such as lighting and appliances are not considered, i.e. in total 36.7 kWh/m^2 is not included. A space heating demand of 15.4 kWh/m^2, domestic hot water demand of 42.15 kWh/m^2 and space cooling demand of 2.36 kWh/m^2 are included as the demand for the building in the calculations.

In Figure 2-17 the x-axis shows the PVT area, the left side of the y-axis shows the electricity that is imported (blue bar) and exported (orange bar) from/to the grid. Moreover, the right side of the y-axis shows the energy generated from the PVT, i.e. the yellow line shows the heat generated and the grey line shows the electricity generated by the PVT. It can be observed from Figure 2-17 that when the PVT area starts to increase the import of electricity starts to decrease and it decreases by 35%; on the other hand the export of the electricity start to increase and it increases by 77%. The main reason for the decrease in the import and the increase in the export of electricity is due to the higher production of electricity by the PVT, i.e. it increases from 3.17 kWh/m^2.floor area to 12.16 kWh/m^2.floor area and simultaneously higher production of the heat energy by the PVT, i.e. it increases from 14 kWh/m^2.floor area to 21 kWh/m^2.floor area as the area of the PVT increases. It can be observed that when the area of the PVT increases to more than 300 m^2 the building becomes a PEB. As this PVT sizes give a combination, where the import of electricity is lower than the export of electricity by the building. When the PVT area is increased to 300 m^2, the exported electricity is larger than the imported electricity. Therefore, as a result the building can be assumed to be a PEB, under such circumstances.

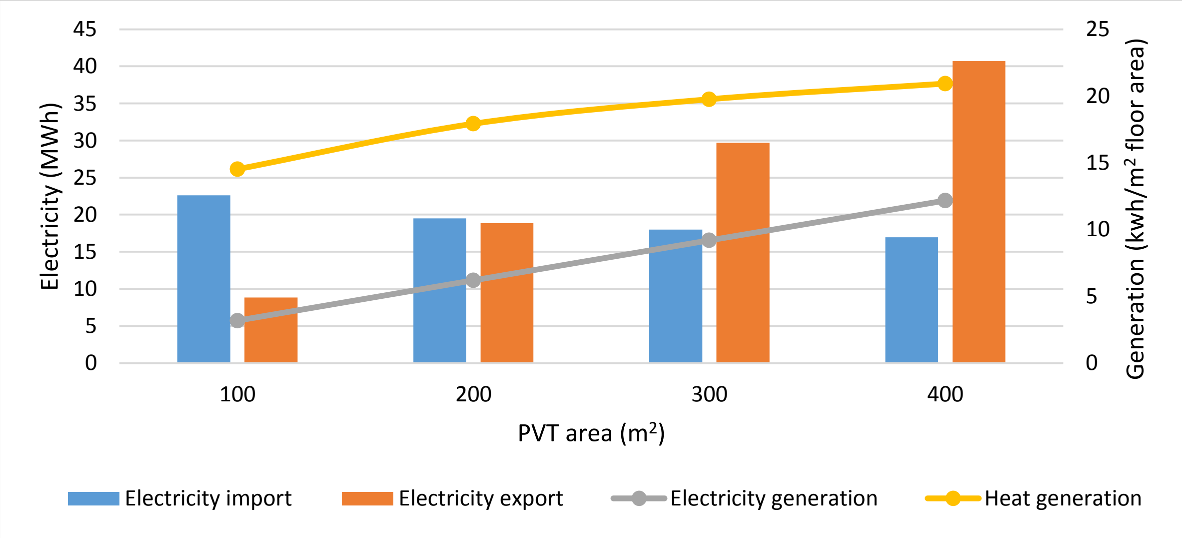

Figure 2-17: The import and export of electricity (y-axis, left side), and heat and electrical generation (y-axis, right side) for different PVT areas under Finnish condition, when electrical load of the building is not included. Source: VTT

2.6.4.2 With Electrical Load

The performance of the energy system is shown in Figure 2-18, when property load such as common spaces appliances, HVAC equipment, sauna, laundry, office lighting, shops lighting, outdoor lighting, elevators and apartment loads such as lighting and appliances are considered, i.e. in total 36.7 kWh/m^2 is included. The space heating demand of 15.4 kWh/m^2, domestic hot water demand of 42.15 kWh/m^2 and space cooling demand of 2.36 kWh/m^2 is also included as the demand for the building in the calculations. In Figure 2-18 the x-axis shows the PVT area, the left side of the y-axis shows the electricity that is imported (blue bar) and exported (orange bar) from/to the grid. Moreover, the right side of the y-axis shows the energy generated from the PVT, i.e. the yellow line shows the heat generated and the grey line shows the electricity generated by the PVT. It can be observed from Figure 2-18 that when the PVT area starts to increase the import of electricity starts to decrease and it decreases by 15%; on the other hand, the export of the electricity starts to increase, and it increases by 93%. The main reason for the decrease in the import and the increase in the export of electricity is due to the higher production of electricity by the PVT, i.e. it increases from 3.17 kWh/m^2.floor area to 12.16 kWh/m^2.floor area; simultaneously higher production of the heat energy by the PVT is observed i.e. it increases from 14 kWh/m^2.floor area to 21 kWh/m^2.floor area as the area of the PVT increases. It can be observed that when the area of the PVT increases the import of electricity decreases and the export of electricity increases, however the building is not able to reach PEB level. According to the EXCESS project's [20] PEB definition, a building is considered as PEB when the export of electricity is larger than the import of electricity when all the demand i.e. thermal and electrical demands are included in the calculations.

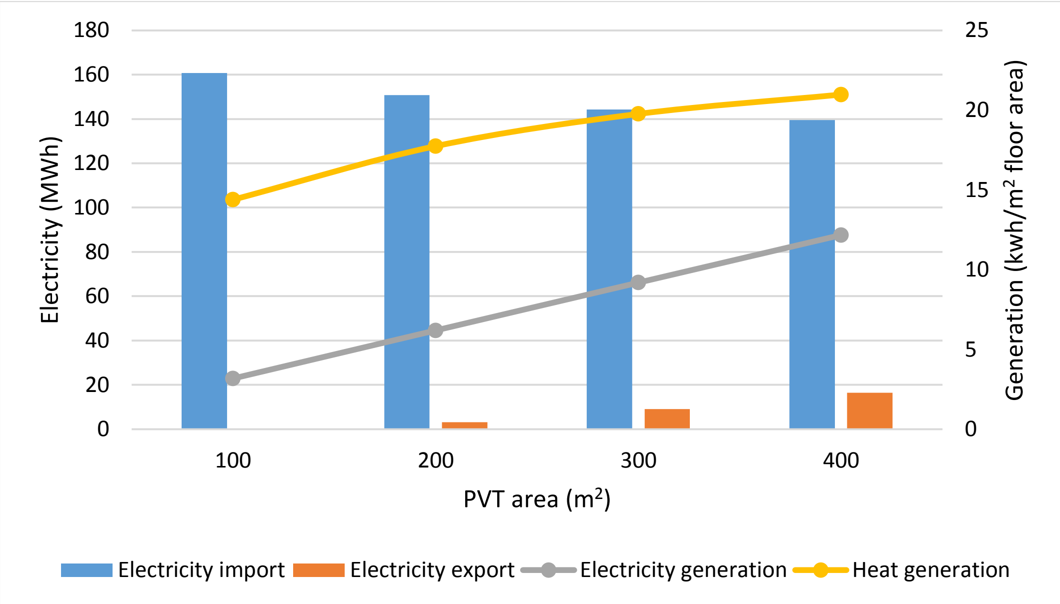

Figure 2-18: The import and export of electricity (y-axis, left side), and heat and electrical generation (y-axis, right side) for different PVT areas under Finnish condition, when electrical load of the building is included. Source: VTT

2.6.5 Photovoltaic (PV) Integration (Façade)

The PV panels used are based on a reference panel and the specifications are mentioned in Table 2-7.

Table 2-7: PV specifications. Source: [21].

Simulation characteristics	Value
PV type	LB0 Kromatix black
Nominal output	190 Wp
Nominal voltage	22.8 V
Nominal current	8.2 A
Short circuit current	8.51 A
Open circuit voltage	26.9 V
Module conversion	12%
Orientation	90^o slope, facing 26^o south-west façade and west façade

2.6.5.1 Without Electrical Load

The PV panel used for the calculations is based on the specifications mentioned in Table 2-7. In Figure 2-19 the x-axis shows the PV area installed on the building's facade, the left side of the y-axis shows the electricity that is imported (blue bar) and exported (orange bar) from/to the grid. Moreover, the right side of the y-axis shows the energy generated from the PVT and PV together, i.e. the yellow line shows the heat generated by the PVT and the grey line shows the electricity generated by the PVT and PV together. For comparison one case is chosen, where the PVT area of 200 m^2 is fixed for all the cases. Moreover, in this case the electrical load of 36.7 kWh/m^2 is not included in the calculations. It is observed that when no PV is installed the import of electricity is slightly higher than the export of electricity. However, in the case when the PV of 50 m^2 is integrated with the southern façade (26^o southwest) and 100 m^2 is integrated with the western façade the import of electricity decreases and the export of electricity increases. Moreover, the electrical generation increases by 39% as both the PV and PVT are producing electricity. Similarly, in the case when the PV of 100 m^2 is integrated with the southern façade (26^o southwest) and 200 m^2 is integrated with the western façade the import of electricity decreases and the export of electricity increases further. The import of electricity reduces by 11% and the export of electricity increases by 78% compared to the reference scenario. Figure 2-19 shows that the building can reach PEB level when PV is integrated with the façade when electrical demand is not included in the calculations.

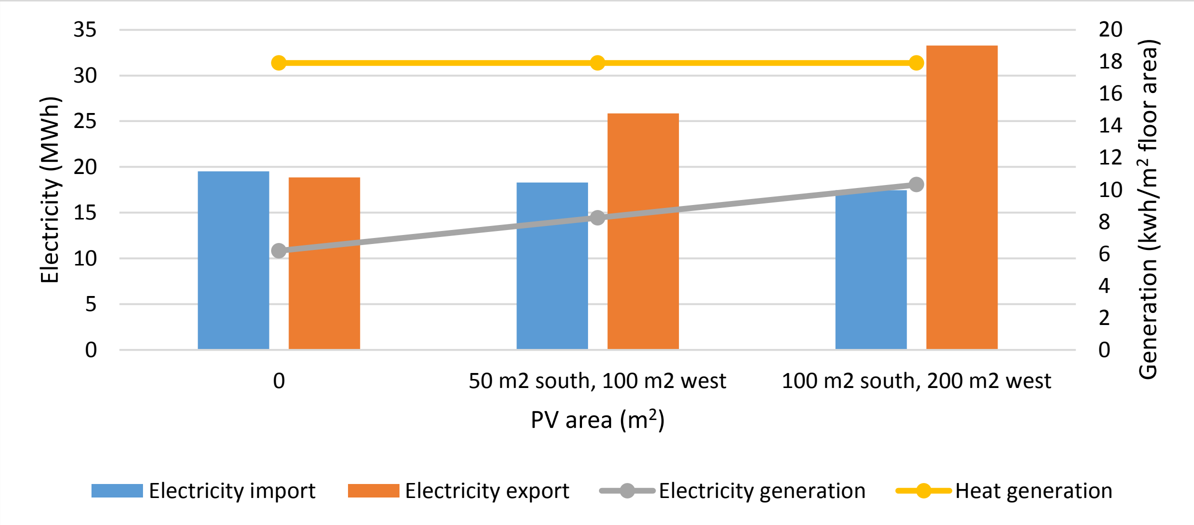

Figure 2-19: The import and export of electricity (y-axis, left side), and heat and electrical generation (y-axis, right side) for different areas of the façade integrated PV (26^o southwest façade and west façade) and 200 m^2 PVT under Finnish condition, when electrical load of the building is not included. Source: VTT

2.6.5.2 With Electrical Load

The PV panel used for the calculations is based on the specifications mentioned in Table 2-7. In Figure 2-20, the x-axis shows the PV area installed on the building's facade, the left side of the y-axis shows the electricity that is imported (blue bar) and exported (orange bar) from/to the grid. Moreover, the right side of the y-axis shows the energy generated from the PVT and PV together, i.e. the yellow line shows the heat generated by the PVT and the grey line shows the electricity generated by the PVT and PV together. For comparison one case is chosen, where the PVT area of 200 m^2 is fixed for all the cases. Moreover, in this case the electrical load of 36.7 kWh/m^2 is included in the calculations. It is observed that when no PV is installed the import of electricity higher than the export of electricity. However, in the case when the PV of 50 m^2 is integrated with the southern façade (26° southwest) and 100 m^2 is integrated with the western façade the import of electricity decreases and the export of electricity increases. Moreover, the electrical generation increases by 39% as both the PV and PVT are producing electricity. Similarly, in the case when the PV of 100 m^2 is integrated with the southern façade (26° southwest) and 200 m^2 is integrated with the western façade the import of electricity decreases and the export of electricity increases further. The import of electricity reduces by 7% and the export of electricity increases by 68% compared to the reference scenario. Figure 2-20 shows that the building is not able to reach PEB level when PV is integrated with the façade when electrical demand is included in the calculations.

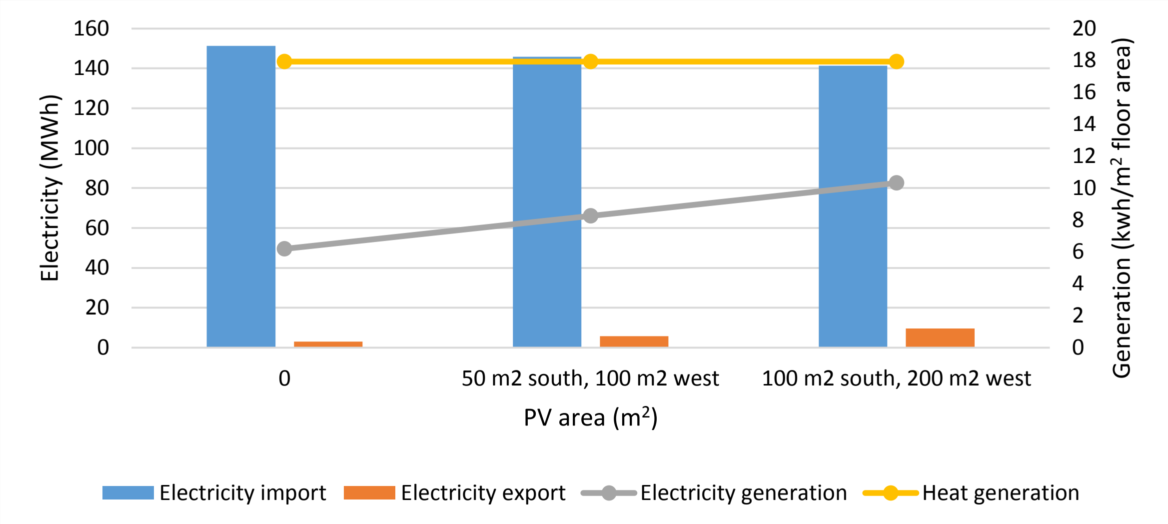

Figure 2-20: The import and export of electricity (y-axis, left side), and heat and electrical generation (y-axis, right side) for different areas of the façade integrated PV (26° southwest façade and west façade) and 200 m^2 PVT under Finnish condition, when electrical load of the building is included. Source: VTT

The PV panel used for the calculations is based on the specifications mentioned in Table 2-7 and the PVT panel used for the calculations is based on the specifications mentioned in Table 2-6. In Figure 2-21, the x-axis shows the PV area on façade and the PVT area, the left side of the y-axis shows the electricity that is imported (blue bar) and exported (orange bar) from/to the grid. Moreover, the right side of the y-axis shows the energy generated from the PVT and PV together, i.e. the yellow point shows the heat generated by the PVT and the grey point shows the electricity generated by the PVT and PV together. For comparison one case is chosen, where the PVT area of 400 m^2 and the PV area of 100 m^2 is integrated with the southern façade (26° southwest) and PV area of 200 m^2 is integrated with the western façade. It is observed that the import of electricity is around 133 MWh and the export of electricity is around 26 MWh. The total electricity generated by the PV and PVT is 16.29 kWh/m^2.floor area and the heat generated is 20.9 kWh/m^2.floor area. The building is not able to reach positive energy building level, when all the loads, i.e. heating, cooling, property and apartment electrical demands are included in the calculations.

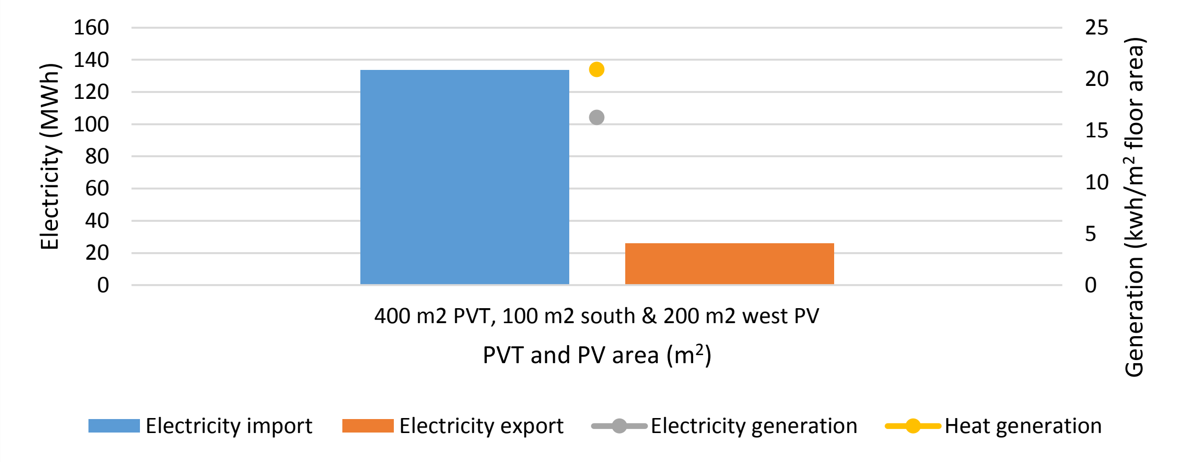

Figure 2-21: The import and export of electricity (y-axis, left side), and heat and electrical generation (y-axis, right side) for different areas of the façade integrated PV (26° southwest façade and west façade) and 400 m² PVT under Finnish condition, when electrical load of the building is included. Source: VTT

2.6.6 Shading Effects

The effect of shading is also tested for the PVT panels that are facing south. The assumed specifications of the shading barrier are given in Table 2-8.

Table 2-8: Shading. Source: VTT

Simulation characteristics	Value
Horizontal distance from the surface	100m
Height of obstruction	Variable
Start of obstruction	South
End of obstruction	West

In the simulations, it is assumed that the PVT area is 400 m² and the obstruction is based on the specifications provided in Table 2-8. In Figure 2-22, the x-axis shows the height of the obstruction, the left side of the y-axis shows the electricity that is imported (blue bar) and exported (orange bar) from/ to the grid. Moreover, the right side of the y-axis shows the energy generated from the PVT, i.e. the yellow line shows the heat generated and the grey line shows the electricity generated by the PVT. The PV integrated on façade and the electrical demand of 36.7 kWh/m² is not included. It can be observed from Figure 2-22 that when the shading height increases, the import of electricity starts to increase and the export starts to decrease. The import increases by 24% and the export decreases by 34% when the height of the obstruction increases from 0m to 90m. The main reason for the increase in the import and the decrease in the export of electricity is due to the decrease in the production of electricity by the PVT, i.e. it decreases from 12.2 kWh/m².floor area to 8.06 kWh/m².floor area and simultaneously lower production of heat energy by the PVT, i.e. it decreases from 20 kWh/m².floor area to 16 kWh/m².floor area as the height of the obstruction decrease. It can be observed that the obstruction near the building can reduce the solar radiation on the PVT panels. Consequently, shading of the PV panel can reduce the overall performance of the system and this factor can be critical to the overall energy system performance.

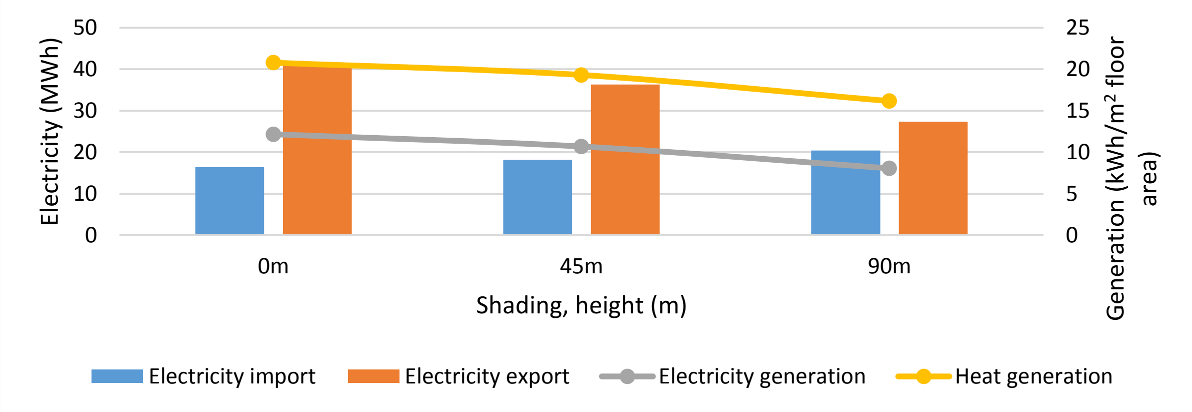

Figure 2-22: The import and export of electricity (y-axis, left side), and heat and electrical generation (y-axis, right side) when the shading effect is accounted for the PVT area of 400 m^2 under Finnish condition, when electrical load of the building is included. Source: VTT

2.6.7 Tank (Buffer) Storage and Heat Pump Integration

The tanks are assumed as stratified tank, so that it can have temperature distribution in the tank. The assumed specifications of the tanks and performance of the heat pumps are shown in Table 2-9.

Table 2-9: Tanks and heat pumps assumed specifications. Source: [22].

Simulation characteristics	Value
PVT buffer tank volume	Variable
Hot tank (for space heating and domestic hot water)	20 m^3
Cold tank for space cooling	2 m^3
Insulation (Rockwool), U value	0.2 W/m^2.K (PVT buffer tank, hot tank) and 0.4 W/m^2.K (cold tank)
Heat pump capacity	60 kW thermal
COP	3-5

The heat pumps are used to charge the hot tank which is used to provide the final space heating and domestic hot water to the building via heat exchangers. The heat pumps take the energy from the PVT buffer tank at 25 ^{o}C or through the BTES, if the tank temperature falls below 15 ^{o}C and no solar energy is available. For space cooling, the heat pumps are used in reverse cycle so that the evaporator side is connected with the cold tank and the condenser is connected with the BTES. The heat pump cools the tank to provide space cooling to the building, while the waste heat from the buildings are used to charge the BTES during summer so that this heat can be used during winters for heating.

The experimental setup is used to explain the impact of buffer tank on the performance of the PVT panel. For the experimental setup, a PVT size of 20 m^2 is used and integrated directly with the buffer tank. Here the working fluid from the tank is provided from the bottom node, it is assumed that the buffer tank is charged at 60 ^{o}C from the top node. Figure 2-23 shows the performance of the PVT based on the buffer tank volume. The x-axis shows the tank volume, the left side y-axis shows the heat production by the PVT and the right side y-axis shows the electricity production by the PVT. It is observed from Figure 2-23 that when the volume of the tank increases from 300 litres to 1000 litres the heat production increases from 2700 kWh/yr to 3750 kWh/yr and the electricity production increases from 1993 kWh/yr to 2014 kWh/yr. This shows the importance of the PVT's buffer tank volume. As the volume of the tank increases, the production of energy from the PVT also increases. This is because when the tank volume is large, the tank can provide the PVT with cold working fluid for longer duration to collect maximum heat or to cool the PVT.

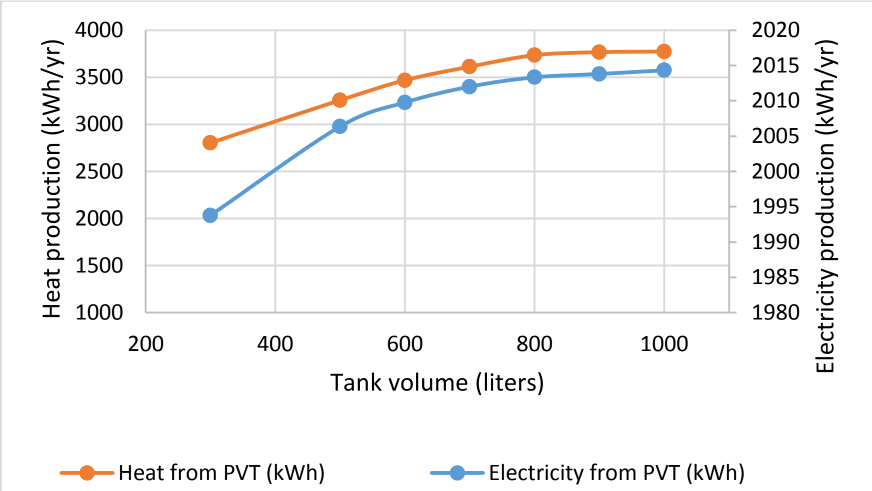

Figure 2-23: The comparison between various buffer tank volumes on the PVT performance under Finnish condition. Source: VTT

In Figure 2-24 the x-axis shows the volume of the PVT buffer tank, the left side of the y-axis shows the electricity that is imported (blue bar) and exported (orange bar) from or to the grid. Moreover, the right side of the y-axis shows the energy generated from the PVT, i.e. the grey line shows the electricity generated by the PVT. The PV integrated on the building's façade and the electrical demand of 36.7kWh/m^2 is not included. The PVT area is assumed to be 400 m^2. Moreover, the volume of the hot water and cold water is kept constant as shown in Table 2-9. It can be observed in Figure 2-24 that when the volume of the PVT buffer tank decreases from 50 m^3 to 10 m^3, the import of electricity increases from 16 MWh to 18.5 MWh and the export of electricity reduces from 41.1 MWh to 40.6 MWh. The increase in the import of electricity is mainly due to decrease in the heat production by the PVT. The heat production is reduced by 21% when the PVT buffer tank is reduced from 50 m^3 to 10 m^3 as shown in Figure 2-24. Lastly it is found that the decrease in the electricity production is not significant compared to the heat production.

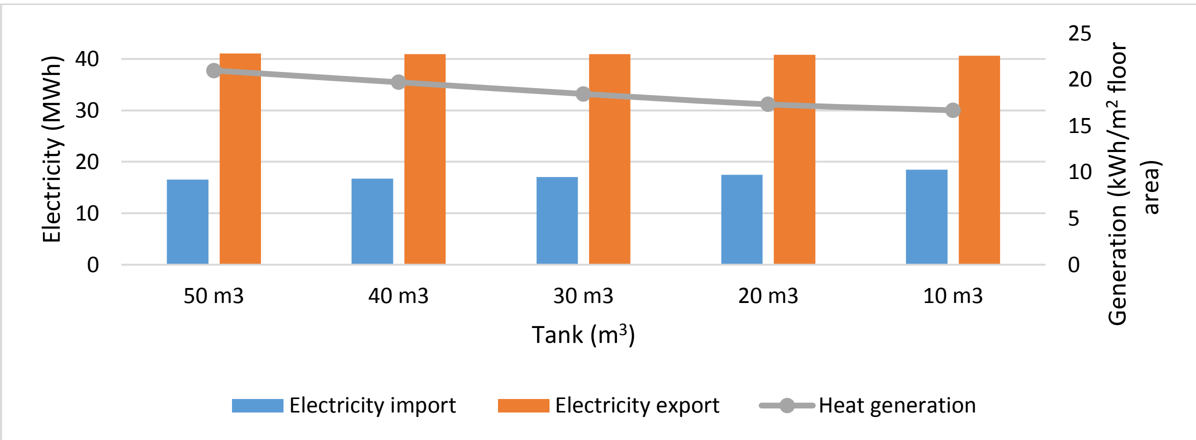

Figure 2-24: The import and export of electricity (y-axis, left side), and electrical generation (y-axis, right side) when the PVT buffer tank volume changes from 10 m^3 to 50 m^3 under Finnish condition, when electrical load of the building is not included. Source: VTT

2.6.8 Borehole Thermal Energy Storage Integration

The glycol mixture of 20% is used for the boreholes that has a density of 1036 kg/m^3 and a specific heat capacity of 3.918 kJ/kg ^{o}C [19]. The borehole design is based on the specifications shown in Table 2-10. It is assumed that the pressure drop is mostly based on the height and due to elbow connections. During the charging phase at 35 ^{o}C the fluid flows from the inner pipe and to the outer pipe. During the discharging phase the fluid flows in reverse direction, i.e. it flows from the outer pipe and to the inner pipe. The discharging occurs when the PVT buffer tank temperature is below 15 ^{o}C and no further solar energy is available. The BTES is also charged from the waste heat from the ventilation. The cool water from the cold tank is supplied to the building and the heat collected from the building during summer is dumped in the BTES via a heat pump. The charging of the boreholes increases by 50% when the waste heat from the building is used to charge the boreholes and the discharging increases by 36% in this condition. The maximum average temperature of the boreholes reached is around 11 ^{o}C to 10 ^{o}C during the charging phase from the PVT and from the waste heat from the building.

Table 2-10: Coaxial type borehole thermal energy storage specifications. Source: [19], [23], [24], [25].

Simulation characteristics	Value
Maximum flowrate	90 kg/hr
Working fluid	Glycol mixture 20%
Volume	1000 m^3
Number of boreholes	3
Height of boreholes	800 m
Insulation (Rockwool) conductivity	0.04 W/m.K
Insulation thickness	2 m
Storage thermal conductivity	3.5 W/m.K
Storage heat capacity	2200 kJ/m^3/K
Inner radius of outer tube	0.0889 m
Inner radius of inner tube	0.01372 m
Ground temperature	5 ^{o}C
Air average temperature	5.6 ^{o}C

To estimate the effect of the design of the BTES on the overall performance of the energy system a parametric study is carried out based on the boreholes height ratio and boreholes density as shown in Table 2-11. It is assumed that the PVT area is 400 m^2 for all the cases. Building integrated PV and electrical load of 36.7 kWh/m^2 are not included in the calculations.

Table 2-11: Coaxial type borehole thermal energy storage parametric study. Source: [14], [19].

Simulation characteristics	Value
Maximum flowrate	90 kg/hr for 400 m^2
Working fluid	Glycol mixture 20%
Volume	1000 m^3
Height to width ratios	1, 3, 5
Boreholes density	0.05, 0.1, 0.15 boreholes/m^2

Figure 2-25 shows the performance of the energy system when the boreholes height varies. In Figure 2-25, the x-axis shows the single borehole height ratio, the left side of the y-axis shows the electricity that is imported (blue bar) and exported (orange bar) from/to the grid. Moreover, the right side of the y-axis shows the heat flows in the boreholes per m^2 of the PVT area, i.e. the yellow line shows the heat discharged, the blue line shows the heat loss in the surrounding and the grey line shows the heat that is charged in the boreholes. To give a perspective in these calculations, the parameters used are shown in Table 2-10 and in Table 2-11. However, the volume of boreholes, i.e. 1000 m^3 and PVT area of 400 m^2 is used and electrical load is not included in the calculations. The boreholes density is also fixed at 0.15 boreholes/m^2 and only the height to width ratio changes from 1 to 5. It is observed in Figure 2-25 that when the boreholes height ratio increases from 1 to 5, the electricity import reduces by 60% and the electricity export increases by 31%. When the boreholes ratio is 1 the building is not able to reach the positive energy building (PEB) level i.e. the import of electricity is more than the export of electricity. However, when the boreholes ratio increases to 3 and 5 the building becomes a PEB building. Here the height ratio of 1, 3 and 5 correspond to the borehole height of 11 m, 23 m and 32 m respectively. It is found that the import of electricity reduces when the height of the boreholes increases. This is because when the boreholes height increases the charging of the boreholes and the discharging of the boreholes increases, due to which the import of the electricity decreases. With larger height, the boreholes have larger storage capacity available that can be charged during summer. Later on, the charged boreholes can be discharged during winter for longer period when the boreholes height is large compared to shorter boreholes. Large charging and discharging capacity of the boreholes means that higher temperature can be provided to the heat pumps evaporator that can increase the heat pump COP ultimately reducing the import of electricity. The charging of the boreholes increases from 29.5 to 40.8 kWh/m^2 of PVT area when the boreholes height ratio increases from 1 to 5. On the other hand, due to an increase in the charging of the heat in the boreholes, the losses from the boreholes also increase from 10.6 to 22.6 kWh/m^2 of PVT area. Therefore, according to the calculations (shown in Figure 2-25) it is recommended to have deeper boreholes compared to shorter depth boreholes if the energy system performance has to be increased.

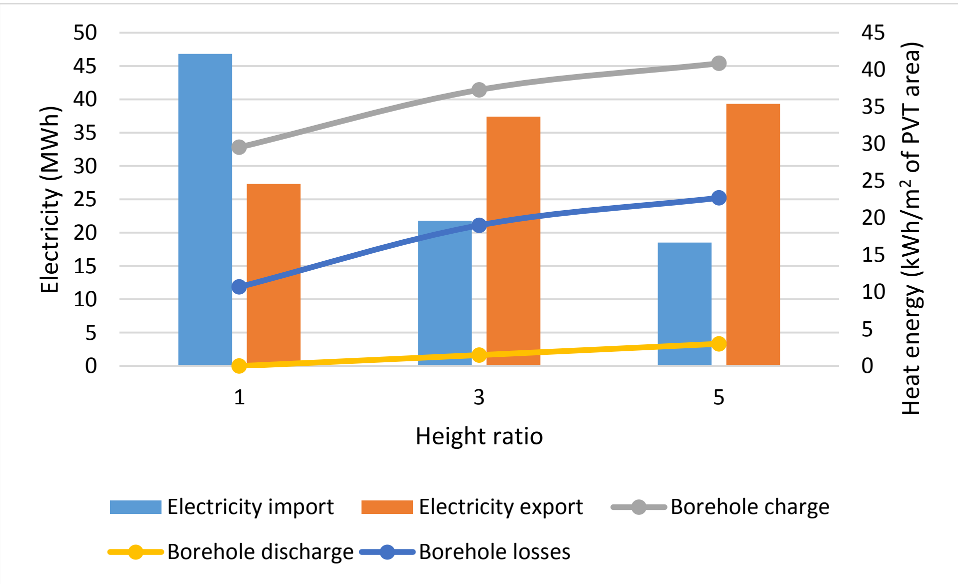

Figure 2-25: The import and export of electricity (y-axis, left side), and heat energy flows in the BTES (y-axis, right side) when the boreholes height ratio changes from 1 to 5 under Finnish condition, when electrical load of the building is not included and PVT area of 400 m^2 is used. Source: VTT

Figure 2-26 shows the performance of the energy system when the boreholes density per cross-sectional area varies. In Figure 2-26, the x-axis shows the boreholes density, the left side of the y-axis shows the electricity that is imported (blue bar) and exported (orange bar) from/to the grid. Moreover, the right side of the y-axis shows the heat flows in the boreholes per m^2 of the PVT area, i.e. the yellow line shows the heat discharged, blue line shows the heat loss in the surrounding and the grey line shows the heat that is charged in the boreholes. To give the perspective in these calculations, the parameters used are shown in Table 2-10 and in Table 2-11. However, the volume of boreholes, i.e. 1000 m^3 and PVT area of 400 m^2 is used and electrical load is not included in the calculations. The height to width ratio is also fixed at 5 and only the boreholes density changes from 0.05 to 0.15. It is observed in Figure 2-26 that when the boreholes density increases from 0.05 to 0.15, the electricity import increases by 16% and the electricity export decreases by 5%. Here the boreholes ratio of 0.05, 0.1 and 0.15 correspond to the number of boreholes as 2, 3 and 5 respectively. It is found that the import of electricity is increased when the boreholes density increases. This is because when the boreholes density increases the charging of the boreholes increases and the losses increases however the discharging of the boreholes decreases, due to which the import of the electricity increases. The charging of the boreholes increases from 25.7 to 40.8 kWh/m^2 of PVT area when the boreholes density increases from 0.05 to 0.15 boreholes/m^2. On the other hand, due to increase in the charging of the heat in the boreholes, the losses from the boreholes also increase from 4.7 to 22.6 kWh/m^2 of PVT area. Therefore, according to the calculations (shown in Figure 2-26) it is recommended to have less boreholes density, i.e. less number of boreholes per m^2 cross section area if the energy system performance has to be increased.

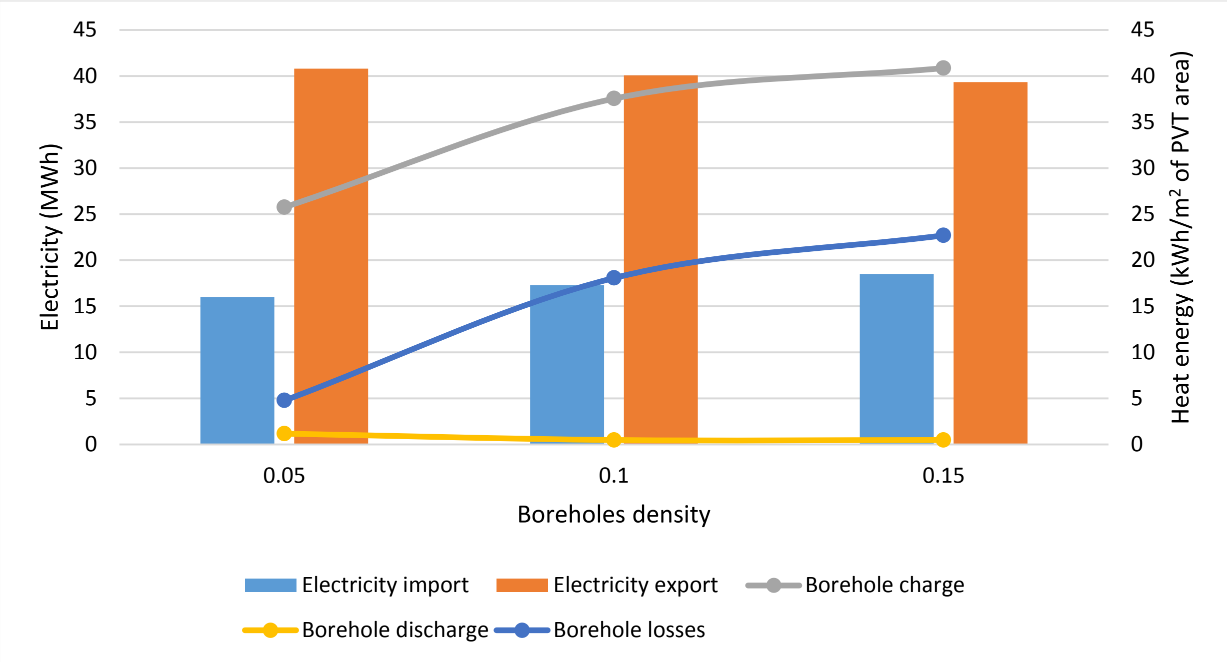

Figure 2-26: The import and export of electricity (y-axis, left side), and heat energy flows in the BTES (y-axis, right side) when the boreholes density changes from 0.05 to 0.15 boreholes/m^2 under Finnish condition, when electrical load of the building is not included and PVT area of 400 m^2 is used. Source: VTT

2.7 Conclusions

The detailed building model is developed using IDA-ICE simulation tool. The use of energy by the user is defined in the building model, to identify the main loads in the building. In addition to the building model, the energy system model is developed using the TRNSYS simulation tool. Both the models of the building and the energy system can be used to study the Finnish demo case to evaluate the performance of each component and the energy system.

Overall, it is observed that the building has good thermal insulation (low U-values) for the floor, roof, walls and windows, as well as high efficiency heat recovery from the exhaust air. As a result, the building has very low space heating demand which is contributed by low temperature floor heating system that have a positive effect on the efficiency of the ground source heat pump. Most of the space heating demand occurs during the winter period. On the other hand, there is cooling demand during summertime, which is relatively small compared to the space heating demand for the year. The domestic hot water demand is significantly high compared to the space heating and cooling demand. The domestic hot water demand is high because of the recirculation, according to the user behaviour and energy use patterns, i.e. most of the domestic hot water demand occurs during morning and evening. To reduce the domestic hot water demand, water saving measures like pressure control and water saving taps will be used. The electrical demand considered is for the appliances, elevators, lighting and HVAC components that are installed in the building and offices. These electrical loads play a significant role in the total demand. The total electricity demand is estimated to be 52 kWh/floor-m^2 from which building systems (heating, hot water, cooling, fans and pumps) compose roughly 50 %, property lighting and appliances 20 % and household use 30 %. The building model can be further used to refine the demand profiles of the building based on the user behaviour, schedule and pattern.

The energy model and simulation results show that a PVT area of 300 m^2 and above facing south is recommended to meet the heating, cooling and domestic hot water demand under Finnish conditions. The building can be assumed PEB building under Finnish conditions when the building has a lower import compared to the export during the year. However, this is not the case when the electrical demand of the property i.e. common spaces appliances, HVAC equipment, sauna, laundry, office lighting, shops lighting, outdoor lighting, elevators and apartment loads such as lighting and appliances are added. In this case, the import of electricity from the grid is higher than the export of the electricity to the grid.

Two important factors are critical for the performance of the PVT. These two factors are the shading of the PVT and the buffer tank size. The lower the shading on the PVT and larger the buffer tank size is, the lower the import of electricity is. The heat collected from the PVT can be stored either in the short-term buffer tank or in the seasonal storage. The heat pump can take this low temperature energy either from the buffer tank or from the seasonal storage during the year to charge the hot tank at higher temperature. The space heating and the domestic hot water can be provided through this hot tank. The space cooling is also provided to the building through the cold tank. The waste heat from the building can be used to further charge the boreholes via heat pumps. The coaxial boreholes are also integrated with the energy system that acts as a seasonal storage. Based on the simulation it is observed that deeper boreholes with wider or large distances between the boreholes are the optimal way to maximize the performance of the system.

In addition to the PVT, the building integrated PV on the building façade are also added in the energy system. Two faces of the building i.e. south-west and west facades are used to integrate the PV with the building. By adding PV on the building, the PVT capacity can be reduced to 200 m^2 to reach PEB level. However, the building is still not able to reach the PEB level, both with the PVT and PV if the electrical demand of the property and apartments are included in the calculations of the PEB in Finnish condition.

The energy system modelling can be used to predict the performance of the building under different climate, demands, control strategy and capacities of the components. The model can help the system designers, integrator and suppliers of the components to improve the performance of the system and to optimize the size and control strategy for the PEB buildings. The forecasting of the weather and energy cost can be integrated with the model to improve the control strategy. For instance, the charging of the tanks or boreholes can be varied depending on the weather and the energy cost to minimize the operational cost of the building by minimizing the import of electricity from the grid. More control strategies and capacities can be evaluated after the final design of building and energy system is done. These models can be used by the Construction Company, energy system integrators and component designers to further improve the system.

The main lesson learned is that the building's demand can influence the overall performance of the energy system; therefore, energy efficiency of the building has to be addressed first. The PVT, buffer tank and seasonal storage are critical components to reach PEB level. Moreover, the control strategy and cooling of the PVT is important. Lastly, the waste heat from the ventilation can be used to charge the boreholes to improve the performance of the energy system. The building integrated PV can improve the performance of the system, but it has slight impact.

3 Case Study in Mediterranean Climate. Spain

3.1 Short Description of the Case Study

The Spanish Demo Pilot is a residential building which is planned to be built in 2021 (start construction phase in July 2021) within the first planned zero energy district in Spain (called "Solar City Nivalis") in Dilar municipality (Granada) (See Figure 3-1).

Dilar is located at the south of Spain, in the Granada province (Latitude 37°04'34"N Longitude 3°36'08"O) at an average elevation of 873 m above sea level.

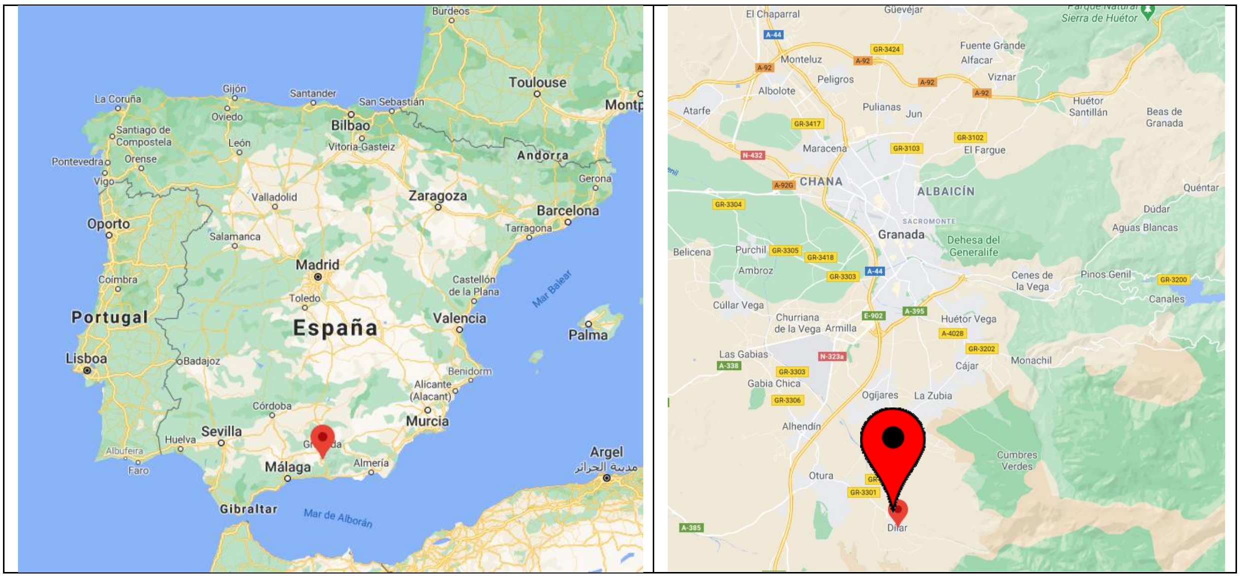

Figure 3-1: Spanish Demo Pilot Location-Dilar (Granada). Source: Google Maps

The building is planned to be located in R-18 plot as it is shown in picture below:

Figure 3-2: Solar City Nivalis.-Zero Energy District Picture. Plot R-18 Source: Urb.Atelier Arquitects

This EXCESS PEB system concept from Spanish Demo Pilot relies on maximizing the electricity production provided by PV panels integrated in building's roof, minimizing the building thermal demand (space heating/cooling and DHW) with both, passive (high efficient envelope) and active solutions (such as motorized blinds and heat recovery systems), and optimize the sizing and working of the thermal generation system.

As the Spanish Pilot is a new building, whose definition is still under development, the model developed in this Task is being taken advantage of defining the geometry and the envelope as well as the sizing of their facilities.

3.2 Climate Description

The local climate conditions in Dilar (Granada) are characterized by mild temperatures and high solar irradiance. The picture below shows the Global, Beam and Diffuse Radiation in every month of the year based on [26].

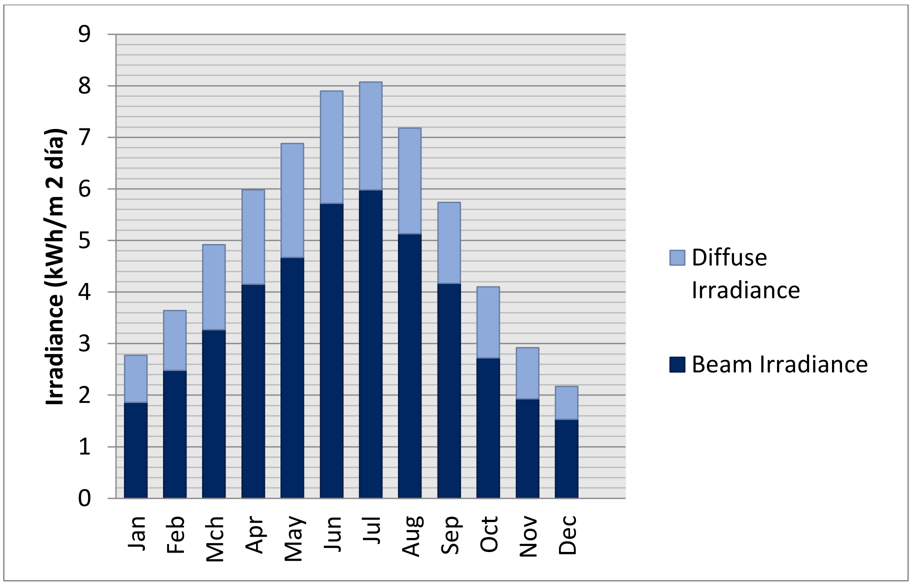

Figure 3-3: Beam and Diffuse Irradiance (kWh/m^{2}day) in Granada. Source: CENER (AEMET)

As per [27], the heating degree days with base 15ºC are 1212 and the cooling degree days with base 20ºC are 680.

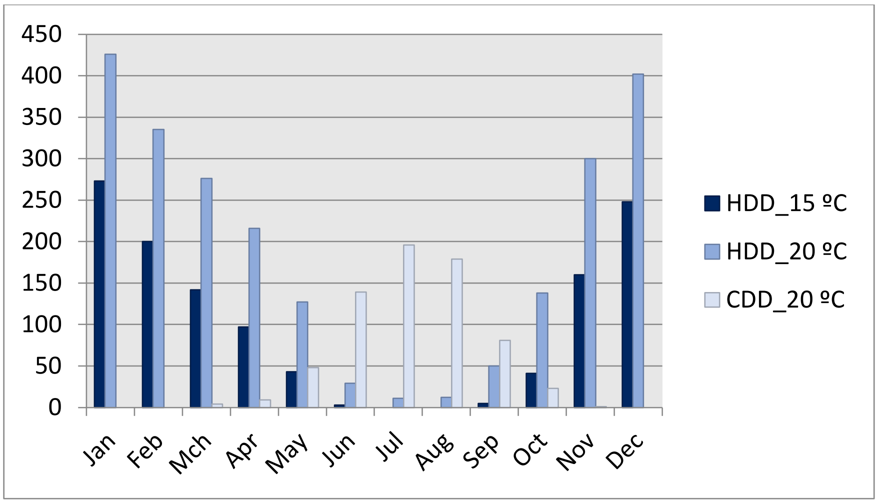

Figure 3-4: HDD_15ºC, HDD_20ºC, CDD_20ºC in Granada-Airport (678 m). Source: CENER (IDAE)

3.3 Building Description

The Spanish Demo Building is planned to be a three-storey building with 30 apartments (10 apartments per floor). In the top floor, 6 out of the 10 apartments will have an attic. The ground-floor will be commercial spaces that they have not been included in the PEB goal. Only private residential spaces have been taken into account, as it was defined in PEB EXCESS definition, in WP1.

The geometrical definition is being developed (by the time writing this document it is still in progress) by Urb.Atelier architects (EXCESS project partner).

A 3D recreation of the current building definition is shown in the picture below:

Figure 3-5: Spanish Demo - Virtual 3D Recreation Building. Source: Urb.Atelier Arquitects (Sketch Up)

3.3.1 Dwellings Typology

There are 8 typologies of dwellings in this building :

Table 3-1: Typologies of Dwelling Spanish Demo Pilot. Source: Urb.atelier architects

Typology	Blue	Red	Grease	Yellow	Brown	Duplex 1 (Orange)	Duplex2 (Green)	Duplex3 (Purple)
Numbered-Typology	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6	Type 7	Type 8
Area (m^2)	133.04	122.82	64.08	90.78	89.31	128.08	140.45	162.9
Location	1st floor 2nd floor 3rd floor	1st floor 2nd floor 3rd floor	1st floor 2nd floor	1st floor 2nd floor	1st floor 2nd floor	3rd floor (attic)	3rd floor (attic)	3rd floor (attic)

The followings Figures shows the 8 typologies of dwellings in first, second, third floors and attics.

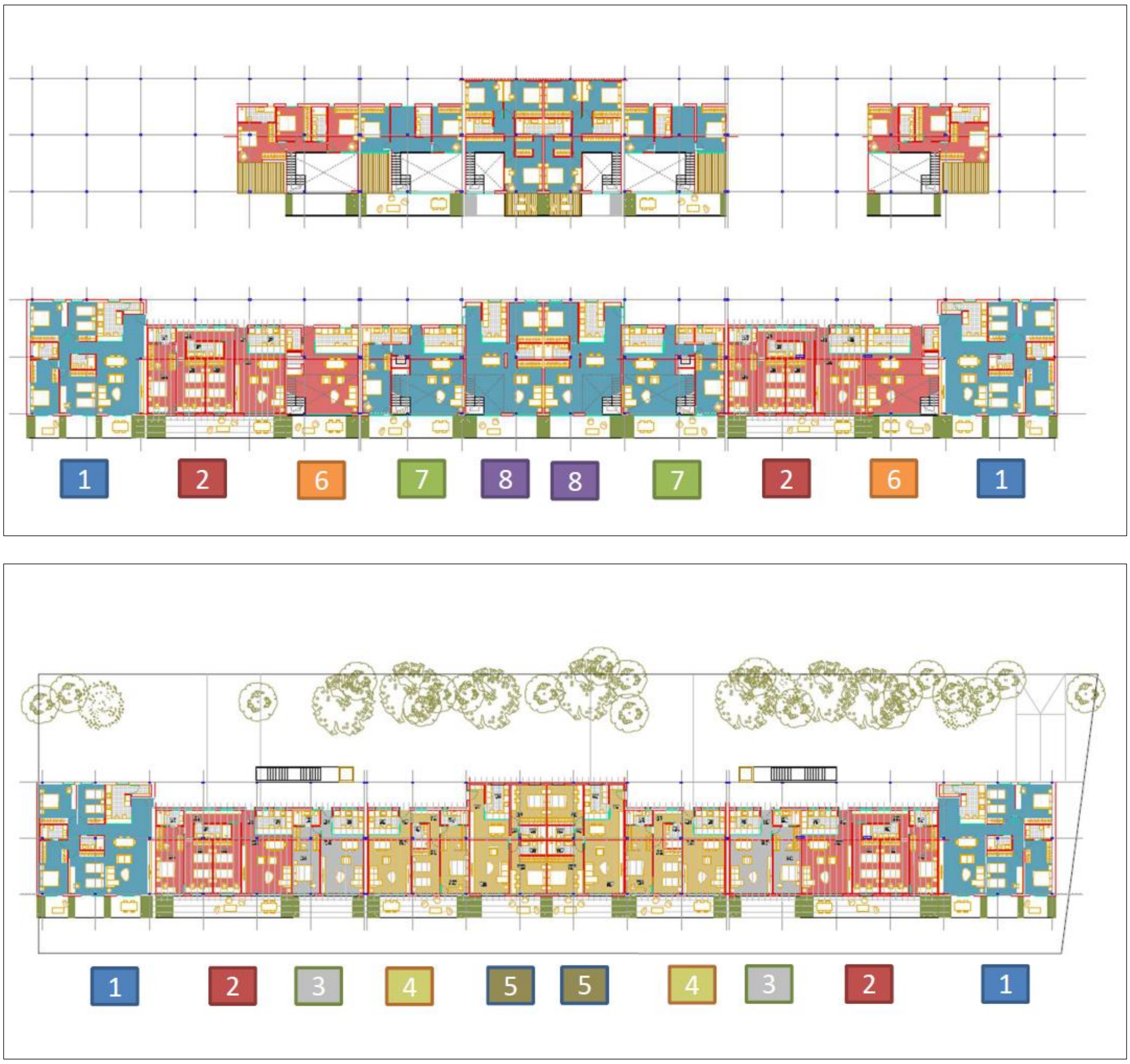

Figure 3-6: Spanish Demo- Top View Floors 1, 2, 3 and attics. Source: Urb.Atelier Arquitects (Autocad)

The building is facing South-West 30°.

3.3.2 Envelope/Windows

The building envelope for all the buildings from this district was defined in a previous project developed by CENER, called *"Solar City Nivalis"* project. A guide was developed by CENER with the technical descriptions that it should be taken into account by the project's developers for all the buildings located in the Solar City Nivalis.

According to the considerations set in "Nivalis Design Guide", the thermal characteristics of the envelope are those defined in Table below:

Table 3-2: Spanish Demo Pilot.- Envelope Definition. Source: Nivalis Design Guide (CENER)

ENVELOPE			WINDOW		
FAÇADE [U (W/m²K)]	ROOF [U (W/m²K)]	GROUND FLOOR [U (W/m²K)]	GLAZING [U (W/m²K)]	GLAZING [g]	FRAME [U (W/m²K)]
0.17	0.16	0.22	0.9	0.55	1.1

3.3.3 Ventilation system/Infiltration Losses

At this stage, the ventilation system has not been decided on yet. For the development of this Task, a decentralized ventilation system has been considered.

The minimum ventilation rate for every dwelling has been calculated in accordance to [28] to accomplish the adequate IAQ requirements in residential buildings.

However, the implemented model enables to modify easily and evaluate the building demand with the ventilation users preferences (if available).

The ventilation rates calculated for every type of dwelling are shown in the table below:

Table 3-3: Ventilation Rate Calculation for type-dwellings. Source: CENER

TYPE DWELLING	Rooms Definition TYPE DWELLING	kg/h
DWELLING TYPE 1 (BLUE)	4bed[1] - 2 bath[2]	219.6
DWELLING TYPE 2 (RED)	3 bed - 2bath	205.2
DWELLING TYPE 3 (GREASE)	1bed - 1bath	93.6
DWELLING TYPE 4 (YELLOW)	2bed - 2bath	154.8
DWELLING TYPE 5 (BROWN)	2bed - 2bath	154.8
DWELLING TYPE 6	0bed - 1bath	64.8
	3bed - 2bath	176.4
DWELLING TYPE 7	1bed - 2bath	93.6
	3bed - 2bath	176.4
DWELLING TYPE 8	1bed - 1bath	93.6
	3bed - 2 bath	176.4

[1]bed: bedroom; [2]bath: bathroom

The infiltration rate of the building has been calculated to accomplish the requirements defined in [28].

3.3.4 Electrical Loads (Lighting & Plugs)

For the development of this study, it has been assumed an electrical profile from lighting and equipment (household appliances and other electrical devices) based on [28] to calculate internal gains in residential buildings and to calculate the electricity demand for these usages.

Also, the implemented model enables to modify these profiles and evaluate the building demand with the prediction of user-behaviour pattern. The lighting/equipment profile is shown in the Table 3-4 below:

Table 3-4: Internal Gains.- Lighting and Equipment (W/m^2). Source: [28].-HE .-Annex D.-Table b

User Profile Private residential Use							
Internal Gains (W/m^2)		**0:00-6:59**	**7:00-14:59**	**15:00-17:59**	**18:00-18:59**	**19:00-22:59**	**23:00-23:59**
Lighting	L, S y F	0,44	1,32	1,32	2,20	4,40	2,20
Equipment	L, S y F	0,44	1,32	1,32	2,20	4,40	2,20

L: weeday; S: saturday; F: holidays

3.3.5 Occupancy

An occupancy profile based on [28] has been assumed to calculate internal gains in residential buildings.

However, the implemented model enables to modify these profiles and evaluate the building demand with the prediction of user-behaviour pattern. The occupancy profile is shown in the table below:

Table 3-5: Internal Gains.-Occupancy (W/m²). Source: [28].-HE .-Annex D.-Table b

User Profile Private residential Use							
Internal Gains (W/m²)		0:00-6:59	7:00-14:59	15:00-17:59	18:00-18:59	19:00-22:59	23:00-23:59
Occupancy(sensitive)	L	2,15	0,54	1,08	1,08	1,08	2,15
	S y F	2,15	2,15	2,15	2,15	2,15	2,15
Occupancy (latent)	L	1,36	0,34	0,68	0,68	0,68	1,36
	S y F	1,36	1,36	1,36	1,36	1,36	1,36

L: weeday; S: saturday; F: holidays

3.3.6 Water Daily Profile

A water daily profile has been calculated as [28] in Annex F and Annex D Table c:

Table 3-6: DHW User Daily Profile in Private Residential Buildings. Source: [28].-Annex D.-Table c

Hora	%*	Hora	%	Hora	%	Hora	%
0 h	1	6 h	3	12 h	5	18 h	5
1 h	0	7 h	10	13 h	5	19 h	7
2 h	0	8 h	7	14 h	4	20 h	6
3 h	0	9 h	7	15 h	3	21 h	6
4 h	0	10 h	6	16 h	4	22 h	5
5 h	1	11 h	6	17 h	4	23 h	6

**%: it refers to DHW daily demand (calculated as Annex F).*

The DHW daily demand has been calculated as Annex F (HE Document) in [28]. The calculation is shown below:

The DHW needs per day/ person are assumed in **28 l/day/person**.

The estimated Occupancy is calculated as Table a from Annex F that it sets:

Table 3-7: Estimated Occupancy in Building. Source: [28]. Annex F.-Table a

Table a-Annex F				
Nº Dwellings	4	8	8	10
Nº Rooms	1	2	3	4
People	1.5	3	4	5

Then, the estimated Occupancy for this building is **112 inhabitants** (4x1.5+8x3+8x3+10x5=112). So, the demand in the building is **3.136 l/day/building**.

But, considering the centralization factor sets in **0.85** for the number of dwellings between 21-50 as Table b from Annex F, then the total DHW daily demand is **2665.6 l/day/building**.

Below, it is shown the water daily profile of the building as Table 3-6:

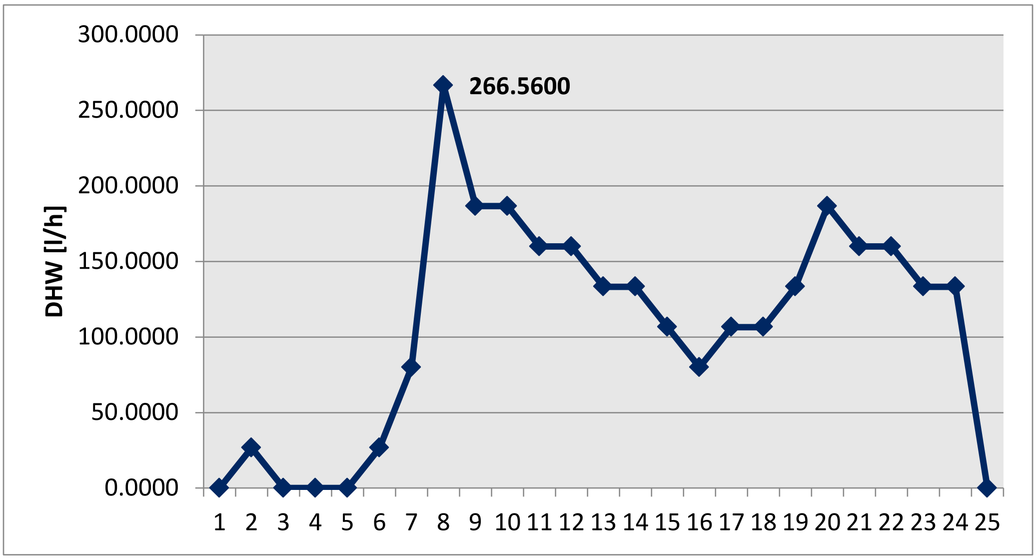

Figure 3-7: Water Daily Profile.- [28](Annex D.-HE). Source: CENER

3.3.7 Operational Conditions

For thermal demand calculation (Heating and Cooling demands), the operational conditions have been set as it was defined in Annex D from [28] (See Table 3-8).

Table 3-8: Operational Conditions. Source: [28].-HE Document .-Annex D.-Table a

		Schedule weekly profile			
		0:00-6:59	7:00-14:59	15:00-22:59	23:00-23:59
Setpoints (ºC) SUMMER	January-May	-	-	-	-
	June-September	27	-	25	27
	October-December	-	-	-	-
Setpoints (ºC) WINTER	January-May	17	20	20	17
	June-September	-	-	-	-
	October-December	17	20	20	17

3.3.8 Control Strategy of devices

Related to Control Strategy in the building, two basic strategies could be implemented and they are under study.

The first strategy that has been studied, is the implementation of a control for the external shading device (motorized blinds controlled). The control strategy states that blinds would be closed if solar radiation on windows would be higher than a minimum threshold (defined or not by the user). This external shading device has been defined with a maximum opaque fraction of 70%.

The second is to implement a control for lighting to take advantage of natural light. The artificial lighting is turned off when the radiation on the horizontal is greater than a set value. Finally, this strategy has not been included in this study because there is not enough available budget in the framework of this project.

3.3.9 HVAC systems

The heating system definition is still under study, but it is expected that will be water-based floor heating with very low water design temperatures (supply 35 °C / return 30 °C).

On the other hand, the cooling system is under study but it is expected that will be FCUs with very low water design temperatures (supply 10 ºC/ return 15 ºC).

These low temperatures will ensure a better COP (EER) of the ground-coupled heat pump.

3.4 Thermal Generation System Description

As it was already explained in previous sections, the Spanish building project development is still under study. Because of this, the final scheme of the Thermal Generation System has not been defined yet.

The optimal definition of this scheme is expected to be one of the main keys to achieve the PEB goal.

Along the period of the development of this Task, two possible schemes of Thermal Generation System (hereinafter referred to as “Scheme T1” and “Scheme T2”) have been modelled and analyzed (See Section 3.6.3).

The description of these schemes are provided in the following subsections.

3.4.1 Scheme T1

3.4.1.1 General Description

In this scheme, the Heating, Cooling and DHW demands are supplied by two GSHP(s). On one hand, the Heating and Cooling demands are supplied by one GSHP (hereinafter referred to as “GSHP1”) and on the other hand, the DHW demand is supplied by another GSHP (hereinafter referred to as ”GSHP2”).

Also, there is a STORAGE TANK for Heating and Cooling demands (hereinafter referred to as “STORAGE1”) and another storage for DHW (hereinafter the “STORAGE2”). Both storages should have sufficient size to achieve a certain energy flexibility in the system.

The model developed might be used for dimensioning of both, GSHP(s) and the STORAGE(s) tanks.

3.4.1.2 Heating/Cooling strategy

The operational conditions of the whole system are explained below:

The GSHP1 (Heating/Cooling provider) works as a Heat Pump in WINTER Season and as a Chiller in SUMMER Season.

The definition of WINTER season and SUMMER season in the Spanish Demo Pilot have been set as [28] (See Table 3-9).

Table 3-9: Winter and Summer Season Definition. Source: [28].

SEASON	WINTER	SUMMER	WINTER
HOURS	0-3624	3624-6552	6552-8760

In WINTER Season, the GSHP1 is switched on to charge the STORAGE 1 in case the temperature level in the storage drops below the defined temperature Setpoint (35^{0}C).

In SUMMER Season, the GSHP1 is switched on to charge the STORAGE 1 in case the temperature level in the storage raises above the defined temperature Setpoint (10^{0}C).

On the other hand, the GSHP2 is only switched on to charge the STORAGE 2 in case the temperature level in the storage drops below a defined temperature Setpoint (set in 60^{0}C for legionellosis prevention Spanish Rules).

The capacities [kW] of these GSHP(S) will be optimized along the development of this Task.

The source of the two GSHP(s) is a Ground Heat Exchanger (hereinafter the "GHX") that was defined in the proposal with 16 boreholes and 150 m of depth. However, as it will be explained in the following sections, the GHX has been modelled to set their optimal sizing, considering some parameters such as the number of BH(s) and depth of them, as variables.

On the other hand, for sizing purposes of GHX, it is needed to know in detail the ground composition and it's thermophysical characteristics. The assumptions for the modelling and simulations are shown below. However, it is expected that a specific detailed Thermal Test Response will be undertaken before the building construction phase, to more accurately define the GHX.

In the table below, the ground thermal properties considered are shown:

Table 3-10: Ground Thermal Properties. Source: CENER.

GROUND THERMAL PROPERTIES	
STORAGE THERMAL CAPACITY	4.68 kJ/h m K
STORAGE HEAT CAPACITY	2016.0 kJ/m^3/K

As it was explained above, this building is still under study along with the definition of its facilities. So, the developed model in this Task 2.6 will be used to calculate the optimal design, based on the assessment of performance.

So, it will take advantage of the developed models to calculate the optimal sizing of the GHX in energy performance terms.

Finally, the building owner (or construction company) will decide along the project development the final sizing based on both considerations, best performance and costs.

3.4.2 Scheme T2

In the scope of the proposal, it was only considered the installation of geothermal heat pump(s). However, another possible scheme has been implemented in the development of this Task to evaluate its advantages. This scheme is explained in detail below:

3.4.2.1 General Description

For this scheme, the SH, SC and DHW demands is supplied by a GSHP and an Aerothermal HP.

The GSHP supplies the heating and cooling demand as well as the DHW demand in WINTER Season, whereas the Aerothermal HP supplies the DHW demand in SUMMER Season.

3.4.2.2 Heating/Cooling Strategy

In WINTER Season, the GSHP is switched on to charge the STORAGE 1 in case the temperature level in the storage drops below the defined temperature Setpoint (35 ^{0}C) and to charge the STORAGE 2 in case the temperature level in the storage drops below the defined temperature Setpoint (60 ^{0}C). When both, DHW and SH demands are required, the controller will prioritize the DHW production.

In SUMMER Season, the GSHP is switched on to charge the STORAGE 1 in case the temperature level in the storage raises above the defined temperature Setpoint (10^0C).

On the other hand, the Aerothermal HP is only switched on to charge the STORAGE 2 in SUMMER Season in case the temperature level in the storage drops below a defined temperature Setpoint (set in 60^0C for legionellosis prevention according to the Spanish Rules).

3.4.2.3 Expected Advantages Scheme T2 vs Scheme T1

It is expected that this scheme has a better performance than the other because in Summer, the outdoor air temperature in the building location is expected to be usually higher than the ground temperature (close to 14.27 ^{0}C). In the development of this Task, this question has been analyzed and evaluated to make decisions about this facility (See Section 3.7).

Another advantage of Scheme T2, against Scheme T1, is that it achieves a higher ground temperature at the end of the year than the other scheme. So, the facility will have a better performance along its life-cycle.

Finally, the Aerothermal HP could be used as an external source of ground recharging. This point could be further evaluated.

3.5 PV Electrical Generation Facility Description

The PV generation facility provides local renewable power generation, which is the main source of this PEB. It is planned that the current building roof will be covered with PV panels. The figure below illustrates the planned building roof definition.

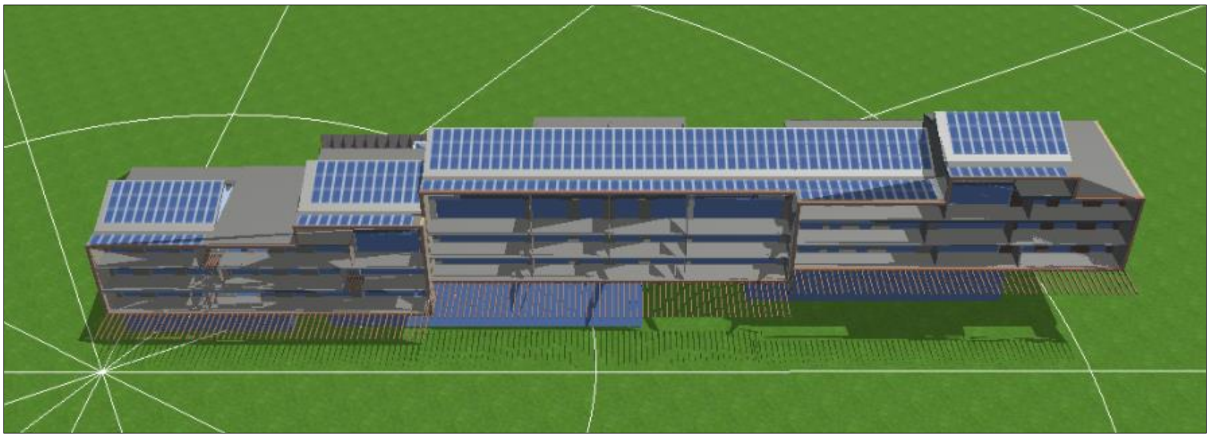

Figure 3-8: Virtual 3D Recreation of BIPV in Spanish Demo Building. Source: CENER (PV SOL)

The PV panels planned to be installed could be 341 REC Solar REC 300 TP2 Twin Peak 300 W (or similar) with dimensions 0,997x 1,675 (Area = 1,67 m^2) and the following electrical features:

Table 3-11: Electrical Characteristics for PV panel. Source: REC SOLAR Datasheet

ELECTRICAL DATA STC Product code*: RECxxx TP2M	
Nominal Power-P_{MPP} (Wp)M	300
Watt Class Sorting -(W)	-0/+5
Nominal Power Voltage- V_{MPP} (V)	33.0
Nominal Power Current- I_{MMP} (A)	9.10
Open Circuit Voltage-V_{OC} (V)	39.5
Short Circuit Current-I_{SC} (A)	9.70
Panel Efficiency (%)	18.9

The estimated values, that have been used to calculate the electricity generated, have been:

Table 3-12: PV Facility Definition. Source: CENER

	Tilted 22º			Horizontal		
	Number	Area (m^2)	Power (kW)	Number	Area (m^2)	Power (kW)
Roof 1	33	55.11	9.90	11	18.37	3.30
Roof 2	33	55.11	9.90	11	18.37	3.30
Roof 3	147	245.49	44.10	62	103.54	18.60
Roof 4	33	55.11	9.90	11	18.37	3.30
TOTAL	**246**	**410.82**	**73.80**	**95**	**158.65**	**28.50**

As this is a first definition of the building's roof at the early stage of the project; the current roof design may have minor changes in the development of the project and the PV roof might have to be re-designed.

Besides this and since the PV panel technology is under continuous development, the building's roof might be finally equipped with PV panels offering a better performance of those explained above.

At this stage, shadings effects in the BIPV are not considered, because it is expected that there will not be nearby buildings during the monitoring period.

As a result, the PV generation profile does not necessarily match the energy consumption in the demo building. In order to obtain energy management capabilities, a lithium-ion battery is planned to be incorporated. To complete the management system of the generated energy, an Energy Management System (EMS) will be installed. This EMS is incorporated in the Integrated Controller corresponding to Task 2.5 and it will be widely described in deliverable D2.5.

The optimization decision-making algorithm uses 24-hour generation (weather) and energy demand forecasts as inputs, together with electricity market price profiles. Based on this information, it calculates the hourly profile of battery operation to obtain the optimum behavior from the economic point of view of the whole facility.

3.6 Model Description

The Model has been implemented in software TRNSYS (Transient System Simulation Tool) v.17. The building geometry has been defined in Google SketchUp 8 and imported TRNBuild by the plug-in Trnsys 3D.

Actually, the Model has been implemented in three separate files and not in a single model, as the computational effort/cost lead to a non-viable simulation time. Some model simplifications could be further studied.

The three parts of Model are:

MODEL PART 1.- BUILDING Model:

The **MODEL PART 1** provides information about the building's thermal building **needs** (Heating and Cooling demands) to guarantee both Comfort and IAQ requirements.

The outputs from this model are the "Total yearly heating demand" and "Total yearly cooling demand".

The **outputs** from this model (heating/cooling demands) are used in **MODEL PART 3 (See below) to calculate the building's electrical consumption** in order to guarantee adequate comfort conditions in the building**.**

This part of the model has been developed to evaluate the building optimal design with the purpose of minimizing Heating and Cooling demands.

MODEL PART 2.- ELECTRICAL GENERATION (PV) Model:

The **MODEL 2** provides information about the energy generated **by the PV facility.**

The output from this model is the "Total yearly PV electrical generation".

This part of the model has been developed to evaluate the optimal design of the electrical generation system with the purpose of maximizing the electrical generation.

MODEL PART 3.- THERMAL GENERATION Model:

The MODEL 3 reports on the electrical consumption to supply Heating, Cooling and DHW demands and to ensure comfort legal requirements. The two schemes defined in Section 3.4 have been implemented, namely, MODEL 3.1 (Scheme T1-based) and MODEL 3.2. (Scheme T2-based).

The output from this model is the "Total yearly electrical consumption of thermal generation system".

This model has been developed to evaluate the optimal design of the thermal generation facility with the purpose of minimizing of thermal generation system consumption.

For the final PEB evaluation (See 3.7.5), the electrical consumption from lighting and household appliances have been estimated, as well as the electrical consumption from fans, fan coils, pumps and common zones (lighting in common zones and lifts).

The three parts of the Energy Model are explained in detail in the following section.

3.6.1 Building Model Description

The Building Model is shown in the following picture:

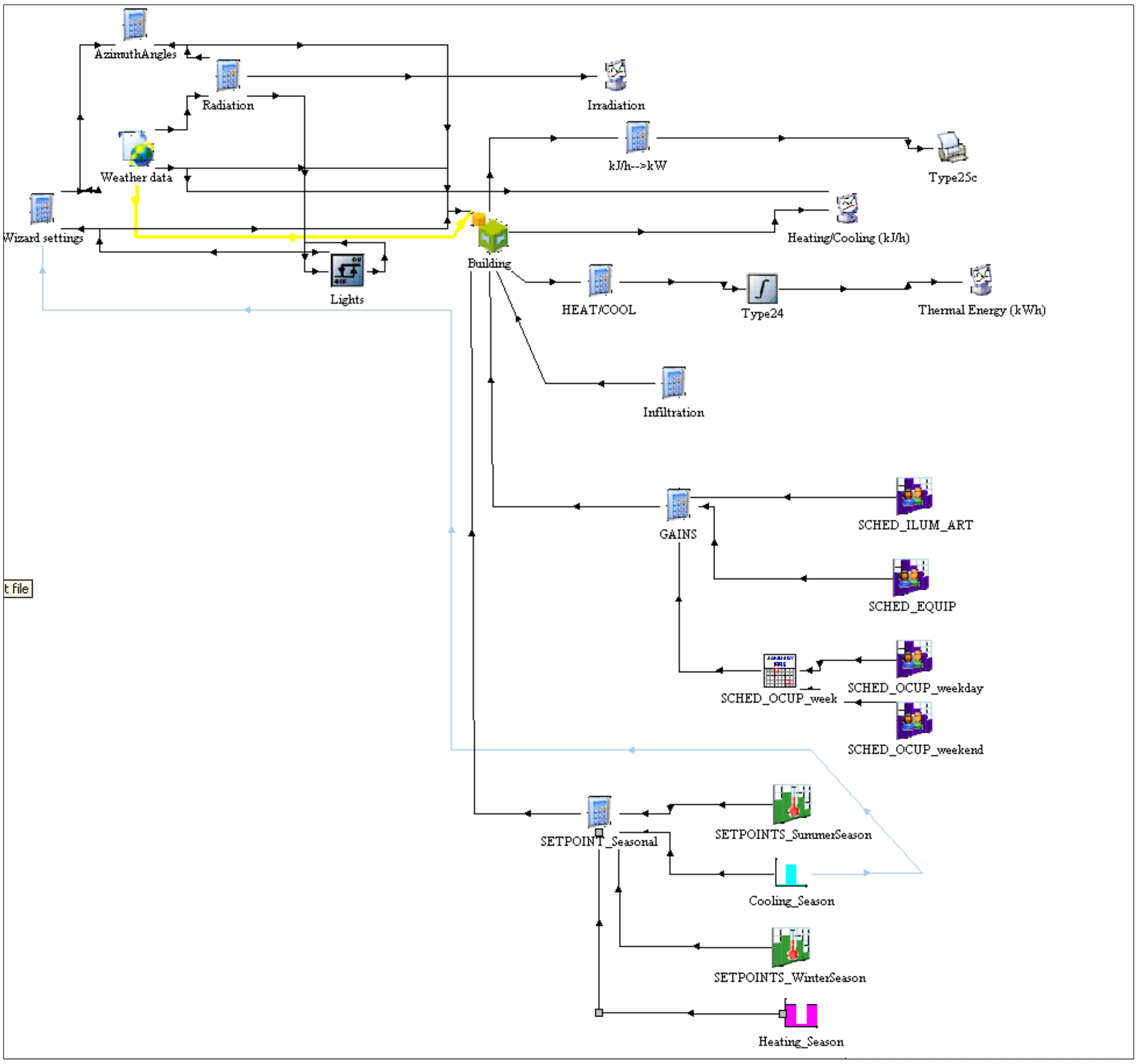

Figure 3-9: Building Model in TRSNSYS. Source: CENER

The description of the various component types used in the Model is shown in the following Table:

Table 3-13: Main components (types) Building Model. Source: CENER

MAIN COMPONENTS (types)
Type 15: Weather
This component reads and interprets weather data available in several series of standardized formats. The data files implemented is "Typical Metereological Year version 2(TMY2) [Meteonorm-generated weather files distributed with TRNSYS generates this format of files]. In addition to reading data files, type 15, calculates total, beam, sky, diffuse, ground reflected solar radiation, the angle of incidence of beam solar radiation, the slope and azimuth of as many surfaces as the user cares to define. The Type further includes calculation of mains water temperature and effective sky temperature for radiation calculations. It also outputs a number of indicators such as heating and cooling season and annual maximum and average temperature, monthly and annual maximum, minimum and average temperature. At this stage, the weather file used to run the model has been a Meteonorm file (*.tm2) for the Dilar municipality. This file will provide the following information in the Model (inputs): - Total tilted surface radiation for surface - Beam radiation for surface - Dry bulb temperature - Effective sky temperature - Percent relative humidity - Ground reflectance
Type65: Building (TRNBUILD)
This component models the thermal behaviour of a building divided into different thermal zones. The geometrical definition and the thermal zone definition were exported from SketchUp with the Trnsys 3d plug-in. Also, in this type can be included the envelope thermal features, minimum rate of ventilation, calculated infiltration and internal gains definition per thermal zone.
Type14a: Time Dependent Forcing Function: Occupancy
This type is used to set Occupancy, Equipment and Artificial Lighting schedules.
Type41a: Load Profile Sequencer - Weekdays and Weekends
This type is used to set different schedules in weekday and in weekend (used in this model for Occupancy).
Type14e: Time Dependent Forcing Function: Temperature
This type is used to set the Setpoints in Winter/Summer Season.
Type14l: Cooling Season
This type is used to define Summer Season.
Type14k: Summer Season
This type is used to define Winter Season.
Type2d: Differential Controller with hysteresis
This type is used to set the control of lighting switching.

INPUTS:

Weather File: included as an external file from Meteonorm data source in Type 15

- Incident Radiation (Total, Diffuse and Beam Radiation on several user-defined tilted surface) [kJ/h/m^2].
- Dry bulb temperature [ºC].
- Relative Humidity [%].

Building file: generated in TRNBUILD (*.b17) with:

- **Geometrical definition**: defined in SketchUp with the Trnsys 3d plug-in and imported in Trnsys Studio.
- **Building Zoning:** defined in SketchUp the Trnsys 3d plug-in and imported in Trnsys. At this stage, a basic zoning of one thermal sector per dwelling has been set. The purpose is to be able to include the user preferences when these are known. However, this zoning produces a quite long simulation time. Because of this, some model simplifications could be taken into account later.

OUTPUTS:

- Thermal demand (Heating/Cooling Demand) [kWh_{th}.] of each zone

EXTERNAL FILES REQUIRED (in Model):

Meteonorm TMY (Typical Meteorological Year) File in format (*.tm2) from Building Location [Dilar (Granada)].

CONTROL STRATEGY:

The control strategy has been implemented in Trnsys by means of a flexible and powerful component "Equation" based in algebraic and logical equations which define and implement the control logic, the required control parameters and their specifications.

In the current Building Model, two control strategies have been implemented:

- Open/Close Shading External Devices based on a certain incident Radiation threshold on Windows in South Façade, in the Cooling demanding period. This way, the cooling load due to radiation is lowered at its minimum.
- Take advantage of Natural Lighting based on Radiation on roof (under study).

VARIABLES:

The "Operational Conditions" (SetPoints Temperature main room/dwelling) and "Usage Profiles" (Occupancy, Equipment, and Artificial Lighting) have been implemented as variables in the Model with the purpose of running the model further on when the comfort preferences forecasting of end-users are available.

Moreover, two other variables/parameters have been implemented in Trnsys, namely, "**MAX_ESHADE**" and "**BRIGHT**". The name of variables is those used by default for TRNBuild. Below, it is explained where these variables can be found inside the Model.

- **MAX_ESHADE** (External Shading Factor): this parameter is included in the component Type 65 [See in very zone: "Surfaces"→ "External Windows"]. This parameter defines the maximum opaque fraction of external shading device. In this study it has been set in 70/100.
- **BRIGHT**: this parameter has been included in the component Type 65 [See in every zone: "Regime"→"Gains"→"Artificial Lighting"]. Ultimately, in this study this parameter has been

implemented for further using it, but its effect has not been analysed because there is not enough available budget to install a lighting control in the framework of EXCESS project.

On the other hand, other meteorological data sources files (e.g. based in weather forecasting) coded in *.tm2 format, can easily be simulated using the same Model.

ESTIMATED PARAMETERS:

At this stage, the values of the operational conditions for each zone have been set in accordance to [28]. Based on those values, the simulations provide the Heating and cooling demands for each zone and the entire building. However, the model enables to set other operational conditions based on comfort preferences of final users, as previously explained.

SIMULATION METHODOLOGY

Several Scenarios (See Table 3-14) have been evaluated with the purpose to reduce the thermal building demand:

Table 3-14: Study Scenarios Building Model. Source: CENER

Study Scenarios:	
0	Baseline Scenario (*)
1	With Heat recovery (50% performance)
2	Scenario 1+ Motorized blinds in Summer in South-West Façade.

(*) Hypothesis, for the Scenario 0 (or Baseline), have been those explained in previous Sections. Below, a summary of hypothesis:

- Envelope as "Nivalis Design Guide" developed by CENER.
- SetPoints Temperature in Winter/Summer as [28] HE Anejo D (Table a)
- Equipment, Occupancy and Artificial Lighting as [28] HE Anejo D (Table b)
- Ventilation as/ [28] HS-3.
- Infiltration Rate calculated as [28].

Regarding Scenario 1, the ventilation rates values were modified, considering a heat recovery performance of 50%. On the other hand, in Scenario 2, the Radiation on Windows threshold value was modified above which external shading device is closed.

In section 3.7, the results of the heating and cooling demands from these Scenarios are presented.

3.6.2 Electrical Generation (BIPV) Model Description

The PV Model is shown below in the following picture:

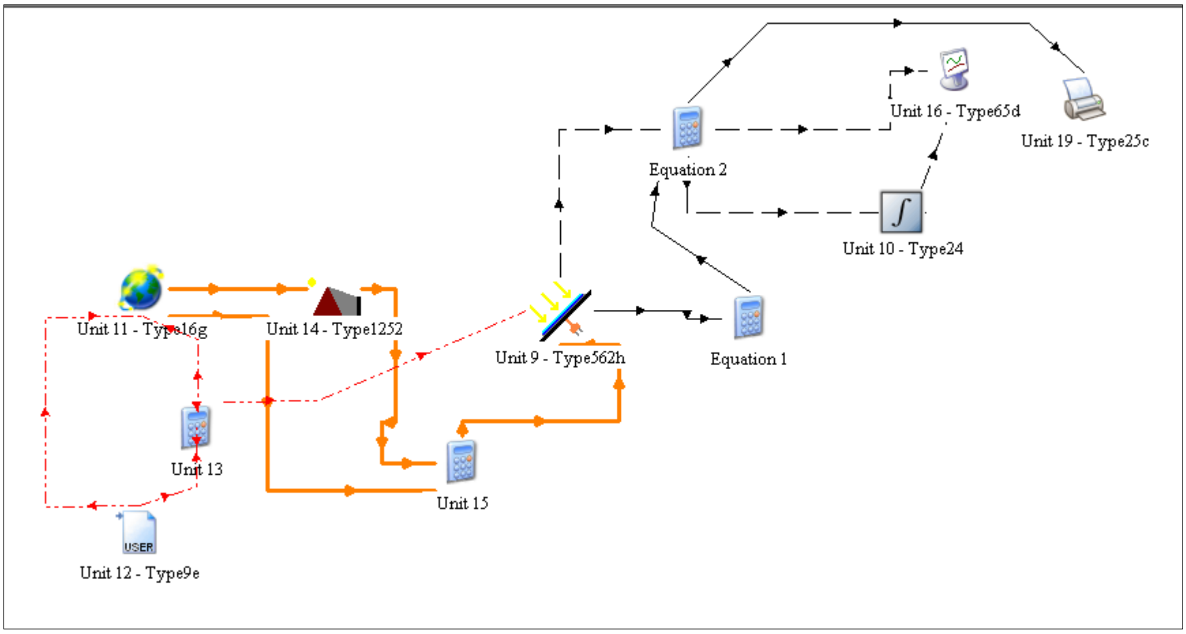

Figure 3-10: PV Model in TRNSYS. Source: CENER

The description of the various component types used in the Model is shown in the following Table:

Table 3-15: Main components (types) Electrical Generation (BIPV) Model. Source: CENER

MAIN COMPONENTS (types)
Type16g: Radiator Processor
This component has been used to provide data about the beam and diffuse radiation on the PV surface.
Type 9e: Data Reader
This component has been used to provide data from external file.
Type1252: Surface Shading for Beam Radiation
This component has been used to evaluate the effect of shading in BIPV due to obstacles. At this stage, no obstacles have been included. It is expected that during the EXCESS monitoring period no other building will have been built close to the Demo building.
Type562h: PV Efficiency Modifiers
This component evaluates the electrical generation in PV roof based on a specific PV module efficiency.

INPUTS: (included as an external file in Type 9e.-Data Reader. The file has been obtained from Meteonorm Software)

- Total Radiation on surface [kJ/h/m^2].
- Ambient Dry Bulb Temperature [^{0}C].
- Sky Temperature [^{0}C].
- Wind velocity (m/s)

OUTPUTS:

- Electrical Generation from BIPV [kWh_e].

EXTERNAL FILES REQUIRED (in Model):

- File (*.txt) obtained by the Meteonorm Software for Dilar location.

CONTROL STRATEGY:

An Advanced Controller is being developed by IRE (Grid Energy Integration Department) in CENER. The integrated controller will be further defined and developed in Task 2.5. The goal for this controller is to optimize control strategies considering load prediction, weather forecast and market prices.

The algorithm of this controller uses the PV generation and demand predictions, together with the electricity tariff schedule, to calculate the optimal battery operation. The energy storage is charged and discharged with the aim of minimizing billing costs, both energy and demand charge in the different tariff periods.

Also, this controller could include another capability related to the management of the charging of thermal storage define in the "Thermal Generation System", but this question is under study because it was not included in the proposal.

VARIABLES:

The dimensioning of the PV system is closely related to the definition of the geometrical roof developed by the Architect team in charge of the building design.

The model has been run including several variables with the purpose of providing recommendations about PV sizing with the perspective of PEB goal. The included variables in the Model related to geometry of roof have been:

- **SLOPE** (PV panel tilting [º]): this VARIABLE is included as an Input in component Type 16g.
- **AZIMUTH** (Azimuth of roof surface): this VARIABLE is included as an Input in component Type 16g.
- **AREA_PV** (PV panel area [m2]): this VARIABLE is included as a Parameter in component Type 562h.

Also, the Model enables to include different areas with different tilting and azimuth in the roof.

Moreover, another variable related to the technology has been included, the panel efficiency:

- **EFF_PV** (PV panel efficiency (%)): this VARIABLE is included as a Parameter in component Type 562h.

ESTIMATED PARAMETERS:

The inverter efficiency has been estimated based on the information provided by its manufacturers (technical datasheets). At this stage, the module efficiency modifiers have been estimated based on technical datasheets from reference manufacturers as well.

SIMULATION METHODOLOGY

Several Scenarios have been evaluated (See Table 3-16) with the purpose to evaluate the BIPV electricity generation:

Table 3-16: Study Scenarios PV Model. Source: CENER

Study Scenarios:	
P0	Baseline: Roof with the last geometry provided by Architects (Urb.Atelier)
P1	Possible extended roof of Scenario 0-Roof
P2	CENER´s Proposed roof based on PEB purpose (Architects working in it)

The results from these three Scenarios are analyzed in section 3.7.

3.6.3 Thermal Generation Model Description

The Thermal Generation Model is shown in the following picture:

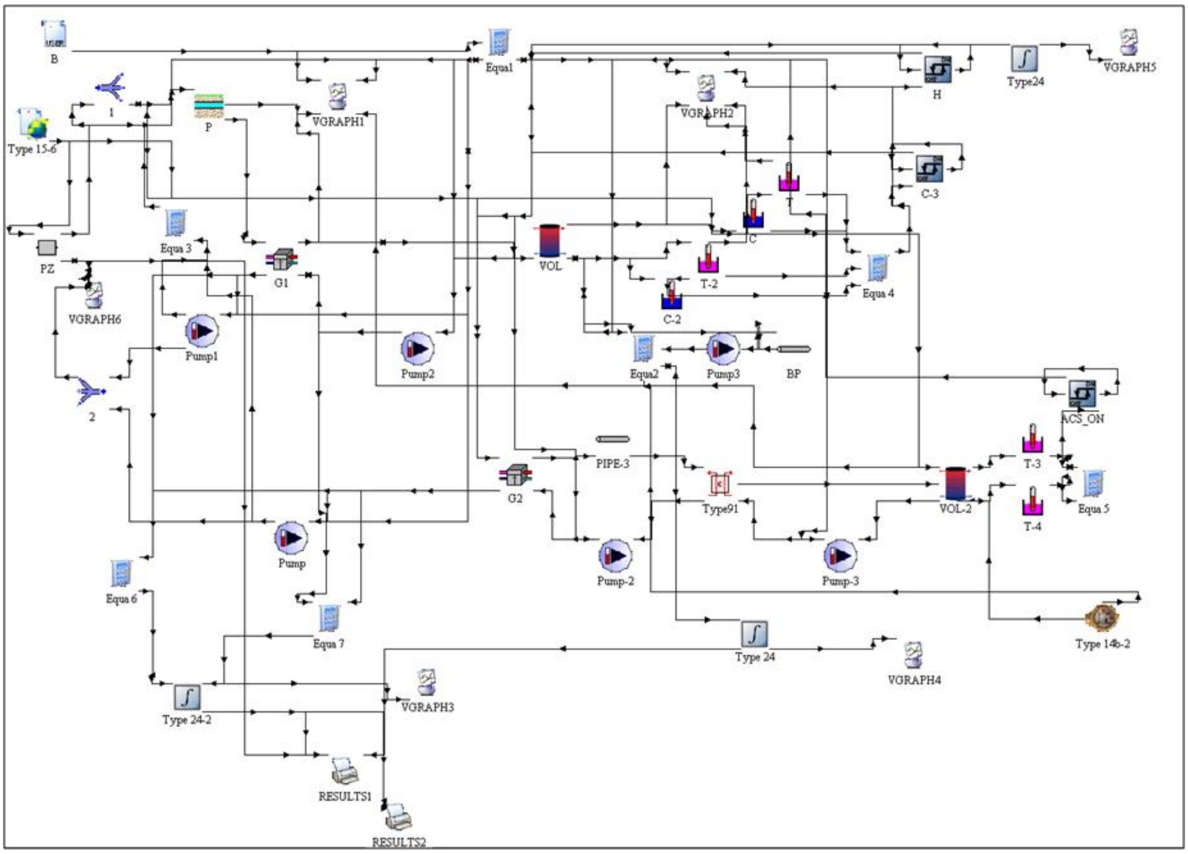

Figure 3-11: Thermal Generation Model in TRSNSYS. Source: CENER

The description of component types used in the Model is shown in the following Table:

Table 3-17: Main components (types) Thermal Generation Model. Source: CENER

MAIN COMPONENTS (types)
Type 15: Weather
This component reads and interprets weather data available in a series of standardized formats. The data files implemented is "Typical Metereological Year version 2(TMY2) [Meteonorm-generated weather files distributed with TRNSYS generates this format of files]. In addition to reading data files, type 15, calculates total, beam, sky, diffuse, ground reflected solar radiation, the angle of incidence of beam solar radiation, the slope and azimuth of as many surfaces as the user cares to define. The Type further includes calculation of mains water temperature and effective sky temperature for radiation heat transfer calculations. It also outputs a number of indicators such as heating and cooling season and annual maximum and average temperature, monthly and annual maximum, minimum and average temperature. At this stage, the weather file used for running the model is a Meteonorm-based file for Dilar municipality.
Type9e: Data Reader
This component has been used to provide data from external file. For this model this type is used to read the thermal demand obtained from "Building Model". The heating and cooling demand are included in the Model as an external file provided by the MODEL 1 outputs.
Type 927: Water-Water Heat Pump Single Stage
This component models a single-stage heat pump. This model is based on user-supplied data files containing catalogue data for the capacity and power draw, based on the entering load and source temperatures to the heat pump, providing an accurate modelling of the transient behaviour when ground temperature varies along the year.
Type 557a: Ground Heat Exchanger Vertical U-tube Standard
This subroutine models a vertical heat exchanger that interacts thermally with the ground. That partial model implements a U-tube ground heat exchanger, using a detailed transient 2-D model. A heat carrier fluid is circulated through the ground heat exchanger and either rejects heat to, or absorbs heat from the ground depending on the temperatures of the heat carrier fluid and the ground.
Type 647 (TESS): Diverting Valve
This type models a diverting valve that splits a liquid inlet mass flow into fractional outlet mass flows. One inlet flow may be split into as many as 100 individual streams.
Type 649 (TESS): Mixing Valve
This type models a mixing valve that combines up to 100 individual liquid streams into a single outlet mass flow.
Type 1502 (TESS): N-Stage Heating Aquastat Mode (or Simple Thermostat)
An N-Stage heating aquastat/simple thermostat is modeled to output N ON/OFF control functions that can be used to control a fluid cooling system having up to N stage heating sources(s).
Type 1503 (TESS): N-Stage Cooling Aquastat Mode (or Simple Thermostat)
An N-Stage heating aquastat/simple thermostat is modeled to output N ON/OFF control functions that can be used to control a fluid cooling system having up to N stage heating sources(s).
Type 91: Heat Exchanger
This component models a zero capacitance sensible heat exchanger as a constant effectiveness device
Type 110: Pump- Variable Speed
This type models a variable speed pump that is able to maintain any outlet mass flow rate between zero and a rated value. The mass flow rate of the pump varies linearly with control signal setting.

Pump power draw, however, is modeled using a polynomial.
Type 4a: Thermal Storage-Stratified Storage Tank.-Uniform Losses
The thermal performance of a fluid-filled sensible energy storage tank, subject to thermal stratification, can be modeled by assuming that the tank consists of N fully-mixed equal volume segments. The degree of stratification is determined by the value of N.
Type 14b: Time dependent forcing function
This component is used to simulate a time-dependent forcing function which has a behaviour characterized by a repeated pattern. The purpose of this routine is to provide the means of generating a forcing function of this type. The pattern of the forcing function is established by a set of discrete data points indicating its values at various times through one cycle.
Type2d: Differential Controller with hysteresis
This controller generates a control function γ_0 that can have values of 0 or 1. The value of γ_0 is chosen as a function of the difference between upper and lower temperatures, T_H and T_L compared with two dead band temperature differences, ΔT_H and ΔT_L.
Type 31: Pipe or Duct
This component models the thermal behaviour of fluid flow in a pipe or duct using variable size segments of fluid.
Type 31b: Buried Horizontal Pipe Simple
This component models the thermal behaviour of fluid flow in a buried horizontal pipe.

INPUTS:

As it was explained before, the outputs of Building Model (Heating/Cooling demands) will be used as inputs in this Model.

Also, the same weather file used in the Building Model has been included in this Model to obtain the following inputs.

- Dry bulb temperature (^{0}C).
- Supply water temperature (^{0}C)

OUTPUTS:

- Electrical consumption from GSHP(s) or/and Aerothermal HP(s) (kWh_e) in a year.

EXTERNAL FILES REQUIRED (in Model):

Meteonorm File (*.tm2) .- Dilar (Granada).

Heating/Cooling Demands (*.txt) provided by Model 1 (See 3.6.1)

CONTROL STRATEGY:

At this stage, basic control strategies for thermal generation facility have been implemented.

The controller implemented (by means of an Equation) sets the switching on of the GSHP(s), HP(s) and pumps when water temperature in heating/cooling/DHW storages is higher or lower than a set value, as it was explained in previous sections.

Also, in Scheme T2 the controller sets the priority to produce DHW when both DHW and space heating are required.

Further market price-based control strategies could be analyzed to make decisions on when the storages should be filled based on the PV generation prediction and thermal load prediction.

VARIABLES in the MODEL:

For this model, several variables have been implemented with the purpose to achieve an optimal sizing of this system:

- GHX design: number of BH(s), spacing between BH(s) [m], depth of BH(s) [m] and the number of boreholes that are connected in series per parallel loop [-].
- GSHP(s) and aerothermal HP(S) Capacity [kW].
- STORAGE Tanks Volume [m^3]: to guarantee a certain energy flexibility to supply the demand. For the evaluation of PEB goal, this parameter is not considered because the definition of PEB in the framework sets that the building has to consume less than it generates over a year span.

In Section 3.7.3 these variables and their evaluated values are further explained.

ESTIMATED PARAMETERS:

At this stage, the ground thermal properties have been estimated, as indicated in previous sections.

However, it is expected that before the building construction takes place a Thermal Test Response could be evaluated with the purpose to obtain a more reliable solution. Also, a Water Daily Profile has been implemented as explained in section 3.3. (*Figure 3-7*)

SIMULATION METHODOLOGY:

For every solution, it has been evaluated:

If the solution supplies the Heating, Cooling and DHW demands.

The GSHP(s) [and HP for SCHEME T2] electrical consumption [kWh_e].

The Ground Temperature at the end of the year [^0C].

The optimal solution for every Scheme will be the one that supplies the thermal demand during more time with less consumption.

3.7 Analysis and Results

As it has been already discussed the Spanish Demo Pilot is a new building, and the overall building project is still under development. A specific set of parameter varying simulations has been run, with the model developed in this Task (See section 3.6). These simulations will be used to make decisions about both sizing and control with the goal to achieve a PEB.

The methodology of the simulations aims to accomplish both of the following objectives:

- Set an optimal design (systems dimensioning)
- Establish the optimal working conditions (systems control)

In order to minimize the total electrical consumption of the building and also maximize the on-site renewable electrical generation, the objective of the final calculation is to evaluate if the building electricity generated is more than it is consumed over the span of a year (see 3.7.5).

The total electrical consumption of the building has been defined as the sum of the following:

- Electrical Consumption to guarantee the comfort conditions in dwellings:
    - Consumption of thermal generation system (heat pumps) and pumps in the generation system (calculated with Trnsys Model).
    - Consumption of pumps in distribution systems.
    - Consumption of fan coils (or any other type terminal units) [at this stage, the type of terminal elements has not been defined yet].
- Electrical Consumption to guarantee the required indoor air quality in dwellings:
    - Consumption of ventilation system (fans).
- Electrical Consumption in Artificial Lighting (data based on [28]).
- Electrical Consumption in Equipment (household appliances and other electrical devices (e.g. Television, Computers, etc.) (data based on [28]).
- Electrical Consumption in Common Zones (artificial lighting and lifts/elevators) of the Building (estimated data based on real data from previous project developed in CENER).

3.7.1 Building Thermal Demand

The Heating and Cooling demands have been simulated by TRNBuild (TRSNYS Software v.17) based on the last version of the building (17/02/2020) provided by Urb-Atelier. The three Scenarios explained in section 3.6.1 were analyzed with the purpose to reduce the thermal building demand.

3.7.1.1 Heating and Cooling Demands.-Scenario 0 (Baseline)

The obtained results from Scenario 0 about Heating and Cooling demands are shown in the following tables:

Table 3-18: Heating/Cooling Demands (kWh_{th}) in a year. Source: Trnsys.-CENER

TIME	Space Heating (kWh_{th})	Space Cooling (kWh_{th})	Total (kWh_{th})
0-8760 h	**70.967**	**50.589**	**121.556**

Table 3-19: Heating/Cooling Demands (kWh_{th}/m^2) in a year. Source: Trnsys.-CENER

TIME	Space Heating (kWh_{th}/m^2)	Space Cooling (kWh_{th}/m^2)	Total (kWh_{th}/m^2)
0-8760 h	**20,28**	**14,45**	**34,73**

3.7.1.2 Heating and Cooling Demands.-Scenario 1 (Heat Recovery 50%):

As it was previously explained, the Scenario 1 evaluates the effect in Heating and Cooling Demands using a heat recovery with a 50% of performance in the Ventilation System.

The obtained results for Scenario 1 about Heating and Cooling Demand are shown in Table 3-20 and Table 3-21.

Table 3-20: Heating/Cooling Demand s(kWh_{th}) in a year. Source: Trnsys.-CENER

TIME	Heating (kWh_{th})	Cooling (kWh_{th})	Total (kWh_{th})
0-8760 h	**39.142,33**	**54.926,89**	**94.069,22**

Table 3-21: Heating/Cooling Demands ($kWht/m^2$) in a year. Source: Trnsys.-CENER

TIME	Heating (kWh_{th}/m^2)	Cooling (kWh_{th}/m^2)	Total (kWh_{th}/m^2)
0-8760 h	**11,18**	**15,69**	**26,87 (Energy Savings: 7,86)**

With this measure, it can be saved 7.86 kWh_{th}/m^2.

3.7.1.3 Heating and Cooling Demands.-Scenario 2 (Heat Recovery + Shading Control Device):

The obtained results for Scenario 2 about Heating and Cooling Demand are shown in Table 3-22 and

Table 3-23:

Table 3-22: Heating/Cooling Demands (kWh_{th}) in a year. Source: Trnsys.-CENER

TIME	Heating (kWh_{th})	Cooling (kWh_{th})	Total (kWh_{th})
0-8760 h	**39.154**	**46.232**	**85.386**

Table 3-23: Heating/Cooling Demands (kWh_{th}) in a year. Source: Trnsys.-CENER

TIME	Heating (kWh_{th}/m^2)	Cooling (kWh_{th}/m^2)	Total (kWh_{th}/m^2)
0-8760 h	**11,18**	**13,20 (Savings: 2,49)**	**24,40 (Energy Savings: 2,47)**

With this measure, it can be saved 2.49 kWh_{th}/m^2.

3.7.1.4 DHW Demand

The DHW Demand (kWh_{th}) has been calculated as [28] Annex F and Annex D Table c.-HE Document-[28] (See Figure 3-7).

It has been implemented in the Trnsys model using a DAILY WATER PROFILE component, as explained in previous sections. However, the model enables to modify the profile with flexibility if an actual profile is known or can be predicted.

The annual results are shown in the following Tables:

Table 3-24: DHW Demand (kWh_{th}) in a year. Source: Trnsys.-CENER

TIME	DHW (kWh_{th})
0-8760 h	**56477.07**

Table 3-25: DHW Demand (kWh_{th}/m^2) in a year. Source: Trnsys.-CENER

TIME	DHW (kWh_{th}/m^2)
0-8760 h	**16,14**

3.7.1.5 Heating, Cooling and DHW Demands DHW.-Summary

As a summary, the following Table shows the total thermal demand for Heating, Cooling and DHW in building for the three Scenarios:

Table 3-26: Total Thermal Demand (kWh_{th}) in a year. Source: Trnsys.-CENER

Scenario	Thermal Demand [kWh_{th}]	Thermal Demand [kWh_{th}/m^2]
0	178.033	50,87
1	150.545	43,01 **(Energy Savings: 7,86)**
2	**141.863**	**40,52 (Energy Savings: 10,35)**

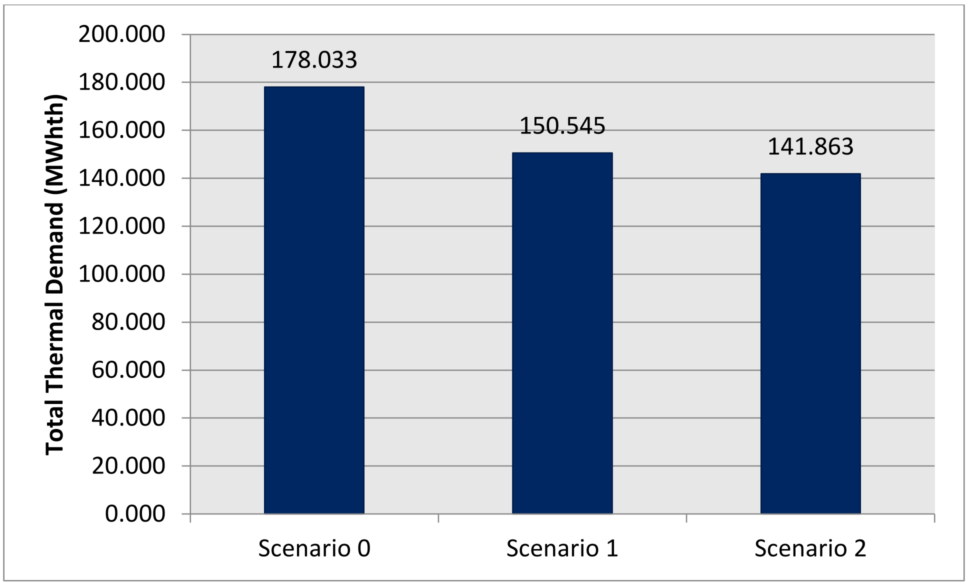

Figure 3-12.-Total Thermal Demand [MWh_{th}] for analyzed Cases. Source: CENER

3.7.2 Electrical Demand (Artificial Lighting, Equipment and Common Spaces in Residential Part of Building)

The electrical demand corresponding to artificial lighting, equipment and common spaces has been also estimated. The estimated values are shown in Table 3-27.

Table 3-27: Electrical Demand (kWh_e/m^2) in a year. Source: [28]

Use	kWh_e/m^2
Artificial Lighting (*)	14
Equipment (*)	14
Common Spaces (**)	4
TOTAL	**32**

(*) Based on [28].-HE Annex D Table b (**) Based on actual monitored data from other projects.

3.7.3 Thermal Generation System (Electrical Consumption)

A set of simulations have been run varying several parameters related to the design of some of main components of the thermal generation facility (GHX, GSHP(s) and Thermal STORAGE(s)).

The obtained results of electrical consumption will be used to make decisions about the final design of this facility. However, the costs of the equipment have not been included in this study for this Task.

The obtained files from the simulations were named as it is shown in Figure 3-13 below:

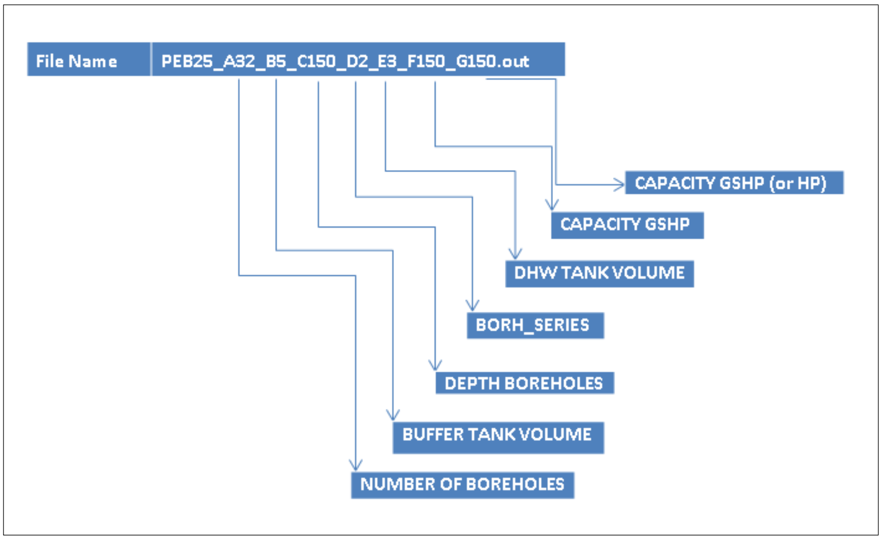

Figure 3-13: Naming Files from Simulations. Source: CENER

As an example, the meaning of the following "name file" is explained below:

File Name	**PEB25_A32_B5_C150_D2_E3_F150_G120.out**
PEB25: it refers to Scenario 1 from Heating/Cooling demands provided by Model 1.	
This file shows "the outputs" for the following combination of parameters: 32 BH(s) (A32), 5 m^3 of thermal storage (B5), 150 m of BH(s)'s depth (C150), 3 m^3 of DHW storage (E3) and 150 kW of capacity for one GSHP (F150) and 150 kW of capacity of the another GSHP or HP (HP only for SCHEME T2) (G120).	

The values of the variables simulated are shown in the following table:

Table 3-28: Variables of Simulations for Model 3. Source: CENER.

Variable Name	Variable Definition	Values
A	number of boreholes	16,25,32
B	volume storage (m^3)	5,10,15,20
C	depth (m)	120,135,150
D	number of boreholes that are connected in series per parallel loop (*)	1,2
E	volume DHW storage (m^3)	3,5,10
F	capacity of GSHP(s) (kW)	60,90,120,150
G	capacity of HP (kW) [only for SCHEME T2]	60,90,120,150

(*) this variable (D) sets the number of boreholes that are connected in series per parallel loop. It is the "parameter 6" for the Type 557a that models the GHX.

In the table below, some of the obtained results from the simulations are shown. The table has been ordered in such a way, where the first row presents the solution with the combination of variables that supply the demand during more time.

3.7.3.1 Evaluation best optimal solution Scheme T1

In Table 3-29, it is shown the first 10 best simulations for the Scheme T1 with the Building Thermal Demand defined as Scenario 1 in section 3.7.1.

Table 3-29: TRNSYS Simulations Results from SCHEME T1 [Scenario 1]. Source: CENER

	FileName	CONSUMPTION_kWhe	DEGREE_DISCONFORT	T_final_ground
1	**PEB25_A32_B5_C150_D2_E3_F150_G150.out**	**37784.81**	**24.84**	**13.89**
2	PEB25_A32_B5_C150_D1_E3_F150_G150.out	37979.98	25.08	13.89
3	PEB25_A32_B5_C135_D2_E3_F150_G150.out	37929.74	25.12	13.85
4	PEB25_A32_B5_C120_D2_E3_F150_G150.out	38113.58	26.01	13.80
5	PEB25_A25_B5_C150_D2_E3_F150_G150.out	38145.40	26.02	13.81
6	PEB25_A25_B5_C150_D1_E3_F150_G150.out	38317.83	26.55	13.81
7	PEB25_A25_B5_C135_D2_E3_F150_G150.out	38350.79	26.90	13.77
8	PEB25_A25_B5_C135_D1_E3_F150_G150.out	38536.16	26.96	13.77
9	PEB25_A32_B5_C150_D1_E3_F120_G150.out	37780.86	27.11	13.88
10	PEB25_A25_B5_C120_D2_E3_F150_G150.out	38663.89	27.34	13.72

As it can been observed in the table, the electrical consumption for the best optimal solution (32 boreholes with 150 m of depth, GSHP(s) Capacity of 150 kW, and Volume of Storage of 5 m^3 (heat/cool) and 3 m^3 (DHW)) and 2 BH(s) connected in series per parallel loop, considering a net floor area of 3500 m^2 is **10,80 kWhe/m²** (considering the net floor area of building of 3500 m^2).

3.7.3.2 Conclusions Comparative Scheme T1 vs Scheme T2

A set of different cases have been evaluated with the same technical solution. In Table 3-30, some of these cases are presented. As it can be observed, all of them show a lower consumption in the Scheme T2 than the Scheme T1 (but not very relevant in a yearly period).

It is likely that the difference between the consumption between Scheme T1 and T2 was actually greater. This could be explained because, at this stage, it has not been possible to get more representative curves from Aerothermal Heat Pump. Indeed, the available curves (included in TRNSYS software models) are only defined for a maximum outdoor temperature of 20 ^{0}C.

A control strategy to take advantage of this Scheme, is to prepare DHW with the Aerothermal HP when the outdoor temperature is higher (by a certain margin) than ground temperature, not only in the predefined Summer Season. This is a point that could be further analysed.

The figure below shows a comparison of the ground temperature and the outdoor temperature in Dilar location, as a graphical proof of the potential of this measure.

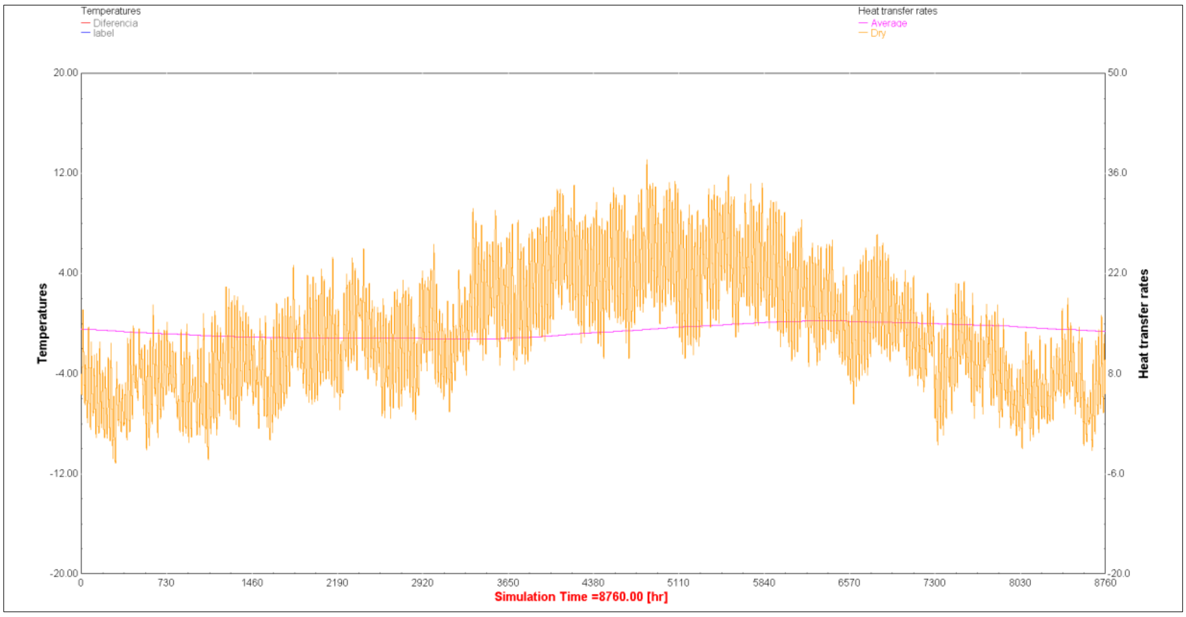

Figure 3-14: Ground Temperature-Outdoor Temperature Comparative in Dilar. Source: Trnsys-CENER

Table 3-30: Comparative SCHEME T1 and 1. TRNSYS Simulations Results Source: CENER

Scheme type	**File Name**	CONSUMPTION_kWhe	DEGREE_DISCONFORT	T_final_ground
CASE 1				
SCHEME T1	PEB25_A16_B5_C150_D1_E3_F150_G150.out	39655.64	28.63	13.65
SCHEME T2	PEB25_A16_B5_C150_D1_E3_F150_G150.out	39205.10	42.05	13.94
CASE 2				
SCHEME T1	PEB25_A25_B10_C120_D2_E3_F150_G150.out	38833.17	35.49	13.77
SCHEME T2	PEB25_A25_B10_C120_D2_E3_F150_G150.out	38664.58	17.43	14.02
CASE 3				
SCHEME T1	PEB25_A16_B10_C135_D2_E3_F150_G90.out	39833.55	52.36	13.67
SCHEME T2	PEB25_A16_B10_C135_D2_E3_F150_G90.out	39520.58	20.72	13.96

On the other hand, most of the results of Scheme T2 show that this scheme is better to guarantee the required Comfort Conditions.

Besides, the ground temperature at the end of the year for Scheme T2-solutions is a bit higher than of the Scheme T1-solutions. This an important point to consider in the design of this facility in order not to exhaust the ground resource.

Finally, taking into account the three considerations in energy terms, best demand cover, less consumption and less risk of ground resource exhausting, the best scheme seems to be Scheme T2.

Nevertheless, a techno-economic evaluation is recommended to make a final sizing decision about what scheme would be more appropriate.

3.7.3.3 Evaluation of electrical consumption of three building demand Scenarios

Apart from the evaluation of the best optimal solution for both schemes described above, the electrical consumption has also been evaluated for one of the solutions of the thermal generation facility with the three Scenarios of Building Demand, explained in previous sections.

This solution is defined by the values in the proposal with 16 boreholes and 150 m of depth. Besides, it has been implemented the capacity of two commercial water-water heat pumps.

The solution evaluated is defined by the values of the variables as it is shown in Table 3-31.

Table 3-31: Evaluated Solution from 3 Building Demand Scenarios. Source: CENER (Trsnys)

Variable Name	Variable Definition	Values
A	number of boreholes	16
B	volume storage (m^3)	5
C	depth (m)	150
D	borh_series (*)	1
E	volume DHW storage (m^3)	3
F	capacity of GSHP(s) (kW)	141.5 (cool)/158.2 (heat) (**)
G	capacity of HP (kW) [only for SCHEME T2]	108.9 (cool)/122.4 (heat) (**)

(*)borh_series : this variable (D) sets the number of boreholes that are connected in series per parallel loop. It is the “parameter 6” for the Type 557a that models the GHX.

(**) Water-Water Heat Pumps (Airlan NXP0600 & NXP0500)

The following table shows the obtained results from the 3 Scenarios:

Table 3-32: Results from MODEL 3 for 3 Scenarios from MODEL 1. Source: CENER (Trsnys)

Scenario	GSHP(s) electrical consumption [kWhe]	GSHP(s) electrical consumption [kWhe/m2]
0	44.078	12,59
1	39.752	11,35
2	34.793	9,94

3.7.4 Electrical Generation System (electrical consumption)

The obtained results from the PV Model in TRSNSYS for the three Scenarios defined in Section 3.6.2 are shown below:

Scenario PV0:

Table 3-33: PV Production in PV0 Scenario .-TRNSYS Simulations Results. Source: CENER

PV Production (kWh_e)	Area (m^2)	
	horizontal	tilted 22º
111.887	0	410.82
39.079	158.65	0
150.966 (43.13 kWh_e/m^2)	**158.65**	**410.82**

Scenario PV1:

For a new design of the building, taking advantage of the current terraces and covering them with PV modules, the PV production is shown in the table below:

Table 3-34: PV Production in PV1 Scenario.- TRNSYS Simulations Results. Source: CENER

PV Production (kWh_e)	Area (m^2)	
	horizontal	tilted 22º
111.887	0	410.82
39.079	158.65	0
21.785	0	80.00
7.390	30.0	0
180.141 kWh_e (51.47 kWh_e/m^2)	**188.65**	**490.82**

Scenario PV 2:

With the objective of achieving the PEB goal, our proposal is to extend the roof at least until 700 m^2 with a 22º tilting. The PV production would be **54,30 kWh_e/m^2**.

Table 3-35: PV Production in PV2 Scenario.- TRNSYS Simulations Results. Source: CENER

PV Production (kWh_e)	S(m^2)	
	horizontal	tilted 22º
190.000 (54.30 kWh_e/m^2)	**0**	**700**

As Summary:

Study Scenarios:		PV Electrical Generation [kWh_e/m^2]
PV1	Roof with the last geometry roof definition	43,13
PV2	Roof extended in 1	51,47
PV3	**Proposed roof based on PEB purpose**	**54,29**

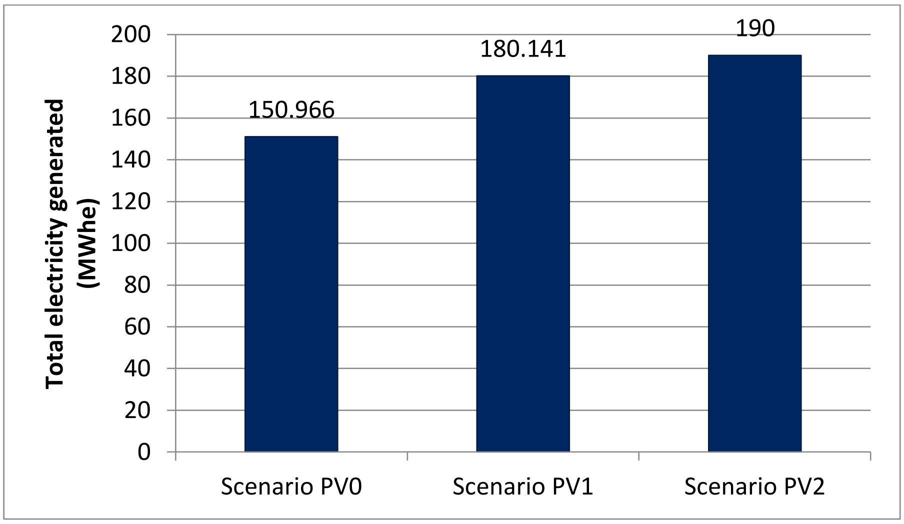

Figure 3-15: Total Electrical Generation [MWh_e] for analysed Cases. Source: CENER

3.7.5 PEB goal

The summary of results from electrical consumption is:

Table 3-36: Results Total Electrical Consumption for Demand Scenarios. Source: CENER

Electrical Consumption Building [kWhe]	Thermal Demand Scenarios		
	Scenario 0	Scenario 1	Scenario 2
GSHP(s) (*)	**12,59**	**11,15**	**9,94**
Distribution	1,89	1,67	1,67
FAN(s)+FCU(s)+Pump(s)	5,98	5,98	5,98
Artificial Lighting	14,00	14,00	14,00
Equipment	14,00	14,00	14,00
Common Spaces	4,00	4,00	4,00
TOTAL	**52,46**	**50,80**	**49,41**

As a summary, the following table shows for the technical solution presented in Table 3-31 the achievement of PEB goal for the three Thermal Demand Scenarios and the Electrical Generation from the three Scenarios of PV roof:

Table 3-37: Results PEB goal. Source: CENER

PEB GOAL (IMPORT < EXPORT)			**IMPORT [$kWhe/m^2$ year]**		
			Scenario 0	Scenario 1	Scenario 2
			52,46	**50,80**	**49,41**
EXPORT [$kWhe/m^2$ year]	Scenario PV0	**43,13**	**X**	**X**	**X**
	Scenario PV1	**51,47**	**X**	✓	✓
	Scenario PV2	**54,29**	✓	✓	✓

3.8 Conclusions

Within this section, an advancing of the simulation results from the Spanish pilot is presented, where a detailed description of the demonstrator (building and facilities) has been provided. The majority of what has been explained is based on assumptions, because the definition of the building and their facilities is still under study. These results have been provided by the Models developed in TRNSYS v.17 and specific simulation sets that have been performed.

The main achievements are the developed building + systems models and the breakdown is as follows:

- Integration of the building and its systems (thermal + electrical + control) in the same transient computational model.
- Parametrization including the main key variables (climate + building + systems) to be versatile and for any given building.
- It allows to easily include information about actual occupancy schedules and users comfort preferences, permitting to model to a real building usage.
- Oriented to provide outputs which enables adapting the design of building based on the simulation of any option or modification.

An additional accomplishment is the comprehensive analysis and discussion on the results, considering the PEB objective defined in Task 1.1.

With regard to continued developments, the key work lines are mainly related to further research work to be done for improvements in the thermal generation system:

- Taking advantage of waste heat of building in summer for DHW preparation.
- Possibility of free-cooling in summer by direct fluid circulation in the ground, plus a dedicated low temperature sizing of Terminal Units. These improvements are in the side of design and it should be evaluated before construction phase.
- Another improvement could be to design heat recovery with a performance above 50% by means of a specific design and large exchange surfaces of heat exchangers in Terminal Units.

Regarding control strategies, the effect of using an Aerothermal Heat Pump could be studied when outdoor temperatures are higher than the ground temperature and so the air becomes a better heat source than the ground.

Another key point could be the study of the control of artificial lighting to take advantage of natural light.

Also, more control strategies could be evaluated when the behavior patterns of the tenants are available and enriched with weather forecasting.

To conclude, the results of the simulations, at this stage of the project, showed that it would be highly recommended to extend the PV roof to achieve the PEB goal. Moreover, both the measures studied (heat recovery and shading control) to lower the heating and cooling demand should be implemented. Also, it should be taken into account to enhance the GHX (add more boreholes) and use an aerothermal heat pump for DHW preparation.

It is important to highlight that the electrical demand for household appliances, artificial lighting and common zones (in accordance with assumptions as [28]) reach almost the 63% (See Figure 3-16) of total electrical consumption of the building. Because of that, it is highly recommended to achieve the PEB goal to work in both, raise the electrical generation via renewable resources, and/or in user-engagement to reduce this demand.

Lastly, more control strategies could be evaluated after the final definition of the building and its facilities based on the best knowledge of tenants' behaviour patterns, weather predictions and market prices.

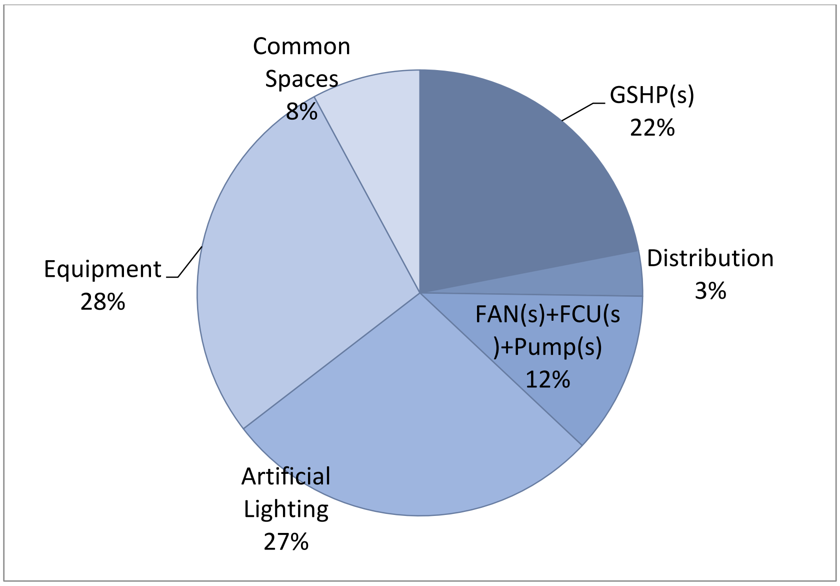

Figure 3-16: % Building Electrical Consumption per Usages. Source: CENER

4 Case Study in Continental Climate. Austria

4.1 Short Description of the Case Study

The Austrian demonstrator project is part of a plan to reactivate a former industrial complex to act as a new and modern city quarter. Surrounded by excellent road infrastructure, public transportation networks (tram, bus) and cycle tracks near the river Mur, it is properly connected with the inner-city center of Graz. The entire area is still designated as a business area and has to be further developed in this category. The surrounding area is divided into industry usage, residential and commercial area. *Figure 4-1* shows on the left the site plan in connection with a larger urban excerpt and on the right an enlarged site plan of the city quarter including the adjacent properties, objects, and the transport infrastructure.

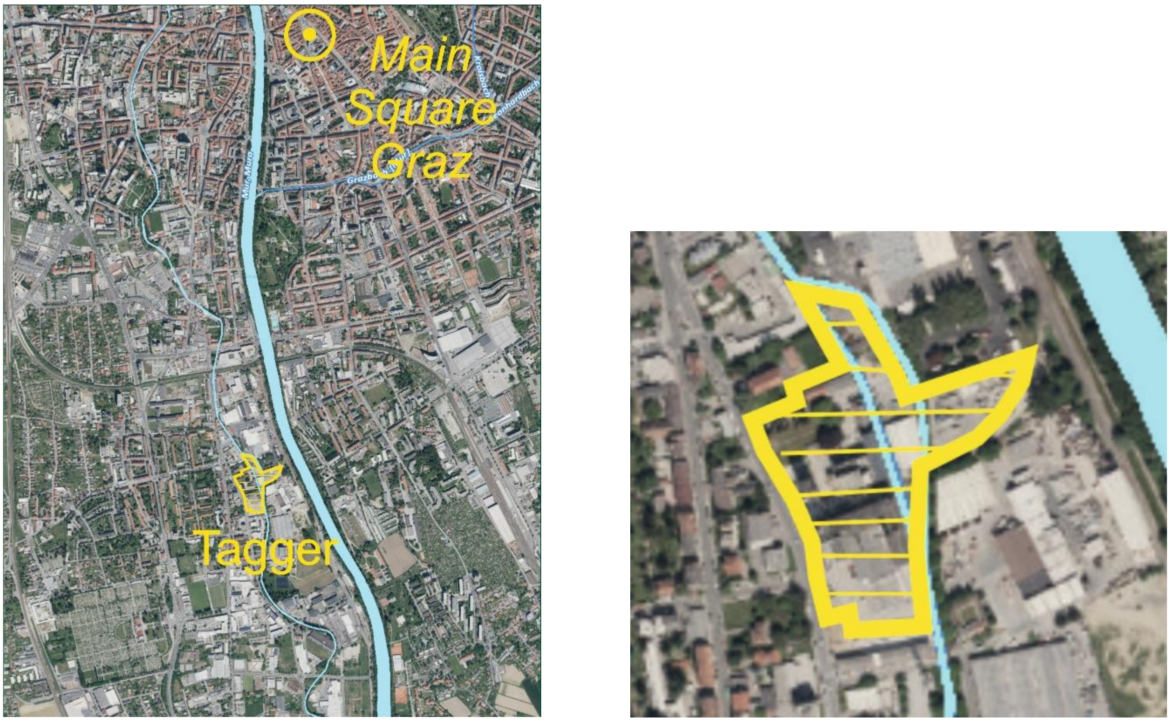

Figure 4-1: Overview of Tagger Area Graz . Source: [29]

In total 19 buildings exist on the area which were formerly used for feed production, as fodder silos, for packaging and logistics as well as for administration and maintenance. The final gross floor area of all buildings in the final development stage is 30,841 m². Almost all of the buildings in this area (except for the concealed, small buildings) are shown in *Figure 4-2* and correspond to four transformations, which are indicated in different colors.

Within the EXCESS Project the focus is only on the refurbishment of the demonstrator building 10 – a former feed silo. The declared goal for this building is to achieve positive energy building standard. To reach this goal, several energy efficiency measures must be integrated (highly efficient façade refurbishment with prefabricated façade elements including integrated building equipment). The building 10 is a high-rise building with 10 floors and 40 m of height respectively (cf. *Figure 4-3*). It comprises around 1,161 m² of gross floor area and developed as a mixed usage building but mainly used as a student hostel.

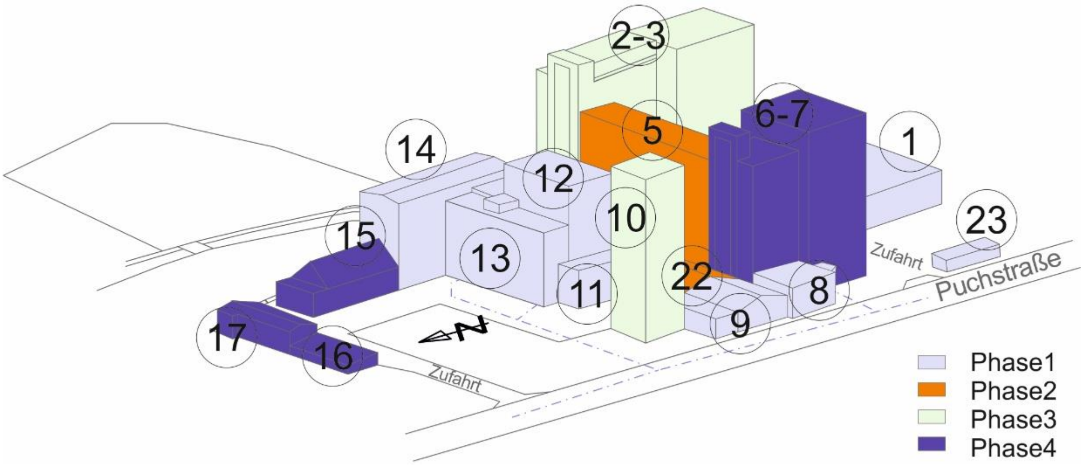

Figure 4-2: Whole building complex Tagger-Area and buildings related to refurbishment phases one to four. Source: BAR Vermögensverwaltung GmbH [30]

Figure 4-3: Demonstrator real building (left) and 3-D model (right). Source: [31]

A groundwater well is available on the property with an existing right for energy usage. Two groundwater heat pumps with a total capacity of 165 kW are already installed and support a currently existing gas burner (400 kW), which should be replaced in medium term by a completely renewable energy supply system. A small hydropower plant with a capacity of 140 kW_p will be installed in the eastward adjacent Mühlgang (bypass of the river Mur). Due to an existing water law, the hydroelectric power plant can be permanently operated with peak performance, except of maintenance work for one or two summer weeks.

Based on this energy concept for the heating and electricity supply, the number of groundwater heat pumps is further extended to replace the gas burner. Also, the on-site photovoltaic areas are increased. The second focus of the concept is to maximize the energy flexibility potential, which is available at the city quarter (thermal activation of the reinforced concrete with active façade elements, decentralized water storage, integration of flexibility potential on the side of tenants and users, provision of first electric cars and multifunctional integration of vehicle batteries into the electrical grid of the city quarter, stationary battery storage).

Table 4-1 summarizes the elements of energy supply system for the whole area and Figure 4-4 shows on a system level the integration of building 10.

Table 4-1: Elements of energy supply for the whole area not only for building 10 (Turm 10). Source: [30]

Electricity Supply
• Small hydropower plant with 140 kW_p and more than 8300 operating hours per year • Electricity demands or surplus energy is balanced by the higher-level grid
Heat and Cold Supply
• 5 cascading groundwater heat pumps with a total heat output of 361 kW and a cooling capacity of 252 kW. • Controlled ventilation systems with heat recovery in buildings with passive house standard • Heat dissipation systems based on low-temperature systems (underfloor heating and wall heating via external component activation)
Energy flexibility elements, Storage and Smart Control
• Decentralized, storey-wise storage tanks for efficient heat distribution and load matching potential with a total volume of 72 m^3 for hot water preparation and space heating supply • 2,720 t thermally activated component mass as heat storage and heat delivery system • Intelligent business and tariff models for attracting tenants and energy consumers with regard to their gain of the flexibility potential of the city quarter • Integration of the e-mobility fleet as a flexibilization element, which concerns the charging times and capacities as well as the usage of the vehicle batteries in the energy concept of the city quarter • Installation of a battery storage with a capacity of 225 kWh. • Superordinate smart control algorithm • Interaction with the higher-level power grid to achieve flexibility potentials and to develop business models

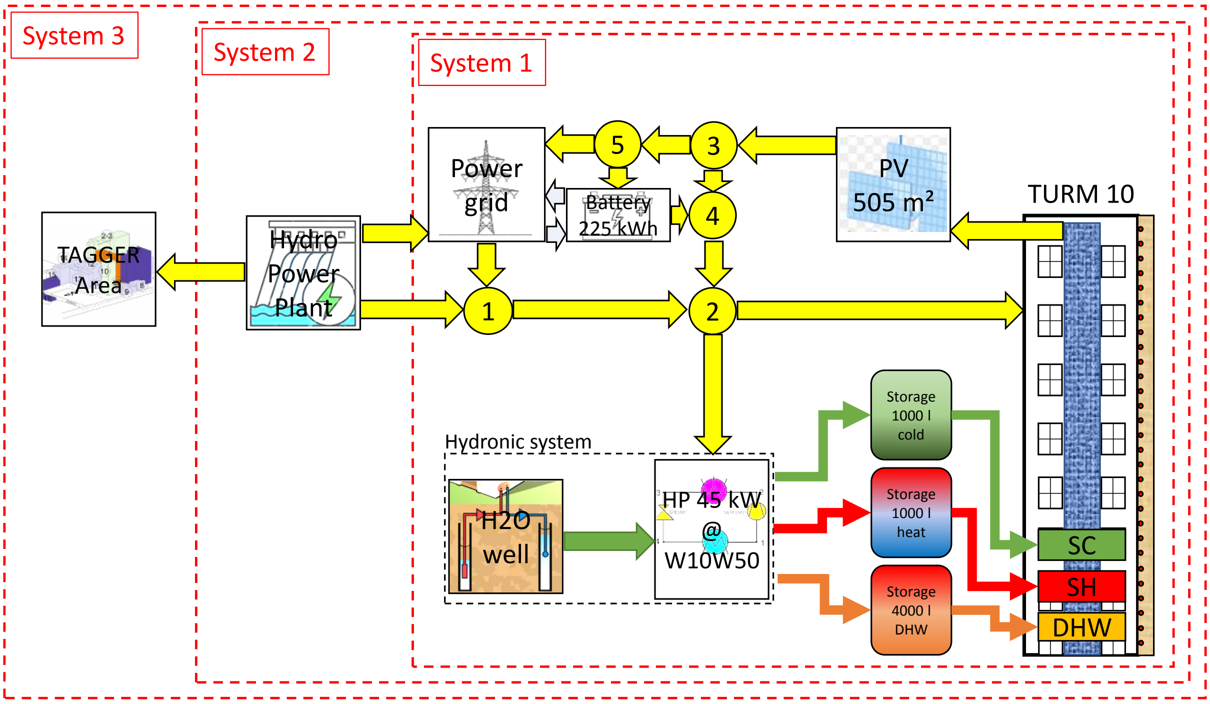

Figure 4-4: Concept on three system level of the Tagger area with focus on Tower 10 with the heat generation, electricity generation, facilities, and consumers. Source: AEE

4.2 Climate Description

The location of the demonstrator is Puchstraße 17-21 in Graz, Austria. For the simulations, the weather data from Graz-Thalerhof Airport is used as this data is close to the object site and the weather data includes typical reference years (TRY). Table 4-2 shows further details on the location with the lowest ambient temperature at -12.2 which is used as a worst-case temperature when designing the heating system and a maximum ambient temperature of 30.9 °C, respectively. Figure 4-5 shows the ambient temperature for the location over a year with the peaks in summer and winter.

Table 4-2: Data for simulation from ASHRAE3 Fundamentals 2013 at Graz-Thalerhof-Airport for location of the demonstrator – Puchstraße in Graz, Austria. Source: AEE

Latitude	Longitude	Elevation in m	ϑ_{min} in °C	ϑ_{max} in °C
47.0 N	15.43 E	340	-12.2 (winter)	30.9 (summer)

[3] © 2011 American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, GA, USA.

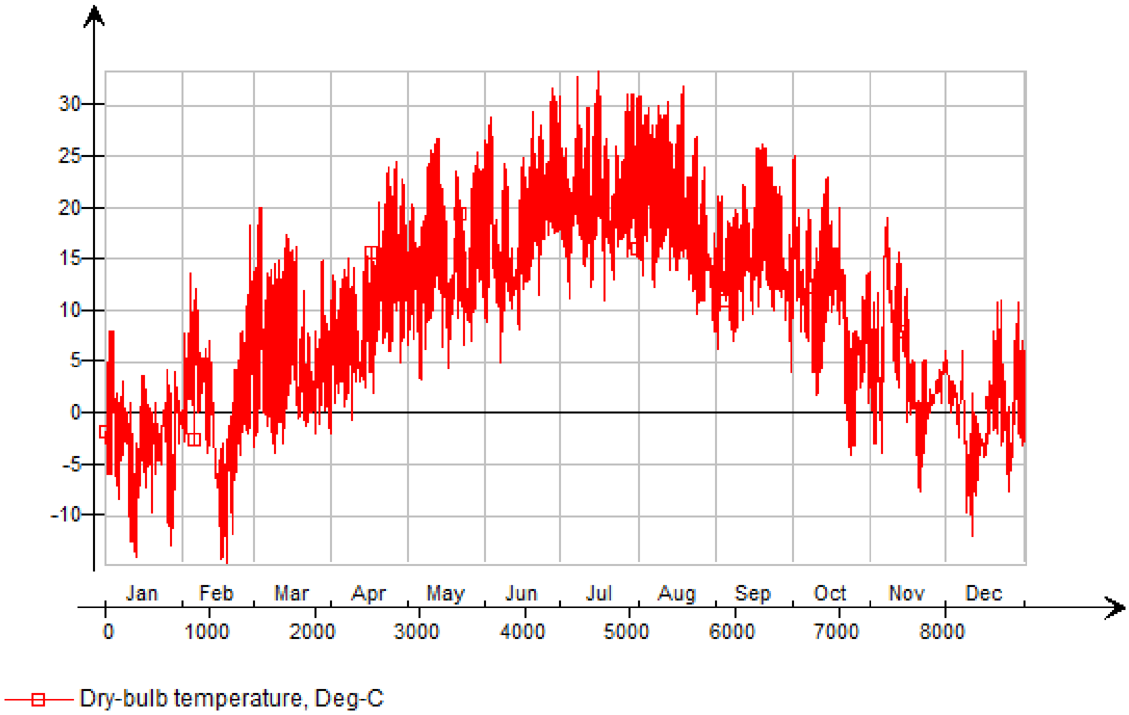

Figure 4-5: Dry-bulb ambient temperature for the location of the demonstrator with the temperature in °C on the y-axis and months on the x-axis. Source: [32]

4.3 Building Description

Additionally to the already described refurbishment plans, building 10 or tower 10 is going to make use of prefabricated active façade elements. As the functioning of an activated façade heavily depends on the materials of the pre-existing building structures, all wall construction details are shown in Table 4-3. Herein, all external walls for ground floor and 3rd to 8th floor feature ferro-concrete outside walls, whereas floor 1, 2 and 9 are made of a vertical coring brick layer. The newly added layers including the mineral wool and the external plaster for all floors and are part of the active façade elements.

Table 4-3: Planned wall structures in the demonstrator with its U-values and where they assigned to. Source: [33]

No.	Name	Structure	Thickness in m	Tot. u-value $W/(m^2 \cdot K)$[4]	Assign to floor
1	External wall 1	Int. plaster	0.015	0.15	3rd to 8th – ext. wall
		Ferroconcrete	0.21		
		Mineral wool	0.24		
		Ext. rendering	0.01		
2	External wall 2	Int. plaster	0.01	0.14	1st, 2nd and 9th – ext. wall
		Vertical coring brick	0.3		
		Mineral wool	0.24		

[4] Heat transfer coefficients according to IDA ICE set with $h_i = 8\,W/(m^2 \cdot K)$ and $h_o = 25\,W/(m^2 \cdot K)$ – only for overview, otherwise variable

		Ext. rendering	0.01		
3	External wall 3	Int. plaster	0.015	3.40	Stairway outside
		Ferroconcrete	0.21		
		Ext. rendering	0.01		
4	Internal wall 1	Plasterboard	0.025	0.24	All internal walls except to stairway
		Mineral wool	0.15		
		Plasterboard	0.025		
5	Internal wall 2	Int. plaster	0.01	0.24	Corridor/ bath to unheated stairway
		Ferroconcrete	0.21		
		Mineral wool	0.15		
		Ext. rendering	0.01		
6	Internal floor 1	Light concrete	0.09	0.62	All internal floors except among 2nd to 3rd
		Mineral wool	0.03		
		Concrete	0.18		
7	Internal floor 2	Light concrete	0.09	0.55	Internal floor between 2nd & 3rd
		Mineral wool	0.03		
		Concrete	0.50		
8	Roof	Light concrete	0.03	0.17	9th floor to Roof
		Light insulation	0.2		
		Concrete	0.2		
9	Floor	Light concrete	0.1	0.51	Slab towards ground
		Cellular glass gravel	0.2		
		Concrete	0.21		

As no information on the properties of the building's windows was given at the time of writing this document, only the area, the orientation as well as the position in the building are documented here. For the modelling process the window' properties are assumed as described later on. Table 4-4 shows the orientation, the amount and the areas of the windows that are going to be installed at tower 10.

Table 4-4: Definition of all used windows in the demonstrator model. Source: [33]

No.	Name	Area in m^2	Orientation[5]	Assign to
1	Win Stair 01	4.4	10x South	Stairway
2	Win San 01	1.4	2x South	Sanitary OG1 & OG 2
3	Win San 02	1.5	6x South	Sanitary OG3 to OG 8
4	Win San 03	2.84	1x South	Sanitary OG 9
5	Win Bed 01	2.1	32x Nord	Bedroom NO & NW from OG 1 to OG 8
6	Win Bed 02	1.38	2x Nord	Bedroom NO

[5] Orientation is approximated as the faces are not exactly orientated to a cardinal direction

				& NW OG 1
7	Win Bed 03	1.87	2x Nord	Bedroom NO & NW OG 1
8	Win Bed 04	3.74	4x East	Bedroom NO OG 1 & OG 2
9	Win Bed 05	2.79	4x West	Bedroom NW & SW, OG 1
10	Win Bed 06	2.86	2x South / 2x West	Bedroom SW & NW & SO OG1 & OG 2
11	Win Bed 07	1.4	2xSouth / 2x West	Bedroom SW & NW & SO OG1 & OG 2
12	Win Bed 08	2.04	2x Nord	Bedroom NO & NW, OG2
13	Win Bed 09	2.2	2x Nord	Bedroom NO & NW, OG2
14	Win Bed 10	1.5	12x Nord / 6x South / 12x West	Bedroom NO, NW & SW, OG 3 to OG 8
15	Win Bed 11	3.0	12x East	Bedroom NO, OG 3 to OG 8
16	Win Bed 12	3.06	6x South / 12x West	Bedroom NW & SW, OG 3 to OG 8
17	Win Cor 01	2.79	2x East	Corridor OG1, OG 2
18	Win Cor 02	2.42	6x East	Corridor OG 3 to OG 8
19	Win Off 01	2.84	2x South / 4x West	Office OG 9
20	Win Off 02	1.5	1x South	Office OG 9
21	Win Off 03	1.41	2x Nord	Office OG 9
22	Win Off 04	2.33	4x Nord / 1x East	Office OG 9
23	Win Off 05	2.85	2x East	Office OG 9
24	Win Café 01	72.58	1x West	Café EG
25	Win Café 02	12.54	1x Nord	Café EG
26	Win Café 03	9.31	1x East	Café EG

The prefabricated façade element and the HVAC system is described in the following chapter.

4.4 Thermal Generation Facility Description

The building 10 is mostly made of solid steel reinforced concrete and is not insulated. To achieve the goal of a positive energy building, and the easier installation in large heights, the owner decided to use well insulated prefabricated façade elements for all external walls.

The curtain facade allows a pre-fabricated integration of ventilation technology. The exterior components of the decentralized ventilation unit will be directly integrated in the curtain façade and the connection to the interior is made via dimensional accurate core drillings in the concrete walls. Figure 4-6 shows exemplarily the planned decentralized ventilation units including a heat recovery system.

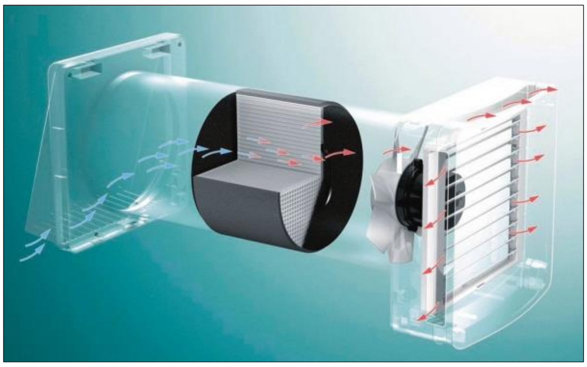

Figure 4-6: Decentralized ventilation system mounted inside of drillings in the external wall(symbol figure. Source: [34]

To implement a dynamic, year-round heating and cooling system, a flexible concept with five groundwater heat pumps is implemented. Depending on the load situation or the availability of renewable electricity generated on site, a wide range of heat and cooling capacity can be retrieved flexibly and temporarily stored in connection with the heat-side flexibilization elements (activated building mass, decentralized buffer storage, screed mass of the underfloor heating, user integration). Three heat pumps are reversible and can therefore also be used for cooling buildings. Finally, a total peak load of 361 kW for the heating and 252 kW for the cooling can be served by the units.

Two heat pumps (each 89 kW of heating, 76 kW of cooling power) are already in operation and will be extended during the refurbishment by three heat pumps (each 65.2 kW heating, 42.5 kW cooling power).

Figure 4-7 shows the DHW distribution to all floors of building 10 which is planned by the building's owner himself. Herein, the 4000 l DHW store and the heat pump to charge the storage is located in the installation room on the ground floor. The distribution line is connected to each floor where heat exchangers as flow heaters are installed with a design heating capacity of 38 KW each. Due to a high pressure head an additional heat exchanger with 130 kW is installed on floor 6 to separate the circuits and reduces the pressure head for both systems. However, also on floor 6 there is a small heat exchanger as flow heater to provide DHW.

To control the outlet temperature of the heat exchanger on the secondary side a flow control valve with a thermostat is installed to provide a temperature level of 39 °C to the taps (cf. Figure 4-7). According to the building's owner the design heating capacity of the heat exchangers is calculated with rules of thumb where a mass flow rate of 1750 l/h is assumed to obtain the heating capacity of 38 kW with a temperature difference of 19 K for water. For the total design heating capacity, simultaneity of 60 % is assumed, also according to the experience of the building's owner.

For DHW heat generation the building owner has foreseen 12 heat pumps with a heating capacity of 12 kW and a COP of 4.58 to charge the 4000 l DHW store.

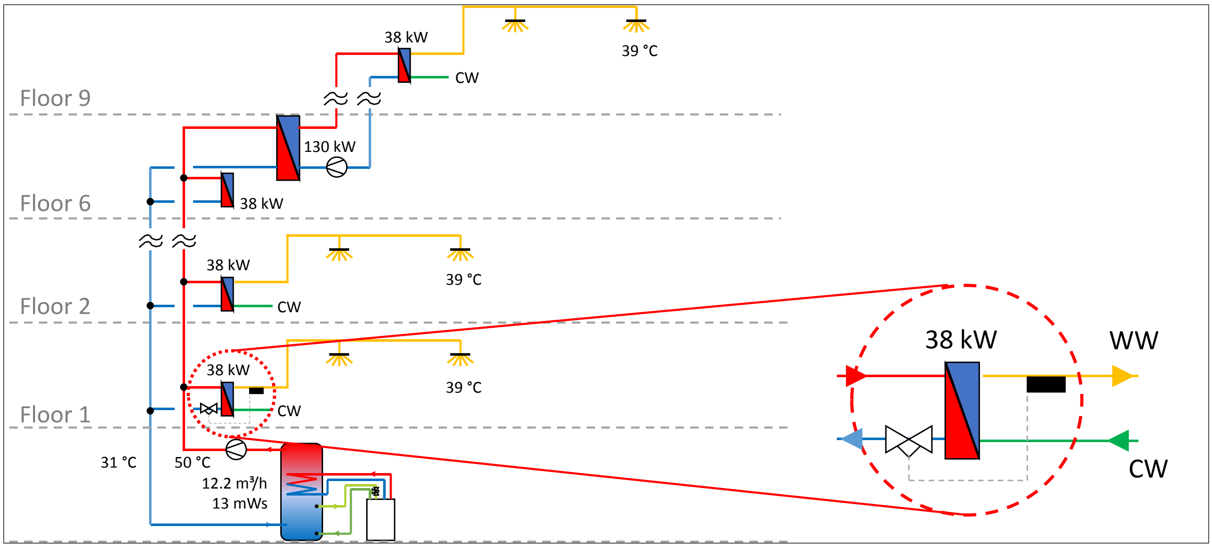

Figure 4-7: DHW system for each floor that is planned for demonstrator. Source: [33]

4.5 Electricity Facility Description

4.5.1 Hydropower plant

A small hydropower plant with a capacity of 140 kW_p will be installed in the eastward adjacent Mühlgang (bypass of the river Mur). Due to an existing water law, the hydroelectric power plant can be permanently operated with peak performance, except of maintenance work for one or two summer weeks.

4.5.2 BiPV for electricity production

Building 10 has no existing photovoltaic elements on the outer surface by now. As part of the thermal refurbishment of the building, photovoltaic elements are aesthetically integrated in the curtain façade. This can be done already during preproduction and so the PV can be installed with the complete façade package on site. For the façade areas oriented to the south and west, these results in a total generation power of 60 kW_p. One example of integrating PV into a curtain wall was shown in the project HVACviaFACADE[6] (*Figure 4-8*).

[6] HVAC via facade, FFG Nr.: 843495; Prefabricated façade elements with the highest level of integrated HVAC-components and systems for stock renovation; https://www.klimafonds.gv.at/foerderungen/gefoerderte-projekte/detail/?plistcall=1&pid=183836

Figure 4-8: Example of an experimental integration of a photovoltaic element in a test-facade during the project HVACviaFACADE. Source: [31]

4.6 Model Description

The building and system models introduced in this chapter help to assure the fulfillment of requirements concerning comfort level and PEB standards. The model is divided in three main sections (cf. Figure 4-4), with a clear focus on “system 1” and “system 2” shown in *Figure 4-9*. The main component of the hydronic system is the heat pump that is connected to the building via storages for domestic hot water (DHW), space heating (SH) and space cooling (SC). To achieve PEB standard a building integrated photovoltaic (BiPV) system is applied to cover electric energy demands of the building such as lighting, heat pump electricity, pumps, fans, etc. The BiPV supplies energy via node 2, node 3 and node 4 to the building (cf. Figure 4-9). A surplus of electric energy from the PV can charge the Battery or is fed into the grid (node 3 to 5). The battery is also able to feed into the grid.

If there is an electricity demand higher than the on-site production the power grid can provide energy over node 1 to 2 to the building. However, to increase the self-consumption electricity should be used from the battery system or from the BiPV directly.

As the definition of PEB is a positive annual energy balance, the production of renewable energy has to be higher than the consumption. The battery system is just a “side” part of the analysis as it just shifts the energy demand or production within a small timeframe and does not have an effect on the annual balance. In contrast, the hydro power plant which is running 24 hours and 7 days a week and contributes a lot of energy to obtain PEB status and is therefore included in the analysis. However, it is not directly involved in the optimization of system 1.

The following sub-chapters describe the boundary conditions and simplifications of the simulations and model as well as the models itself. By evaluating the defined KPIs the simulation results are assessed and optimization suggestions are proposed for the system. The findings are then summarized and interpreted in the conclusion part of this chapter.

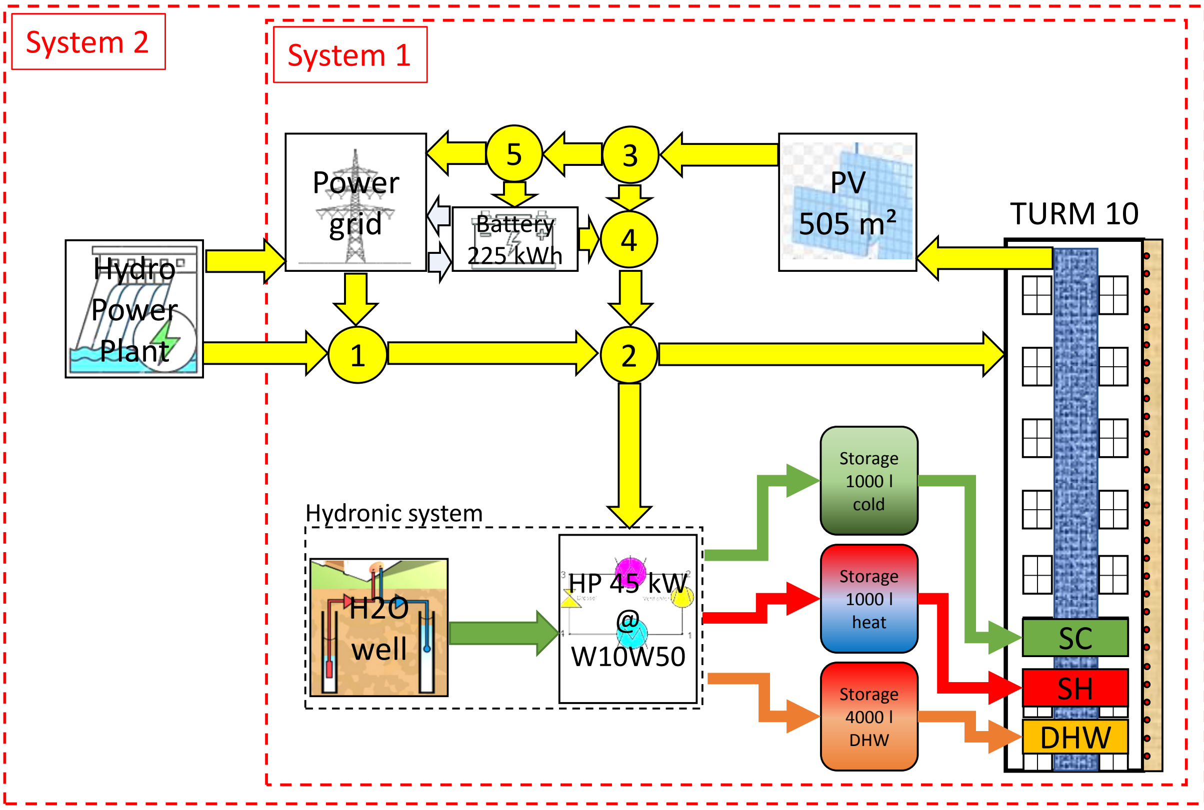

Figure 4-9: Concept on system level of the Tagger area Tower 10 with the heat generation, electricity generation, facilities, and consumers for the simulation. Source: [33]

4.6.1 Boundary conditions and simplification of modelling

Within this chapter the boundary conditions as well as the simplification of the total energy system is described. The simulation uses the climate conditions for Thalerhof Graz that has already been described in section 4.2.

4.6.1.1 DHW load profiles

DHW load profiles are time series according to SIA2024 with 20 kWh/m² to yield a daily consumption of 1.63 kWh/(Pers.d). Table 4-5 shows the detailed assumption for the DHW preparation in the DHW section on the secondary side of the storage.

The DHW distribution over a reference day is shown in Figure 4-10 based on presence of tenants according to SIA2024 (2015). The maximal power for DHW is calculated with 26.08 kW at 7 o'clock, whereby the total energy per day is calculated with 78.24 kWh/d. The Floor 9 is excluded from this calculation since it is used as an office.

Table 4-5: Boundary conditions for DHW demand for the load profile. Source: [35]

Name	Supply temperature in °C	Cold water temperature in °C	Floor area in m²	DHW demand hot water in l/(per.day)	Spec. annually demand in kWh/(per.day)	Tot. annually demand[7] in kWh
MFH	50	10	920.58	35	1.63	28.514

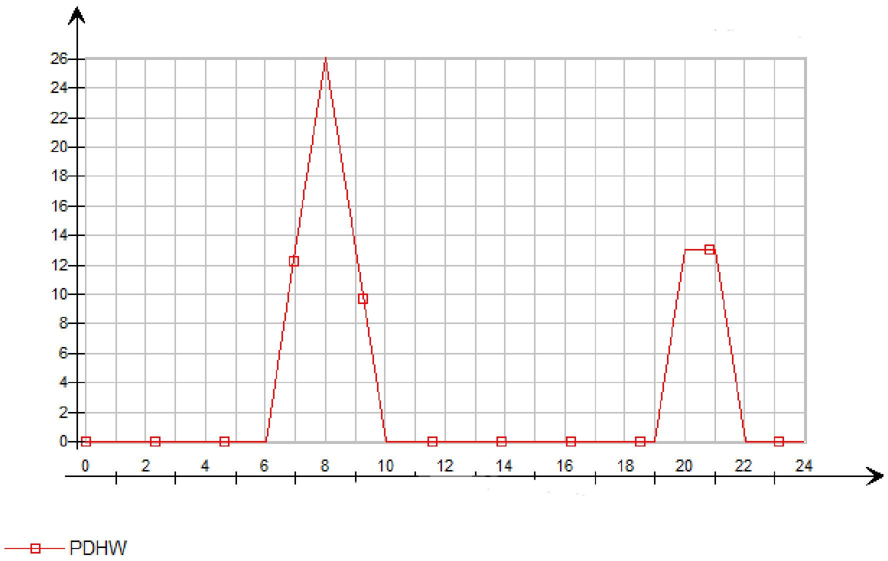

Figure 4-10: Daily DHW profile for all Floors with the capacity in kW on the y-axis, and the time of day in h on the x-axis according to [35] – linearly interpolated between hours

The stairway which is connected to each floor is unheated and does not have any ventilation system nor shading for the windows. No person is considered to be present in the stairway for the simulation and the windows have the same properties as in the other parts of the building.

4.6.2 Building Model Description

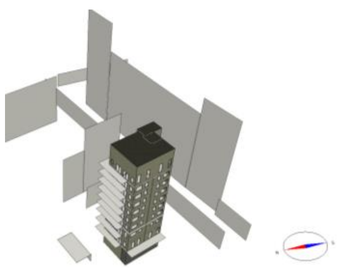

Figure 4-11: Model of Turm 10 and its site shadings as well as balcony. Source: AEE

4.6.2.1 Walls, constructions, windows, doors, etc.

Wall constructions, windows and components are modelled based on the chapter 4.3. The active layer element is always in between the existing external wall, e.g. ferro-concrete or vertical coring brick or external plaster, and the attached insulation.

Figure 4-11 shows the model of the demonstrator with its site shadings and balconies. The net floor area may deviate a little from the real building and is assumed with

[7] Calculated with 6 persons each floor and 8 floors and a temperature difference of 40 K ($\vartheta_{dhw,sup} = 50\,°C$ & $\vartheta_{cw} = 10\,°C$)

1161.04 m² excluding stairway.

For all windows the chosen properties are shown in Table 4-6. The windows have an integrated window shading called BRIS in IDA ICE (Equa, 2020) but no external one. Also, there is no opening schedule used as a controlled ventilation system is implemented. This is also assumed for the doors as the duration of them being open for passing people is very short compared to the time where they are closed.

Table 4-6: Assumption of properties for all windows. Source: AEE

Solar heat gain coeff. g-value	Solar transmittance T	Visible transmittance T_{vis}	Glazing U-value in W/(m².K)	Frame: Fraction of the total win. area and U-value in W/(m².K)
0.52	0.5	0.72	0.6	0.1 & 2.0

4.6.2.2 Ventilation system / infiltration losses

The infiltration losses are calculated with IDA ICE whereby the air tightness of the building is assumed to be 1.0 1/h at a pressure difference of 50 Pa. In addition, the losses depend on the wind direction and velocity hitting the building and use pressure coefficients for each external wall based on their angle.

The ventilation system is modelled with a constant air volume flow system (CAV) for each room, corridor and bath / WC and the flow values are shown in Table 4-7. The ventilation system is always running as it is assumed that the decentralized system is switched on all the time. This differs for the office and the Café where a variable volume flow rate (VAV) based on presence of persons is assumed. The maximum flow rates are also listed in Table 4-7 at the end

Table 4-7: Air volume flow rates for each room. Source: AEE

	Room	Corridor	Bath / WC	Office	Café
Flow rate in L/(s.m²)	0.41	0.41	1.63	2.92	5
Flow rate in m³/h	45	17	60	1131	2178

4.6.2.3 Control strategy of devices

The remaining control strategies concern the shading of windows and the day light in each room or in the office area as well as in the corridor and bath/WC. The shadings of windows are closed if the solar radiation level exceeds 100 W/m² at the outer surface of the window and if the solar radiation incident angle is below 90°. The shading opens in case the solar radiation is lower than 100 W/m² (cf. Table 4-8).

Also, the lights at workplaces or in the rooms are controlled in a similar way. As the daylight is able to exceed the setpoint plus the upper deadband the artificial light is switched off. In case the daylight drops below the setpoint the artificial light is switched on, and controlled in a way to reach the light level of the setpoint until the minimum lux level of the daylight – setpoint minus lower deadband – is reached. At this stage the artificial light is at 100 % and uses the max. electricity as well as max. light level. The artificial light level is controlled linearly between the setpoint and the setpoint minus the lower deadband. Table 4-8 shows the setpoints for all rooms, corridors, bath/WC and the office.

Table 4-8: Definition of basic control strategy for 1st to 9th floor (including office). Source: AEE

No.	Variable	Setpoint	Upper deadband	Lower deadband	Other conditions
1	Shading window	100 W/m2	0	0	Shading is drawn over 100 W/m² on the outer surface and opened again below 100 W/m²
2	Day light office	500 lux	0	400	Artificial light is switched on below 500 lux (daylight) and increases the artificial light intensity to its maximum until 100 lux (daylight) and depends on schedule
3	Day light room/bath/WC	200	0	100	Artificial light is switched on below 200 lux (daylight) and increases the artificial light intensity to its maximum until 100 lux (daylight) and depends on schedule
4	Day light corridor	100	0	50	Artificial light is switched on below 100 lux (daylight) and increases the artificial light intensity to its maximum until 50 lux (daylight) and depends on schedule

4.6.2.4 Inner loads

The inner loads from occupants in the simulation are different from a normal multi-family house as there the number of persons per area and other dynamic effects are lower. According to SIA2024 (2015) there is an area of 30 m² for one person, but for our assumptions there are 48 people on 920 m² which results in about 19 m² for one person. Due to this fact the area-specific heat gains from people is higher and calculated with about 20 kWh/(m².a) in contrast to literature which suggests about 9.5 kWh/(m².a) at an usual clothing and activity level. The assumption for the simulation features an activity level of 1.2 MET and a clothing factor of 1.0 in winter and 0.5 in summer.

Table 4-9 shows the inner loads for all rooms that were set up for the simulation according to SIA2024 (2015). The room temperature setpoints are set with an upper and lower dead-band of 1 K. For corridor and bath/WC no summer setpoint is considered and the appliances are also neglected due to less presence of people. The heating setpoint in bath/WC agrees with the owner’s suggestion and deviates from the standard which would be 21 °C. However, for all inner loads – also for presence of people –the time schedule suggested from SIA2024 (2015) is considered.

Table 4-9: Boundary conditions for set points summer / winter, people, appliance, lighting and ventilation (electricity consumption). Source: [35]

No.	Description	Setpoints summer/ winter in °C	Appliance in W/m²	Lighting in W/m² & kWh/(m².a) (full load hours per year in h)	El. ventilation consumption in W/m² & kWh/(m².a) (full load hours per year in h)
1	Living – MFH	25/22	8	2.7 & 4 (1450)	0.3 & 2 (6130)
2	Office – Floor 9	25/22	10	12.5 & 23 (1860)	2 & 5.3 (2700)
3	Café – Floor 1	25/22	2	6.9 & 17 (2430)	9.9 & 15.3 (1550)
4	Corridor	n.a./18	0	7 & 21 (2970)	1.1 & 3 (3120)
5	Bath/WC	n.a./24[8]	0	10.5 & 13 (1240)	4.5 & 5 (1160)

4.6.3 Thermal Model Description

4.6.3.1 Heat pump system with water well source

Figure 4-12 shows the total hydronic scheme of the observed system from tower 10 within the Tagger areal which is optimized by means of simulations. On the left-hand side the water-well is situated and provides energy to a heat exchanger which separates the circuits to avoid dirt or sediments in the main system especially in the evaporator. However, on the secondary side there is a 3-way-valve as well as a 4-way-valve to enable all control strategies, also for the optimization.

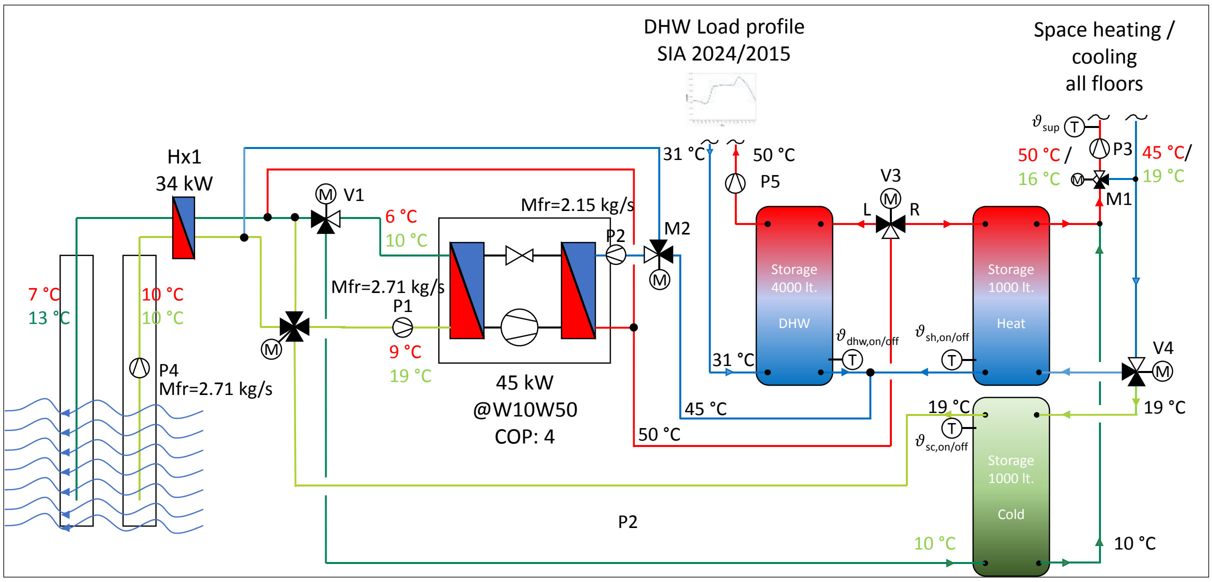

Figure 4-12: total scheme of the hydronic system with heat pump, water-well as source, storages (hot and cold) and distribution system. Source: [33]

[8] Deviates from the Standard SIA2024/2015

Heating strategy

For the baseline only a 3-way-valve is necessary to provide heat for the heat pump on the source side. Herein, V1 in Figure 4-12 is set for A-AB (straight flow through the valve) where the water well HX is directly connected to the evaporator of the heat pump system. The flow rate is ensured by the circulation pump P1 at the source side and P4 for the water well. Total mass flow rate is set over the evaporator as well as the condenser. The heat pump provides heat to charge the DHW storage (4000 l) or the SH storage (1000 l). Sizes of both tanks are based on the information from the owner of the demonstrator. On the secondary side of the storages the heat is delivered to the active façade elements or the floor heating system and to the DHW. Latter one is here done by implementing a load profile which is discussed later on.

All pumps with their design conditions are listed in Table 4-10 and Table 4-11 shows the main components with their properties.

Table 4-10: Circulation pumps for hydronic system its identification and parameters whereby the efficiency is assumed with 50 %. Source: AEE

No.	Pump	Nom. mass flow rate in kg/s	Pressure drop at nom. flow rate in Pa	Control strategy (set point / propband)	Position
1	Pump 1 (P1)	2.71	80 000	P-Ctrl[9]	Source side heat pump flow line
2	Pump 2 (P2)	2.15	50 000	On/off	Sink side heat pump return line
3	Pump 3 (P3)	1.71	50 000	P-Ctrl[9]	Space heating/cooling pump
4	Pump 4 (P4)	2.71	50000	P-Ctrl[9]	Water well
5	Pump 5 (P5)	0.21	70 000	Load profile	DHW pump

Cooling strategy

The cooling strategy in the baseline can be described as follow: the heat pump on the source side is connected to the cold storage via the 3-way-valve V1 where B-AB (90° direction) is used and meanwhile the exit from A-AB is closed. To drive the fluid the pump P1 is activated similar to the heating strategy with the same nominal mass flow rate defined in Table 4-10. To re-cool the heat pump, a connection on the sink side to the water well is assumed where the fluid passes the 3-way valve M2 in 90° direction and P2 towards the heat exchanger.

[9] P-Ctrl: „Smoothed version“ of a P-controller with variable setpoints and sine function to avoid events

Table 4-11: Main components in the hydronic system and design properties. Source: VTT

No.	Name	Capacity in kW	Volume in l	Comments I	Comments II
1	HX1	34	n.a.	Counter flow	A-side in/out: 10°C / 7 °C B-side in/out: 6 °C / 9 °C
2	Heat pump	45	n.a.	@W10W50	COP: 4
3	DHW store with water	n.a	4 000	U_{tot} = 0.4 W/m².K shunt = on[10] & $\vartheta_{sh,set} = 50\ °C$	$z_{hp,in} = 2.9\ m$ $z_{hp,out} = 0.1\ m$ $z_{dhw,in} = 0.1\ m$ $z_{dhw,out} = 2.9\ m$ $h_{store} = 3\ m$ $z_{sens,dhw} = 0.3\ m$
4	Space heating store with water	n.a	1 000	U_{tot} = 0.4 W/m².K shunt = on[10] $\vartheta_{sc,set} = 50\ °C$	$z_{hp,in} = 2.0\ m$ $z_{hp,out} = 0.1\ m$ $z_{sh,in} = 0.1\ m$ $z_{sh,out} = 2.0\ m$ $h_{store} = 2.03\ m$ $z_{sens,dhw} = 0.2\ m$
5	Space cooling store with water	n.a	1 000	U_{tot} = 0.4 W/m².K shunt = on[10]	$z_{hp,in} = 0.1\ m$ $z_{hp,out} = 2.0\ m$ $z_{sc,in} = 2.0\ m$ $z_{sc,out} = 0.1\ m$ $h_{store} = 2.03\ m$ $z_{sens,dhw} = 1.9\ m$

Figure 4-13 shows a section of the simulation model in IDA ICE where the heat pump, the controller, the storages for heat, cold and DHW are shown and the distribution system. In IDA ICE the modelling of split and merge water systems is done with additional very small storages to get numerical stability and convergence. However, using additional pumps for the small storages is not considered in the results.

[10] shut on means that always the given set point temperature is available at the outlet of the double port unless the temperature in the tank does not reach the level

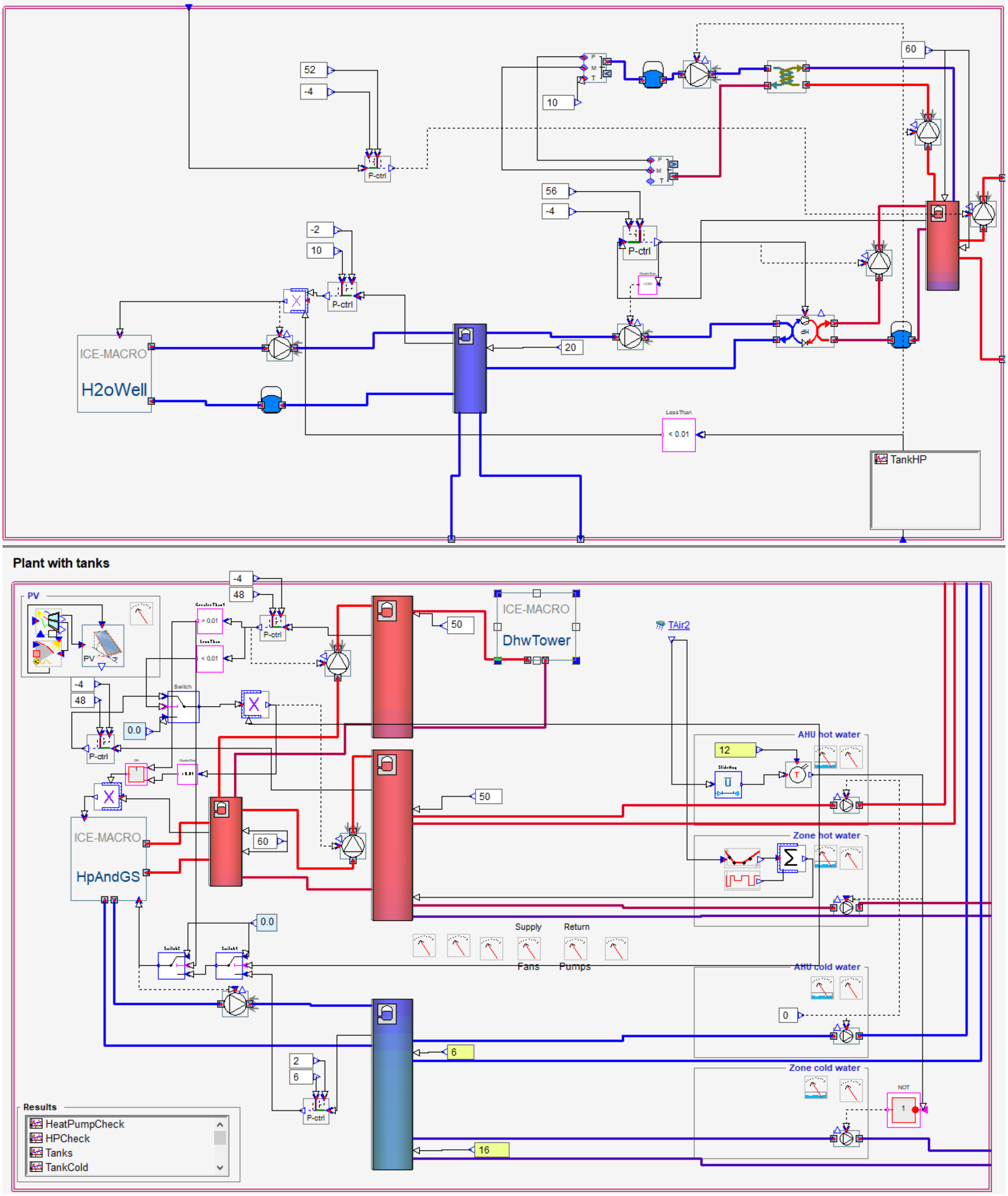

Figure 4-13: Section of the modelling concerning hydronic system with heat pump and storages in IDA ICE. Source: AEE, [36]

4.6.3.2 Control strategy

The control strategy for the baseline is set in a way that DHW preparation has priority as DHW is the most important criterium for tenants and their comfort. In this case hot water is supplied from the storage to the according floors and transfer the energy to the cold water via the heat exchanger (cf. *Figure 4-7).* In case the temperature level in the storage drops below the temperature setpoint the heat pump is switched on to charge the storage until the high temperature setpoint in the storage is reached. However, in the simulation model the DHW system is modeled with a load profile as described beforehand and the tank supplies the demanded temperature and mass flow rate if possible. As the temperature level decreases in the tank the sensor at the position (cf. Table 4-11) switches to “on” and activates the heat pump and according pumps instantly. Due to a hysteresis of the controller (P-ctrl) the system is not switched “on” and “off” within a short period of time.

Table 4-12: Controller definition for the hydronic system with their set points and strategies. Source: AEE

No.	Controller name	“OFF”[11] set point in °C	“ON”[12] set point in °C	additional conditions	comments
1	DHW	52	48	Priority	source side of tank
2	SH	52	48	Only active as $\bar{\vartheta}_{amb,24h}$<12 °C and DHW off	source side of tank
3	SC	6	8	Only active as $\bar{\vartheta}_{amb,24h}$ ≥12 °C and DHW off	Inverse strategy since cooling purposes; source side of tanks
4	HP	depends on controller 1 - 3	depends on Controller 1 - 3	“ON” / “OFF” if Controller 1 – 3 has a demand	HP
5	CTR Pu	depends on HP	depends on HP	“ON” / “OFF” if HP is “ON” / “OFF”	DHW pump

4.6.3.3 Prefabricated active façade element modelling and its design and validation

The linkage part between building and plant is the prefabricated active wall where an active layer is integrated (cf. Figure 4-14). This active layer consists of an aluminum absorber/heat spreader with a thickness of 0.4 mm and a PE-X pipe with 16x2 mm to transfer heat to the existing wall that conditions the room behind. However, the absorber is not fully connected to the existing wall so that a constant air gap of 2 mm is assumed in the simulation to consider a not perfectly plane existing wall. Due to owner’s specification the middle pipe distances of the absorber is 12.5 cm, and the corresponding HTC value is determined with 10.5 W/(m².K) which has to be set up in the simulation software IDA ICE. The HTC value describes the heat transfer from the fluid through the pipe to the first slab/surface layer, i.e. the existing wall. As this HTC value is used for calculation by means of IDA ICE it was beforehand compared to HTflux to validate some HTC values. Hengel et al. (2020) shows some HTC values for different configurations and the validation between the simulation software IDA ICE and HTflux to ensure properness of the assumptions. The here applied HTC value came from HCP_air (B) with a pipe distance of 12.5 cm.

[11] „OFF“ set point means that if the temperature exceeds the set point temperature the controller switches to off or “0” or depends on other controller’s “OFF” set points for heating purposes (inverse for cooling)
[12] „ON“ set point means that if the temperature undercuts the set point temperature the controller switches to on or “1” or depends on other controller’s “OFF” set points for heating purposes (inverse for cooling)

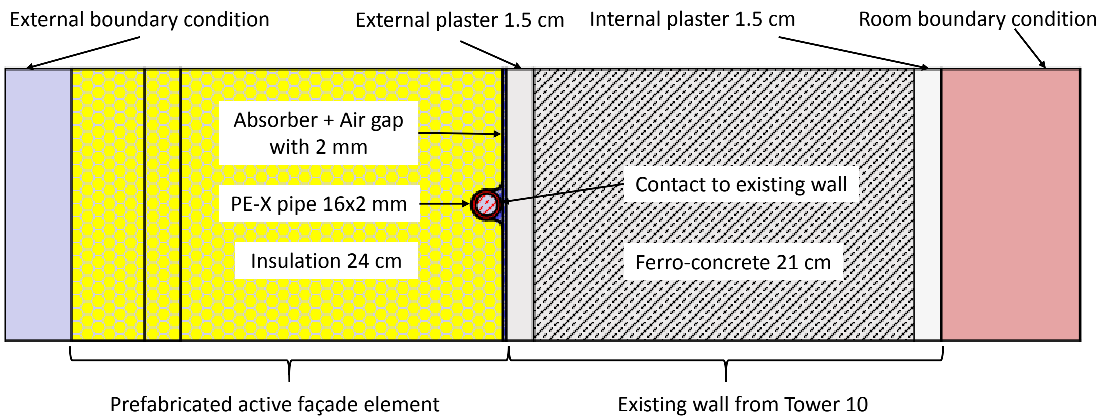

Figure 4-14: Construction of the prefabricated active façade element connected e.g. to the 3rd floor with ferro-concrete. Source: [37]

With the heat load calculation of the building (ideal components in IDA ICE) the prefabricated active wall can be designed. The heat load calculation is a function in IDA ICE where the synthetic weather file is used but with a fixed ambient temperature based to the design ambient temperature of -12.2 °C. Within the simulation also the clearness number is set to zero which means that there is no cloud coverage. All internal loads are neglected as well as the solar radiation e.g. through windows.

The results show that the worst-case room is located at the north-east corner in the 2nd floor – 1st floor is quite similar –both floors feature a few more windows than the remaining ones. Almost all rooms have design heating capacity between 400 W and 600 W or 15 W/m² to 20 W/m² based on the floor area. These numbers were now rebased on the wall area available for wall heating in every room. The max. specific design heating capacity is calculated with 30 W/m² (wall area) for all floors and 25 W/m² (wall area) for the first floor to fulfil the comfort criteria. To yield this heating capacity a supply temperature of 50 °C with a return temperature of 45 °C has been set for the heat pump system (cf. Figure 4-15).

A similar process was done to get the design cooling capacity where the room at the 2nd floor shows the worst-case condition. The room with the highest design cooling capacity of 840 W is the room north-west which is mainly due to solar radiation in the afternoon. The remaining rooms range between 700 W and 840 W respectively between 20 W/m² to 25 W/m² of floor area. The cooling load is also calculated in IDA ICE where dynamical effects from the synthetic weather file are considered and the percentage of internal gains is set to 100 %.

However, the cooling capacity according to the design diagram depicted in Figure 4-15 shows a max. cooling power of 10 W/m² (for wall area with the construction vertical coring brick) at a mean average temperature difference of 7.5 K. This temperature difference is the max. possible to avoid condensation on and inside the wall. For the construction ferro-concrete a design cooling capacity of 20 W/m² according to the design diagram (not shown here) is determined.

As the cooling demand cannot be reached with the active façade element it is just used with its max. cooling capacity. However, cooling of a residential building is not mandatory in Austria and therefore is not a first level priority.

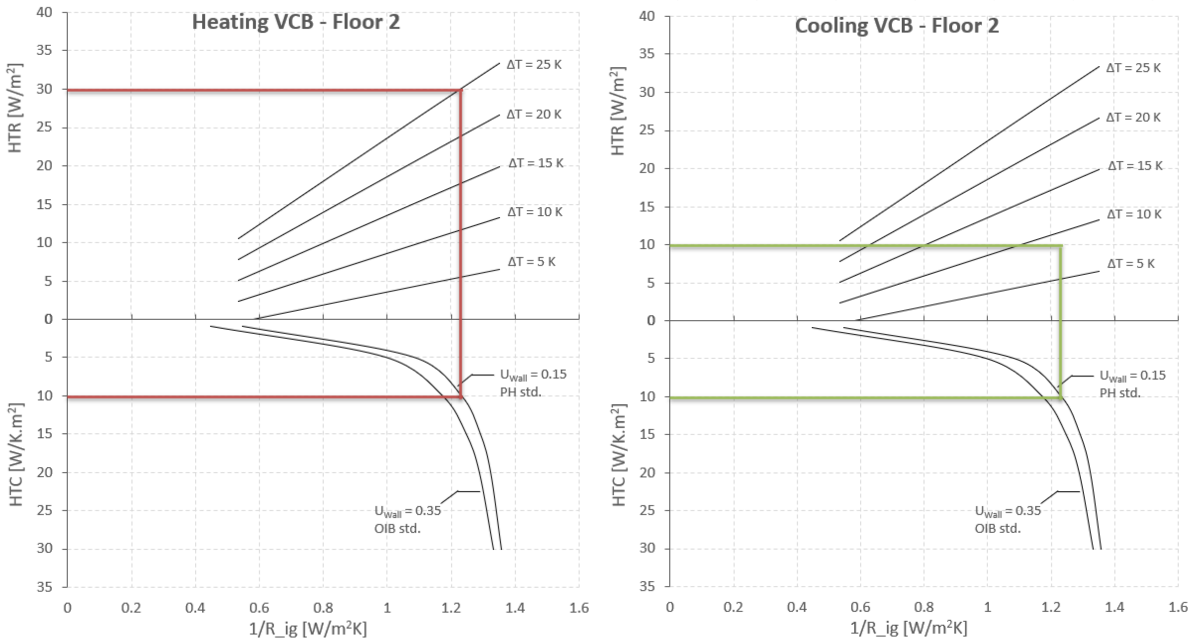

Figure 4-15: Design diagram for active wall façade elements with vertical coring brick (VCB) for heating (left) and cooling (right) of the demonstrator at 2nd floor. Source: [37]

4.6.3.4 Distribution losses of the hydronic system

The distribution energy losses of the system are set to a "good" value called in IDA ICE. That means for DHW, heating and cooling a fixed value of 0.212 W/(m²) based on the floor area is used. This can be justified since the installation of the pipes and devices are new and well insulated.

4.6.4 Electricity Model Description

4.6.4.1 Hydro power plant

For the hydropower plant an operation duration of 8662 h/year with an electrical power 140 kW_p is assumed as it is stated in chapter 0. The total electric energy production is calculated with 1 212 680 kWh/a.

4.6.4.2 BiPV

To achieve the goal of a PEB a building integrated photovoltaic (BiPV) system is implemented in the simulation model. One – BiPV2 – is oriented approx. in south direction (161.1°) and the other one – BiPV1 – approx. to the west (251.1°). BiPV2 is partially shaded due to other building at the site and due to the projection of the stairway. The other one - BiPV1 - does not have major limitations due to shadings (cf.). Table 4-13 shows details about the BiPV with its orientation, numbers of modules, electric power and efficiencies.

Table 4-13: Orientation and configuration of the BiPV. Source: AEE

Name	Orient-ation	Number of modules	Panel Size in m²	Tot area in m²	Panel peak power in W	Panel efficiency in %	Inverter efficiency in %	Total PV system efficiency in %
BiPV1	West (251.1°)	230	1.421	326.83	240	16.9	98	16.6
BiPV2	South (161.1°)	136		193.26				

4.6.4.3 General

For the electric consumption of the controller 5 W per device is assumed for 8760 h, whereby there is a controller for heat pump, pumps in total, ventilation system, DHW storage, heat storage and cold storage. On the supply system, there is a controller for zone heating and zone cooling as well as for DHW preparation. This yields to 9 controllers and a total electric energy demand over a year of 394.2 kWh/a.

4.7 Analysis and Results

4.7.1 Definition of KPIs

4.7.1.1 Electricity (self-) consumption

The electricity consumption $W_{el,cons}$ is calculated for all devices, ventilation$W_{el,vent}$, pumps $W_{el,pu}$, controllers $W_{el,ctr}$, heat pump $W_{el,hp}$ that is used for both heating and cooling purposes, and electricity for lighting $W_{el,light}$ and appliances $W_{el,appl}$ and is defined in the equation 4-1.

$$W_{el,cons} = \int_{t=0}^{8760} \left(P_{el,vent} + P_{el,pu} + P_{el,hp} + P_{el,ctr} + P_{el,light} + P_{el,appl}\right) \cdot dt \qquad 4\text{-}1$$

4.7.1.2 Electricity production

To reach our goals for a positive energy building (PEB) the production of electricity has to be higher than the total consumption. As for the Austrian demonstrator two sources are installed to generate electricity, the building integrated photovoltaic (BiPV) $W_{el,BiPV}$ and the hydro power plant (hydro) $W_{el,hydro}$. The production is defined in 4-2.

$$W_{el,prods} = \int_{t=0}^{8760} \left(P_{el,BiPV} + P_{el,hydro}\right) \cdot dt \qquad 4\text{-}2$$

4.7.1.3 Space heating energy demand

The total space heating energy demand of the pilot $Q_{th,pilot}$ is calculated as the energy provided to every zone/room $Q_{th,room,i}$ also including the café and the office, the heat losses due to distribution $\dot{Q}_{th,dist,loss}$ and those from the heat storage $\dot{Q}_{th,store,loss}$. Another condition is that the calculation is done during the heating season which is between January to End of April (0 h to 2880 h a year) and from Beginning of October to End of December (6552 h to 8760 h of the year). With rooms also corridors and sanitary rooms (bath/WC) included. Equations 4-3 to 4-5 show the calculation respectively, and equation 4-6 shows the specific energy demand of the demonstrator based on the floor area.

$$Q_{sh,pilot,1} = \int_{t=0}^{2880} \left(\left(\sum_{i=1}^{n=43} \dot{Q}_{sh,room,i} \right) + \dot{Q}_{sh,dist,loss} + \dot{Q}_{sh,store,loss} \right) \cdot dt \qquad 4\text{-}3$$

$$Q_{sh,pilot,2} = \int_{t=6552}^{8760} \left(\left(\sum_{i=1}^{n=43} \dot{Q}_{sh,room,i} \right) + \dot{Q}_{sh,dist,loss} + \dot{Q}_{sh,store,loss} \right) \cdot dt \qquad 4\text{-}4$$

$$Q_{sh,pilot} = Q_{sh,pilot,1} + Q_{sh,pilot,2} \qquad 4\text{-}5$$

$$q_{sh,pilot} = \frac{Q_{sh,pilot}}{A_{pilot}} \qquad 4\text{-}6$$

4.7.1.4 Space cooling energy demand

A similar calculation is set up for the space cooling demand with the difference being that it is not applied in the heating season but between 2881 h and 6551 h. So, the total space cooling demand is calculated with equation 4-7 and the specific demand in equation 4-8.

$$Q_{sc,pilot} = \int_{t=2881}^{6551} \left(\left(\sum_{i=1}^{n=43} \dot{Q}_{sc,room,i} \right) + \dot{Q}_{sc,dist,loss} + \dot{Q}_{sc,store,loss} \right) \cdot dt \qquad 4\text{-}7$$

$$q_{sc,pilot} = \frac{Q_{sc,pilot}}{A_{pilot}} \qquad 4\text{-}8$$

4.7.1.5 DHW energy demand

The total DHW energy demand is calculated using the load profile and the distribution loss over the whole year and is shown in equation 4-9.

$$Q_{dhw,pilot} = \int_{t=0}^{8760} \left(\left(\dot{Q}_{dhw,profile} \right) + \dot{Q}_{dhw,dist,loss} + \dot{Q}_{dhw,store,loss} \right) \cdot dt \qquad 4\text{-}9$$

4.7.1.6 Comfort-criteria

To meet the comfort criteria the room temperature (without corridors) must not undercut a temperature of 20 °C in the heating season and for DHW preparation the outlet temperature at the DHW storage must not undercut 45 °C to ensure a temperature level at the end of the pipe (tapping temperature of about 38 °C). If the comfort criteria cannot be satisfied the simulation is excluded and has to be reconfigured with a proper setup.

4.7.2 Heating and cooling load

Firstly, before we are analyzing the energy demands of the building and whether we reach our goal to have PEB the design heat and cooling load of the building is shown in Figure 4-16. Herein the design loads are split in every floor of the building, whereas the highest loads are caused by the café followed by the office. This can be explained with the high share of windows as well as the higher volume flow rates to ensure good indoor air quality. However, for the residential rooms the thermal design loads are between 1.7 kW to 2.1 kW for heating and 2.2 kW to 2.4 kW for cooling. The total design heat load for the demonstration is 28 kW and the design cooling load is about 30 KW, respectively. These values are used to design the prefabricated active layer facades in chapter 4.6.3.3, which is used to transfer heat to the thermal zones.

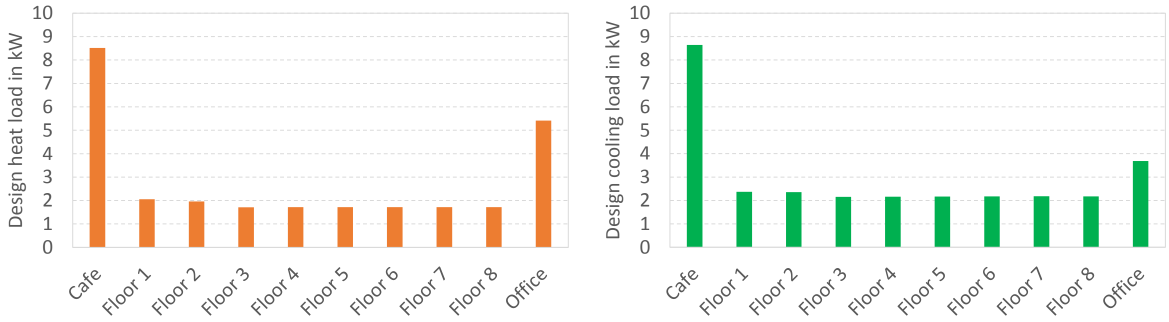

Figure 4-16: Design heat load (left) and cooling load (right) shared for each floor. Source: AEE

4.7.2.1 Heating, cooling and DHW demand

With the attached prefabricated active façade element and the described hydronic system this chapter discusses the heating and cooling demand based on the definition of the KPIs. As also mentioned above the modelled net floor area is 1161.04 m² which is used to calculate the specific values.

Table 4-14 shows the results for heating, cooling and DHW delivered energy over a year for the demonstrator. As one can see the delivered heating energy is lower compared to the delivered cooling energy which leads to the conclusion that the inner loads and the solar radiation into the rooms are dominant. Herein a proper shading strategy has to be set to avoid high cooling energy demand. The high value of 23.73 kWh/m² for the DHW consumption can be justified by the high number of people (e.g. students) in less living space as in the standard SIA2024 (2015) assumed.

Table 4-14: Results for heating, cooling and DHW energy demand over a year for the demonstrator. Source: AEE

$Q_{sh,pilot}$ in kWh	$q_{sh,pilot}$ in kWh/m²	$Q_{sc,pilot}$ in kWh	$q_{sc,pilot}$ in kWh/m²	$Q_{dhw,pilot}$ in kWh	$q_{dhw,pilot}$ in kWh/m²
23 738.7	20.45	39 219	33.78	27 549	23.73

Figure 4-17 shows the minimum and maximum temperatures of all rooms reached during simulation in the heating season. The setpoint of 22 °C for the rooms and 24 °C for bath/WC can be reached very well and no temperatures undercut the comfort criteria of 20 °C. For the corridor just 18 °C is desired. The maximum temperatures reach approx. 32 °C for some rooms in the heating season, but with the restriction that cooling is only activated above a 24 hour mean ambient temperature of 12 °C (only rare occurrence). To avoid overheating window opening during heating season could help.

Figure 4-18 shows the minimum and maximum temperatures during cooling phase. In this diagram only the maximum temperature of each room is important, but as one can see the maximum temperatures in almost all rooms exceeds 27 °C. This can be explained with the cooling power of the active façade elements not being enough to avoid such high temperatures. As one can see for the wall construction ferro-concrete the heat transfer is higher and yields to lower maximum room temperatures. For the vertical coring brick, the maximum room temperatures exceed even 30 °C. In this case an additional cooling device is necessary or the inner loads as well as the solar gains have to be reduced.

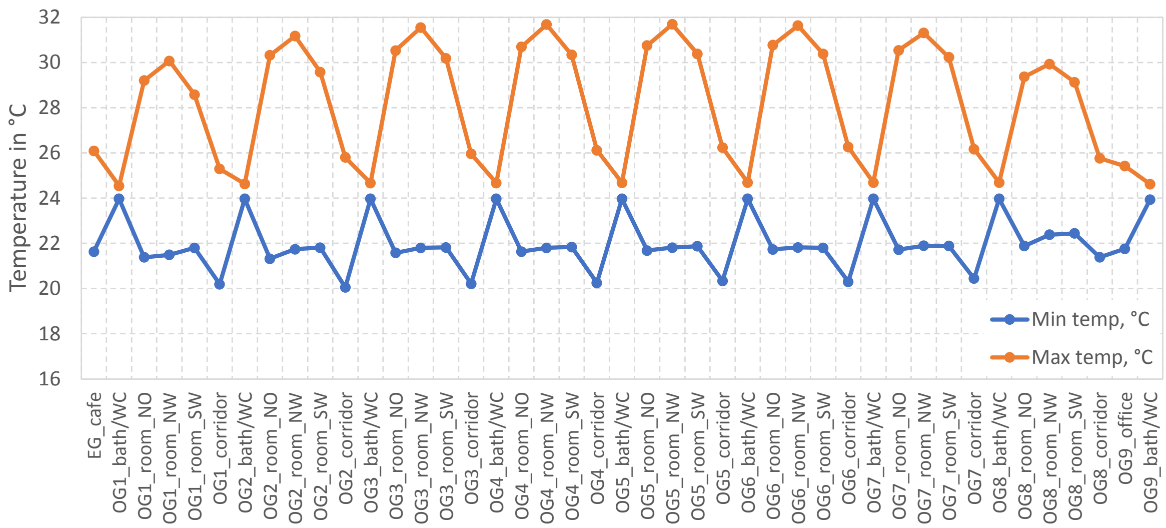

Figure 4-17: Min. and max temperatures of each room in the demonstrator in the heating season. Source: AEE

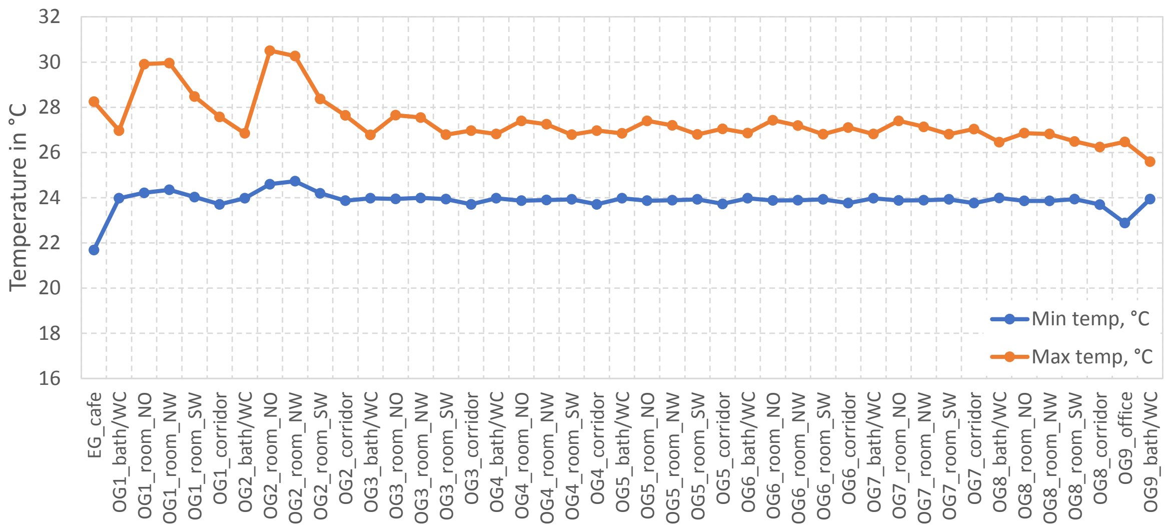

Figure 4-18: Min. and max temperatures of each room in the demonstrator outside the heating season. Source: AEE

4.7.2.2 Production and consumption of electricity

To reach the PEB status the electricity is important for the assessment. So, in Table 4-15 the electric energy consumption of all devices in the demonstrator is shown. The heat pump consumes the highest share of energy with about 47 MWh as it is responsible for heating and cooling, followed by the appliances, the ventilation and pumps and the artificial light in the demonstrator. The energy consumption of the controllers is just a very small part of the energy share.

Table 4-15: Results for electric energy consumption for the demonstrator. Source: AEE

$W_{el,vent}$+$W_{el,pu}$ in kWh	$W_{el,hp}$ in kWh	$W_{el,ctr}$ in kWh	$W_{el,light}$ in kWh	$W_{el,appl}$ in kWh	$W_{el,cons}$ in kWh
7 837.7	47 045	394.2	4 779.8	12 680.7	72 737.4

The energy consumption for ventilation and pumps, artificial light and appliance match very well with the standard SIA2024 (2015), where specific values of 6.64 kWh/m², 4.05 kWh/m² and 10.75 kWh/m² (cf. Table 4-16), respectively are in the range (compared chapter 4.6.2). In total an electric energy consumption of 72 737.4 kWh or 61.66 kWh/m² is calculated for the whole demonstrator.

Table 4-16: Results for specific electric energy consumption based on total net floor area for the demonstrator. Source: AEE

$w_{el,vent}$ + $w_{el,pu}$ in kWh/m²	$w_{el,hp}$ in kWh/m²	$w_{el,ctr}$ in kWh/m²	$w_{el,light}$ in kWh/m²	$w_{el,appl}$ in kWh/m²	$w_{el,cons}$ in kWh/m²
6.64	39.88	0.34	4.05	10.75	61.66

In contrast, the electricity production of the BiPV is about 62 MWh or 53.35 kWh/m² which adds to the hydropower plants generation.

Table 4-17: Results for absolute and specific electric energy production based on total net floor area for the demonstrator. Source: AEE

$W_{el,BiPV}$ in kWh	$W_{el,hydro}$ in kWh	$w_{el,BiPV}$ in kWh/m²	$w_{el,hydro}$ in kWh/m²	$W_{el,prod}$ in kWh	$w_{el,prod}$ in kWh/m²
61 996.97	1 212 680	53.35	1 043.61	1 274 677	1 096.97

Figure 4-19 shows the electric energy gains from the BiPV described in the electricity model chapter on a monthly basis. Interestingly, the south-oriented BiPV does not produce as much electric energy as the west-oriented one over the moths and in total. This can be explained as there is less area facing to the south and also the site shadings. The none optimal slope of the sun due to building integration in the vertical façade also effects the south facing PV panels more than the west facing ones. A good choice is to implement a PV on the building facing to the west as incidence angle is approximately normal to the BiPV and maximizes the gains in the summer. However, from summer to winter the gradient of the electric energy gains is higher for the BiPV facing west since the slope of the sun does not reaches the height in the afternoon compared to the summer months.

The hydropower plant produces a total amount of energy of about 1 213 MWh per year with the assumptions made in the model description chapter. As the hydropower plant is not just only for the building 10 it is just mentioned here but not considered to reach PEB status.

The aim is to yield PEB with only the BiPV which is directly integrated to the investigated building as it is shown in Figure 4-9 (System 1).

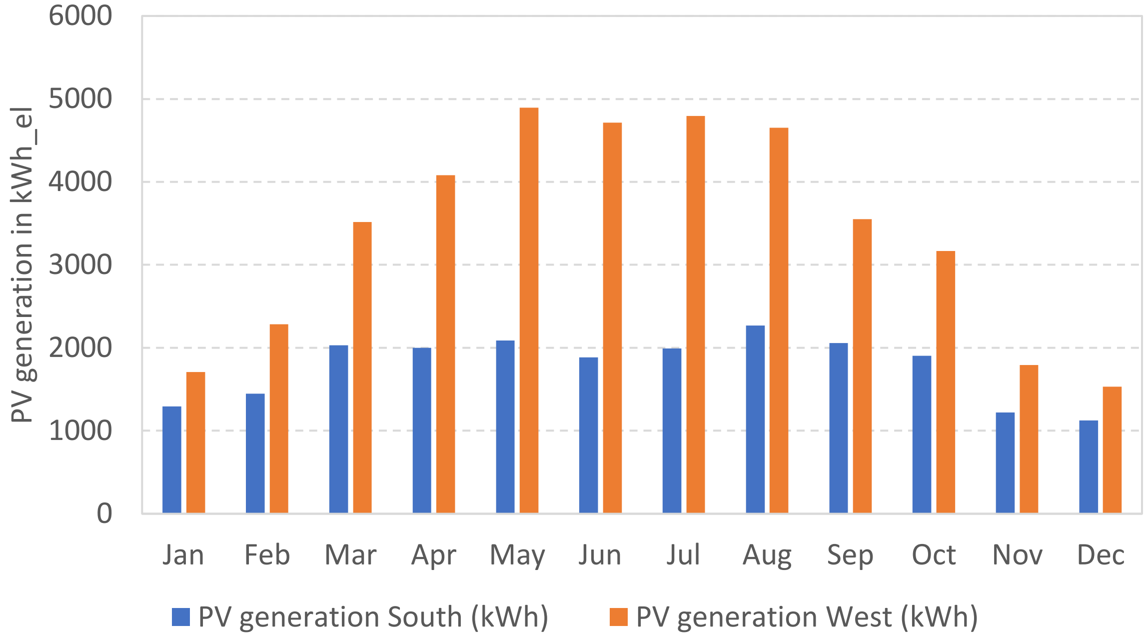

Figure 4-19: BiPV production attached to the south and west wall of the demonstrator on a monthly basis. Source: AEE

4.7.3 PEB goal

Table 4-18 and Table 4-19 give an overview of the consumed and produced electricity to assess whether the goal of PEB is reached or not. With the results and assumptions discussed above the status of PEB – no hydropower plant is considered – cannot be reached as the electric energy consumption is about 8.3 MWh higher compared to the electric energy production for system 1. To get the status PEB the consumption has to be reduced and this mainly in the case of cooling energy. However, an optimized scenario has been worked out and is discussed in the following section.

Table 4-18: Summary of electric energy consumption to assess PEB. Source: AEE

Electrical Consumption Building	**kWh_{el}/m^2**
Water/water heat pump	39.88
Controllers	0.34
FAN(s)+Pump(s)	6.64
Artificial Lighting	4.05
Equipment	10.75
TOTAL	**61.66**

Table 4-19: Summary of electric energy production to assess PEB. Source: AEE

Electrical Generation BIPV	**value**
Façade integrated photovoltaic system in kWh_{el}/m^2	**53.35**
Hydro power plant in kWh_{el}/m^2	left out

4.7.3.1 Control strategy optimization for PEB goal

Table 4-22 shows the results for heating, cooling and DHW delivered energy over a year of the optimized scenario for the demonstrator. Compared to the former simulations the setpoints for DHW, heating and cooling purposes were set in a way that the temperature difference at the heat pump (evaporation and condensation) is minimized. The new storage temperature setpoints for the optimized scenario are shown in Table 4-20. On the supply heating side, the setpoint was linearly decreased from 40 °C to 30 °C at an ambient temperature from -30 °C to +20 °C, respectively. Table 4-21 shows the changes for the shading devices that are set in a way to close at a lower solar radiation on the outer surface.

Table 4-20: Controller definition for the hydronic system with their set points and strategies. Source: AEE

No.	Controller name	"OFF"[13] set point in °C	"ON"[14] set point in °C	additional conditions	comments
1	DHW	48	44	Priority	source side of tank
2	SH	42	38	Only active as $\bar{\vartheta}_{amb,24h}$<12 °C and DHW off	source side of tank
3	SC	10	14	Only active as $\bar{\vartheta}_{amb,24h}$ ≥12 °C and DHW off	Inverse strategy since cooling purposes; source side of tanks

Table 4-21: Definition of basic control strategy for 1st to 9th floor (including office). Source: AEE

No.	Variable	Setpoint	Upper deadband	Lower deadband	Other conditions
1	Shading window	70 W/m2	0	0	Shading is drawn over 70 W/m² on the outer surface and opened again below 70 W/m²

Table 4-22 displays the updated results with the new control strategies. The energy provided for the space heating is similar to the results beforehand while still fulfilling the comfort criteria. On the other hand, the space cooling energy decreases due to the new control strategy for the shading devices, and the DHW consumption decreases due to lower temperature differences as well, but remains high with 22.4 kWh/m² due to the high numbers of tenants in the building.

[13] „OFF" set point means that if the temperature exceeds the set point temperature the controller switches to off or "0" or depends on other controller's "OFF" set points for heating purposes (inverse for cooling)

[14] „ON" set point means that if the temperature undercuts the set point temperature the controller switches to on or "1" or depends on other controller's "OFF" set points for heating purposes (inverse for cooling)

Table 4-22: Results for heating, cooling and DHW energy demand of the optimized scenario over a year for the demonstrator. Source: AEE

$Q_{sh,pilot}$ in kWh	$q_{sh,pilot}$ in kWh/m²	$Q_{sc,pilot}$ in kWh	$q_{sc,pilot}$ in kWh/m²	$Q_{dhw,pilot}$ in kWh	$q_{dhw,pilot}$ in kWh/m²
24 653	21.1	38 166	32,9	26 019	22.4

For the DHW preparation the storage temperature at the top of the store does not undercut 47 °C where the outlet to the tapping is located and hence fulfil the comfort criteria. For the room temperatures, Figure 4-20 and Figure 4-21 show similar results to the non-optimized scenario and additionally it also fulfills the comfort criteria.

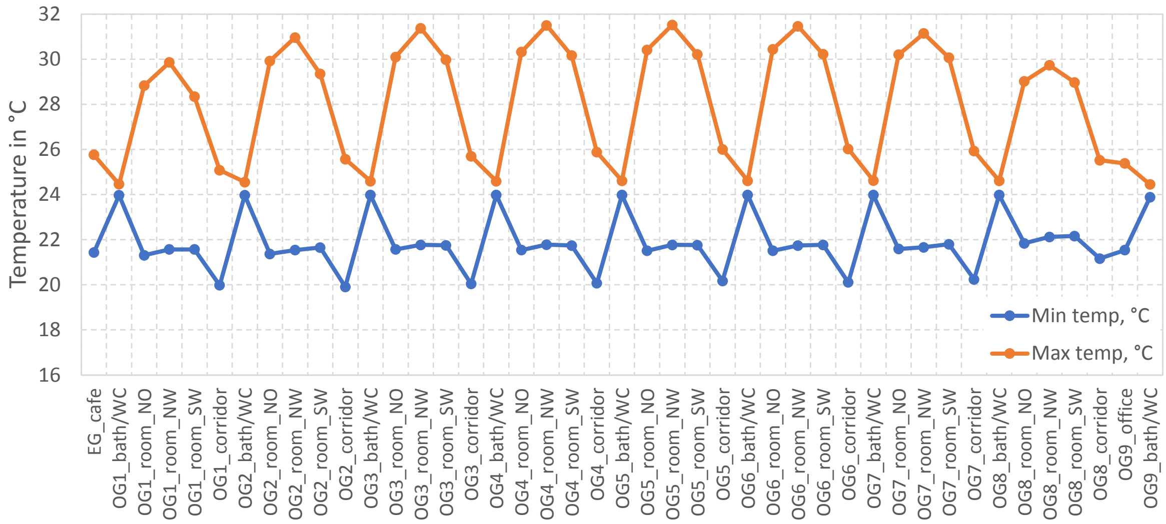

Figure 4-20: Min. and max temperatures of each room in the demonstrator in the heating season of the optimized scenario. Source: AEE

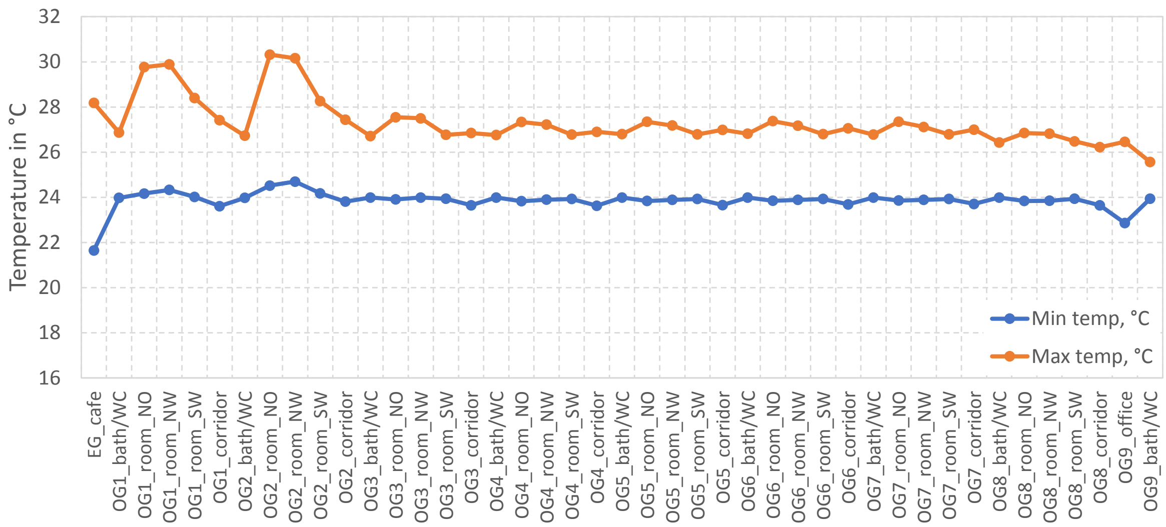

Figure 4-21: Min. and max temperatures of each room in the demonstrator outside the heating season season of the optimized scenario. Source: AEE

The updated electricity results, for the optimized scenario, are shown in Table 4-23 for energy consumption and in Table 4-24 for their specific values. The energy production or gains are still the same as in the former scenario.

However, the impact by changing the setpoint is quite high as the heat pump can work with higher COPs and hence use less electricity. So, the runtime can also be reduced to produce less heat losses of the distribution system including the storage tanks. The result shows minor savings for pumps and ventilation system but very high savings of the electricity coming from the plant system with the heat pump for heating and cooling. It can be concluded that a lower temperature difference between the evaporation and condensation temperature has a huge impact to the electricity consumption of the system. But it should keep in mind that always the comfort criteria have to be fulfilled that is done in this case as discussed above.

Table 4-23: Results for electric energy consumption of the optimized scenario for the demonstrator. Source: AEE

$W_{el,vent}$+$W_{el,pu}$ in kWh	$W_{el,hp}$ in kWh	$W_{el,ctr}$ in kWh	$W_{el,light}$ in kWh	$W_{el,appl}$ in kWh	$W_{el,cons}$ in kWh
7 232	29 404	394.2	4 887	12 084	54 002

The electricity demand for light and appliance remains approximately the same compared to the non-optimized case. The total electric energy consumption is calculated with approx. 54 MWh or 46.5 kWh/m² for the optimized scenario.

Table 4-24: Results for specific electric energy consumption based on total net floor area of the optimized scenario for the demonstrator. Source: AEE

$w_{el,vent}$ + $w_{el,pu}$ in kWh/m²	$w_{el,hp}$ in kWh/m²	$w_{el,ctr}$ in kWh/m²	$w_{el,light}$ in kWh/m²	$w_{el,appl}$ in kWh/m²	$w_{el,cons}$ in kWh/m²
6.23	25.33	0.34	4.21	10.41	46.51

Table 4-25 and Table 4-26 gives again an overview of the consumed and produced electricity to assess whether the goal of PEB is reached for the optimized scenario. So, in this case about 6.8 kWhel/m² of surplus of electricity is obtained to fulfill the PEB status. In absolute values the difference is 8 MWh of surplus over a yearly balance.

Table 4-25: Summary of electric energy consumption to assess PEB for optimized scenario. Source: AEE

Electrical Consumption Building	kWh_{el}/m^2
Water/water heat pump	25.33
Controllers	0.34
FAN(s)+Pump(s)	6.23
Artificial Lighting	4.21
Equipment	10.41
TOTAL	**46.51**

Table 4-26: Summary of electric energy production to assess PEB for optimized scenario. Source: AEE

Electrical Generation BIPV	value
Façade integrated photovoltaic system in kWh_{el}/m^2	**53.35**
Hydro power plant in kWh_{el}/m^2	left out

4.8 Conclusions

Within this chapter the simulation results from the Austrian pilot are presented, where a detail description of the demonstrator is shown. With some simplifications, a plant and building simulation was set up in IDA ICE and profiles for the building were taken from literature, e.g. SIA2024 (2015). After the description of the boundaries and building model, the thermal model and the electrical model is discussed (building integrated photovoltaic and hydropower plant). The main part of the hydronic system is the water-to-water heat pump – with a water-well – that provides heat for DHW, space heating, and for space cooling to the building. The latter ones use the innovative prefabricated active façade elements as dissipation system to transfer heat to the corresponding thermal zones. The design of the components was done with a heat load or cooling load calculation in IDA ICE as well as from literature. Firstly, for the simulations, an initial control strategy was set to fulfill the comfort criteria and to reach PEB.

However, the results show that the active façade elements cannot fulfill the cooling requirements since the heat transfer rate for cooling purposes – especially for vertical coring bricks – is too low. To tackle this issue a proper control strategy for the shading devices has to be set, but this is not done within this deliverable and is mentioned in the outlook below.

Differently is it for heating purposes during the heating season, where all comfort criteria can be fulfilled. The analysis shows that the minimum temperature does not undercut 20 °C, even for the vertical coring brick used for the external wall in the first and second floor. As mentioned, the restriction for this construction material is that the heat transfer rate is much lower compared to the ferro-concrete wall. However, the comfort criteria for DHW preparation can be fulfilled very well.

The results are assessed with the defined KPIs and show that with the first set of temperature setpoints the goal of PEB cannot be reached due to high electric energy consumption and too low production of electric energy with the BiPV. The mentioned hydropower plant is left out in this case as the electric energy production can also be provided for the whole area. However, with the optimized scenario the electric energy consumption should be reduced to reach PEB. This was found by decreasing the temperature setpoints for DHW preparation, space heating and space cooling under consideration to fulfil the comfort criteria. The results show that PEB can be reached properly by decreasing the setpoints as the savings of electric energy from the heat pump was sufficient. The savings can be justified since the temperature difference between evaporation and condensation decreases and hence the COP of the heat pump increases.

However, some further research work has to be done like using free-cooling without heat pump operation or simultaneously preparation of DHW while charging the cold buffer storage. Another research issue is to apply a proper control strategy for shading devices to reduce solar gains and hence cooling capacity and demand. But it has to be considered that by closing the shadings the thermal loads increase by switching on the artificial lighting. Concerning the active façade elements, the heat transfer rate has to be increased e.g. by reducing pipe distances or different concepts of the active layer element. However, also using a MPC strategy can be applied to utilize the potential of high thermal masses of the demonstrator.

5 Case Study in Oceanic Climate. Belgium

5.1 Short Description of the Case Study

The demo site (Figure 5-1) in Hasselt (BE), completed in 2018 and built in three phases, consists of social housing facilities and it includes 68 apartments and 22 houses in total. The demonstrator includes 4 residential apartment buildings with 20 dwellings. The residential units are connected to a centralized heating system consisting of different thermal sources (geothermal heat pumps, gas-fired geothermal heat pumps and backup gas-fired boilers), and the thermal energy is distributed through a district heating network. Moreover, a wind turbine and a cogeneration unit currently produce electricity to be consumed locally by the heat pumps.

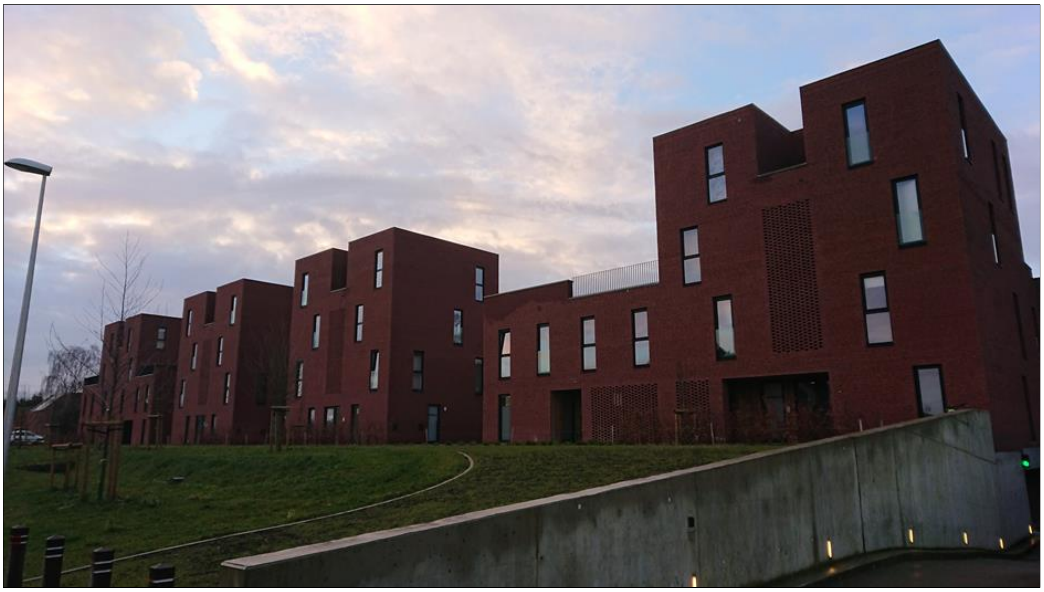

Figure 5-1: The Hasselt demonstrator site. Source: VITO

In each residential unit, a substation is installed to use the local district heating network for space heating and domestic hot water production. In the substation, a thermal energy storage is present, in which domestic hot water is stored, thereby adding an additional source of flexibility to the energy system. Within the framework of the Excess project the energy system will be improved to convert the buildings to positive energy buildings. This will be achieved by integrating the following technologies or features:

- Heating substations providing thermal and electrical flexibility (see deliverable D2.4)
- PVT panels
- Additional electrical ground-source heat pump
- Improved control strategy

5.2 Climate Description

The climate in Belgium can be classified as **temperate maritime** influenced by both the Atlantic Ocean and the North Sea. Regional variations throughout Belgium are small due the small size of the country, although the coastal area experience less pronounced temperature variations throughout the year. In the higher regions of the High Fens, located at an elevation of about 600 to 700m in the East of the country, the temperature is generally 4-5 °C lower compared to the rest of the country.

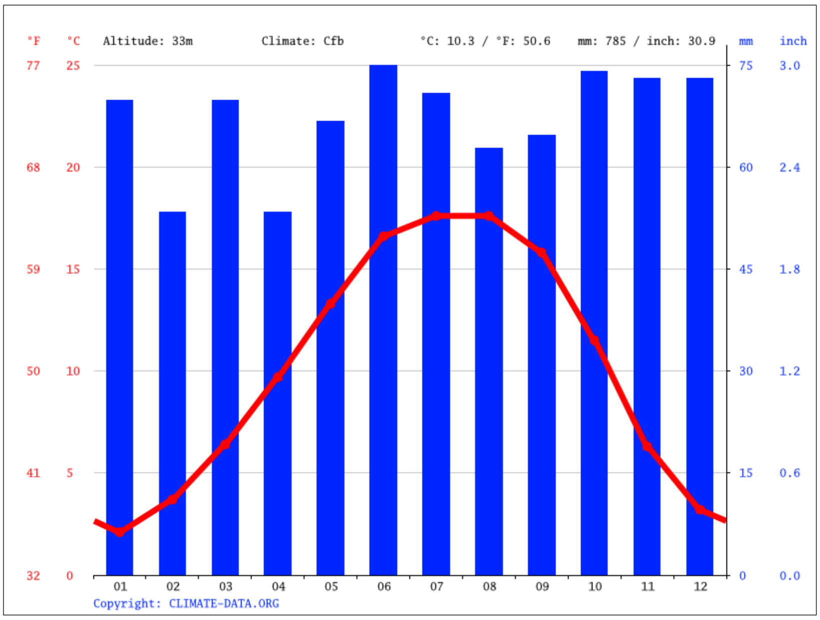

Figure 5-2: Average temperature (red line) and rainfall (blue bar) on a monthly basis for Brussels. Source: VITO

As Belgium is located at the average latitude of the Northern hemisphere, the climate is also influenced by the position of the polar front. This is the position where cold air masses from the Polar Regions meet warmer air of subtropics nature. The position of the polar front is mostly to the North of Belgium in summer, leading in general to nice weather, while in winter it is positioned to the South, resulting in cold and wet conditions. Especially in fall and winter, string Atlantic low-pressure systems can lead to gales and uncomfortable, breezy weather.

The temperate conditions lead in general to cool and humid summers; and relatively mild and rainy winters. Rain is distributed throughout the year, with a small decrease between April and September. Heat waves have become more prominent during the last years.

Solar irradiation follows a typical seasonal pattern between a minimum value of 20-30 kWh/m² in December/January to 160-190 kWh/m² in June/July.

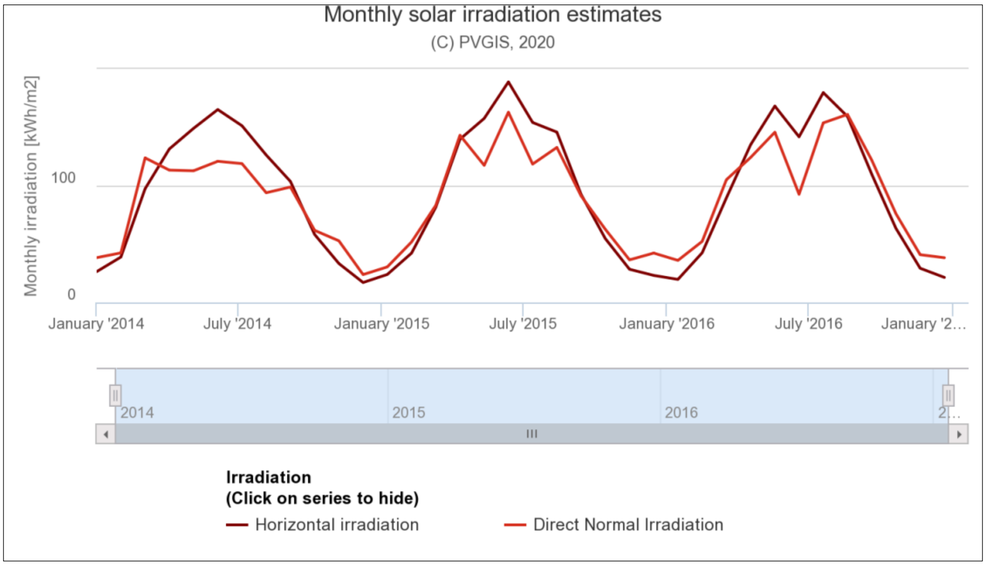

Figure 5-3: Solar irradiation profile for Uccle, Belgium, on a monthly basis (2014-2016).Source: VITO

5.3 Building Description

The Belgian Excess demo site has 4 buildings with different types of dwellings (see Figure 5-4). The communal basement (see Figure 5-5) covers all 4 buildings and also includes the energy generation system. Each tenant has a storage space and car parking space. An overview of the characteristics of the apartments is given in the table below (Table 5-1), where KvAxxx stands for apartments and KvGDxxx for the communal parts such as stairways and corridors

Table 5-1: Thermal and building-specific characteristics of the apartments. Source: VITO

Apartment	Thermal loss surface area [m²]	Volume [m³]	Compactness	Overall U-value [W/m²K]
KvA101	261.55	388.73	1.49	0.35
KvA102	118.68	329.59	2.78	0.47
KvA103	118.68	329.59	2.78	0.47
KvA104	261.55	368.73	1.41	0.35
KvA121	219.65	374.98	1.71	0.37
KvA122	219.65	374.98	1.71	0.37
KvGD01	34.64	132.92	3.84	0.64
KvA201	208.47	369.07	1.77	0.39
KvA202	208.47	369.07	1.77	0.39
KvA221	170.62	280.72	1.65	0.37
KvA222	170.62	280.72	1.65	0.37
KvGD02	34.64	113.86	3.29	0.63
KvA301	208.47	369.07	177	0.39
KvA302	208.47	369.07	1.77	0.39
KvA321	170.62	280.72	1.65	0.37
KvA322	170.62	280.72	1.65	0.37
KvGD03	34.64	113.86	3.29	0.63
KvA401	261.55	388.73	1.49	0.35
KvA402	179.01	332.85	1.86	0.39
KvA403	118.68	329.59	2.78	0.49
KvA404	208.91	366.47	1.75	0.39
KvA421	219.65	374.98	1.71	0.38
KvA422	166.56	323.28	1.94	0.39

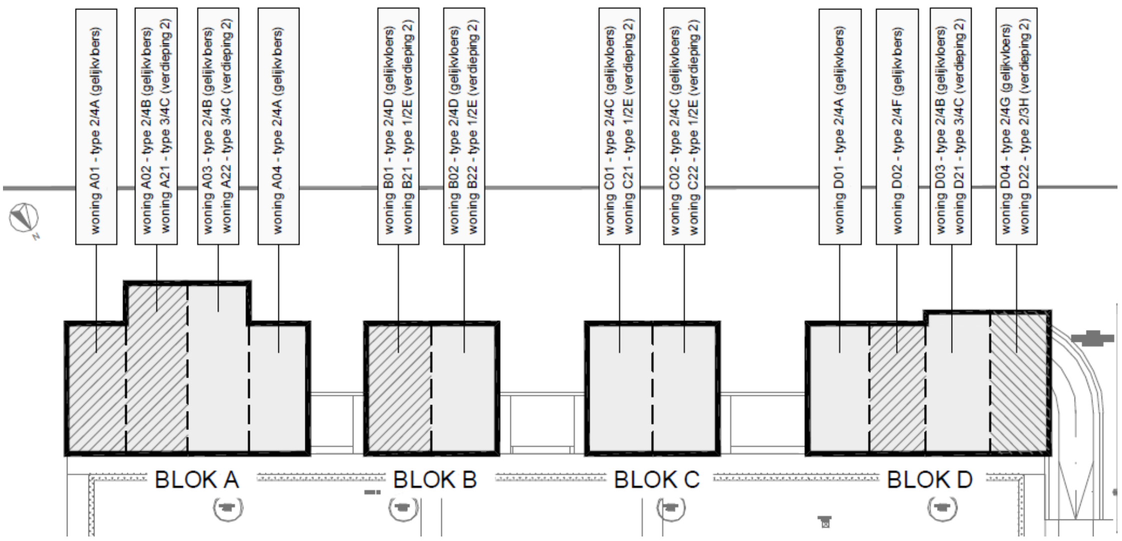

Figure 5-4: Overview of the 4 building blocks and the apartment types. Source: VITO

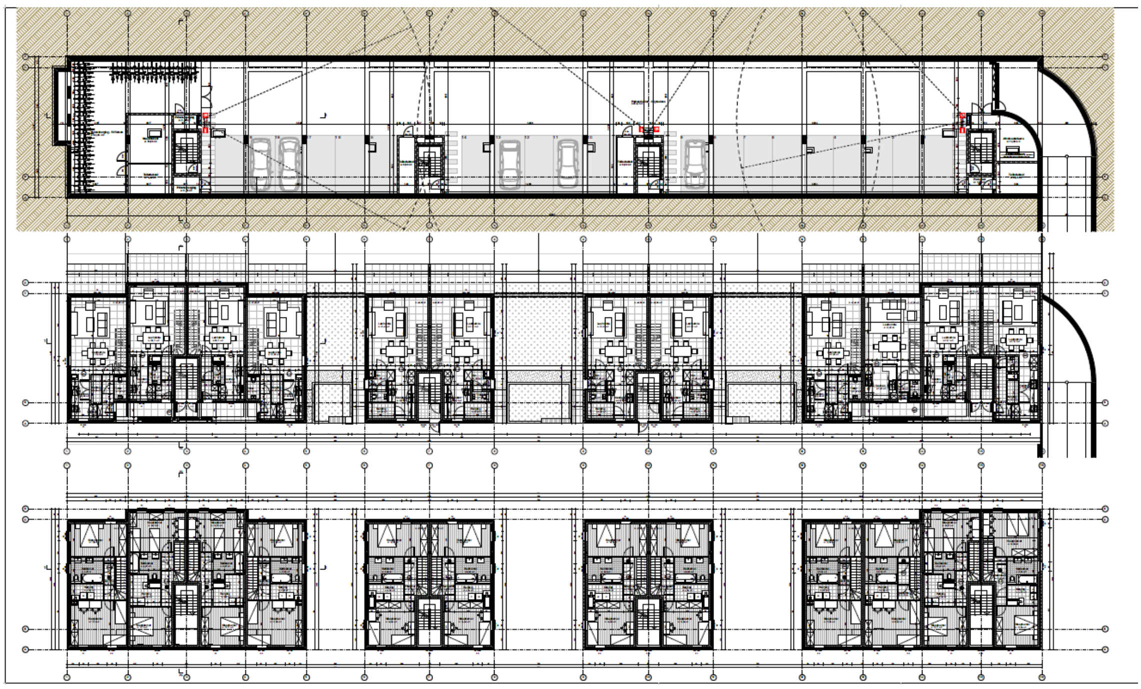

Figure 5-5: Basement and first two floors. Source: VITO

5.4 Thermal Generation Facility Description

Currently the building is heated by a cascade of different heat sources with the following priority:

1. Geothermal electrical heat pump (20 kW_{th})
2. Geothermal gas-fired heat pump (36 kW_{th})
3. Gas-Fired backup and peak boiler (130 kW_{th})

In the context of the EXCESS project, the heating system will be adapted in order to make the buildings Positive Energy Buildings. Therefore, the gas-fired boiler will be replaced by an energy efficient electrical ground-source heat pump (40 kW_{th}). In addition, PVT panels will be installed to generate renewable electricity for the heat pumps and for the production of domestic hot water. The P&ID of the new heating system is given in Figure 5-6.

The heat is distributed to the apartments by a district heating system which currently operates at 65/55°C. This temperature regime can be reduced by boosting the domestic hot water at apartment level. As a result, the heat pumps will operate more efficiently. The district heating system also connects other houses and apartments in the vicinity of the demonstrator. This means that excess heat (e.g. from the PVT panels) can also be used to heat other buildings.

Another important component of the thermal energy system is the substation which is installed in each apartment. Currently, they operate on a rule-based strategy which does not offer any flexibility towards the heat generation side. Within the EXCESS project, VITO will enhance the controllability of these substations in order to increase energy efficiency and the use of local renewable energy production units. This includes activation of the following features:

- Room setpoint temperature control
- Domestic hot water tank temperature control
- Thermal energy source selection for charging boilers (district heating / electrical)

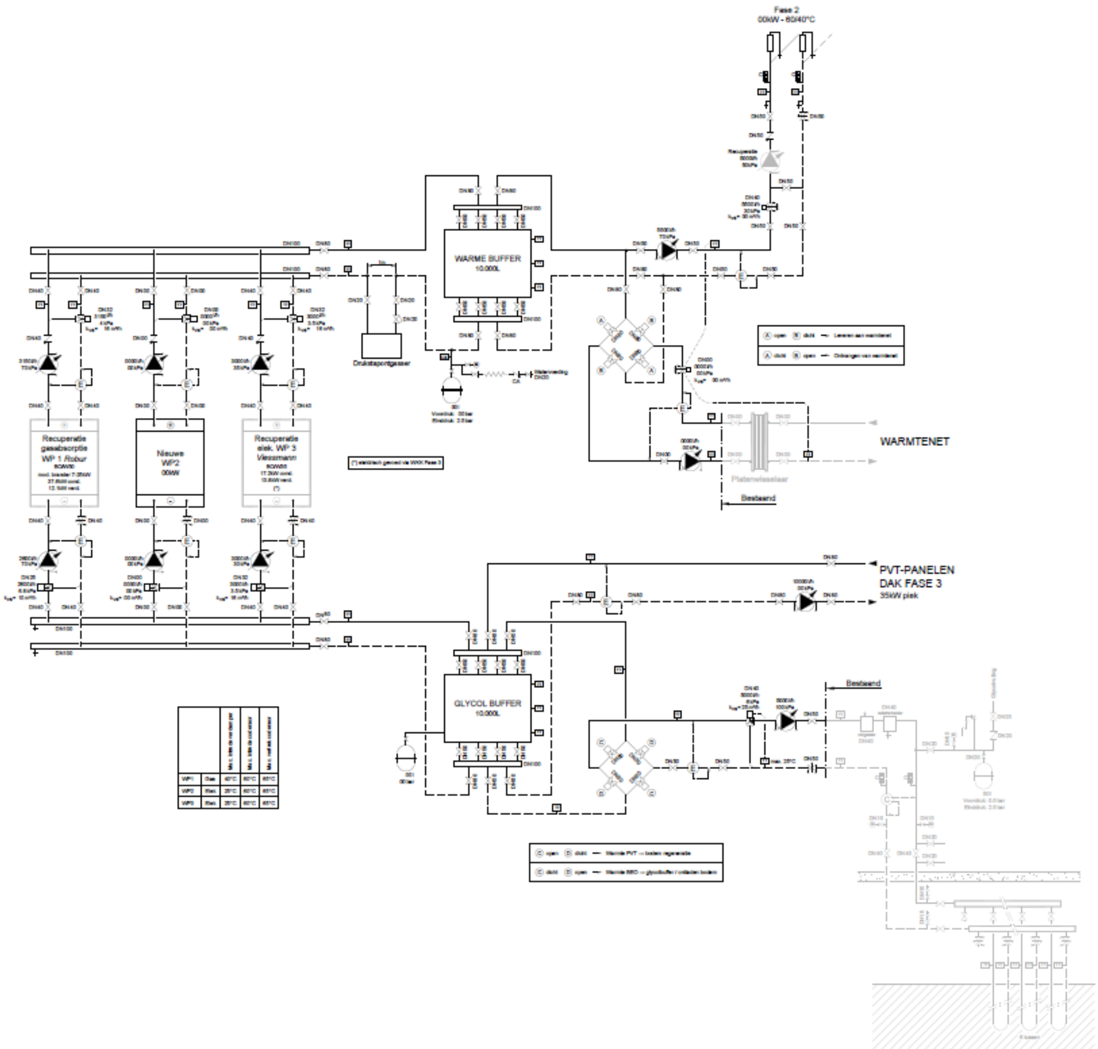

Figure 5-6: P&ID of new heating system. Source: VITO

5.5 Model Description

5.5.1 Building Model Description

Different approaches exist to model and simulate the thermal response of a building as a function of the topology, envelope composition, user behaviour and ambient conditions. The most detailed approach uses so-called white-box models, which contain detailed information on the building in question. The information contained in these kinds of models includes, but is not limited to:

- Definition of multiple thermal zones. These usually correspond one-to-one with the different rooms in the building[15]. The medium contained by the thermal zone is usually defined as air with a modified specific heat capacity to accommodate for the thermal mass of e.g. furniture that is present in the zone. The multiplication factor to correct for this is usually set to 5.
- Definition of the different components to constitute the building envelope. In a more abstract way, it can be stated that each interface between different zones has to be defined. It should be noted that the ambient air and ground also have to be considered as thermal zones from this perspective. This has the consequence that e.g. the front façade of a building has to be divided into different subsections, each of which is in contact with a single thermal zone inside the building. Walls with different orientation have to be integrated as separate entities since the influence of solar irradiance will be different depending on this. Each building envelope component defined in this way, is labelled depending on the type of component (External Wall, Roof, Floor, Internal Wall, etc.). Finally, it is defined between which thermal zones a given envelope component forms the interface.
- Definition of the structure of all the different component types. In this step the different layers that are contained in the building envelope component type are listed, from the outside to the inside of the building. For example, and external wall can be defined as a 7 cm brick layer, 10 cm cavity, 11 cm limestone layer and finally a 1cm plaster layer on the inside of the building.
- Definition of the thermal properties of the different materials that are used in the previous step. For each material, like bricks or limestone, the density, thermal conductivity and specific thermal capacity have to be defined.

Once a building model is created by following the steps above, it can be connected with an energy system. Different approaches exist, depending on the level of detail desired. One can explicitly model a heat pump, including a performance map which depends on modulation, supply and ambient temperature, combined with PID control using measured indoor temperatures, as well as a model of floor heating or radiators. Depending on the size of the building, the inclusion of a detailed energy system can potentially lead to small time constants and thus have a negative impact on the required simulation time. Alternatively, one can opt to include a simplified heating system in which heat is directed to each zone individually purely based on the current temperature. A similar strategy can be applied to the ventilation system, if present in the building. White-box modelling can be done in e.g. MODELICA or TRNSYS.

[15] From a simplicity perspective, aggregation of zones can be considered, especially for smaller zones which are less susceptible to ambient conditions.

A radically different approach is black-box modelling. In this strategy, historic data of a building like measured indoor temperatures and heat delivery, as well as the ambient conditions are used as input in the training phase and used to identify the correlation or transfer function between the measurable input signals (zone temperature and ambient conditions) and the heat demand of the building. In this strategy, the internal working principle of the model is irrelevant and does not correspond to physical phenomena that occur in reality. The training data might be obtained from a real building or data generated using a white-box model.

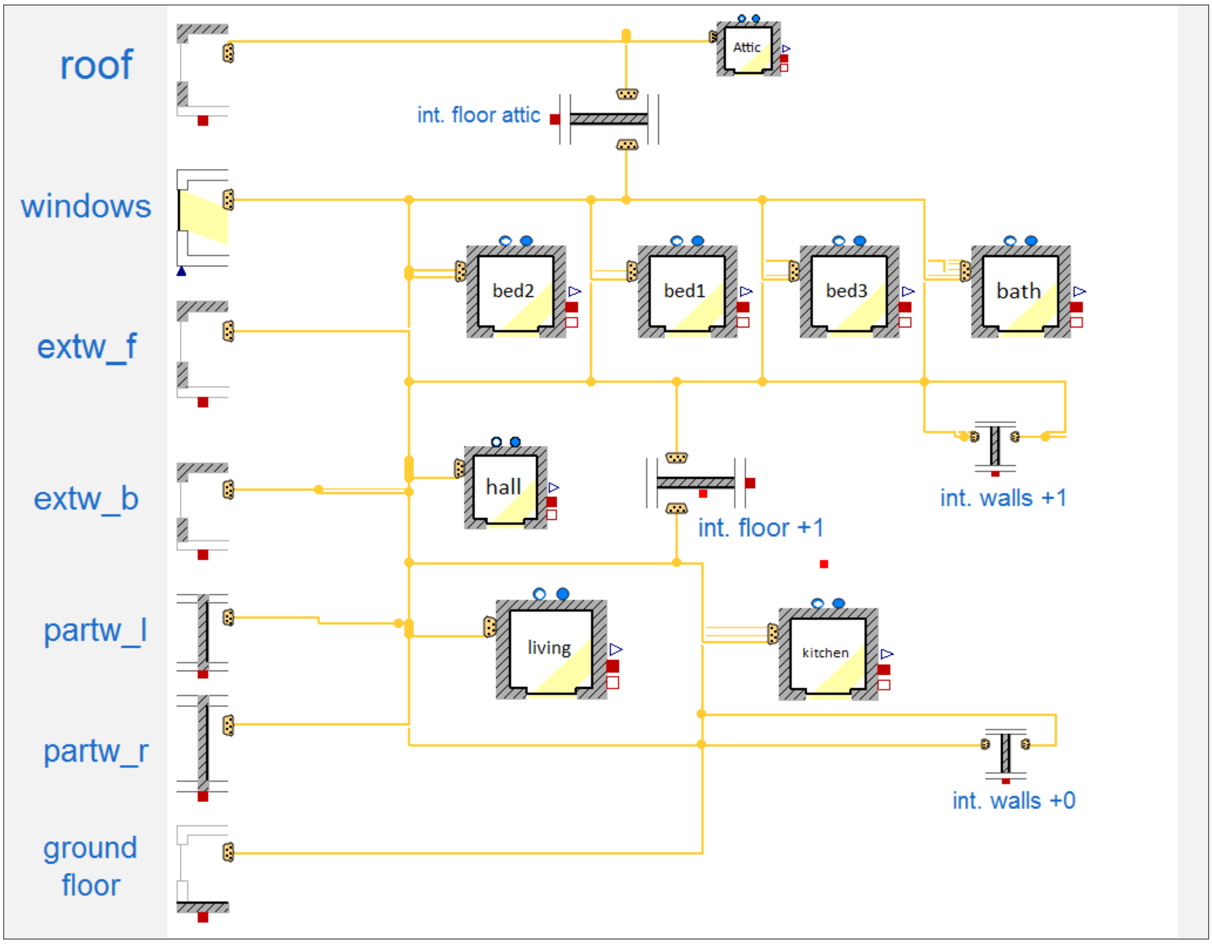

Figure 5-7: Graphical representation of a white-box model for a house containing 8 thermal zones. Implementation was done in Modelica. Source: VITO

The approach that will be followed here falls in between the two methods described above. It is therefore called gray-box modelling. This methodology uses a simplified structure of a building which is presented as an electrical circuit. Depending on the complexity or order of the model, one can identify e.g. the external walls or floor in the circuit. From this perspective it is *whiteish*. On the other hand, the model parameters are fitted or identified based on historical data, either directly available as measured in an existing building, or obtained from a virtual experiment using a white-box model. Hence, the approach also has a *blackish* shade.

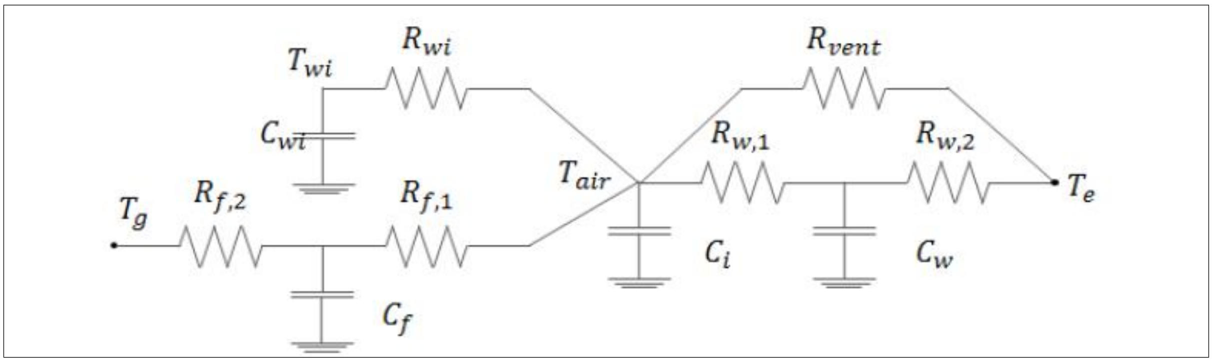

Figure 5-8: Example of a 4th order RC model. See text for details. Source: VITO

An example of a 4th-order gray-box model, also called RC model, is shown in Figure 5-8. In this model framework, voltage levels represent temperatures, while current is an analogue for energy flows. This flow of energy between two given components depends on the voltage (or temperature) difference and the electrical (or thermal) resistance between them. Hence, the resistances in the RC-model will depend on the thermal conductivity of the building envelope components. Using the thermal mass of a building for energy storage can be done using the different capacitors in the RC-model.

The centrally placed Tair, represents the indoor temperature in the building (modelled as a single zone), which is for instance 297.15 V (corresponding to 20 °C expressed in Kelvin units). Towards the lower left, one can find Rf,1, Cf and Rf,2 which lead to Tg. This part of the RC model represents the connection towards the ground via the floor. Tg is the ground temperature and is fixed to the yearly average ambient temperature of 10 °C or 287.15 V in the model. The thermal mass of the floor, which is represented by Cf, is in between Tg and Tair, and is characterised by Tf (the floor temperature, not shown on the figure). Depending on the values of all components involved, current, or thermal fluxes, can be present from the thermal zone towards the floor or opposite. In general, there will always be a flux from the floor through Rf,2 towards the ground which represent thermal losses through the floor. When floor heating is present, application of it will directly impact the magnitude of Tf.

Similar reasoning can be applied to the other components in the model, which are briefly addressed here. The top-left part of the model involves the indoor walls in the building (internal thermal mass). These are not in contact with the ambient nor ground. Any difference in temperature between the indoor air and the walls will lead to flux of energy between them. Ci near the middle bottom depends on the volume of the building and the thermal mass available in the air and furniture placed inside. Finally, the structure to the right models the losses through the external walls and roof towards the ambient, in a similar fashion as the floor is modelled. It should be noted here that Te, the ambient temperature, is not fixed but varies through the year. One additional resistor connecting Tair and Te is present here to model ventilation losses. Note that ventilation losses are immediate and cannot be associated to a thermal mass.

One can simplify the model structure presented in Figure 5-8 by eliminating RC branches. E.g. the internal thermal mass can be omitted and absorbed in Ci, albeit with different time constant. The simplest RC-model includes only Tair, Ci, Re and Te. Hence all thermal mass is included in Ci, while Re models all losses to the ambient. Solar gains are explicitly included in most model structures, although it is not visualised in Figure 5-8.

Within the EXCESS project RC-models will be created and identified for the Belgian case study. As was discussed in the Building description section, the buildings under investigation are multi-family residences, each with individual heat supply and user behaviour. A reduced-order model is desirable for each individual dwelling. However, the 4th-order gray-box model from Figure 5-8 is not suitable in its current form and thus needs to be adapted to accommodate the influence of neighbouring dwellings. This can be done by including a new branch connecting Tair with a newly defined Tneigh (neighbours). This connection can contain either a single resistor or double resistor and capacitor combination like the floor or external walls. Depending on the composition of the internal floors and walls and topology of the building it might be necessary to include two parallel connections between Tair and Tneigh. For simplicity, Tneigh will be set to a constant value. The exact requirements of the new model structures, which will also depends on which floor level the dwelling under investigation is located, will be studied later in the project.

5.5.2 Input data requirements

When applying the gray-box modelling strategy the model parameters, namely the values of the different resistors and capacitors as shown for the example model structure in Figure 5-8 have to be identified. In most cases one has to relay on data measured in an existing building. The following data should be available in order to perform the parameter identification procedure presented in the next section.

- **Indoor temperature data**: The most convenient way is by accessing the (smart) thermostat installed in the apartment. If not available, at least one temperature sensor should be installed in every apartment;
- **Ambient conditions** have been provided in the form of hourly outside temperature data and are used directly as input parameter by the fitting routing;
- **Solar irradiance** is highly recommended to measure on site. The influence on indoor temperature through solar gains in the newly-built environment is non-negligible and its effect is included in the RC-models as mentioned earlier. In case a dwelling's outer walls are oriented mostly away from the sun, the influence of solar gains will be reduced by lowering the related parameter in the model. If no local pyranometer is available to measure solar irradiance, alternative methods can be used to estimate this value. Common methods use either local PV coverage or local cloud fraction which is usually available from local weather stations.
- **Thermal supply** has to be available on apartment level. This allows for identification of the model parameters on this level of granularity.
- **The volume of the thermal zone** should be supplied to set an initial value for the thermal capacity of the dwelling (Ci) and guide the fitting procedure.

The time resolution of the data should be at least at hourly level, although a smaller resolution is favorable. A period of 2 to 3 weeks should be sufficient to provide ample data to identify the model parameters. An additional 1 to 2-week period of measurements is needed for cross validation.

A major issue when using in-situ data is the quality of the data. To allow for accurate model parameter identification it is of great importance to include as much thermal dynamics in the training data set as possible. One of the drawbacks of using measured data is the lack of these dynamics since the indoor climate is governed by a single set-point temperature, sometimes also including a night-time setback. Heat demand is therefore driven mainly by the ambient conditions, which vary slowly. A better approach would be to vary the heat supply, both in magnitude and frequency, and monitor the response in the indoor temperature. However, this is often difficult to achieve, not only from a control perspective but since it also has an impact on the resident's comfort.

5.5.3 Parameter Identification Procedure

As described in Section 5.5.1, the RC-models that are used have a fixed structure. To obtain a model for a specific dwelling, we need to identify the values of the various resistors and capacitors, also referred to as **model parameters**, for the dwelling. This is done in a data-driven way by applying the following procedure in order to identify the model parameters:

1. First historical data has to be collected in order to *identify* the models. The data collected is a time series data containing measurements of indoor temperature, corresponding heat input, outdoor temperature and solar irradiation (see also Section 5.5.2). This is illustrated in the picture below. Note that temperatures are quoted in Kelvin, heat input is specified as W[16].

	indoortemp	heat	outdoortemp	solarirr
time				
2017-01-01 00:00	293.149994	3000	283.750000	0.0001
2017-01-01 00:15	293.428528	3000	283.736725	0.0001
2017-01-01 00:30	293.644135	3000	283.718750	0.0001
2017-01-01 00:45	293.810730	3000	283.691406	0.0001
2017-01-01 01:00	293.938843	3000	283.649994	0.0001

Figure 5-9: Data collected. Source: VITO.

2. The models introduced earlier need to be (time) discretized, in order to use them in a setting required for parameter identification. For this several schemes can be used. The simplest ones could be Euler or Runge Kutta. For instance, application of the Euler scheme to discretize the system of equations for a second order RC model (indoor air capacity and building envelope capacity included) will give us

$$C_i \frac{T_{i,k+1} - T_{i,k}}{\Delta t} = \frac{T_{w,k} - T_{i,k}}{R_{vent}} + (1 - f_{rad})\dot{Q}_{h,k} + g_A\,\dot{Q}_{Sun,k}$$

$$C_w \frac{T_{w,k+1} - T_{w,k}}{\Delta t} = \frac{T_{i,k} - T_{w,k}}{R_{vent}/2} + \frac{T_{e,k} - T_{w,k}}{R_{vent}/2}$$

Where the additional subscripts k and k+1 denote the time steps Δt the time step length. The above set of equations describes what the indoor and wall temperature at the next time step would be, given the current temperatures and inputs ($\dot{Q}_{h,k}, T_{e,k}, \dot{Q}_{Sun,k}$). From this a linear state space system can be distilled which can be expressed as follows:

$$\begin{bmatrix} T_{i,k+1} \\ T_{w,k+1} \end{bmatrix} = A \begin{bmatrix} T_{i,k} \\ T_{w,k} \end{bmatrix} + B \begin{bmatrix} \dot{Q}_{h,k} \\ T_{e,k} \\ \dot{Q}_{Sun,k} \end{bmatrix}$$

Where A and B are matrices with entries explaining the dependencies in the discretized equations. Similarly, the matrices for all other RC-model structures can be constructed.

[16] The unit which is used for heat input is irrelevant. This can be W, kW, kWh during the period, kJ/h, … As long as the same unit is used during the entire process.

3. After the discretised system is obtained, it is possible to impose an optimal control problem for parameter identification as follows. For simplicity again the example for a 2nd order RC model is shown, but the same framework can be replicated easily for other network structures.
4. In this case it is needed to identify C_{Wal}, C_{Zon}, R_{Wal}, g_A
5. Get measurements from T_{Zon}, T_{Amb}, Q_{Rad}, I
6. The Error between measured and estimated indoor temperature is defined as: $$e(t) = T_{Zon,m}(t) - T_{Zon,est}\,(t)$$
7. An initial guess of the parameters is derived from actual physical properties of the building system.
8. Starting from the initial guess, the model parameters are varied to find the best values for the training data set. After convergence, the model parameters for the model structure under investigation are fixed and saved.
9. The procedure moves to the next model structure and the procedure outlined above repeats itself.
10. Once all possible model structures have been fixed, the validation data set is loaded. A new loop over all identified model structures is done, using ambient temperature, solar irradiance and heat demand as input.
11. For all model structures, the evolution of the indoor temperature is simulated based on the input data and compared with the actual evolution.
12. Again, the error is calculated and used to determine the best model structure.

5.5.4 Example

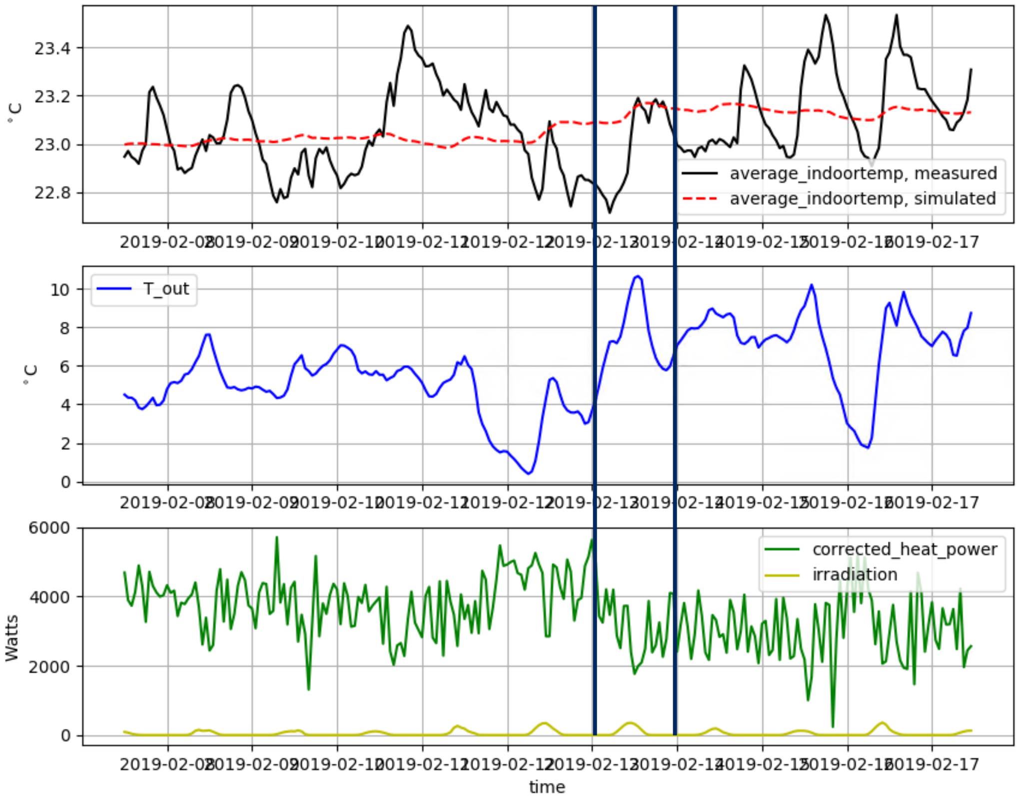

Figure 5-10: Example of a RC-model fitting result for a residential building. Source: VITO

The present section will show some examples from previous projects and associated learnings. A first example comes from a residential building in Sweden. The fitted indoor temperature (top pane, Figure 5-10) does at first sight not look very realistic and does not follow the measured temperature profile variations. It should be noted that the absolute variations in the measured indoor temperature are small. During this 10-day period it ranges between 22.8 °C and 23.4 °C. Additionally, the provided heat shows a rather constant behaviour albeit with rapid oscillations. When considering the thermal inertia of buildings, these rapid oscillations are in general averaged out and rarely visible in the indoor temperature variations. The result of the fitting procedure is therefore expected: the model will reproduce the general trends of the indoor temperature and provide an R value that leads to thermal losses to the ambient which are compensated by the heat delivered by the heat pump. This is for instance particularly evident in the indicated zone where a rapid increase of the indoor temperature can be observed, without any changes in the ambient temperature, heat pump power or solar irradiation. The model is not capable to include these features since they most probably arise from e.g. internal gains. Because of these reasons, sensitivity to the value of C, the thermal mass of the zone, is therefore limited in this case.

Fitting model parameters using this kind of in-use data should therefore be done with care. It is recommended to gather training data which include sufficient data on the thermal dynamics of the building. This can be achieved by using a pseudo-random binary control signal for the heat pump. This control sequence is apparently random despite the fact that it is fact deterministic and includes a wide range of frequencies.

Finally, the importance of solar irradiance is shown in the next example. Here, RC-model identification was done for a building in a setting where no info on solar irradiation was available. The training period spans 15 days, starting at January 1st. No resampling or additional filtering of the data was done. In case of missing data points, a linear interpolation between the last known data points was applied. After the model parameter identification phase, the remainder of the data period (unit January 31st) is used for cross validation.

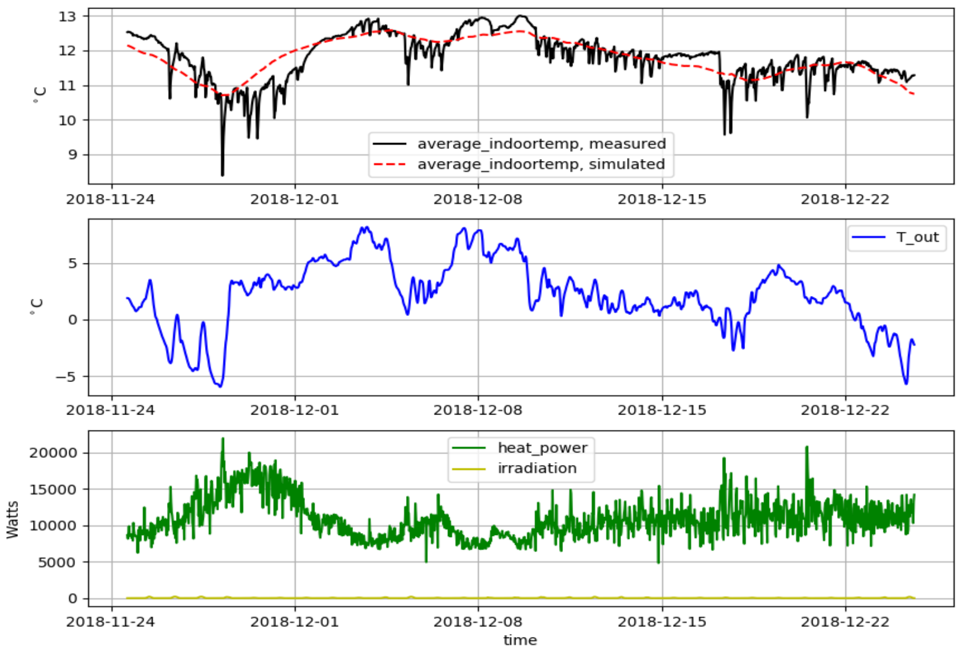

Figure 5-11: Example from fitting a RC model to a warehouse. Source: VITO

In Figure 5-11 the results for a warehouse are shown which exhibit a very distinct temperature profile. In contrast with the previous example, the indoor temperature shows more variations, namely between 8.5 °C and 13 °C. Striking are the rapid temperature swings that are observed. These are most probably caused by opening the doors or gates of the building since they occur in a distinct pattern following weekdays. Weekends show a flatter behaviour. Again, the model shows a good overall reproduction of the indoor temperature apart from the rapid swings. Including the occurrence of this effect in the model, which is independent of external factors like solar irradiation and ambient temperature, is at the present moment not possible. On the other hand, the fitted values for R and C will include these effects in an average way. One should also consider the influence of temperature sensor position. In case the indoor temperature sensor is located near a gate or door which is opened at regular times, the recorded temperatures are not representative for the whole thermal zone.

RMSE values from the fitting procedure for the two examples above are respectively 0.294 and 1.869 °C for the training data set and 0.770 and 1.349 °C during the validation period.

Figure 5-12 and Figure 5-13 below show the best fits for building 1-01 in training and validation mode. It can be seen that the model is capable of reproducing the general trend of the indoor temperature evolution in the building. However, the diurnal variation is lost. It should be noted that during the training, solar gains have been disabled. There are several arguments that indicate the importance of aforementioned solar gains on the thermal behavior of the buildings and hence their role in the reduced-order model identification. In the absence of solar gains, the losses to the ambient are depending on the temperature difference between the inside and the ambient. These differences vary between 20 and 30 °C on a daily basis. The decrease in indoor temperature is therefore expected to be the strongest at night. This is however not the case when examining the data and strong declines are also observed when the ambient temperature peaks. Furthermore, the temporal profile of the indoor temperature matches the ambient conditions remarkably well. Between January 5th and 7th the ambient temperature profile changes from the diurnal pattern and stays constant for 2 days. This indicates cloudier weather and hence no, or at least, less, effective solar gains. The simulated indoor temperature slopes upward in this period. This indicates that the value of R is overestimated in the fitting routine since, in the absence of solar gains, the heat supplied by the heating grid is the only source thermal source for the zone. More heat is supplied than is dissipated through the walls

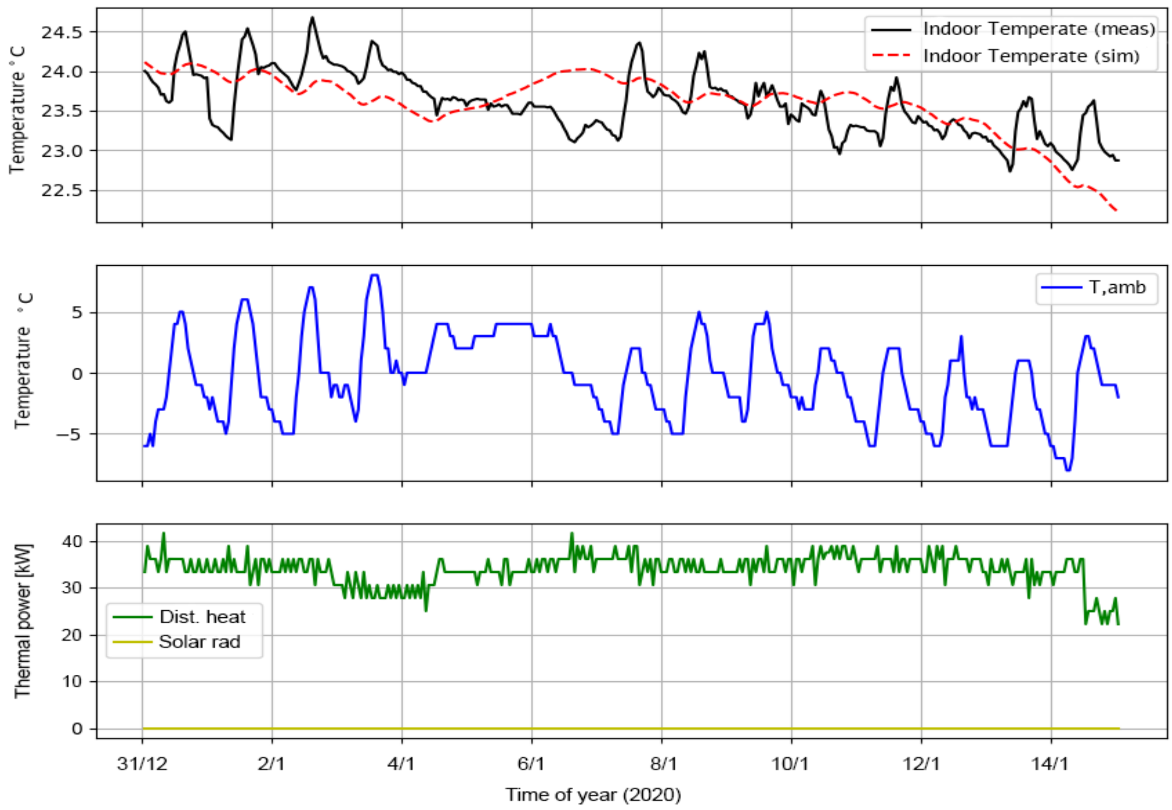

Figure 5-12: Sample building training results. Top: Indoor temperature, middle: Ambient temperature, bottom: heat input and solar irradiance. Source: VITO

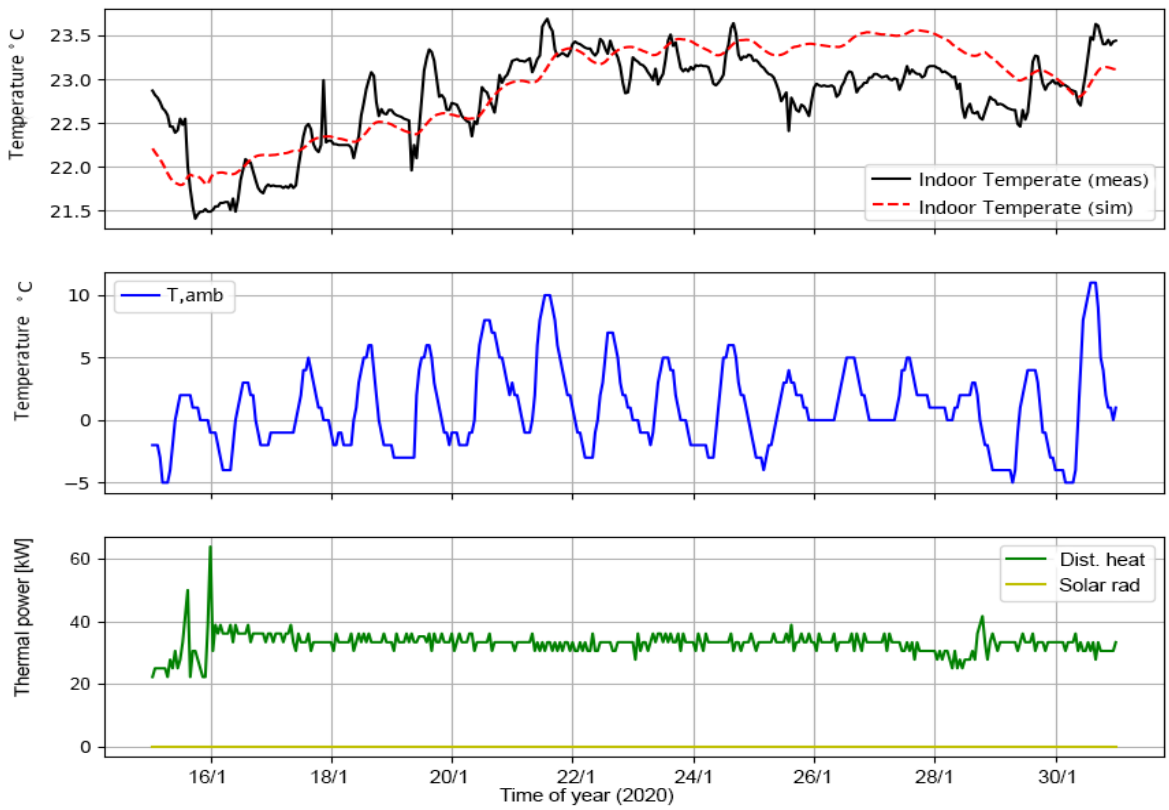

Figure 5-13: Validation period results. Source: VITO

and causes the rise. Also, the opposite reasoning is valid. During the other days, in reality, also heat is due to the solar gains, which influences the indoor temperature. To compensate for this, the fitting routine increases the R value to avoid the rapid losses of this missed source. To validate this assumption, and in the absence of empirical data, fake solar gain profiles were added to the fitting routine. The profiles have a typical Gaussian shape, with amplitude that varies between 250 and 750 W/m2, based on statistical data available for previous years. Only for the period between January 5th and 7th the solar input was set to 0 as discussed before.

The results below show the model performance for 2 different buildings, both for auto and cross validations. Daily variations are better reproduced, when including solar gains, even with random amplitude. RMSE values of 0.2 °C and 0.4 °C are achieved during the training period and validation period respectively. During the validation period a drift in the calculated indoor temperature can be consistently seen (underestimation), potentially due to accumulated errors in the mismatch between the provided and effective solar radiation.

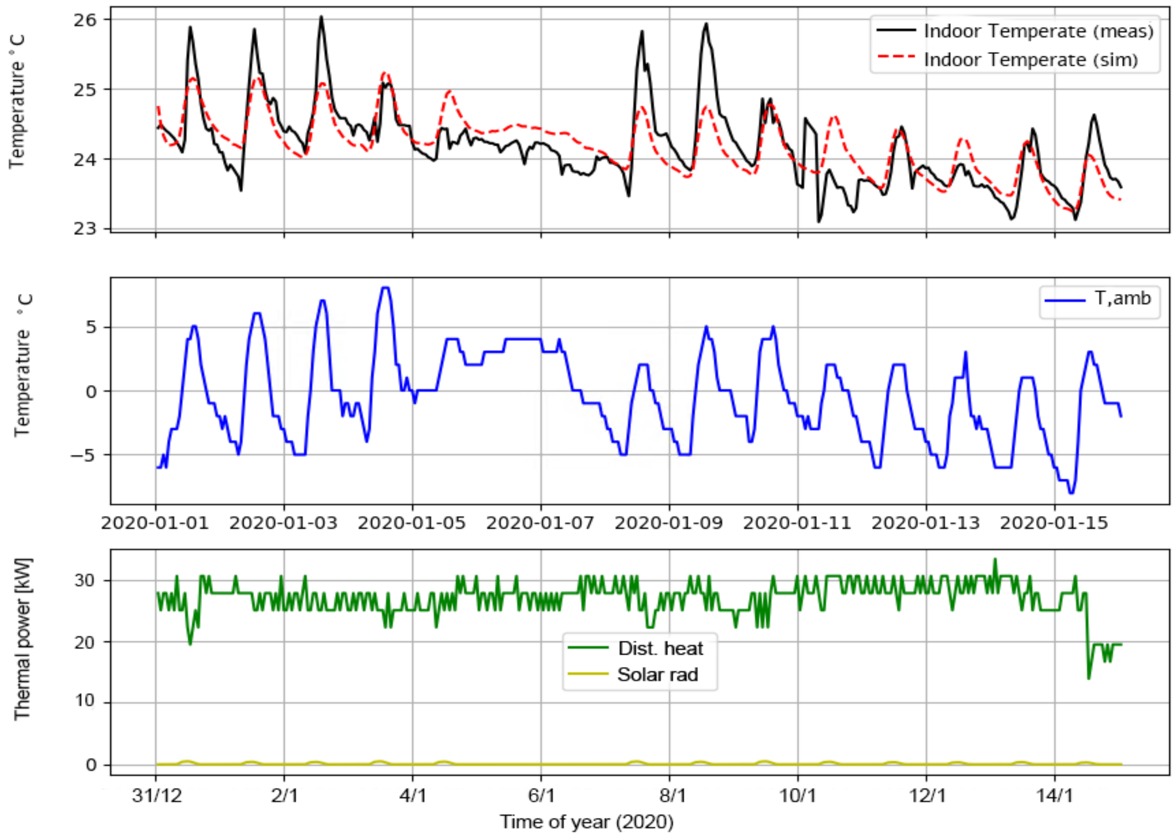

Figure 5-14: Training data results including assumed solar irradiance. Source: VITO

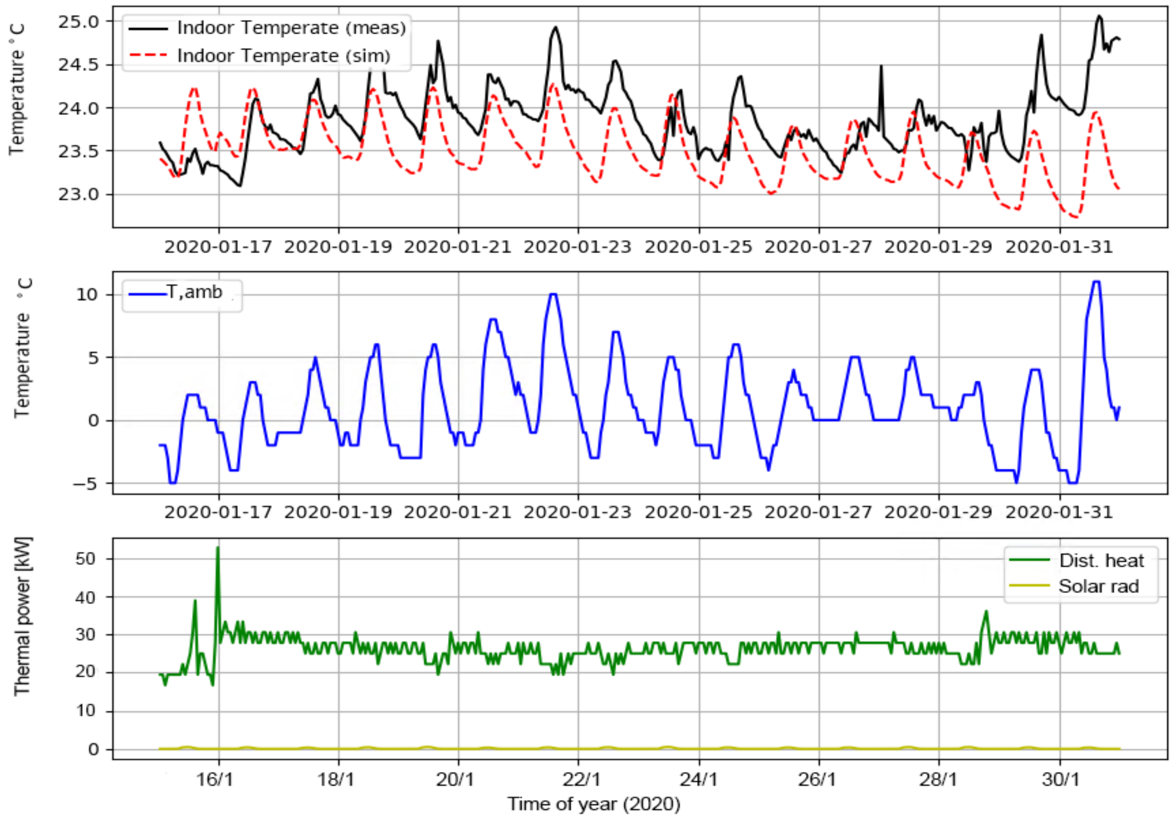

Figure 5-15: Validation period results including assumed solar irradiance. Source: VITO

5.6 Analysis and Results

The buildings on the Belgian demo site were completed in 2013.

In contrast with the other three demo sites, there is no need for detailed dynamic energy simulation modelling in order to estimate the heating demand of the buildings.

Historical data about energy consumption is available on dwelling level and this information can be used for the re-design of the energy system (heat generation and local renewable energy production).

Additionally, VITO uses a data-driven approach for the optimization of the energy management system. Therefore detailed monitoring data is necessary and additional sensors have to be installed (solar irradiation, indoor temperatures,…). All necessary data for setting up the data model will be available in the beginning of 2021 and subsequently it will be used to train the building models as described previously.

6 Conclusions

Along the contents of this Deliverable, a detailed description of each Demo Pilot has been provided as well as the climate conditions particularities of the four locations.

After a thorough description of the buildings and their constitutive subsystems, the developed models for each one of the four Pilots has been explained and their respective simulations results have been presented.

A detailed analysis of the obtained results from the carried out simulation sets has been discussed. Additionally, an evaluation of the performances and energy consumptions of each one of the four buildings has been performed from the scope of PEB.

The main achievements of this Task are the four developed energy models, which can be utilised as a powerful tool to evaluate the performance of buildings and their facilities for each Demonstrator from a holistic modelling scope.

Moreover, such models can be utilised by the construction companies involved in the construction of each building to achieve more accuracy, evaluating the effects of modifications of improvements at the design phase of the buildings. Also, the building facility managers could evaluate different operational conditions and weather scenarios to optimize the energy consumptions whilst ensuring user-comfort requirements.

An outcome of all this comprehensive work is that several simulations tools have been used for the development of the models for every Demo Pilot. Whereas the Finnish and Austrian Pilot used IDA-ICE for their Building Model, the Spanish Pilot Building was implemented using TRNSYS software. On the other hand, the systems, thermal and electrical, were implemented in TRNSYS in the Finnish and the Spanish Pilot and in IDA-ICE for the Austrian Pilot. Lastly, the Belgian Pilot is developing an RC-Model (gray-model) for its Demo Pilot.

With regard to continued developments and with the information provided by this Deliverable, some research work could be further done to study and evaluate new control strategies and to improve the design to reach PEB status level. It is expected that there is still room for improvement.

For example, the Spanish Pilot is concerned about the possibility to extend the PV facility. Also, both the Spanish and the Austrian Pilot propose using free-cooling without heat pump and taking advantage of the heat waste in Building in summer period for DHW preparation. Additionally, the Finnish and the Spanish Pilot (new buildings) consider that more control strategies could be evaluated after the final definition of the buildings and their facilities.

Finally, specific conclusions about the results of each Pilot have been exhibited in sections 2.7, 3.8 and 4.8 respectively. However, a summary of conclusions and lessons learned for the four Pilots are exposed below, as well as common aspects of all of them.

By the time being, one of the main conclusions from the study developed along this Task is that the achievement of PEB standard, as it was defined in the D1.1, is difficult to be fulfilled in the Finnish Pilot, but it could be reached in the Spanish Pilot and Austrian Pilot with some enhancements. The Belgian pilot is not evaluated yet because the required data are not available yet (target Spring 2021).

One lesson learned is that an accurate evaluation tool is essential for enabling an optimal dimensioning of the building and its systems (e.g. ground heat exchanger and energy generation systems) in order to achieve the PEB standard, as well as the evaluation of optimization of control strategies.

Another lesson learned is that the thermal energy for user-comfort requirements, under these works assumptions, has as much influence (or even a bit less in the Spanish Pilot though) as the rest of electrical energy consumptions of the building (artificial lighting, household appliances, electrical devices, electrical consumption in common zones). Therefore, it is needed to work as well in reducing the electrical consumption of artificial lighting and household appliances with the user-engagement for PEB achievement.

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