ENERGY SIMULATION OF SHEET METAL CENTER WITH IDA ICE SOFTWARE

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ABSTRACT

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Supervisor(s)	Jarmo Havula	

ABSTRACT

The long-term study of buildings with advance energy solutions has resulted in the need of continuous calibration and validation of energy models. Often the first essential step in this work is to create a base model that runs with reasonable computed time and results. The main purpose of this Bachelor's thesis was to make a base energy model of Sheet Metal Center, the pioneer commercial-research hall aimed at near-zero-energy building (nZEB) compliance in Finland. The thesis was commissioned by Sheet Metal Center (within HAMK's project ''Multi-skilled designer in energy technology in building'').

The building case materials were mostly taken from HAMK's facility management library documents and commissioning report of AXSuunnittelu. The simulation work was performed with IDA ICE (v4.1). This program provided the possibility for detailed inputs, customized technical plant and investigation of all relevant variables and parameters.

The simulation process was the focus and the obtained results were either discussed and/or compared with some empirical measurement data. Two models were presented. The first model indicates a good design when sizing the heating equipment. The second one showed a positive sign for compliance with the latest Finnish draft regulations about nZEB. Nevertheless, there were still some questionable discrepancies between the model results and actual building energy consumption.

Overall, the model's geometry, structure and technical plant were built thoroughly. Some views on the possible causes of mismatches were presented and a plan was proposed for future research. It is clear that an accurate calibrated model will be valuable for various applications, such as optimized building controls, fault detection and energy piles study.

Keywords IDA ICE, simulation, Sheet Metal Center (SMC), energy modelling.

Pages 52 p. + appendices 9 p.

ACKNOWLEDGEMENT

After a four-year long journey, I finally arrive at the last note of my Bachelor’s thesis. This project marked the most complex energy-simulation-model that I have done with IDA Indoor Climate and Energy simulation software. It has been a challenging but also a joyful learning experience, both at professional and personal level. Therefore, I would like to reflect on all people who have helped to make it happened.

Foremost, I would like to express my gratitude to my thesis supervisor, Jarmo Havula, for his support and patience. It was his idea that I could have the opportunity to work extensively in a long-term energy-efficiency project by investigating Sheet Metal Center case. Even though his main expertise was not in my research area, his comments and feedback helped me significantly in directing the topic. A great thanks to Kimmo Hilden, my teammate, for personally working with me through certain stages during the modelling process. He also initiated and participated in IDA ICE trainings and project meetings, which brought me useful materials.

Special thanks go to Ruukki Construction Oy. I also take this note to thank EQUA Simulation Finland Oy, especially Mika Vuolle, CEO and Erkki Karjalainen, assistant engineer. Without their willingness to share knowledge, my journey would have been much more difficult and time-consuming. Besides, I also appreciate the assistance from my study counselor, Anu Virtanen and my English teacher, Helena Parviainen.

Deeply in my heart, I’m grateful to my family, friends and other colleagues. Though most of you didn’t understand exactly why I chose this direction and what I was working on, you all showed support. Finally, I love Finland, the peaceful land that have nurtured and challenged me till this very moment.

Growth is the development through problems, findings and support along the way!

Hong Nhung Nguyen
Hämeenlinna, 14 October 2017

CONTENTS

1 INTRODUCTION

1.1 Background

Research shows that buildings are responsible for 40% of energy consumption and 36% of CO_2 emissions in the European Union. Consequently, the building sector has been playing an important role to achieve the 20/20/20 targets, which are reduction in greenhouse gas emissions, increase in the share of energy from renewables and improvement in energy efficiency. (DIRECTIVE 2012/27/EU on energy efficiency/2012.) These three targets are inter-related. For instance, by using energy more efficiently, people can lower their energy bills, reduce the reliance on foreign sources of fossil fuels, such as oil and gas. This usually contributes to the reduction of CO_2 emission, too.

In Finland, the general trend of greenhouse gas emissions and energy consumption was decreasing for period 2010 – 2015. Noticeably, in 2015, about 25% of the total energy use of Finland resulted from the heat for space heating. (Statistics Finland, 2016.) As a member of the EU, as well as a pioneer country in energy technology, Finland has emphasized energy savings for decades. Policies on subsidies and regulations have been implemented. Companies and communities also showed much increase in awareness of energy planning. The newest draft of regulations suggests that near-zero-energy-buildings (nZEBs) are expected to consume even less energy than the modern efficient buildings built today (Ympäristöministeriö, 2017). nZEBs will also lay more stress on a high quality indoor environment during their long lifetime. More than ever before, many combined technical solutions and new innovative options are offered at the design stage. As a result, energy analysis and simulation have become more and more relevant due to the increased complexity of projects, customer needs and fulfilling regulations.

All over the EU, the member countries will be very soon required for their new buildings to be built as nZEBs from 2020 December 31st, and all of their new buildings owned and occupied by public authorities from 2018 December 31st (DIRECTIVE 2012/27/EU on energy efficiency/2012). There have been some prototype nZEBs in Finland. Sheet Metal Center (SMC) is a pilot as such, which belongs to Häme University of Applied Sciences (HAMK). As a matter of fact, it has many energy saving features when planned but certain changes during construction and operation stages happened. This thesis is partially under “Multi-skilled designer in energy technology in building” project, which is carried out by HAMK, supported by Ruukki Construction and an EU funding program. As part of the work, the modeler created energy models of the building. In this report, two models will be discussed. The first one aimed for heating load calculation, which is to see if the technical system was sized sufficiently. The second model was developed as a future reference for assessing energy performance of the up-to-date building.

1.2 Aim

The primary aim of the thesis is to create feasible energy models of the specific Sheet Metal Center, a case nZEB, which will facilitate a long-term study in regard to energy consumption pattern. The focus of the thesis is the modelling process itself. Detailed input, such as thermal properties of the envelope, heating devices, lighting and so on, were supplied, but also simplified when necessary.

Another point which can be considered as a secondary aim in this project is the investigation of the required time and effort to make an energy model for a case like SMC. Because Sheet Metal Center staff background was mainly related to Structural Engineering and/or Materials Science, it was with great internal interests that some would acquire knowledge about building performance simulations for the unit's future development.

In order to reach the aim, sub-research questions have been formed:

– What are the critical points in modelling the geothermal heating system?
– How to model the thermal storage solutions: heat from solar collectors and heat charge from a cooling effect?
– What kind of considerations are there for generation side and distribution side of a heating system?
– How to balance the output result and running time? Which parts potentially could be simplified for modelling?
– How to use monitoring data to assess the quality of the energy models?
– What are important steps for future plan to calibrate the models?

1.3 Outline

The thesis is organized into 6 sections.

Section one, Introduction, tells the background of this modelling study, the general purposes and scope of the project.

Section two, Building Energy Simulation, shortly introduces the software used for simulation. It also summarizes points of the fundamental knowledge that one should pay attention in order to get started with energy modelling.

Section 3, Methods, presents a brief writing about the building case, few early assumption and delimitation for this particular model in the report.

Then, description of common inputs and of the technical systems are given case by case.

In section 4, Simulation result and discussion, the simulation results are presented and discussed. The section closes with a short writing of some encountered problems of the authors during the work process.

The 5th section, Proposal for continuing research, reflects on some areas which need improvement in the model and proposes a calibration plan. At last, some possibilities on usages of the outcome from the current simulation and continuing calibration was listed.

Finally, section 6, Conclusion, sums up the whole thesis.

2 BUILDING ENERGY SIMULATION

2.1 IDA ICE – software description

Until the 1960s, energy demand and consumption of a building was normally coupled and calculated based on simple steady-state methods. The most common calculation was heat-energy demand which accompanied closely with degree-day methods. For both heating and cooling analyses, more detailed bin methods were available. (Ayres & Stamper 1995, 841-842.) From a mathematical perspective, the more accurate and detailed result one wants, the more different equation types need to be solved, and even simultaneously. With the calculation increased and spread further, the first dynamic simulation methods, i.e. the first kind that time was taken as an independent variable, appeared after the mid-60s. (Jokisalo 2008, 11). Nowadays, computer-aided programs have matured to a level of being able to simulate dynamically with extensive inputs and parameters. The role of simulation tools in the design and engineering of buildings has been evolved rapidly, and currently considered essential in sustainable construction. Some of the common names in the European market are IES VE, IDA ICE, EnergyPlus, TRNSYS, Bsim, Design Builder, ESP-r.

IDA Indoor Climate and Energy (IDA ICE) is a tool for multi-zone simulation of the indoor air quality, thermal comfort and building energy consumption. It is an extension of the general IDA simulation environment that has been under development by the KTH Royal Institute of Technology, and the Swedish Institute of Applied Mathematics since the 80s. The software is now primarily developed by a Swedish company EQUA Simulation AB while the first commercial version dates back to the 1990s.

IDA ICE is capable of handling a great amount of details input, such as local weather records, wind profile, envelope materials, glazing properties, shading and control, lighting, occupants, scheduling, HVAC equipment, and so on. IDA solver, unlike many other counterparts, is a general-purpose variable time step solver, which automatically adapts to the nature of the problem. User-defined tolerance parameters productively remove the numerical errors. Furthermore, the software offers the possibility to look at how all these numbers interact with each other in second time-step resolution, if chosen. (EQUA Simulation AB, n.d.) The version which was used in this thesis is IDA ICE Expert edition 4.7.1, the most updated one at the study time.

Overall, there are a few reasons to choose IDA ICE for the author's research:

- IDA ICE user interface offers both traditional table/window form and 3D graphical model, which makes the building, simulating, also visualizing easily.
- Models in IDA ICE are equations based on Neutral Model Format (NMF). The mathematical model is well-transparent. Every underlying equation can be browsed, and every variable can be logged. For the complexity of the study model, this means a possibility to control signal and inspect all parameters responsively by the modeler. (EQUA Simulation AB, n.d.)
- Like other software, a model comes with a standard plant (a boiler and a chiller) at start. But there is another unique feature in IDA ICE, which is ESBO plant. It helps to construct the base for complex technical systems quickly and effortlessly.
- A rich library of air and water based components is available in Expert edition. They are very useful for customizing the AHUs and the technical plant for the study project.
- Due to the origin of most researchers and developers of IDA ICE, as well as the market is Nordic Region, or more recently Baltic Sea Region, setting compiling with Finnish local conditions and requirements, is well available.

2.2 Fundamental Knowledge

Although computer power has been growing, which led to machine capable of modeling everything in our world, it is still difficult to ensure the quality of simulation results. Anyone who has worked with simulation know it is not a simple task (Hensen & Lamberts 2011, 3). The objective reason is that a building is inherently complex (Figure 1). Always there are interactions between its sub-systems. This leads to a challenging question when addressing energy consumption: how to take all those interactions into account, in other words, to get the best picture (output) from the optimal amount of inputs and control programming (Figure 2). So, to what extent compromises between accuracy and flexibility a modeler should aim at? This section 2.2 reflects the author's experience and opinions about elemental knowledge one should have to get a hand of modelling work.

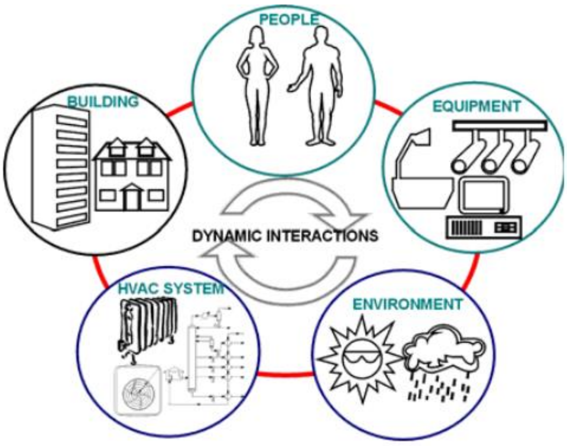


Figure 1. Dynamic interactions of (continuously changing) sub-systems in buildings (Hensen & Lamberts 2011, 2)

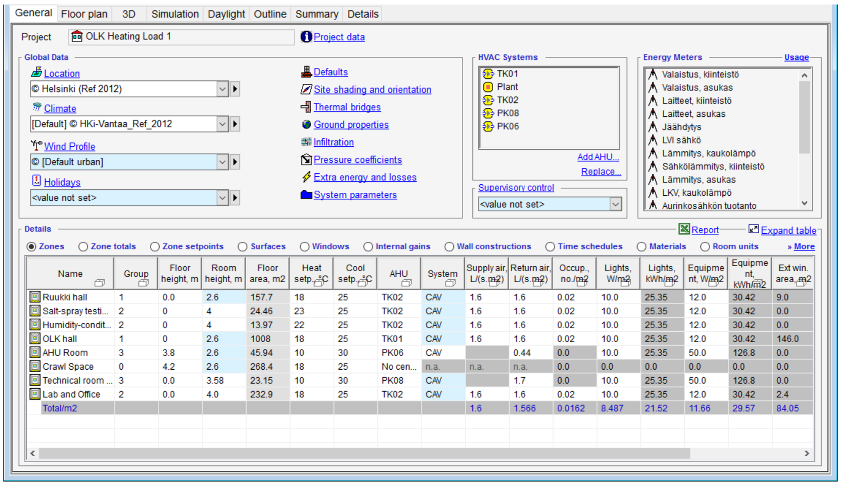


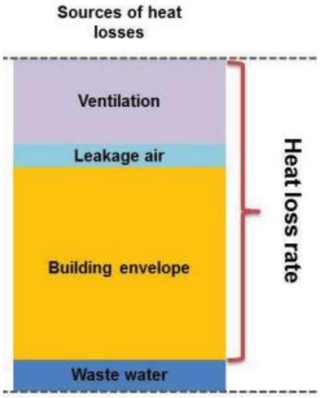
Figure 2. User interface of IDA ICE in ''General'' Tab with many input-fill-in possibilities

2.2.1 Building Physics – Building Envelope

A research at Tampere University of Technology (TUT) developed an average model for Finnish building stock, which estimated that the heat loss rate comes from the walls, roof, ground slab and openings. This model corresponds quite well to a predictive calculation from a previous research between TUT and Technical Center of Finland VTT. In that research, using EKOREM[1], the result suggested a large amount of consumed energy, ranging from 20% to 50%, is to compensate the heat lost through the

[1] EKOREM, developed in TUT, is a building stock calculation model which can be used to determine energy consumption and greenhouse gas emission of the building stock in different cross-section years.

building envelope to outdoor environment (Heljo, Nippala & Nuuttila 2005, 39). The general comparison is shown in Figure 3.



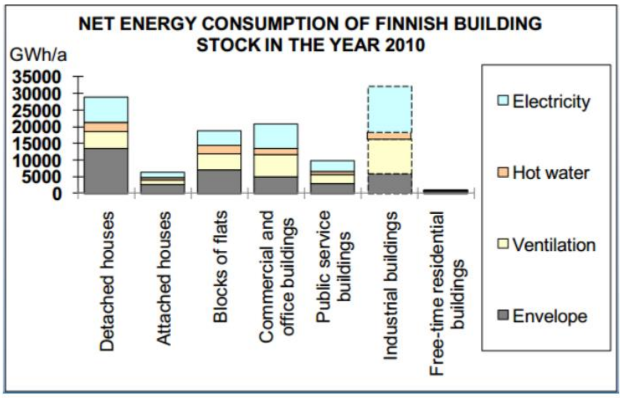


Figure 3. Left graph – Illustrative simplified heat loss rate – an average model for Finnish building stock (Vihola, Sorri, Heljo & Kera, 2015) Right graph – Predicted net energy consumption of Finnish Building Stock in the year 2010 (Heljo et al. 2005, 39)

From a mathematical viewpoint, the compensated energy discussed above, can be estimated roughly from three main categories:

– Conductive heat loss through building components
– Convective heat loss with air leakage
– Linear heat loss between structural connections.

Improving the orientation, form and design of building envelope with its surrounding environment, in regard to energy performance is the study of building engineering physics, or commonly building physics. . In a nut shell, the field deals principally with the flows of energy, both natural and artificial, within and through buildings. The related areas include, but not limit to: air movement, thermal performance, control of moisture, ambient energy, acoustics, light, climate and biology. (The Royal Academy of Engineering 2010, 6-10.)

In simulation work, building physics knowledge can help remarkably to assess the result and optimize the real energy profile. In other words, basic understanding and appropriate data for below input is a must to get started:

– Orientation and shading
– Climate profile (ambient temperature, wind load, solar radiation, etc.)
– Thermal bridge and building elements definition
– Building form and primary usage(s)
– Infiltration and pressure co-efficient

2.2.2 Heating Ventilation Air-conditioning (HVAC)

Ventilation and Air-conditioning

People in Finland spend typically 90% of their time indoors. As a country with a high standard of having a good, healthy, safe and productive life, the indoor environment is one key element in Finnish well-being. (Talotekniikkateollisuus ry n.d.) A good indoor climate is achieved by means of a combination of a thorough design and well-managed operation of the building. According to National Building Code Part D2, indoor climate comprises: thermal comfort, air quality, acoustic conditions and lighting. Out of the four components, air quality, and to a lesser extent, thermal comfort are directly determined by the ventilation system.

In modern design, ventilation systems are often responsible for delivering clean air, exchanging air in spaces, as well as part of heating/cooling tasks. In a simple look, ventilation removes contaminated air and replaces it with fresh air. Contaminated air usually refers to impurities in the form of gases and particles, such as CO2 and chemical substances. What people may easily neglect, is excess heat and moisture indoor. These can also be regarded as impurities in some cases. For example, in industrial and commercial buildings, the indoor climate is likely to get bad because of too high temperatures. The leading reason is large quantities of heat, which is given off significantly from machinery, electric equipment, people and solar radiation. (Pedersen, 2011.) Air-conditioning is a more specific system, which delivers a certain amount of air (not necessarily fresh air) at a required temperature, and possibly at a set moisture content as well, to cool or heat the space (Roulet 2008, 303-304).

Large buildings nowadays in cold climates, such as Sheet Metal Center, are often equipped with mechanical ventilation due to strict regulations on indoor climate demand and energy consumption. A mechanical ventilation system typically has an air-handling-unit (AHU), ducts, pumps, diffusers, grilles and so on. An AHU itself can include other components, for instance fans, heating coil, cooling coil, heat exchanger. Modeling AHUs and their control programs is one of the most important tasks in whole building simulation.

Ventilation systems clearly have a notable impact on thermal comfort, indoor air quality and heating bills. To move, warm up, dry or humidify and even clean the air need energy, often in form of both electricity and heat. Though contemporary mechanical ventilation tries to utilize as little resource as possible while meeting occupant comfort, the previous graphs in Figure 4 (page 6) show that the share may go up to 30% out of total net energy consumption for commercial/office category.

Technically, the accuracy of simulation tools relies on the appropriate setting of boundary conditions and parameters. For a mechanical ventilation system, it is important to be able to sort out these initial matters:

- What is the required air flow rate? Is it a balanced ventilation, meaning supply and return flows equal?
- How many systems are there (air handling units, exhaust fans, etc.)?
- Which one of those are critical for modelling to predict energy consumption?
- What are the controlling program? For instance, is the air flow constant? Are there different programs for winter and summer and/or weekday and weekend?

Heating

Heating energy generally consists of space heating, ventilation heating and domestic hot water (DHW) production. The heating system ensures the indoor thermal comfort in an economical way despite the outdoor air conditions during the heating season.

A heating system is made up primarily of generation side (heat source), distribution side and control system. Heat sources can be, for example district heating, heat pump or a boiler supplied with oil, natural gas or wood chips. Hybrid options are also gaining popularity, such as a combination of solar collectors for DHW and a ground-source heat pump for space heating. A hydronic or water based heating system is the most popular distribution system in buildings. It is more efficient than air heating, because water is a 4.2-time better heat carrier than air. In hydronic heating, normally the hot fluid is circulated in a network and heat is delivered to spaces by emitters, such as radiators or radiant panels. (Laukyte 2014.) At last, control devices such as integrated thermostats, sensors and valves will regulate the hot water flow to ensure the desired indoor air temperature.

Conventionally, a heat generator (generation side) is firstly sized according to the maximum heat loss in the worst scenario (described in regulations). Then, depending on the budget and willingness of clients, options for the relevant equipment will be presented. The requirement for the distribution side and control system can be quite loose nowadays. The reason behind that is that common equipment can maintain thermal comfort with flexible temperature set point range and allow fluctuation in cases. After all, the energy consumption of a heating system, is heavily based on the working schedule and its individual component performance. Because a heating system itself consists of three sub-systems, the simulation work could be easily seen as triple in complex design, especially in highly energy-efficient buildings. Therefore, the author suggests finding answers to some inevitable questions at the beginning of modelling:

- What does the generation side consist of? If a hybrid system is used, determine which source supplies to what end.
- Will the base heating work independently or are there any back up system? What are the shares of those?
- What kind of distribution side equipment are there?
- What kind of set points are there for supplying different purposes (DHW use, space heating, ventilation heating) and spaces?
- Similar to the ventilation system, are there different controlling programs?

2.2.3 Power and Energy Calculation

According to Finnish National Building Code Part D3, normally, the maximum heating power (kW) in a building is the sum of the peak of AHU heating, zone heating, plus the power needed for DHW production at the same instance. The sum will be used for dimensioning the heat generating devices' capacity. Regarding SMC, the design of hot storage tanks helps to reduce the stress on the heat source. Because the large power peaks of domestic hot water may be supplied during off-peak hours, then be reheated slowly for the actual use using very little power. Thus, DHW production power was not considered towards the final maximum heating load.

Building energy need (kWh) comprises the energy required for heating, cooling and electrical energy for lighting and different appliances over a period of time. The heating energy need is calculated from the sum of space heating, DHW production, supply air heating, minus the solar gains, energy recovered from exhaust air and internal heat loads. Net energy needs represent the ideal need of a building, which does not include specific system losses, such as distribution loss, generation efficiency and hot water tank loss.

The purchased energy is the result of the net energy (taken system losses into account) subtracting any renewable energy that exists in the big picture. Renewable locally-generated energy can be for instance wind power, electricity from photovoltaic (PV) panels, or heating energy from a heat pump's heat source. To minimize the deficiency and variation in the current market, basic rules for calculations are given. It must be noticed that some set rules change along with the type of building, in other words, the building usages. They are weather data, air-tightness, occupancy time, people, internal heat gains, DHW, standard room temperature set point and minimum (constant) ventilation air flows.

In dynamic simulation results presented later, building purchased energy per heated squared meter, multiplied by primary energy weighting factor (specific for each energy carrier) results in energy performance value (EPV).

Figure 4 summarizes this sub-section's content by graphic illustration.

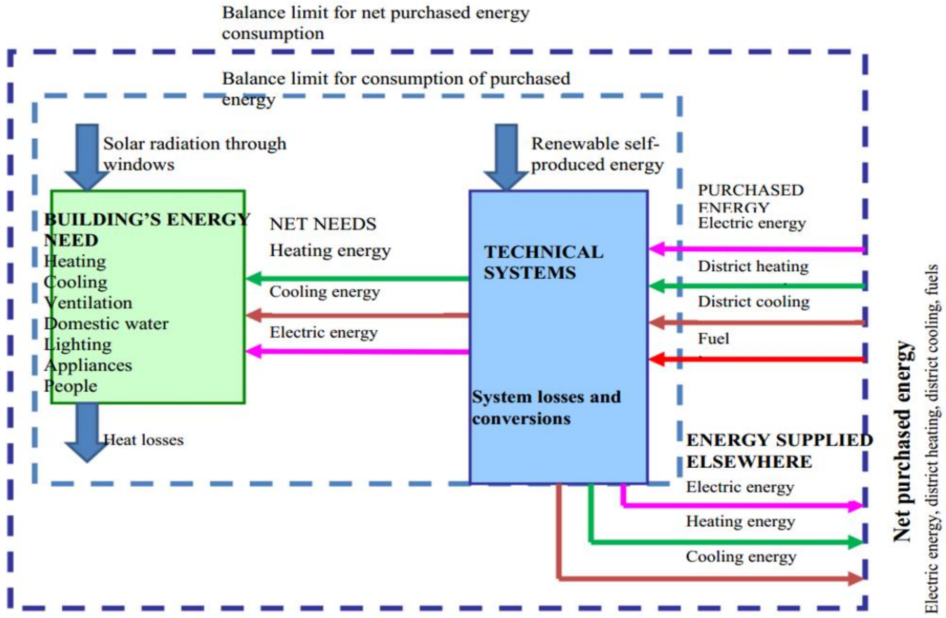


Figure 4. A building's balance limit for consumption of purchased energy (Adapted from D5 Suomen rakentamismääräyskokoelma/2012).

3 METHODS

3.1 Case Description

Design and Construction

Sheet Metal Centre (SMC) is the oldest research unit of Häme University of Applied Sciences. The unit focuses on improving the competitiveness of Finnish sheet metal products, manufacturing, and application. In 2015, the new research building, named after the unit, was completed on the main campus of the university. This was the first near-zero-energy single-story research hall in Finland. It has been used for R&D and teaching purposes by the university and Ruukki Construction Company. For the design stage, a simulated energy model was made by Tallin Technical Univeristy. Most of the input and control logic at the time had been very similar to the technical system when the actual building was built.

To achieve the design goal, the building was regarded as a whole entity for utilization and optimization. The building was constructed in a fairly compact form with a well-insulated and airtight envelope. With the engineered sandwich panels, the wall thickness was 230 mm and reached an effective U-value of 0.16 W/m^{2}K. The roof used prefabricated PIR elements. Its U-value is about 0.12 W/m^{2}K (Figure 5). The commissioning measurement gave an excellent airtightness of the entire building of 0.76 $m^3/h.m^2$.

Figure 5. Sandwich panels 230 SPA E for wall (left) and sandwich elements PIR 230 for roof (right) (Rautaruukki Corporation n.d.)

The sizes, U-values and location of the building’s windows were optimized for overall comfort and energy efficiency. For instance, at south-west façade, opal polycarbonate glazing windows were opted. Those windows can be seen from Figure 6 below. Polycarbonate glazing windows diffuse day-light and isolate heat well in summer. Lighting simulations, carried out by Tallinn Technical University, predicted a reduction of about 50% in the spaces adjacent to those windows. (Kesti 2016.) Although the heat loss is larger (U-value higher) than a low-energy window, the energy for lighting and cooling is simultaneously reduced. For SMC, a building that works as a research and office unit with a lot of substantial-heat-produced equipment, this choice resulted in an optimal balance.

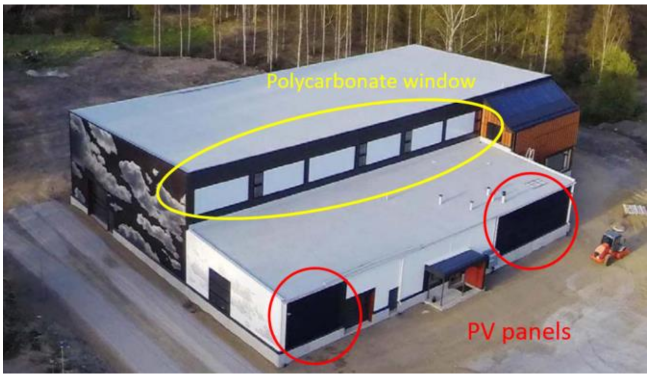


Figure 6. Polycarbonate windows and integrated photovoltaic panels on the south-west façade of Sheet Metal Center

Another feature was the hybrid system of solar-geothermal plant. Solar collectors play a role of thermal storage while geothermal energy source (energy piles and heat wells) acts as the main heat supplier. The heat pump was sized to meet approximately 40% of the heating load on a coldest winter day. Electric resistors in water tanks shared the remained part, also being a backup whenever needed. Part of the geothermal source acts as a free cooling source in the summer time. On the distribution side, radiant heating/cooling ceiling panels and under floor heating were applied. Moreover, the façade is integrated with 61 m^2 of PV panels. Figure 7 on next page shows pictures of the pipe work for the energy pipes, the radiant ceiling profile and solar collectors module for roof.

Figure 7. In order: 1- Pipe work for the energy pile. 2- Ruukki classic solar collector model integrated with roof finishing. 3- Ruukki radiant ceiling profile (Source 2 & 3: Kesti 2016)

Operation

Since the completion in 2015, the building has operated smoothly. There have been a few big changes in the premises and equipment. No smart lighting control has been implemented yet. There are a new hydraulic loading machine with a power of 132 kW (testing area) and a weather testing chamber of 8.4 kW (lab area). These respectively have their own chillers with a very big cooling capacity of 57.7 kW and 6 kW at full-load. Both machines can have tests that run continuously for a couple of weeks to several months.

The original cold storage is now used for accommodating the new hydraulic machine and its oil tank (Figure 8). The space is required to be kept at 15°C when the machine is at rest. When the machine is running, the air temperature is not allowed to go higher than 40°C. An air duct system for exchanging air with the hall and exhaust fans were installed in order to ensure the desired temperature.

Figure 8. The new hydraulic machine and a part of the duct (behind) that exchanges air with OLK hall to condition the space.

3.2 Initial Assumption and Delimitation

Building energy consumption is assessed by simulation algorithms that require hourly meteorological data. According to Part C4 - National Building Code, Helsinki and Hämeenlinna are in the same design-condition region. Therefore, the climate file and wind profile chosen in the simulation software are Helsinki-Vantaa 2012 test reference year (available in IDA ICE library). The data was constructed by using weather observations at Vantaa stations during 1980–2009, then converted into twelve months, each having weather conditions close to the long-term climatological average. However, climate conditions in close locations in the same period can have considerable differences, even more significant from different years. Thus, the simulated result should be seen as a prediction while light errors and variations are inevitable.

As seen from Figure 6 earlier, there are two groups of photovoltaic panels on the south-west façade of the building. However, IDA ICE can only show one PV panel in 3D. If one created two groups of PV panels, the second one's location would have to be changed "blindly" by parameters in form. In a simulation context, PV can be considered independent from other systems of the building. Therefore, at this stage, to reduce the complexity of our case, PV panels were not included in the model.

For the thesis project, when equipment load input (W/m^2) was inserted, the author specifically took the base for the commercial and office category from Part D3 - National Building Code. Due to the nature of testing services, the actual thermal load from laboratory instruments and machinery can be periodically or locally much higher than in the standard. The model at this stage did not try to incorporate this detailed data. This assumption might have underestimated internal gains.

At last, this study was done to see the potential of an energy simulation program and the effort that would need to make a base model for an unconventional building. The thesis was mostly accomplished by literature research and computer modelling in a limited time-frame. Therefore, the main systems and their operating control were modelled, some local ventilations and heating equipment were omitted. Those were mostly associated with the hydraulic machine and the laboratory areas. They were often activated for uncertain periods.

3.3 Data Collection

IDA ICE input construction, orientation and openings were collected from the Architectural/Structural drawings provided by HAMK. Boreholes data and modelling structure were largely, either extracted or deduced from Tallin Technical Univeristy's and Ruukki's publications and co-authored:

– Geothermal energy piles and boreholes design with a heat pump in a whole building simulation software (Fadejev & Kurnitski 2015)
– The role of an energy pile system in the heat extraction and heat storage (Kesti, Döring, Reger, Nieminen & Buday 2014)
– HAMK OHUTLEVYKESKUS ENERGY PERFORMANCE – Final report (Kurnitski & Fadejev 2016)

Most of the control logic and equipment data relied on the commissioning report of AXSuunnittelu, Revision A, 11.04.2016. Besides, central AHUs components such as fans and heat recovery wheels properties input was read from HAMK's facility management library, AXSunnittelu design drawings (2014). The data was the manufacturing information and measurement by Recair Modular Oy (2014) and JL-Ilma Oy (2015).

Metered data for the comparison in section 4 was collected from HAMK's Visamäki campus, A-building, facility management room. The recording was in the form of Excel files. The presented figures, when applicable, were normalized from the reading of sensors and meters between Jan 2016 and February 2017.

3.4 Modelling Process

Common input data are covered at start, then detailed heating plant, distribution side, zoning solution and so on are further demonstrated. Figure 9 below briefly described the steps in the modelling process.

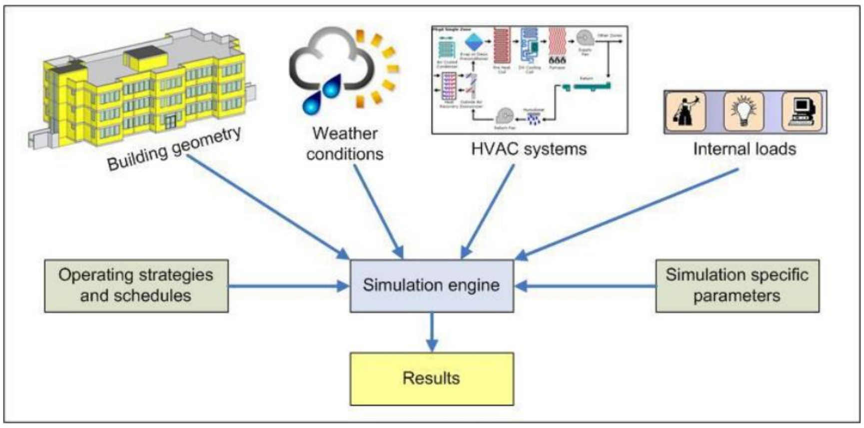


Figure 9. General data flow of simulation engines (Maile, Bazjanac & Fischer 2007)

3.4.1 Geometry and Building Structure Characteristics

Weather Data

The weather input condition for SMC is taken as in Table 1.

Table 1. Weather input data for SMC simulation model

Location/Climate	**Wind profile**	**Pressure Coefficient**
Helsinki-Vantaa Ref 2012	Default Urban	AIVC Semi-exposed

Ground

The calculation method of the thermal loss through the ground followed the European Standard ISO 13370/2007, which was assigned in the software. The ground layer under the slab was the default from Finnish localization package of IDA ICE.

Orientation and Geometry

The actual building has windows either on high or non-shaded positions. Thus, in IDA ICE, no site-shaded-object was specified (Figure 10).

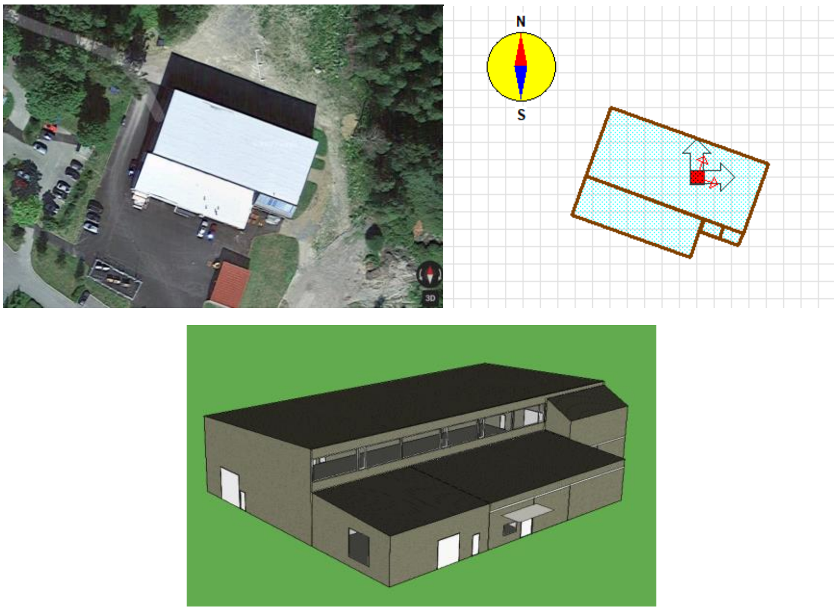


Figure 10. Sheet Metal Center picture from Googlemaps and its model in IDA ICE

Construction Materials

Most of the unwanted heat transfer occurs through the building shell. Therefore, the thermal transmittance of external building elements have high importance. In case of exterior walls, ground slabs and roof, the material properties from IDA ICE database were briefly modified so that computed U-values meet the structural design and Ruukki's product properties. All the physical properties of the construction components are later listed in Table 2, page 17.

For example, the manufactured sandwich wall had a mineral wool core pressed in between of two thin steel layers of 0.6 mm and 0.5 mm. Ruukki's wall products had a thermal transmittance of 0.16 W/m^2.K, whereas the default materials in the software first gave the same structure a U-value of approximately 0.19 W/m^2.K. This happened most likely because the database was taken from Part C4 - National Building Code Part C4. These standards are usually the minimum properties ensured for the specific materials. Simply put, they are poorer than the one provided by suppliers/manufacturers. For a modelling purpose, the layer properties were then changed to get the desired value (Figure 11).

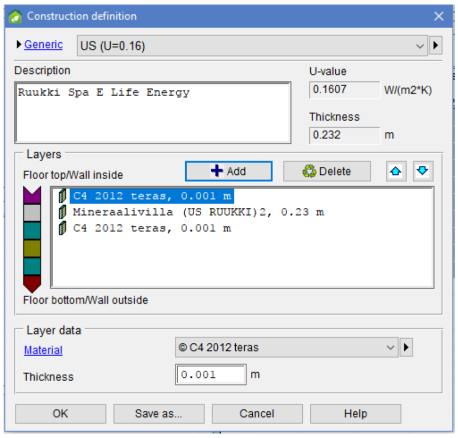


Figure 11. Defining external wall in IDA ICE

Simple window object models were used, meaning that the number of glazing layers were not described in details. Instead, the properties, including solar transmittance, visible transmittance, solar heat gain emissivity, and thermal transmittance were used as of only one glazing layer existed. No integrated shading was defined.

For polycarbonate windows, attention must be paid to the way thermal transmittance of glazing was specified. The frame proportion is relatively small. The thermal transmittance value was calculated for the total window taking the fenestration frame into account. Thus, both U-value of the glazing and the frame part were similar there. Figure 12 shows the exact parameters for the polycarbonate windows in IDA ICE.

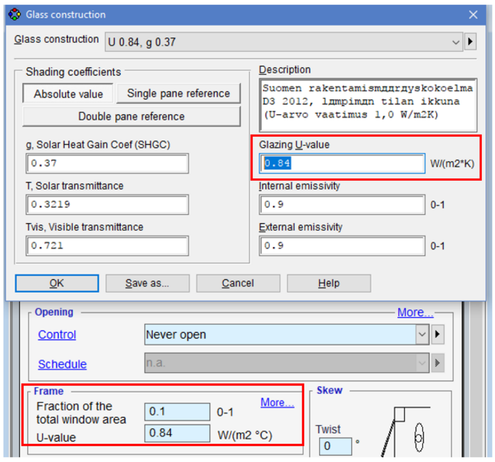


Figure 12. A polycarbonate window of SMC was defined in IDA ICE

Table 2. Construction components properties used in IDA ICE

Components	**U-value (W/m²·K)**	**Area (m²)**
External wall	0.16	1214.5
Roof	0.12	1477.3
Ground slab	0.14	1469.3
Doors[2]	1	85.3
Polycarbonate windows (SHGC g = 0.37)	Glazing: 0.84 Frame: 0.84	74.46
Other windows (SHGC g = 0.51)	Glazing: 0.6 Frame: 0.71	82.94

Thermal Bridge and Infiltration

Compact and excellent detailed design of the building led the modeler to choose the "Good" option for thermal bridge prevention design. This was the best level set up in IDA ICE, while still considering that thermal bridge existed. Appendix 1 shows the coefficients for each joint type. The software later calculated the relevant heat loss from those coefficients.

Infiltration rate represented the air leakage of a building. The input took the real value measured with a standardized air-tightness test (pressure difference 50 Pa) by Ruukki. Each zone with external surface area got the distributed effects automatically in IDA ICE. The exact number supplied to the software are displayed in Figure 13.

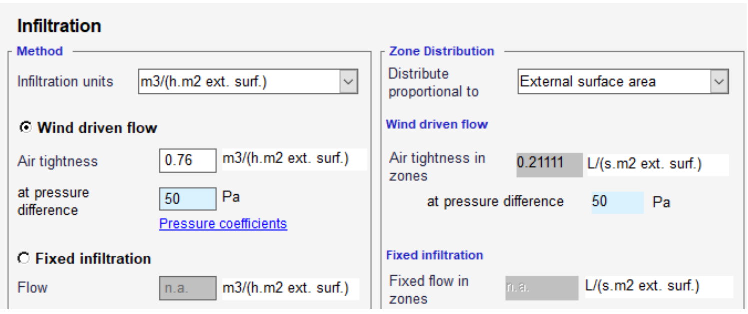


Figure 13. Infiltration rate input in IDA ICE

Extra energy and losses

All of the extra energy and losses in DHW production, ventilation and heating distribution system used the parameters adopted for Finnish commercial buildings. Default additional energy use for Finnish localization package was kept. Additional energy meant to be accounted for in the total

[2] All the doors were assumed to have the same thermal properties U = 1 W/m²·K, which meets the minimum requirement from National Building Code part D3

delivered energy (from the utility), but does not enter the building heat balance. Auxiliary electricity for meters or small equipment in the heating distribution system is an example. A screen shot of these values can be found in Appendix 1.

3.4.2 Ventilation Control Logic: Central Air-handling-units

Both central ventilation unit TK01 and TK02 were equipped with rotary heat exchangers with efficiency of 80%. TK01 served the hall section (approx. 1000 m^2) while TK02 served Ruukki space and laboratories (approx. 430 m^2). The total design air supply/return capacity in the hall was 1.6m^3/s and in Ruukki hall + laboratories part was 0.7m^3/s. They had the same control program. The supply sides of AHUs are equipped with basic functions: filtration and heating (AXSunnittelu, 2014).

General control

TK01 and TK02 ran with time schedules. The machine worked at full speed from 7 a.m. to 6 p.m. Other than the period of use of the building (occupancy schedule), ventilation ran at 7.5% of its capacity. When outdoor air dropped below 15^{o}C, frost protection would activate, meaning that the fan speed reduced to half of the set maximum (AXSuunnittelu 2016, 21-23). The supply air temperature changed according to the exhaust air temperature (Figure 14).

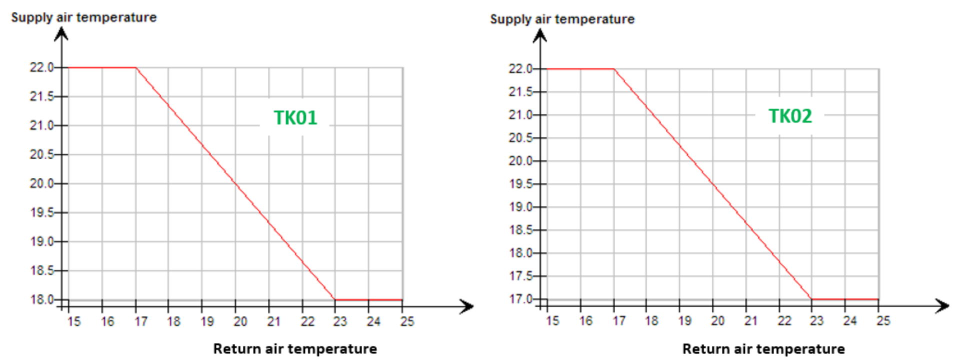


Figure 14. Current heating curve setup for supply air as a function of return air at the time of modelling.

Summer control

From May to September, there was an additional set up. During the night time, if the indoor temperature was over 23^{o}C and the ambient air temperature was between 9^{o}C and 17^{o}C, full outdoor air intake would be launched. The heat recovery wheel and heating coil would be switched off, as well as other mechanical cooling for spaces. (AXSunnittelu 2014.)

To model our ventilation units in IDA ICE, at first default AHUs with "supply air temperature as a function of return air temperature" were chosen. Because there was no air cooling or drying in the AHUs, the cooling coil elements were turned off. The heating coil liquid temperature drop was set to 10ºC, in relation to the design of in/out water flow from heating plant. The illustrative components and control logic are shown in Figure 15.

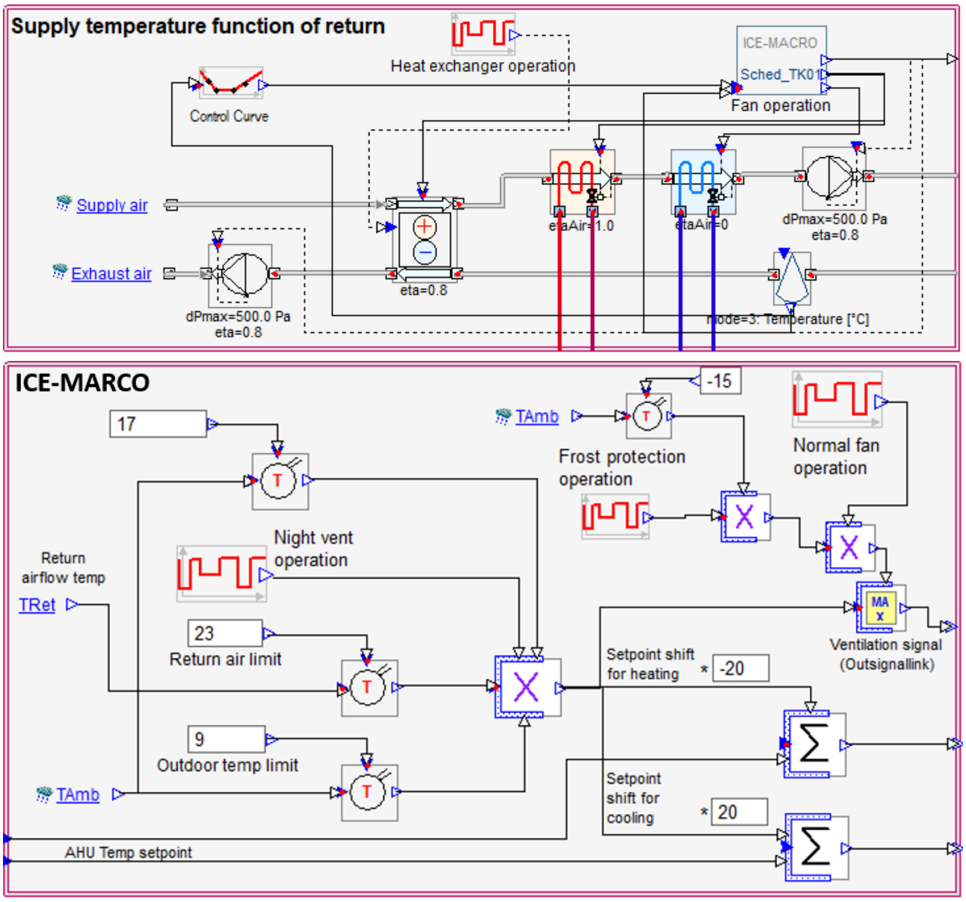


Figure 15. TK01 and TK02 control logic in IDA ICE. Upper diagram is the overall schematic control. Lower diagram is the ICE-MARCO schedule for fan operation.

In order to integrate the frost protection and summer control program, a control marco for fan operation was created. In this simulation context, the author assumed that the night ventilation run the fans between 18:00 and 07:00, from Mon to Friday, May 1st through Sept 30th. Fans may operate in the night ventilation mode when all mandatory conditions (three thermostats) were to be fulfilled concurrently (multiplier). Then, the supply air set point to the heat exchanger and the heating coil is lowered by 20°C (adder) to avoid any heating in the relevant AHU. It is necessary to understand that the cooling limits in occupied space were set at 25ºC, which was higher than the trigger to run the night mode. Therefore, with this control logic, concretely no mechanical space cooling would be running at the same time.

3.4.3 Model 1: Heating Load

Zoning and Heating Distribution Side

Model 1 was carried out purposely to identify the maximum heating load of the building. The model took the default setting (Figure 16), which is also the worst case scenario: no internal heat gain, synthetic weather with no solar radiation gain (cloudy day) and constant ambient temperature of -26°C. The simulation kept this condition for a whole day. This is the standard design condition for building in a location like SMC[3].

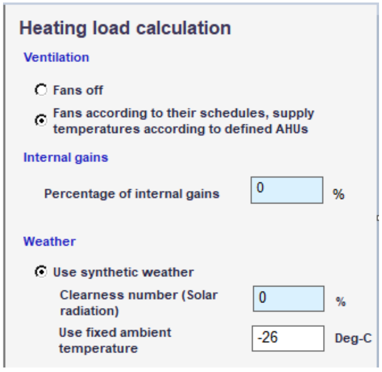


Figure 16. Heating load calculation set-up

To break it down during modelling, the distribution side only consisted of ideal heaters. They were set up so that there had an unlimited capacity. This was to ensure that we could see the maximum heat supplied, meaning heat required to relevant zones, no matter how big it is. Therefore, only large zones from the rooms/spaces which shared the same setting temperature and/or AHUs were created (Figure 17 and Table 3). In this way, the zone number was optimal: the model simulated faster and with very little differences. Overall, the total amounts of air flow rate were unchanged, because in IDA ICE supply and return flows to zones were defined as l/s/m^2.

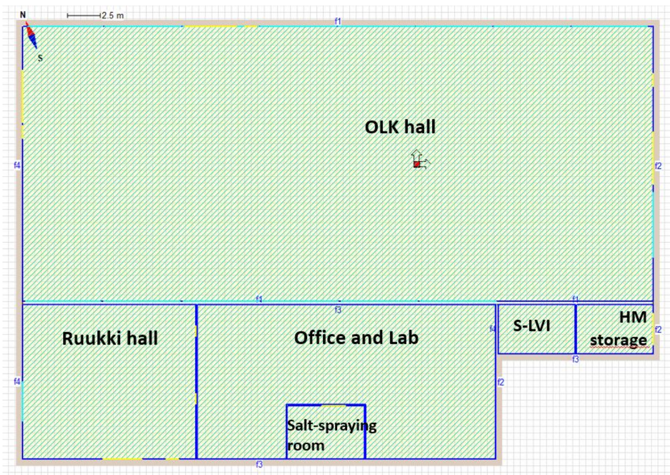


Figure 17. Zoning for Model 1 in IDA ICE

[3] weather zone II, National Building Code Part D5

Table 3. Zone set up and parameterized for Model 1

Zone	Windows/Floor area (m2)	Heating Setpoint (oC)	Supply/Return air (l/s/m2)
OLK hall	146/1008	18 (ideal heater)	1.6/1.6
Ruukki hall	9/157.7	18 (ideal heater)	1.6/1.6
Lab and Office	2.4/246.9	18 (ideal heater)	1.6/1.6
Salt-spray test room	-/24.5	234 (ideal heater)	1.6/1.6
AHU room[5]	-/45.9	(no heating)	-/-
S-LVI room	-/23.3	(no heating)	-/-
HM storage[6]	-/22.9	15 (ideal heater)	-/-
Plenum[7]	-/268.4	(no heating)	-/-

Technical Plant

As described above, the main attention was to see the highest power that the system should cover. For that reason, the heat supply side was modelled with an unlimited-capacity boiler (efficiency 0.9). Because there were two different settings for temperatures of supply hot water, the plant was created with a tank. The tank had a mixing shunt by default. From the tank, hot water was provided to three sub-systems: DHW, AHU heating and zone heating.

DHW had its own requirement of constant 55ºC for hygienic matters. AHU heating and zone heating supply temperature, on the other hand, varied according to the ambient air. The warmer the outside got, the lower the supply temperature of the water needed to be. The relationship was a linear change, as can be also seen in Figure 18.

[4] At the study time, it was documented that the room temperature was kept at 23ºC for the whole winter and most likely between 22-23ºC for the whole year due to the nature of the tests performed by the SMC staff.

[5] AHU room lied on top of HM storage and S-LVI room.

[6] HM storage means Hydraulic Machine storage. It is a semi-heated but unoccupied space.

[7] A plenum space is a part of a building that provides separate pathways for services and air ducts. In our case, it is the space between the structural roof and the drop-ceiling above the laboratories and office area.

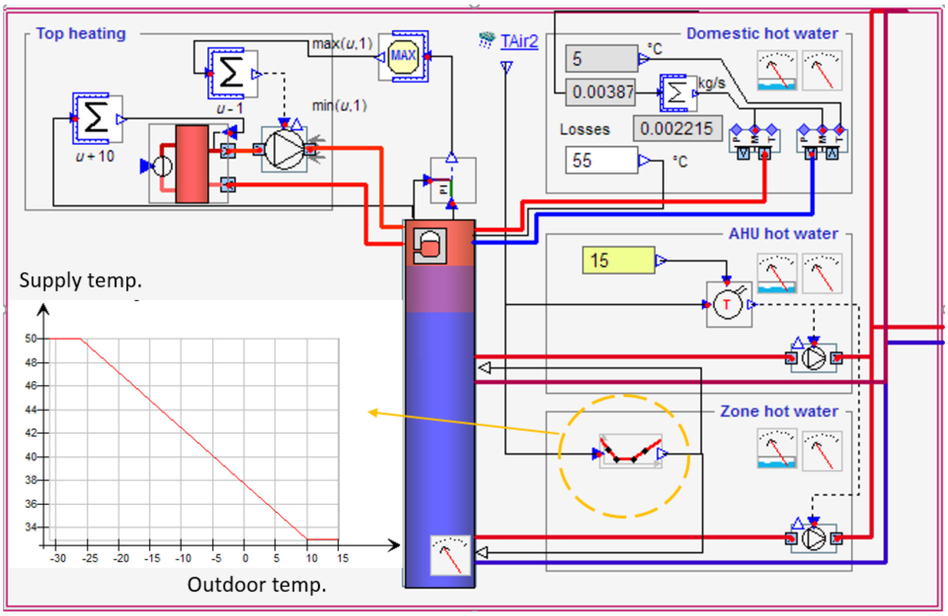


Figure 18. Technical plant of Model 1

3.4.4 Model 2: Energy Consumption

Zoning

Model 2 was done, aiming at simulating a whole year energy performance of the building. Comparing to a heating load simulation, this type would require more details from the zone definition so that the calculation becomes more reliable. The first model represented an ideal scenario. In the actual building, most of the spaces have heating devices while some rooms are heated only by a supply air from ventilation (figure 19).

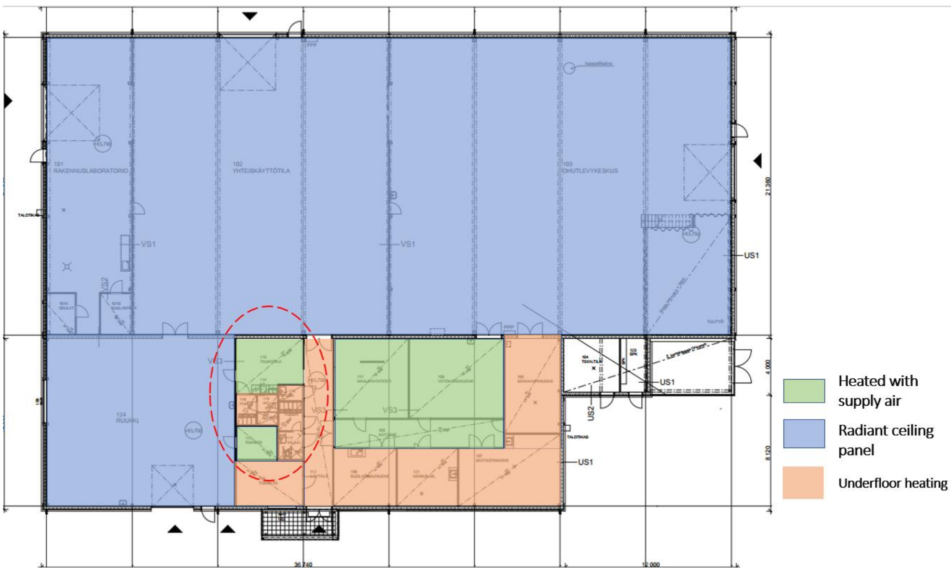


Figure 19. Distribution side: heating devices in Sheet Metal Center

Model 2 looked into the effects of different parameters of both generation and distribution side of the heating/cooling system. For that purpose ideal heaters were removed from all the zones. Radiant ceiling panels and underfloor heating devices were placed. The zoning definition, as a consequence, changed slightly. The “Lab and Office” zone from Model 1 was split into smaller zones to accommodate a more detailed heating arrangement. Because some of the rooms (red circle) either had a doorway or were surrounded by the rooms with underfloor heating, a simplification considered that they made up of only one zone with their neighbors (Figure 20).

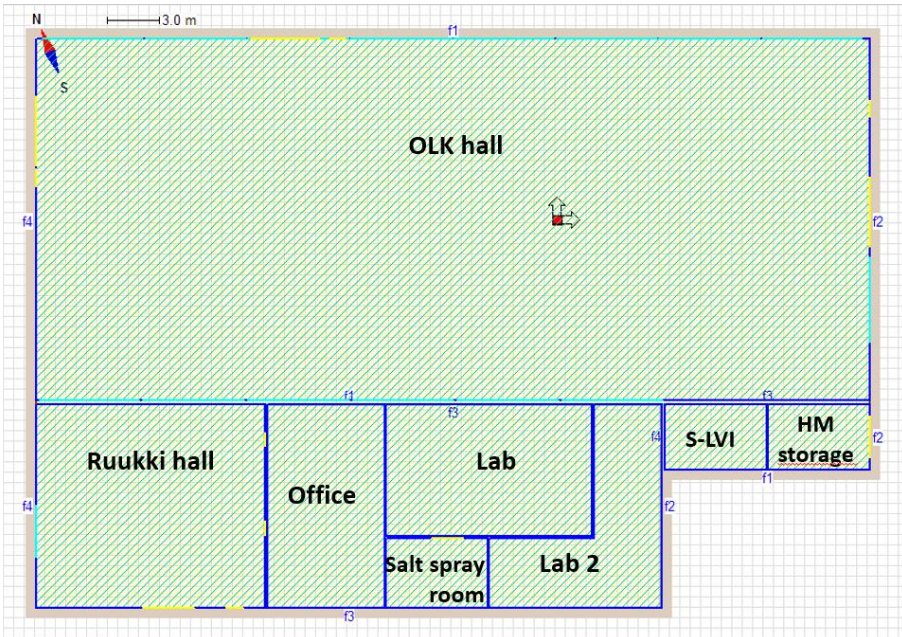


Figure 20. Zoning for Model 2 in IDA ICE

Internal Heat Gains and Their Schedules

The internal heat sources in zones contributed to the total heat gain. The typical sources are grouped as lighting, occupants and the equipment, producing heat according to their specifications and schedules summarized in Table 4.

According to the staff working at SMC (both Ruukki and HAMK), a regular average number of 10 people could be considered. They were evenly distributed in occupied zones, excluding AHU room, technical S-LVI room, plenum and HM storage. The same went for lighting effects. Lighting was LEDs that consumed little electricity but gave a very high luminous emittance. As for heat emitted from equipment, the input was not similar. The highest rate 12 W/m^2 was chosen for technical zones. The value fell between medium and medium/heavy load[8] office buildings, the type that have plenty of work stations, printers and faxes (ASHRAE 2005). For occupied zones, the heat production was taken as low as 1 W/m^2, which was the base for a commercial building type from Part D3-National Building Code.

[8] This often can be considered conservative estimates for highly automated area.

Table 4. Summary description of common internal heat source for modelled area.

Internal Gains	Description	Schedule
Occupancy	10 people Activity level: 2 MET [9] Clothing: 0.85 ± 0.25	8:00 – 17:00 (Mon – Fri) Factor: 0.6
Lighting	10 W/m^2	8:00 – 17:00 (Mon – Fri) Factor: 1
Equipment	1 W/m^2 12 W/m^2	8:00 – 17:00 (Mon – Fri) Always on Factor: 1

Heating Distribution Side

Radiant ceiling panel

The units were in reality integrated on the high ceiling elements of OLK hall and Ruukki hall. The radiant ceiling panels worked as heating devices in winter and enabled cooling with a free ground circulation from heat well during summer. In the heating mode, the design temperature difference was $\Delta T = 6^{o}C$ while in cooling mode, $\Delta T = 3.5^{o}C$. Altogether the panels have water circuit with a flow of 1.6 l/s. The maximum heating capacity for both OLK hall and Ruukki hall is around 40 kW, whereas the cooling capacity is close to 17kW. (AXSuunnittelu 2016, 13, 27.) An example of input for radiant panels on ceiling of OLK hall is shown in Figure 21.

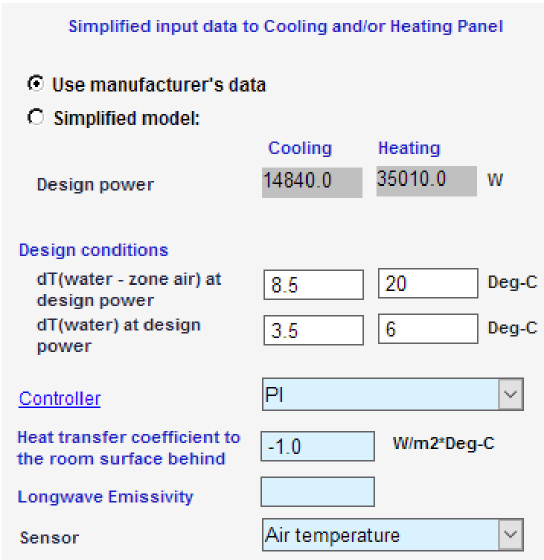


Figure 21. Example - setup of the panels on OLK hall ceiling

[9] The activity levels and the amount of clothing, define how much heat (sensible and latent) and carbon dioxide a person emits. 2 met can be considered for activity as office lifting, walking slow, light machine work (Source: ASHRAE Fundamentals).

Underfloor heating

Underfloor heating covered a part of the laboratory space and office area. The floor heating circuit had water. The design temperature gradient ΔT was 5°C. The computational power was about 3.5 kW in total (AXSuunnittelu 2016, 15). IDA ICE had a default idealized controller, like a circulation valve for underfloor heating unit in real life. Although in the main heating circuit, the supply temperature could go up to 50°C, it kept the temperature of the water entering the actual underfloor heating device not higher than 35°C.

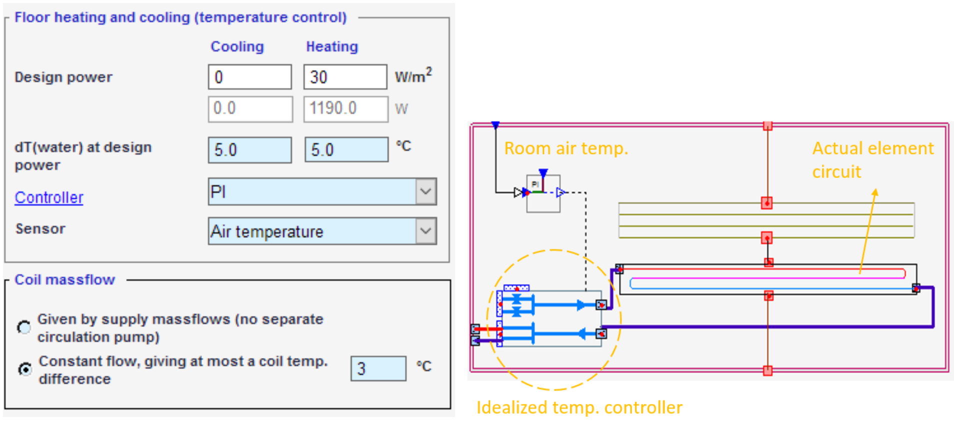


Figure 22. Example - setup of underfloor heating in zone ''Office'' and the same element in schematic (advance) model

Hydraulic machine storage zone: air exchange with OLK hall

The storage place for the hydraulic machine was required to be kept above 15°C. There was no separate heating system but instead, heating was done by blowing the warm air from OLK hall into the storage by fans and through ducts. The fans capacity could not be investigated at the study time. Thus, the author herself assumed the maximum flow based on the size of the ducts and the room's heating needs.

The situation was modelled in IDA ICE with two leaks on the shared partition wall between the storage and OLK hall. Each leak (hole) could provide a constant flow up to 25 l/s. The leaks, working like dampers, opened whenever the air temperature in the storage fell below 14°C and closed again when the temperature reached 16°C. This was accompanied by a thermostat control strategy, having a set point at 15°C and a dead band of 2°C.

Ventilation

Central AHUs

According to the description of AXSuunittelu Commissioning report, TK01 has been running so that the total design air flow had dropped from the design value of 1.6 m^3/s to roughly 1m^3/s in real operation, which meant approximately 1 $l/s/m^2$ in OLK hall zone. This was taken into account in Model 2.

Local ventilation of technical rooms: Exhaust fans PK06 and PK08

PK06 and PK08 were ventilation fans for technical premises, respectively AHU room and technical S-LVI room. PK06 had a capacity of 20 l/s. PK08 had a capacity of 40 l/s. Both fans had on-off control, which acted to keep technical facilities not heated over 24°C. Replacement air came through the circular grilles on the outer wall section. (AXSunnittelu 2014.)

Apart from leaks on external surfaces to represent the grilles, the control logic was primarily modelled in IDA ICE with the help of a thermostat and P-controller with a linear segment. They gave two compulsory conditions for the fans to start. Firstly, with the P-controller, the outdoor temperature was checked to see if there is potential to cool-off the zone. Secondly, a dead band of 2 degrees for the thermostat was set, so that whenever indoor air reached 24°C, the fan will start and run constantly until the temperature drops below 22°C (Figure 23).

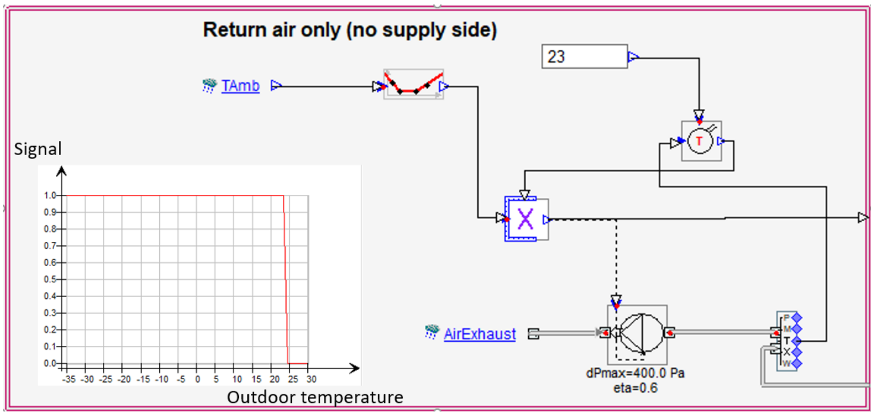


Figure 23. PK06 and PK08 control logic in IDA ICE.

A summary of the setup can be seen in Table 5 on next page.

Table 5. Zone set up for Model 2

Zone	Heating/Cooling Setpoint (°C)	Equipment (W/m^2)	Supply/Return air (l/s/m^2)
OLK hall	18/25 (radiant ceiling panel)	1 (5 days, 8-17)	1/1
Ruukki hall	18/25 (radiant ceiling panel)	1 (5 days, 8-17)	1.6/1.6
Office	18/25 (under floor heating)	1 (5 days, 8-17)	1.6/1.6
Lab 2	20/23 (under floor heating)	1 (5 days, 8-17)	1.6/1.6
Lab	18/25 (air heating)	1 (5 days, 8-17)	1.6/1.6
Salt-spray test room	22/23 (under floor heating)	1 (5 days, 8-17)	1.6/1.6
AHU room	-/24 (no heating device)	12 (always on)	-/0.44
Technical LVI room	-/24 (no heating device)	12 (always on)	-/1.7
Oil tank storage	15/40 (air exchange with OLK hall)	-	-/-
Plenum	-	-	-/-

Technical Plant: Geothermal Loops and Heat Pump Control Logic

Energy Piles Field

The energy pile system was based on steel foundation piles and used Uponor double-U collectors, material PE-Xa. Each pile was 11 m in length and had a diameter of 115 mm. The brine was ethanol with a concentration of 28%. Under the building, the first filling layer was light-weight aggregate, then a clay layer extended to a depth of 11 meters. (AXSuunnittelu 2016, 5.)

Energy piles field was modelled with IDA-ICE borehole model extension version 1.1. The 3D model is based on a superposition of cylindrical 2D fields around each borehole and a 1D vertical field for the undisturbed ground temperature which considers the ground surface temperature (EQUA SIMULATION AB 2014, 2). There were two main relevant restrictions in the author’s model: Homogeneous ground property and Constant borehole resistance.

Because there were altogether 60 energy piles with the same properties, distributed almost systematically under the building, the author decided to implement a symmetry option in borehole model. This was the most effective way to speed up the simulation time. The principle was that the software calculated a small section and mirrored the result around x and y axis. In order to facilitate this mirroring, some of the pile coordinates input had to be changed to get the symmetric pattern. The building was also translated so that the modeled pattern fitted (The drawings showing detailed distribution of energy piles in reality can be seen in Appendix 3).

In this model, the piles on the virtual x-y axes will be mirrored once while the others twice. As a result, the location of only 17 energy piles was needed, instead of 60 different ones (Figure 24). The speedup was roughly 3.5 times faster than conventional build-up.

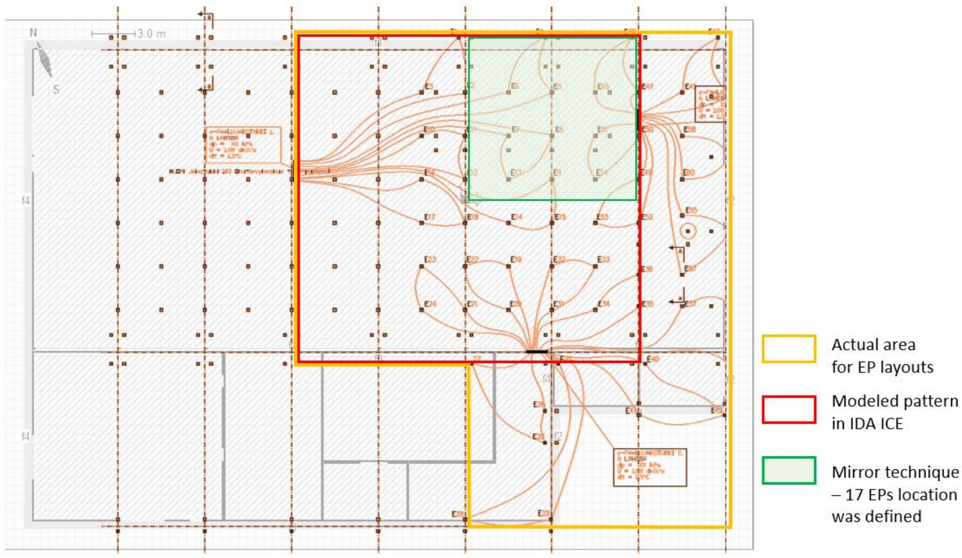


Figure 24. Energy Piles field of the actual building and how it was modelled in IDA ICE

In the default borehole model, the ground surface is connected to ambient temperature. However, for this energy pile model, the ground surface variable was linked to the computed variable of temperature below the floor slab. The purpose was to consider the heat loss from the floor to the ground, which directly affects the heat extraction and recharging of energy piles. The reasons for such modification (although not exactly similar steps) are described in more details by Fadejev and Kurnitski (2015) in a study: Geothermal energy piles and boreholes design with heat pump in a whole building simulation software.

It should also be noted that since no thermal test response (TRT) was done for this site, energy pile thermal resistance input was calculated by an estimation equation (developed for borehole application) from ASHRAE Transactions (Shonder & Beck 1999, 458-466):

$$R_b = \frac{1}{2\pi k_g} \ln\left(\frac{d_b}{d_p\sqrt{n}}\right)$$

Where:
- R_b is borehole thermal resistance (m.K/W)
- kg is grout thermal conductivity
- d_b is borehole diameter (m)
- d_p is pipe diameter (m)
- n is number of U-pipes

Thus, in our case, we got a thermal resistance:

$$R_b = \frac{1}{2\pi \times 2.1} \times \ln\left(\frac{0.115}{0.025 \times \sqrt{2}}\right) \approx 0.09 \text{ (m.K/W)}$$

Table 6 listed the main input for the energy piles model.

Table 6. Input for energy piles model.

Parameter	Value
Mean temperature in ground (°C)	8
U-pipe amount	2
U-pipe outer diameter (mm)	25
U-pipe wall thickness (mm)	2.3
Mass heat capacity of pipe wall (J/kg.K)	2300
Heat conductivity of pipe wall material (W/m.K)	0.35
Ground (Clay) heat conductivity (W/m.K)	1.1
Mass heat capacity of ground (J/kg.K)	1500
Density of ground (kg/m^3)	1300
Surface layer (Light-weight aggregate) heat conductivity (W/m.K)	0.1
Mass heat capacity of surface layer (J/kg.K)	1000
Density of surface layer (kg/m^3)	400
Grout (Concrete based) heat conductivity (W/m.K)	2.1
Mass heat capacity of grout (J/kg.K)	880
Density of grout (kg/m^3)	2200
Brine (Ethanol) heat conductivity (W/m.K)	0.43
Brine freezing temperature (°C)	-17

Heat wells

Heat wells, in other words, boreholes model shared many common properties with energy piles model. The main differences to the energy piles model were:

- Each borehole was 200 m deep.
- The ground was granite, instead of clay. Therefore, the ground heat conductivity was 2.5 W/m.K; mass heat capacity was 790 J/kg.K and density was 2800 kg/m^3.
- Ground surface temperature variable was connected to ambient air temperature variable.

Solar collectors

A total of 24m^2 of Ruukki Classic solar collectors were installed on the roof of the AHU zone. The units were flat plate collectors. All input properties were taken from manufacturer’s brochure (Figure 26). The circulating liquid was Propylene glycol 50% which had a freezing temperature of about -32°C. The stated output was 15kW when the flow reached 0.12l/s (AXSuunnittelu 2016, 16-17).

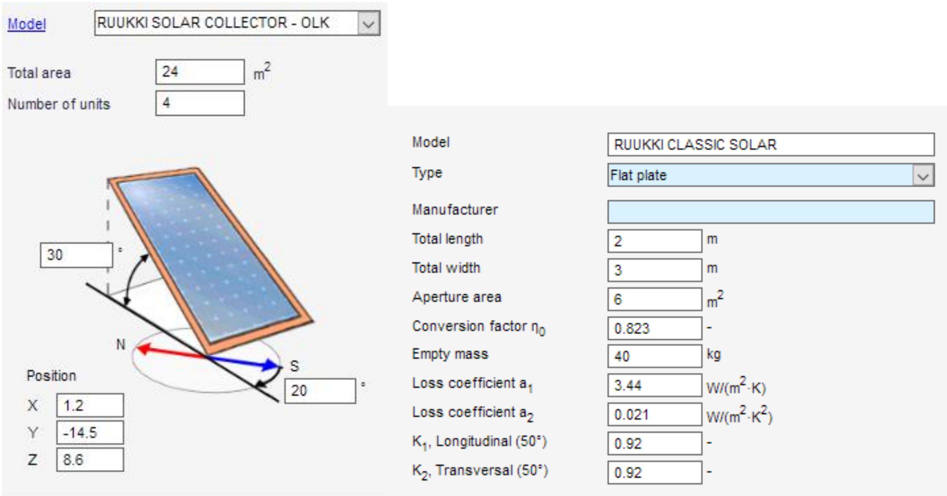


Figure 25. Solar collectors properties and orientation supplied to IDA ICE

Heat pump

The plant used a Gebwell T2 heat pump. The capacity was 32 kW which covered up to 40% of the design heat load at ambient air temperature of −26°C. The author took the default "brine to water heat pump'' model in IDA ICE and modified some of its parameters and rating conditions, according to the manufacturer's data sheet, as well as standard EN 14511-2:2013 (Section 4, Table 9).

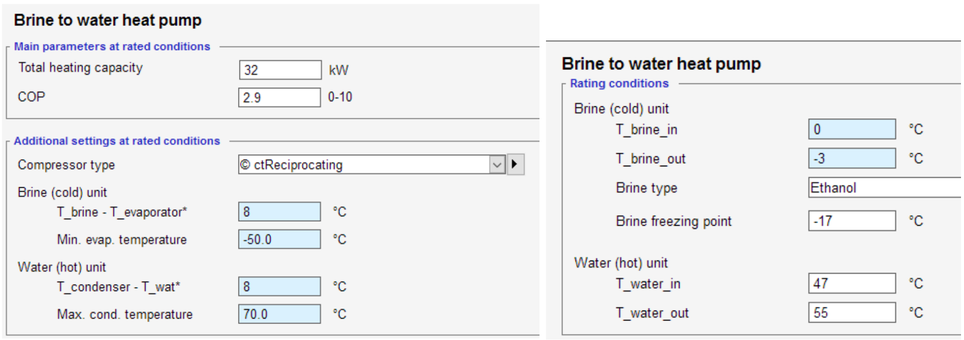


Figure 26. Heat pump parameters supplied to IDA ICE

Connection and Control Logic

– Heating season
  For the evaporator side of the heat pump, there were two separate connected loops, one with the energy piles and the other with heat wells. The condenser side of the heat pump was linked to an ideal stratification tank. An electric boiler is also connected to the same hot water tank to cover the rest of building peak heating loads in extreme cold days or additional heat for DHW production.

The maximum design flow in the system was 4.9 l/s (3.24 l/s flow from energy piles and 1.65 l/s flow from heat wells) (AXSunnittelu 2014). The heat pump would operate full load whenever there was a heat demand and the temperature in one of the loops was above the set point of 0°C. The purpose of this set point was to prevent formation of ice in the ground, which in real life would be the leading root to frost heave.

It was modelled with two thermostats. The dead band for both thermostats was 1°C, actually letting the brine temperature a possibility to be as low as -0.5°C before giving a signal 0, ''turn-off'' to the circulation pump in the relevant loop. Additionally, to minimize the risk of numerical errors and lengthy simulation time, a signal smoother was inserted before the final signal to the heat pump.

Heat extraction from the hot tank was regulated by a constant set point of 55°C for DHW utilization. In case of AHU hot water and zone heating water, the supply temperature followed a heating curve[10] and the pump operated if the outside the air was colder than 15°C.

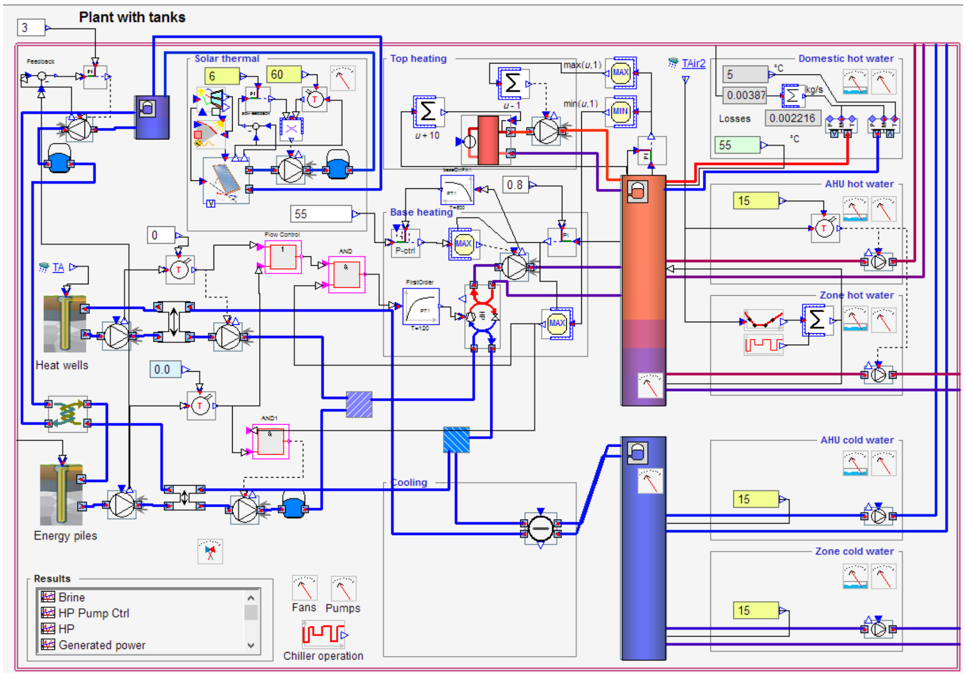


Figure 27. Technical plant of Model 2

– Cooling season
  Cooling equipment consisted of the stratification tank (cold) connected to the heat exchanger which took advantage of the free cooling effect from heat wells loop. The cooling started whenever the heat pump did not operate and there was potential to cool-off the

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[10] A similar heating curve shown in technical plant of model 1 (figure 19)

water (15°C) in the cold tank. In such a situation, only energy wells loop (1.65 l/s) would flow through free cooling heat exchanger.

At the same time, because the heat pump was off, the signal to the secondary pump of EP loop (after decoupler) would also be off. Now, energy piles loop liquid flowed through to a heat exchanger to get possible heat supply (heat charge) from the solar collector tank.

– Any season
  The solar thermal storage tank had water in it and was parameterized to accommodate a volume of 1.5 m^3. In the technical plant model in figure 28, the connecting circuit on the right had propylene glycol 50% (AXSuunnittelu 2016, 7) while the one on the left had propylene glycol 25%.

  From solar collectors loop to the thermal storage tank, a designated control was applied. If the collector temperature was 6°C higher than the tank temperature, the pump would start (AXSuunnittelu 2016, 7-8). The pump speed would increase up to 1.5 time if the maximum temperature 60°C set for the collector was reached. This would be in order to cool-off the collectors faster when the collected heat was plentiful.

  The charging from the tank to energy piles would occur if enough heat was available in the storage tank, meaning at least 3°C higher than the temperature from the energy piles circuit side. The principal interaction between solar collectors and energy piles is demonstrated below.

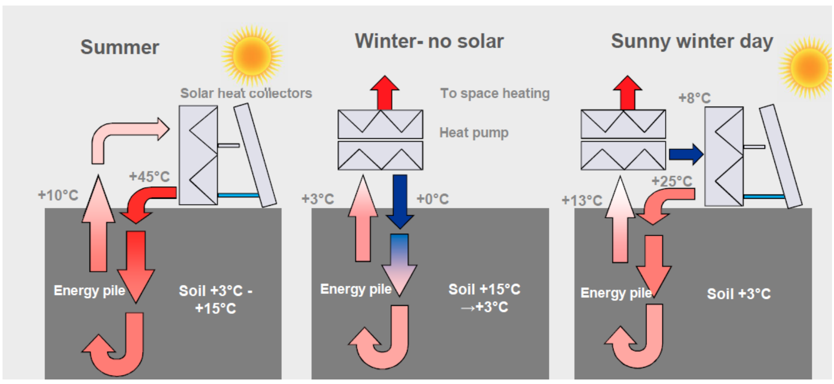

Figure 28. Interaction of solar collectors and energy piles (Kesti 2016)

Main difference in the actual buildings versus the model plant

Table 7 summarizes the most significant differences between the building's technical plant and Model 2's plant.

Table 7. Summarized main differences

	Actual building	**IDA ICE model**
Energy Piles	Non symmetrical	Simplified and symmetrically mirrored
Increased speed of pump from solar collectors to storage tank	Depends on temperature difference between tanks and collectors. (AXSuunnittelu 2016, 8)	Depends on output temperature from collectors
DHW and general heating supply	2 separate tanks	1 tank
Maximum temperature asked from heat pump	63°C (AXSuunnittelu 2016, 10)	55°C

4 SIMULATION RESULT AND DISCUSSION

4.1 Model 1: Heating Load

4.1.1 Simulation result

The simulation report showed that the peak heating power to zones and AHUs was about 69 kW. Figure 29 indicates that the share of the heat for air supply to the room was 16% higher than space heating at that point.

	Max., kW
Zone heating	28.8
AHU heating	40.1
Total	68.9

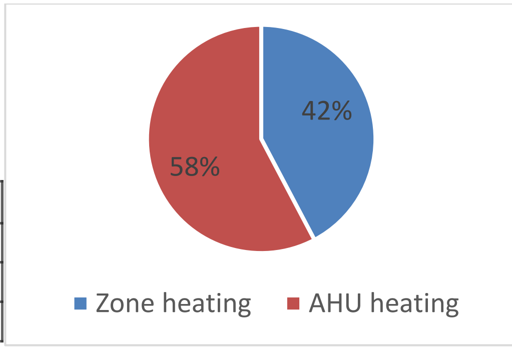

Figure 29. Heating power needs for AHU and zone heating – simulated result

When the ventilation started to run at its full speed at 7 a.m. (one hour before occupant arrival), the supply air flow increased dramatically, which provided a lot of heat to the space. Thus, the heating need for zone (ideal heaters) began to reduce (Figure 30). The opposite pattern occurred around 6 p.m., as ventilation returned to minimal speed. Generally, the trend was quite stable because the outdoor condition was constant for 24 hours.

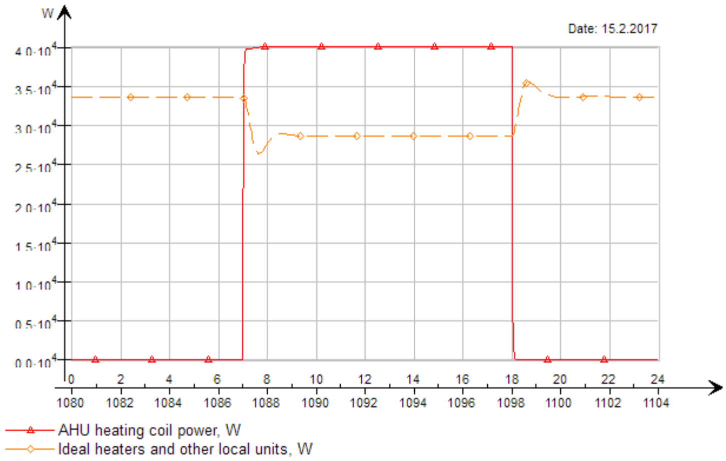

Figure 30. Simulated heating power for supply air and space heating during 24h under design condition

4.1.2 Comparison with design heating load

The building design heat load was originally 84 kW in the planning stage. With model 1, the maximum heat load was hovering around 70 kW, which suggests a reduction of 16.7%. There can be a few explanations:

- At the planning stage, the building shape might have been simplified for calculation. Instead of creating roofs with slopes, the designer often made conventional box-style zones. This often changes the external surface area of the envelope and heat loss associated with it.
- Another point could be that at the planning stage, the highest flow from ventilation was presumed, instead of the real scenario. Model 1 ventilation fan speed equals only half of the maximum design capacity. The reason is the activation of frost protection (-15oC) from control logic. Therefore, the air supply and return from zones resulted in 0.8 l/s/m2 each[11].
- The area/volume that must be heated was smaller than the total area/volume of the premises. This was because in technical spaces and plenum, there was no need for ideal heater devices.
- Zone heating set point was more precise in Model 1 as taken from building operation. At the planning stage, the overall heating set point was 18^{o}C for all modelled zone.

It must be understood that Model 1 was meant for to validating the heating plant's capacity according to the design condition. After all, it proved a checked point for designers and operators. The current system, at a first glance, should be able to serve well in extreme situations, and even has room for extra load, most likely without any upgrade in the heat generation side.

[11] In zone definition, the air flow was 1.6l/s/m2, which is the maximum capacity from the AHUs.

4.2 Model 2: Whole year simulation

The whole year simulation is chosen for period between 1st of January and 31st of December. No holiday was specified so the system ran basically with weekdays and weekends schedules.

4.2.1 Whole building energy performance

Energy balance in zone

As shown in Figure 31, the heat loss through envelope (external walls, roofs, ground slabs and thermal bridge) was the most significant component of energy loss of the building. Internal heat produced by equipment, general lighting and occupants was mostly constant and during winter months, could compensate up to 40% of the heat loss through the envelope.

kWh (sensible only)

Month	Envelope & Thermal bridges	Internal Walls and Masses	Window & Solar	Mech. supply air	Infiltra-tion & Openings	Occu-pants	Equip-ment	Lighting	Local heating units	Local cooling units	Net losses
1	-10617.1	41.6	-1656.0	-446.4	-1577.5	2051.0	920.0	2942.7	8251.8	-0.0	79.4
2	-9662.3	-9.5	-556.7	-574.1	-1616.9	2017.8	879.9	2942.7	6499.5	-0.0	74.3
3	-9050.2	-42.2	823.1	-706.1	-1493.9	2220.5	948.6	3223.7	3989.2	-0.0	79.4
4	-6970.8	-68.1	2710.1	-1201.8	-941.4	1916.1	899.8	2941.4	732.2	-89.2	71.8
5	-4830.3	-19.4	3550.2	-2648.7	-780.3	1702.6	934.2	3082.7	39.0	-1064.0	20.1
6	-3599.2	-53.8	3866.9	-3144.5	-631.8	1616.5	914.1	3082.6	15.7	-2037.6	-36.7
7	-2624.4	-38.6	4514.3	-3189.8	-622.5	1474.5	920.0	2942.7	1.6	-3278.9	-103.2
8	-2798.4	55.0	3148.3	-3348.3	-695.0	1648.2	948.4	3222.2	0.6	-2157.7	-40.8
9	-4731.8	31.1	2327.6	-2539.1	-679.0	1751.9	914.0	3081.2	24.4	-254.6	62.6
10	-5492.5	91.7	-124.3	-1011.5	-830.0	1981.8	920.0	2942.7	1412.8	-0.0	79.4
11	-7813.8	33.1	-1087.5	-546.4	-1161.3	2162.7	914.1	3082.5	4326.6	-0.0	76.8
12	-9579.1	10.2	-1521.9	-475.8	-1513.7	2159.0	934.2	3082.6	6809.9	-0.0	79.4
Total	-77770.1	31.1	15994.2	-19832.6	-12543.3	22702.6	11047.5	36569.4	32103.4	-8882.0	442.5

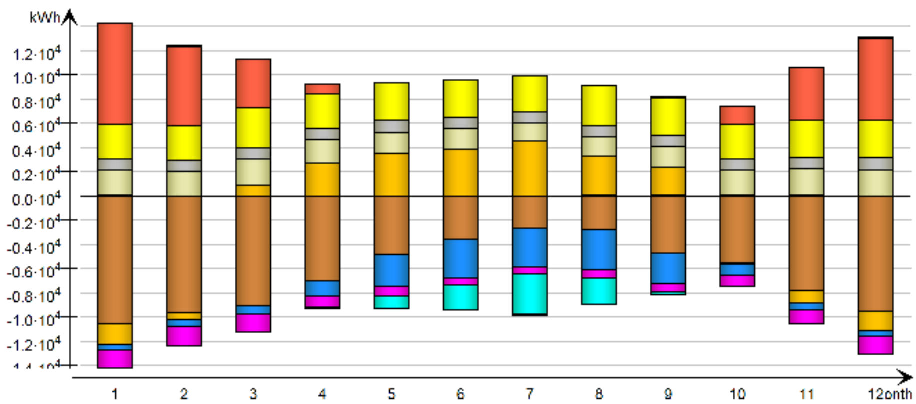

Figure 31. Whole year energy balance of Sheet Metal Center

Zone heating was operating mainly from October until April, with the highest load in January and December. Positive energy gain through windows (net of radiation heat and transmission loss) occurred from March till September, tipping at 4513.4 kWh in July. The system cooling load picked up between May and September, closely followed the main trend of solar gain.

From cold months to warm months, the energy pattern, in form of heat loss by infiltrations, decreased. It was largely because the temperature difference between indoors and outdoors got smaller. In summer months, as heat gains was high and inside it was even hotter than outside occasionally, the mechanical supply air would then help to cool down the building and was seen as a noticeable loss in Figure 32 above.

Required Energy

For the building to operate, a total 125094 kWh of heat and electricity was required. Table 8 in the following page shows the simulation result in details. Energy for heating took up the biggest part, about 43%, while general lighting came at second, almost 30% out of the total energy need of the building. The cooling load, electricity for fans, pumps, and other auxiliary equipment made up for the rest, ranging from 5% to 8%.

Table 8. Simulated energy needs in a whole year

	Energy needs (kWh)	**%**
Heating energy	53679	42.9
- DHW	9912.2	
-AHU heating	8098.3	
- Space heating	35668.8	
Cooling	9876.6	7.9
Fans	10344.8	8.3
Pumps	7718.6	6.2
Lighting	36569	29.2
Other auxiliary devices	6906	5.5
Total On average	125094 84.3 kWh/m^2.a	100

A breakdown of energy for heating can be seen in Figure 32. Domestic hot water production was uniform throughout the year. Zone heating and AHU heating had different values but follow a fairly similar pattern. Energy for cooling presented primarily in summer months. Overall, the trend reflected the Finnish climate clearly.

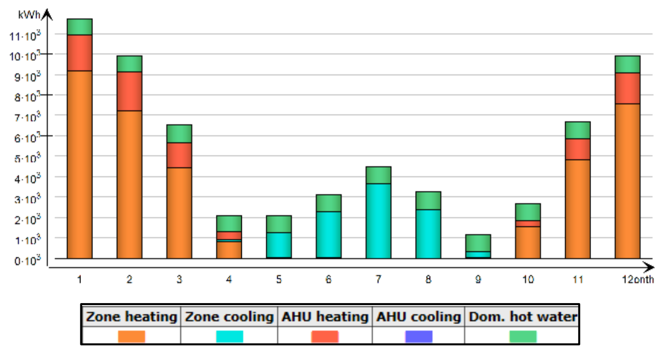

Figure 32. Simulated heating and cooling energy needs of Sheet Metal Center

Purchased Energy

The simulated purchased electricity was 81625kWh, which was about 0.65 times the needed energy of the building. The difference came from the efficient heat pump and “free cooling’’ solution of the plant. The full result can be seen in Table 9.

Table 9. Simulated purchased energy in a whole year

	Energy purchased (kWh)	**%**
Heating electricity		
- Top-up heating	6536.3	8%
- Heat pump	13551.6	17%
Cooling	0	0%
Fans	10344.8	13%
Pumps[12]	7718.6	9%
Lighting	36569	45%
Other auxiliary devices	6906	8%
Total On average	81625 55 $kWh/m^2.a$	100%

System operation

The simulation result further showed that the heat pump compressor consumed 13551.6 kWh and total condenser production was 478120 kWh, which equaled to an overall heat pump seasonal coefficient of performance (SCOP) of 3.53. In terms of the whole heating system, considering the sum of electricity for top-up heating, pumps and heat pump compressor as input, we got 27806.5 kWh. The output in this case was the generated heat of 53679 kWh, which resulted in a SCOP of 1.93.

The temperature of the supply brine to the evaporator side of the heat pump is presented in the coming Figures 33 and 34. In the cooling season, the same brine temperature represented the free cooling loop inlet temperature. The entering brine temperature peaked at +17°C in August, when the cooling was active and the flow through heat pump was only 1.6 l/s.

During winter operation, HW loop worked constantly (flow rate 1.6 l/s) while EP loop pump was on-off quite often. The reason was due to the control program described in sub-section 3.4.4, which attempted to keep the outlet temperature of both energy piles and heat wells loops stayed above 0°C. Exception occurred for only a short period on February 1st. At some point HW loop stopped but EP loop was still delivering to the heat pump (flow rate around 3.3 l/s). As the heating load was big for only energy piles loop to cover, quickly, it turned to almost no flow in the system, which

[12] Electricity used by pumps for solar collectors’ loops are also included here.

meant the outlet temperature from both loops dropped below 0°C at the same time.

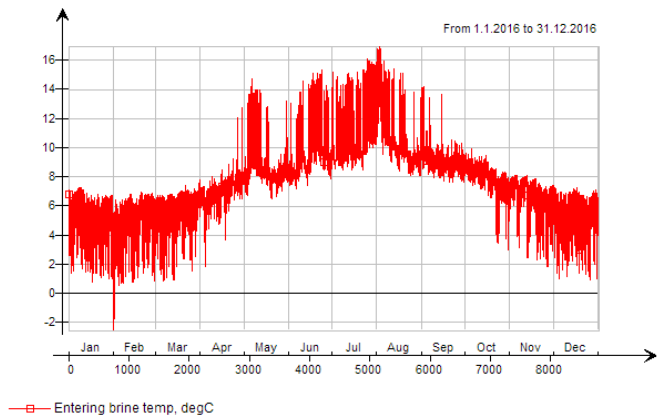

Figure 33. Entering brine temperature to evaporator side of heat pump

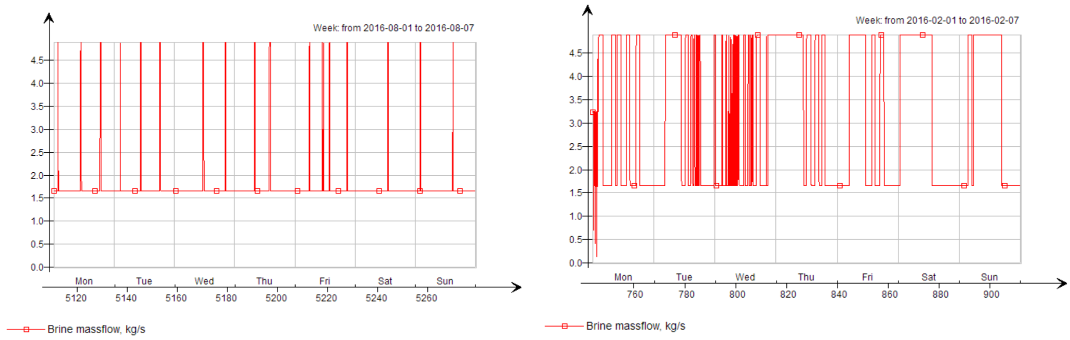

Figure 34. Entering brine mass flow to evaporator side of heat pump in 2 representative weeks

Energy piles and solar collector

The collected energy from solar collectors was modelled and resulted in roughly 14.8 MWh for the whole year simulation. The peak power reached 15.7 kW in July, as shown in Figure 35. During the main active season, between April and September, the temperature from the collector loop to storage tank managed to be above 30°C for most of the time (Figure 37).

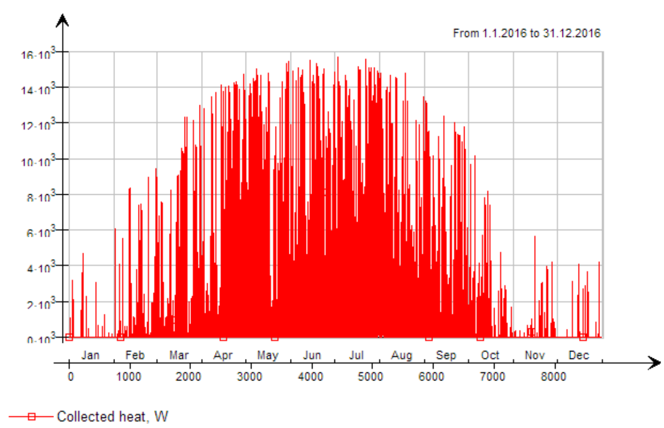

Figure 35. Simulated collected heat from solar collectors

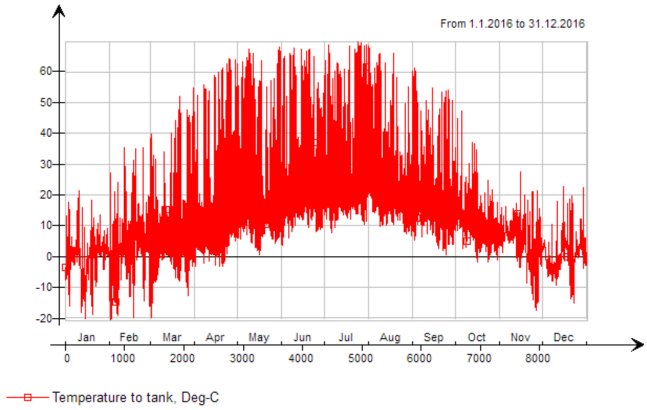

Figure 36. Temperature of Propylene glycol from solar collectors to thermal storage tank

The temperature of Propylene glycol from (heat exchanger inside) the thermal storage tank to charge energy piles was maintained between 10°C and 30°C for the same period (Figure 36). This temperature was greatly lower than the temperature of the supply flow from the solar collectors (to the tank) because of the storage tank volume, 1.5 m^3. The time that took to heat up the whole tank was significant. Additionally, both flows mostly happened at the same time, whenever the potential heat fulfill the control logic described in sub-section 3.4.4. The positive effect on EP loop can be recognized as the temperature of the outlet liquid started to raise and eventually rich its highest point, 13.7°C on the first day of August. The developments are displayed in Figure 37.

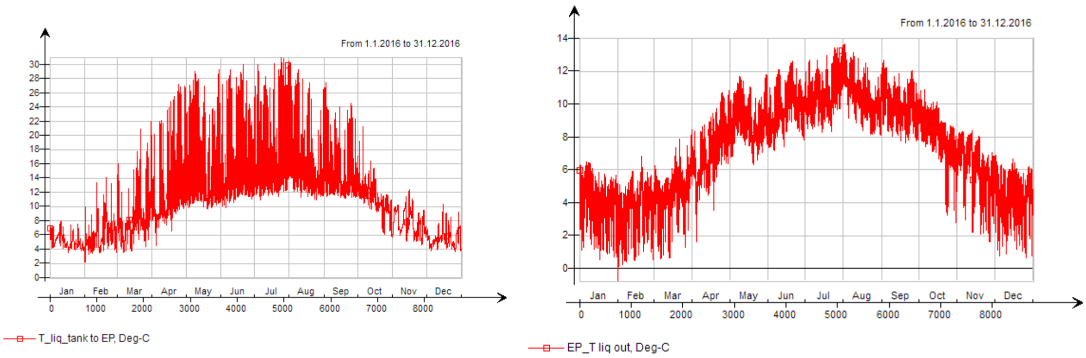

Figure 37. Upper: Temperature of Propylene glycol from heat exchanger in thermal storage tank to heat exchanger with EP loop
Lower: Temperature of the outlet liquid from EP loop

Heat wells and free cooling effect

Generally, the outlet brine temperature from HW loop was about 1-2°C higher than from EP loop. In May and the second half of August, because heating and cooling needs appeared intermittently, the temperature of the fluid showed noticeable fluctuation comparing to its counterpart development in EP loop (Figure 38).

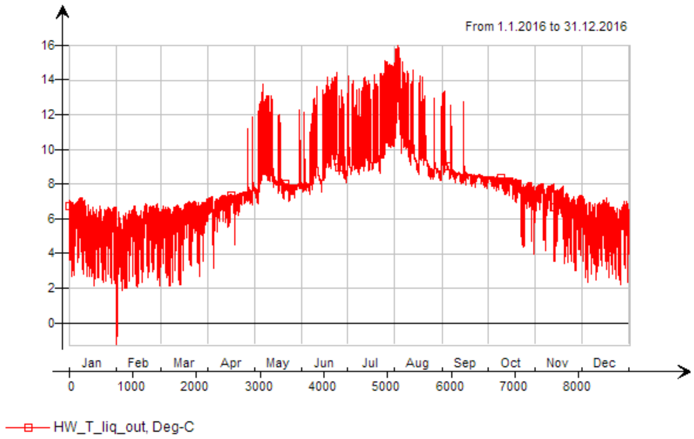

Figure 38. Temperature of the outlet liquid from heat well loop

The increase of brine temperature during summer was due to the excess heat from the halls, transferred by cooling effect of radiant ceiling panels. According to the simulation, the fluid peaked at 16°C (Figure 39), but the radiant panels could not manage to keep indoor air temperature at desired set point of 25°C during the whole season. In OLK hall and Ruukki hall, the amount of unmet cooling hours[13] was close to 17% and 6% out of total simulated hours (May-August), respectively (Figure 39).

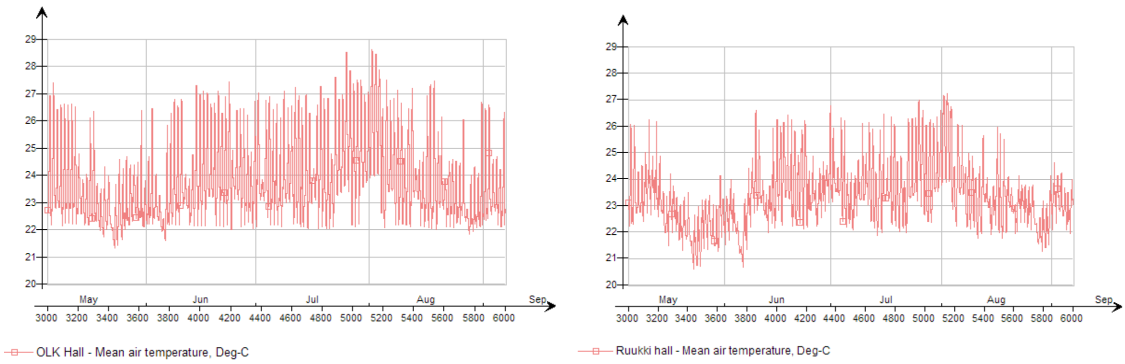

Figure 39. Mean air temperature in OLK hall and Ruukki hall during cooling season

4.2.2 Compliance with nZEB definition

The latest draft regulation on Finnish nZEBs definition was made available in February 2017. The primary weighting factor for purchased electricity is defined as 1.2. Some of the key points from the energy efficiency requirements are:

– For commercial hall category, EPV should be ≤ 135 kWh/m2.a (Ympäristöministeriö, 2017), which also corresponds to energy class

[13] Unmet cooling hours meant the total time (during the simulated period) when the mean air temperature in zone is above the cooling setpoint plus the tolerance parameter given in System parameters (1°C by default). This measure is frequently used in ASHRAE standards.

“B” in the current European Energy Directive (DIRECTIVE 2012/27/EU on energy efficiency/2012).

– Air leakage is not more than 4 $m^3/h.m^2$
– The mechanical ventilation system with supply and exhaust fan specific electric power (SPF), each should not exceed 1.8 kW/(m^3/ s)

Other points are not a must if EPV is followed, but often they are valuable for designing to achieve nZEB:

– District heating, the geothermal heat pump or the air-water heat pump must be used as a heating source for the building.
– Annual efficiency of heat recovery from extract air is not less than 70%.

A summary of general assessment for SMC case from simulation result is shown below in Table 10.

Table 10. Comparison between simulation result and design of SMC with Finnish nZEB requirements

	SMC	**Finnish nZEB**	**Compliance**
EPV[14] (kWh/m^2.a)	66	135	x
Air leakage ($m^3/h\cdot m^2$)	0.76	4	x
Supply/Exhaust fan SPF (kW)	1	1.8	x
Heat source	geothermal heat pump	District heating/ geothermal heat pump/ air-water heat pump	x
Heat recovery in AHUs (%)	80	70	x

There was no official definition of nZEB in Finland at the time of constructing SMC. Now, according to the simulation result, at a first glance, it is clear that SMC would fulfil the draft regulations on nZEB. However, it should be noticed that there is still room for adjustment and improvement, such as the cooling arrangement in summer. The new regulation generally lets room temperature (occupied hours) between 20°C and 27°C outside the heating season. From previous graphs, the scenario in the hall areas tends to occasionally get above the recommended range.

[14] The reduction from PVs are not included yet.

4.2.3 Comparison with metered data

The metered data shown in this sub-section was in monthly intervals from the reading records for period January 2016 to February 2017. The normalization was done for heating energy consumed for AHUs and space heating. It is based on heating degree days data of Lahti station from Finnish Meteorological Institute (FMI). FMI defined a map of regions so that the consumption of heating energy could be standardized to compare buildings in different municipalities. Hämeenlinna belongs to the region with the main station in Lahti.

Solar collector performance

IDA ICE provided a whole year possible 14.8 MWh-heat-collected from solar collectors while the actual measurement in 2016 showed a final 16.1 MWh. The difference accounted for just 8%. On average, the simulation result pattern fitted well with the recorded meters in 2016, from January to April and from August to December. Between May and July, the development of simulation and measurement was opposite to each other, which resulted in a total deviation of 0.73 MWh, in other words, about half of the overall difference. Figure 40 presents the all the normalized data and simulation result in form of a column-graph.

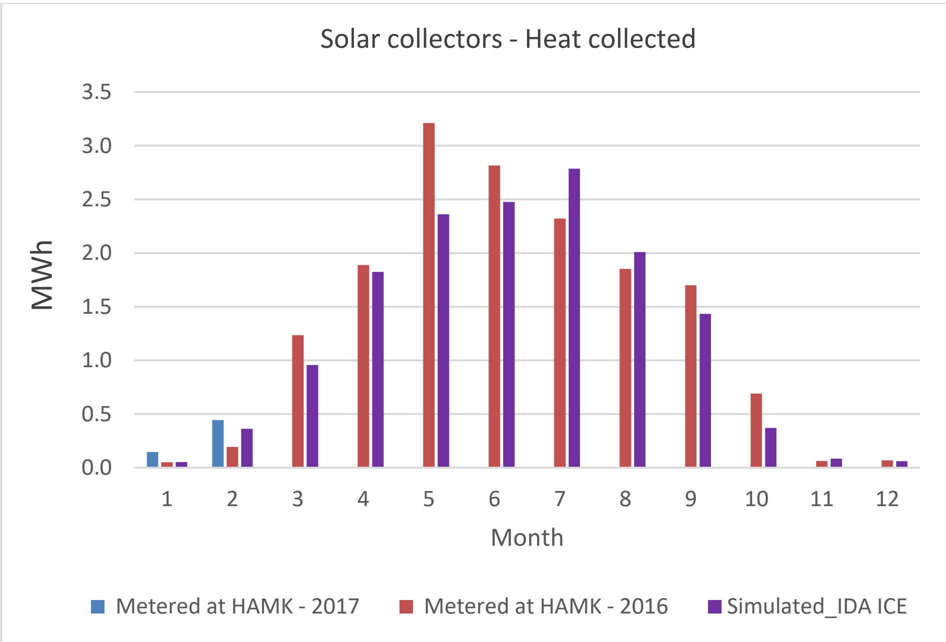

Figure 40. Heat collected from solar collectors - comparison between simulation and metered reading.

When looking only at January and February, it can be seen that the measurement in two consecutive years have their own variation. During the first two months, the same collectors yielded 0.59 MWh in 2017 while 0.24 MWh in 2016, which means 2.5 times less. The simulation, on the other hand, suggested a value of 0.41 MWh, which is very much close to an average of 2016 and 2017. Thus, it was likely that the deviation was more or less resulted from the actual weather at the location.

AHUs heating

In 2016, SMC used 27.5 MWh in term of heat to warm up the supply air. The simulation of a whole year from IDA ICE predicted solely 8.1 MWh for the same purpose. When looking at the comparison more carefully, such a huge discrepancy came mainly from January, followed by February. For the rest of 2016 and even the first two months of 2017, however, the meters demonstrated a completely different picture, where the values were much closer to IDA ICE simulation (Figure 41). The initial likely reason behind the dissimilarity between 2016 and 2017, as well as with the simulation result is possibly some technical errors in ventilation (e.g. heating coil, heat recovery), certain special operation (e.g. continuous opening of the large service doors, manual adjustment of controls) and/or combination of those.

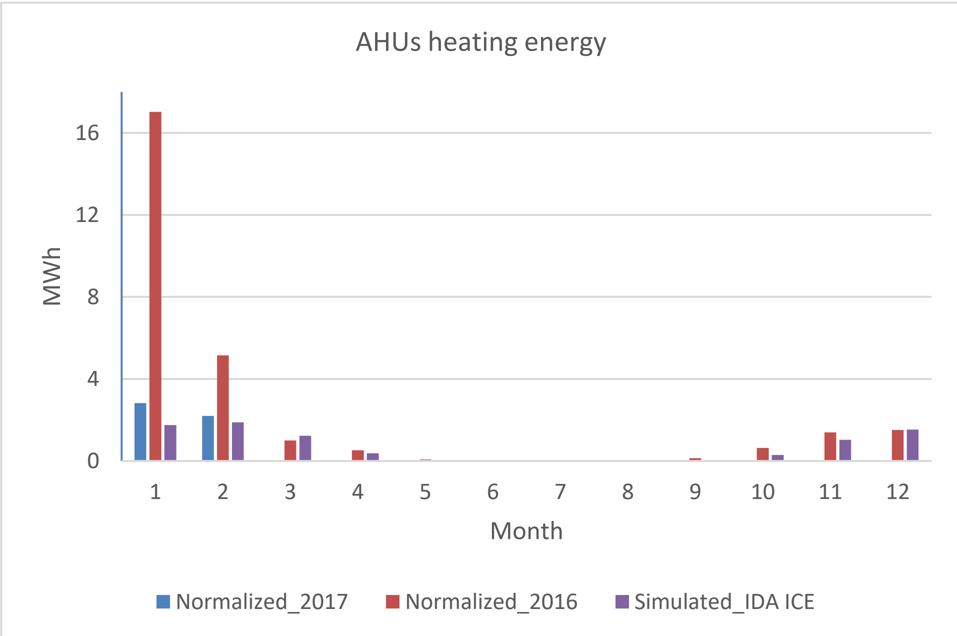

Figure 41. AHUs heating energy - comparison between simulation and normalized metered reading

Heat pump's heat generation

The project was interested in one aspect which was the performance of the ground source heat pump. Although electricity consumption data was not available, the author managed to collect the data of heat production from the heat pump (including DHW production, normalized space heating and normalized AHUs heating). The comparison with the energy calculation from simulation is illustrated in Figure 42. As a sum, a whole year IDA ICE simulation was barely close to 50% of the calculated data of 2016.

The model projected a predictable trend for heat pump production along with warm and cold months, being highest in January, then constantly reducing to almost a plateau[15], from May until September, before starting to pick up again from October. On the contrary, the data of 2016 showed various fluctuation from October to April, but as a distinction, was much higher than IDA ICE projection, with an exception of December. For instance, in October, the meters reported about three times higher than the simulation result. For the data of the beginning of 2017, a great gap was also present. For transition months and during cooling season, a.k.a. May to September, the overall difference in numerical values was rather insignificant.

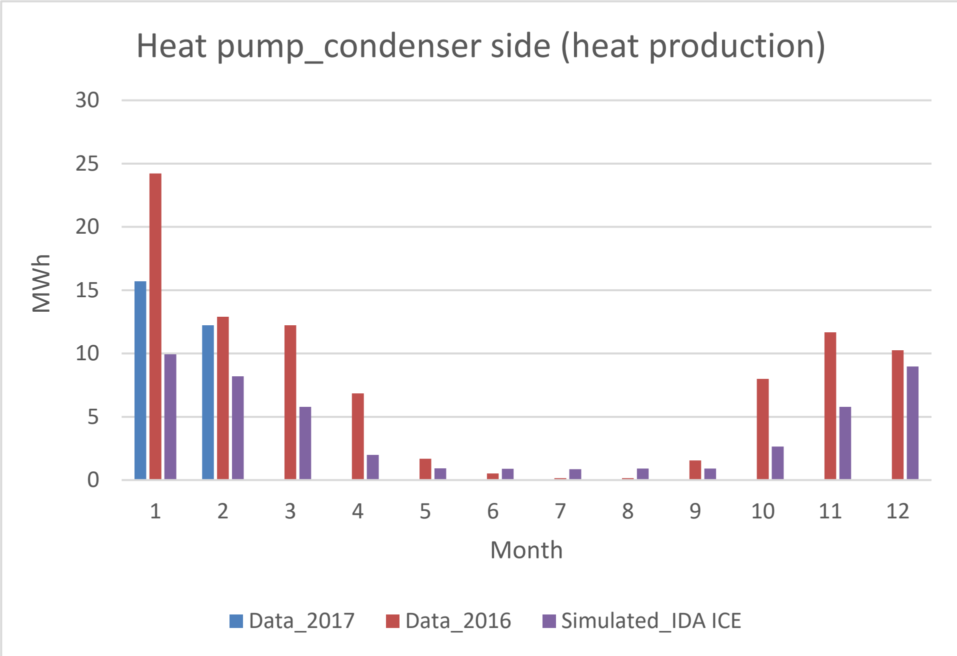

Figure 42. Heat pump heat production - comparison between simulation and normalized metered reading.

Because heat pump is the main heat source of the heating system, given the enormous influence of weather conditions on the building, the first suspected cause for this deviation of simulation results is the climate profile. Helsinki reference year might not be adequate. The second thought, which in fact, may be as significant as the first to the root of the error, was possibly the way the model plant was built. In the real building, there are two water tanks receiving the flow from the heat pump. One tank is for DHW usage, and the other for other heating purposes. One must understand that the heat production, partly regulated by how high the delivered temperature and how much the delivered flow should be, is associated with the signal from water tanks. However, the author in this thesis, chose to represent the system with only one hot tank. The third reason could be related to possible unknown manual adjustments of facility management personnel during the period between 2016 and 2017. Last but not least, the assumption of DHW

[15] The heating needs from May to September is heavily shared by hot water production, which is evenly distributed monthly.

consumption and other boundaries, as well as system schedule was likely too standardized. It is believed to have a certain impact on the poor results of some parts in the simulation. In section 5, a brief proposal for further calibration and analysis is presented.

4.3 Problems Encountered

The author acknowledged that the absence of fundamental knowledge in the beginning hindered the work significantly. Because of the background in Structural Engineering, the transition took a considerable time to get the first satisfaction with the simulation results.

The second model required a great deal of input information, as well as custom built sub-systems. Because minor changes can easily make notable differences, the repeated process of collecting data, modeling and validating took much more time than the author’s expectation.

Some data was unavailable or difficult to assess, such as heat generated by equipment, heat transfer coefficient from heat exchangers to water tanks and so on.

Originally, the metered data from the monitoring system was supposed to be well accessible. However, due to technical errors, many recordings were considered unreliable. Only few fairly good measurements were discussed in sub-section 4.2.3.

5 PROPOSAL FOR CONTINUING RESEARCH

5.1 Potential Areas for Model Improvement

Ultimately, the goal is to have a good base model before calibration for future purposes. With the basic comparison in sub-section 4.2.3 and discussion with other professionals, several areas, which should or could be improved, were already noted in the modelling approach.

Input

Climate Profile
Weather, such as wind speed, sky clearness, temperature, constant changes, from year to year, from location to location. Though IDA ICE has been developed for the purpose of generating synthetic weather data from the reference weather profile as input for places, where the actual data is not available, the risk of jeopardizing the results may still be significant. It is therefore important to supply a more accurate, real-time actual-location-based micro-climate profile.

Schedules

It is no denial that a realistic schedule set-up for internal heat gains and plant operation, even occupant behaviors (e.g. regular door opening) plays an essential role in ensuring a reliable simulation result. The current models more or less, take a standardized and simple approach. To improve the simulation performance, up-date system operation data, testing schedule (which involves significant heat generation), actual usage routines and so on need to be considered.

Equipment heat generation

As stated before, the thermal load from laboratory instruments and machinery in SMC often fluctuates and can rise enormously for a considerable period. For example, a fatigue test that runs with the new hydraulic machine can be continuously for days or even weeks. A better approach to this may be the automatic logging of actual equipment power use and usage of a weighting-factor for calculating the sensible load from them. The value should be continuous or adequately periodical to be used in form of an input schedule for simulation.

Technical Plant

At the moment of writing, there is one main point that the author believed that should be investigated in the next model change. It is a better approach to represent two hot water tanks for heating purposes. Apart from that, incorporation of PV panels, though adding to computational time, is another interest.

Boreholes model

IDA ICE borehole model was designed at the first place for the simulation of borehole field (HWs), not specifically for EPs. Besides, in this report, the model used a simplified field layout with mirroring technique. There have been few studies about the application and modelling of EPs with IDA ICE. The overall impression is that the modification from the original default model and field simplification needs thorough understanding and experience. Thus, it is essential to pay attention to improvement and justification of HW and EP models in future application.

Another noteworthy point is that later the author got access to more information about the values used in the design process. The borehole resistance value K/(W.m) used by designers was 0.11, instead of 0.9 as in this modelling process. The number 0.11 was the reference value from a test side which was in close proximity (about 2.5 km) with the building site. Such information should also be considered for validation/calibration process.

5.2 Proposed Plan for Calibration

The accuracy in simulation programs depends largely on the ability of the user to supply reliable input parameters and model appropriate HVAC system. The computed results are expected to resemble the measured data up to a certain extent in order to allow good analyses to be made for study or development. The closer the match, the better the outcome of future application. (Claridge 2011, 374.)

After this thesis, along with modelling improvement (comparative testing), a proposed plan for calibration (empirical validation) of the base model is summarized below:

Data preparation

- Make sure to have a period of an applicable level of uniform HVAC system operation
- Do logging of equipment heat gains
- Record the temperature in EPs, HWs and other ground measurement at start, and throughout the period.
- Supply a climate profile generated from a weather station on site

Process

- Supply the input of climate and heat gains from preparation.
- Check and modify if needed so that IDA ICE model matches all the current control logics and set-point for the relevant period
- First run the simulation. Then analyze and compare the result with both measured data from automation and independent monitors. Change likely parameters, rule of thumb as one parameter at a time, in a new direction. This process is repeated until an acceptable low difference is achieved

Recommendation

- The minimum time for data preparation, in other ways, data monitoring should be at least 2 full weeks. This is to assess the transition of energy usage from weekdays to weekend and vice versa.
- The ideal time for such validation should be during either an only-heating-season or only-cooling-season. The transition time often is more complicated to correct or adjust the model.
- The author suggested the simplest target for base calibration is compliance with methods and threshold in ASHRAE Guideline 14-2002.
- Attention should be paid to the soil behaviors also as it put great influence on the heat pump performance. One way is to ensure a reasonable start-up time and preliminary parameters.

5.3 Possibilities of Other Applications

Simulations can be valuable tools in diverse applications, especially when a calibrated model is made available. While in this report, the focus was primarily on the whole-building energy performance prediction, the software, IDA ICE itself could have been used for several studies, such as thermal comfort and lighting, simultaneously.

Here are some further possibilities:

– Study on the building indoor environment and different ventilation control strategies
– Study on daylight and possible impact of lighting control on energy consumption
– Study on different combined control code and optimize automation system for energy savings
– Research about behavior of a heat pump and/or long-term performance of energy piles and heat wells combination
– Research about the long-term performance of energy piles with thermal storage by solar collectors
– Tools for on-going commissioning and fault detection in operation
– Study on certain equipment at component scale and its performance at the whole building level

6 CONCLUSION

The aims of the thesis were to create feasible energy models of the current Sheet Metal Center building and to assess the effort needed to be invested from a modeler with indirect engineering background.

Most of the materials related to the building were provided either by HAMK or Ruukki Construction while modeling technique with IDA ICE (v4.7.1) were supported by EQUA Finland Simulation Oy, as well as referenced from external research publications. The whole modelling process lasted for several months. The work was part-time and the information for input changed a lot. Plenty of information was first supplied from the drawings and documents from planning stages, then updated one was revealed later.

The focus of the modelling in this context was the process itself and the results aimed at the general building energy performance. Thus, some of the local ventilation and cooling was skipped or modified. All in all, the heating energy could be more precise than cooling energy delivered in the report.

The first model showed a direct indication of a good job of the designers when sizing the heating equipment. The second model, taken a lot of details and consideration, at a quick look backed up the statement of nZEB compliance of Sheet Metal Center. However, the simulation result itself, had some significant mismatches with the building's real metered data. The author presented some opinions on this matter and suggested that climate profiles, internal heat generation and plant modelling approach might be the main sources of such difference.

Regardless of the discrepancy, the model was rather thorough and improving the quality of results should be possible. When a good calibration model is done, the output data can be investigated for much more extensive analyses. Furthermore, such a model and results from this modelling work would be invaluable in many other application, namely a few in sub-section 5.3.

After conducting this modelling work, it has become clear that an energy model indeed needs a lot of effort to achieve reasonable results. IDA ICE was designed for construction professionals to use, particularly at the early design stage. It could also be utilized during post occupancy. For an energy efficient building, this is becoming a natural part of the process, since everyone wants to learn and will benefit from how the building performs in a long term in practice.

To conclude, in the author's opinion, Finland already has the technology and capabilities to start transitioning towards the near-zero-energy-buildings. To ensure the quality of initial design throughout the building lifetime, there is still a great deal of questions to be answered. These can be supported by practice of good energy simulation and follow-up analyses.

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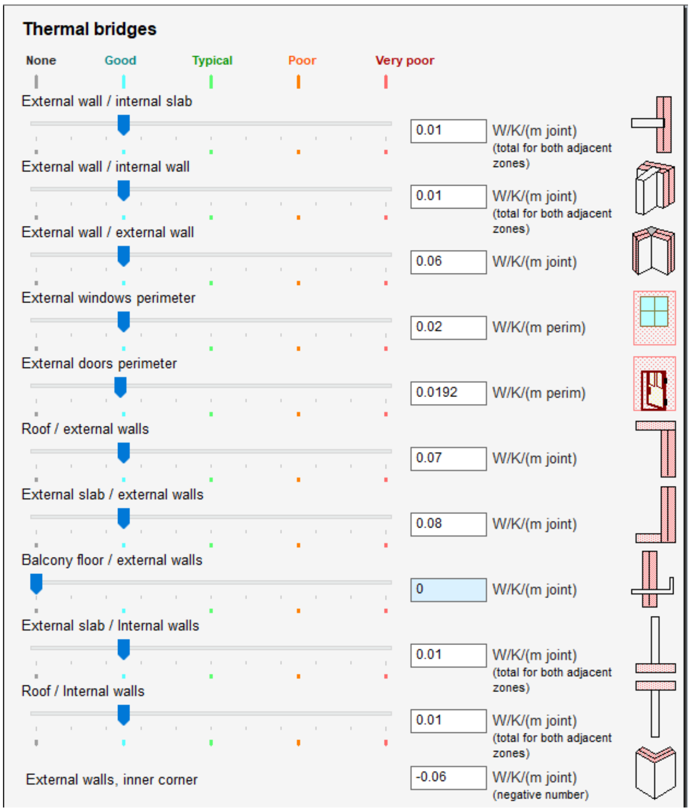
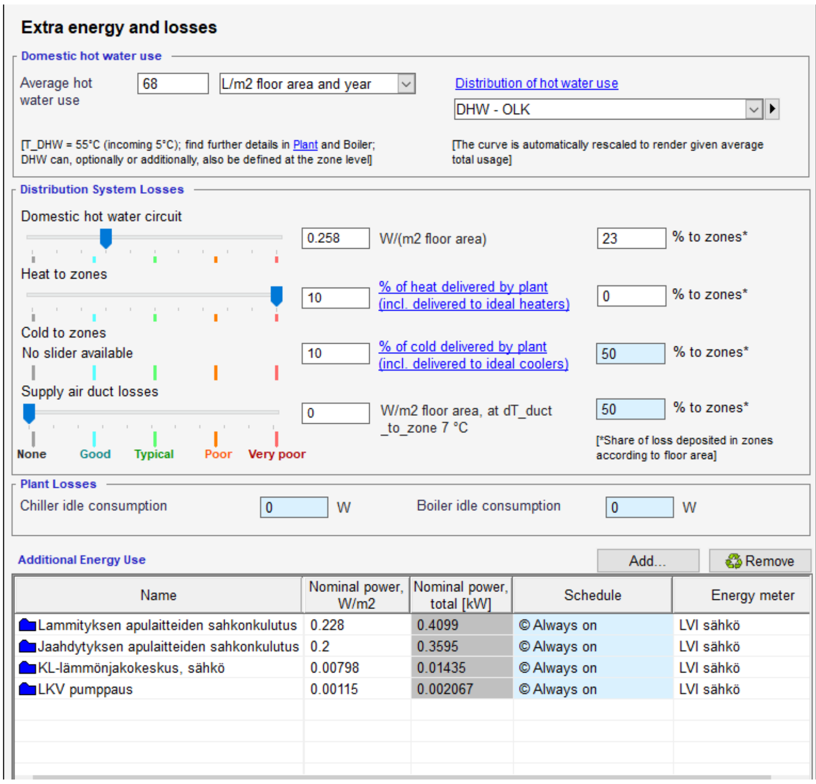
IDA ICE - THERMAL BRIDGES, EXTRA ENERGY AND LOSSES DEFINITION Appendix 1





MODEL 2 SIMULATION RESULT FROM IDA ICE

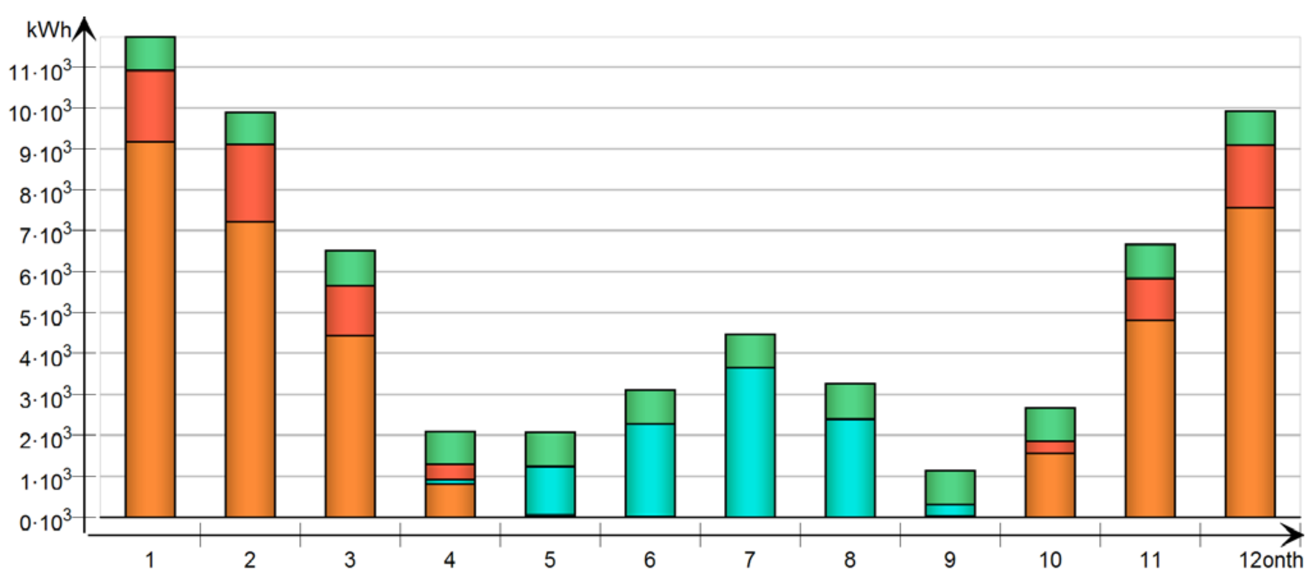
Appendix 2

EQUA SIMULATION TECHNOLOGY GROUP		**Systems Energy**	
Project		**Building**	
Model 3		Model floor area	1484.0 m^2
Customer	HAMK	Model volume	12536.0 m^3
Created by	Hong Nhung Nguyen	Model ground area	1468.2 m^2
Location	Helsinki (Ref 2012)	Model envelope area	4403.7 m^2
Climate file	[Default]	Window/Envelope	3.6 %
Case	OLK Simplify - 3 -log 1	Average U-value	0.169 W/(m^2 K)
Simulated	27.8.2017 15.08.41	Envelope area per Volume	0.3513 m^2/m^3

Used energy

kWh (sensible and latent)

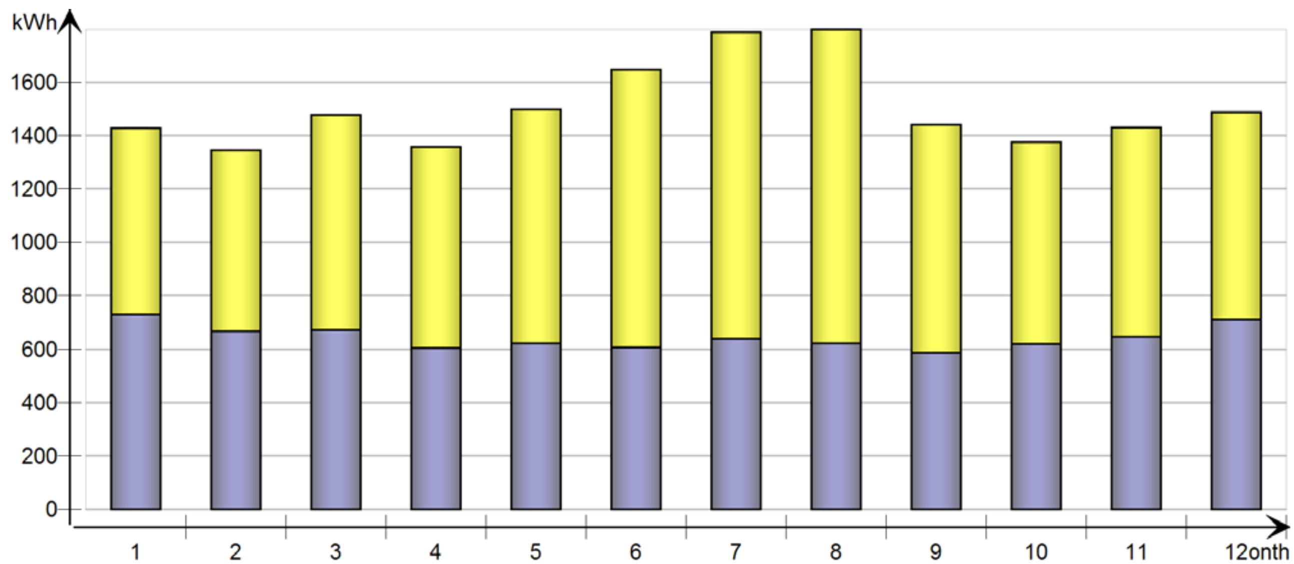
Month	Zone heating	Zone cooling	AHU heating	AHU cooling	Dom. hot water
1	9169.0	0.0	1749.0	0.0	811.8
2	7220.0	0.0	1886.0	0.0	789.1
3	4432.0	0.0	1226.0	0.0	859.3
4	814.0	99.2	381.7	-0.0	804.4
5	43.5	1183.0	0.0	-0.0	838.7
6	17.6	2267.0	0.0	-0.0	827.4
7	1.8	3646.0	0.0	-0.0	816.1
8	0.7	2400.0	0.0	0.0	860.8
9	27.1	283.2	2.4	0.0	827.6
10	1570.0	0.0	291.2	0.0	815.6
11	4807.0	0.0	1028.0	0.0	825.3
12	7566.0	0.0	1534.0	0.0	836.1
Total	35668.8	9878.6	8098.3	0.0	9912.2



Auxiliary energy

kWh

Month	Humidification	Fans	Pumps
1		698.5	728.3
2		678.2	665.5
3		807.2	671.1
4		752.5	604.6
5		875.3	620.1
6		1040.9	607.1
7		1148.9	638.2
8		1174.3	622.3
9		854.2	585.9
10		756.1	618.7
11		782.7	645.2
12		776.1	711.6
Total		10344.8	7718.6



Distribution Losses

kWh

Month	Domestic hot water circuit	Heating	Cooling*	Air ducts*
1	345.2	916.9	0.0	0.0
2	322.9	722.0	0.0	0.0
3	345.2	443.2	0.0	0.0
4	334.1	81.4	9.9	0.0
5	345.2	4.4	118.3	0.0
6	334.1	1.8	226.7	0.0
7	345.2	0.2	364.6	0.0
8	345.2	0.1	240.0	0.0
9	334.1	2.7	28.3	0.0
10	345.2	157.0	0.0	0.0
11	334.1	480.7	0.0	0.0
12	345.2	756.6	0.0	0.0
Total	**4075.7**	**3566.9**	**987.9**	**0.0**

*positive loss when conduit is cooler than building

IDA Indoor Climate and Energy

Version: 4.71

License: IDA40:8888

EQUA SIMULATION TECHNOLOGY GROUP		**Delivered Energy Report**	
Project		**Building**	
Model 3		Model floor area	1484.0 m^2
Customer	HAMK	Model volume	12536.0 m^3
Created by	Hong Nhung Nguyen	Model ground area	1468.2 m^2
Location	Helsinki (Ref 2012)	Model envelope area	4403.7 m^2
Climate file	[Default]	Window/Envelope	3.6 %
Case	OLK Simplify - 3 -log 1	Average U-value	0.169 W/(m^2 K)
Simulated	27.8.2017 15.08.41	Envelope area per Volume	0.3513 m^2/m^3

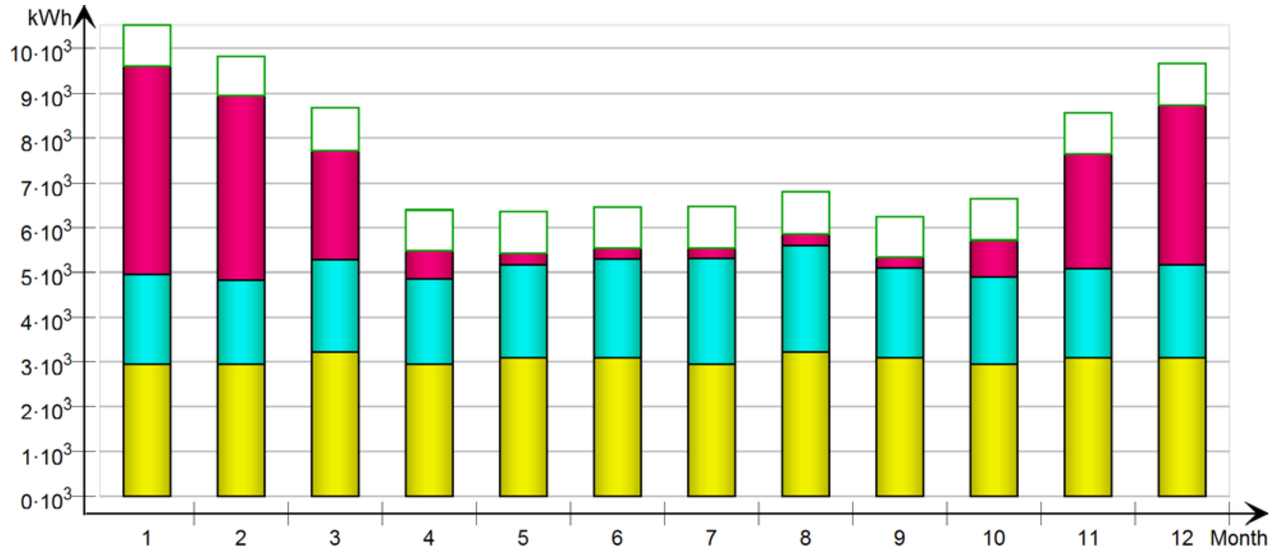
Building Comfort Reference

Percentage of hours when operative temperature is above 27°C in worst zone	0 %
Percentage of hours when operative temperature is above 27°C in average zone	0 %
Percentage of total occupant hours with thermal dissatisfaction	15 %

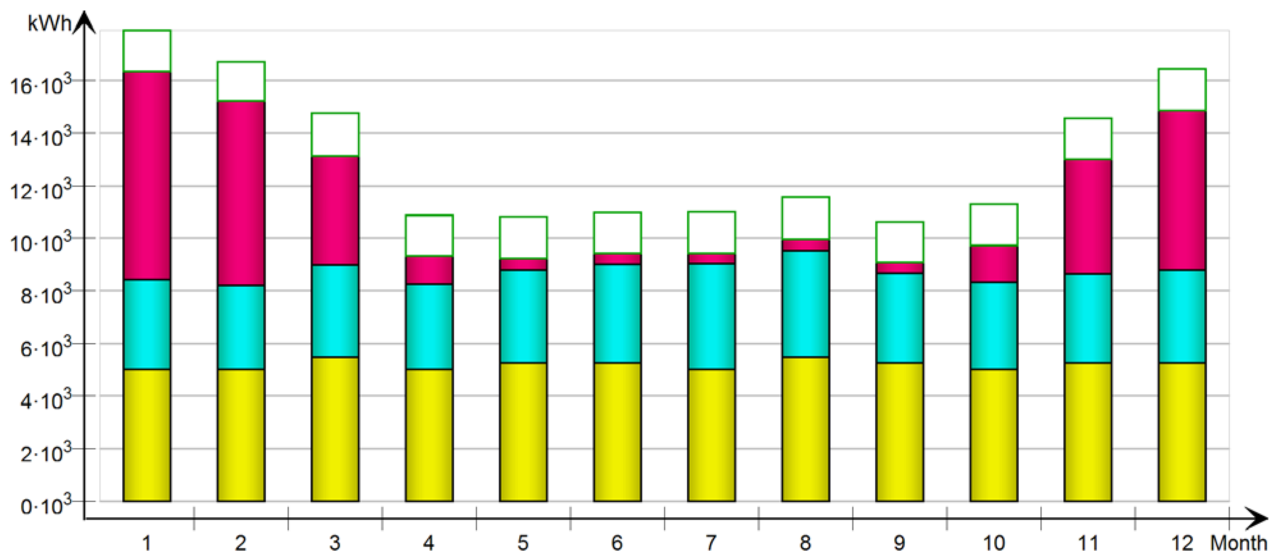
Delivered Energy Overview

	Used energy		**Purchased energy**		**Peak demand**	**Primary energy**	
	kWh	**kWh/m²**	**kWh**	**kWh/m²**	**kW**	**kWh**	**kWh/m²**
Valaistus, kiinteistö	36569	24.6	36569	24.6	14.37	62167	41.9
Jäähdytys	0	0.0	0	0.0	0.0	0	0.0
LVI sähkö	24970	16.8	24970	16.8	5.72	42449	28.6
Sähkölämmitys, kiinteistö	20088	13.5	20088	13.5	70.11	34149	23.0
Total, Facility electric	81627	55.0	81627	55.0		138765	93.5
Total	81627	55.0	81627	55.0		138765	93.5
Laitteet, asukas	11047	7.4	11047	7.4	2.3	18780	12.7
Total, Tenant electric	11047	7.4	11047	7.4		18780	12.7
	Generated energy		Sold energy		Peak generated		
CHP tuotto	0	0.0	0	0.0	0.0	0	0.0
Total, Produced electric	0	0.0	0	0.0		0	0.0
Grand total	92674	62.5	92674	62.5		157545	106.2

Monthly Purchased / Sold Energy

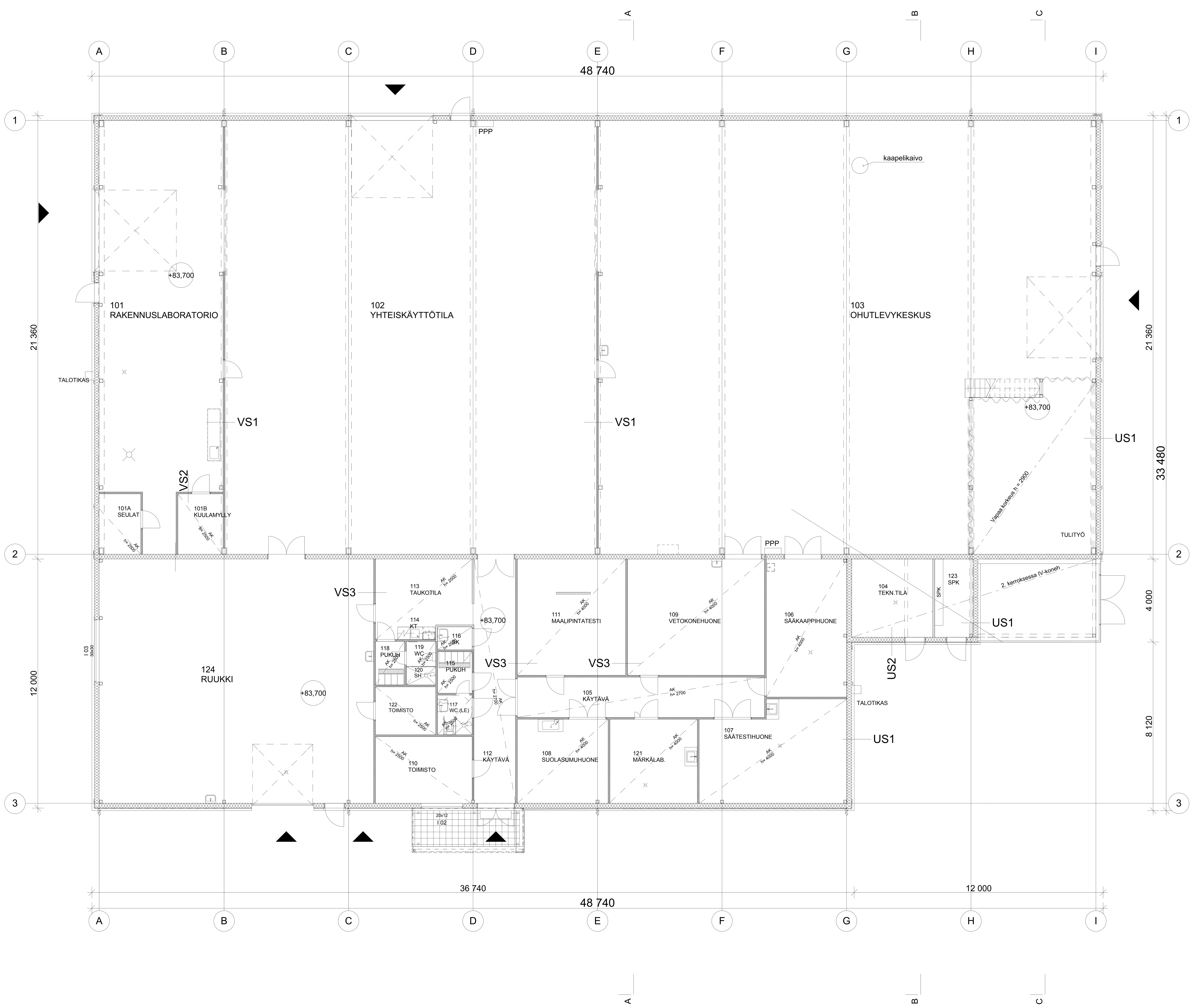


Monthly Primary Energy



Month	Facility electric								Tenant electric		Produced electric	
	Valaistus, kiinteistö		Jäähdytys		LVI sähkö		Sähkölämmitys, kiinteistö		Laitteet, asukas		CHP tuotto	
	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)
1	2943.0	5003.1	0.0	0.0	2012.0	3420.4	4659.0	7920.3	919.9	1563.8	0.0	0.0
2	2943.0	5003.1	0.0	0.0	1891.0	3214.7	4133.0	7026.1	879.9	1495.8	0.0	0.0
3	3223.0	5479.1	0.0	0.0	2063.0	3507.1	2436.0	4141.2	948.5	1612.5	0.0	0.0
4	2941.0	4999.7	0.0	0.0	1923.0	3269.1	628.8	1069.0	899.8	1529.7	0.0	0.0
5	3083.0	5241.1	0.0	0.0	2080.0	3536.0	262.4	446.1	934.2	1588.1	0.0	0.0
6	3083.0	5241.1	0.0	0.0	2214.0	3763.8	251.6	427.7	914.2	1554.1	0.0	0.0
7	2942.0	5001.4	0.0	0.0	2372.0	4032.4	240.2	408.3	919.9	1563.8	0.0	0.0
8	3222.0	5477.4	0.0	0.0	2382.0	4049.4	254.3	432.3	948.4	1612.3	0.0	0.0
9	3082.0	5239.4	0.0	0.0	2006.0	3410.2	252.3	428.9	914.0	1553.8	0.0	0.0
10	2942.0	5001.4	0.0	0.0	1960.0	3332.0	823.0	1399.1	919.9	1563.8	0.0	0.0
11	3082.0	5239.4	0.0	0.0	1994.0	3389.8	2574.0	4375.8	914.1	1554.0	0.0	0.0
12	3083.0	5241.1	0.0	0.0	2073.0	3524.1	3573.0	6074.1	934.2	1588.1	0.0	0.0
Total	36569.0	62167.3	0.0	0.0	24970.0	42449.0	20087.6	34148.9	11047.0	18779.9	0.0	0.0

EXTRACT DRAWINGS FOR OLK   Appendix 3



RAKENNETYYPIT:

AP 1 (U=0.14 W/m²K)
Hallin lattia
Pintamateriaali
200 Teräsbetonilaatta
150 Solupolystyreeni
>300 Salaojitussora
Perusmaa

AP2 (U=0.14 W/m²K)
Toimisto-osan lattia
Pintamateriaali
120 Teräsbetonilaatta
150 Solupolystyreeni
>300 Salaojitussora
Perusmaa
Huom. kosteat tilat: vesieristys

AP3 (U=0.14 W/m²K)
IV-konehuoneen lattia
Pintamateriaali
Vedeneriste
120 Steelcomp-liittolaatta
300 Mineraalivilla
9 Tuulensuoja
22 lauta
alakatto

VP1
Parvi
Pintamateriaali
180 Steelcomp-liittolaatta
Pintamateriaali

VP2
IV-konehuone
Pintamateriaali
120 Steelcomp-liittolaatta
Pintamateriaali

YP 1 (U=0.12 W/m²K)
Hallin katto
PVC -kate
230 Kattoelementti

YP 2 (U=0.12 W/m²K)
IV-konehuoneen katto
Ruukki Classic solar -lämpökatto
32 Ruukki rei`itetyt orret
PVC-kate
230 Kattoelementti

YP 3 (U=0.12 W/m²K)
Sivusiipi
PVC -kate
230 Kattoelementti
Välitila
Poimupelti

US 1 (U=0.16 W/m²K)
Hallin ja toimisto-osan ulkoseinä
230 Ruukki-seinäelementti

US 2 (U=0.16 W/m²K)
IV -konehuoneen seinä
Ruukki Classic
32 Ruukki rei`iteyt orret
Hattuprofiili pystyyn
230 Ruukki-seinäelementti

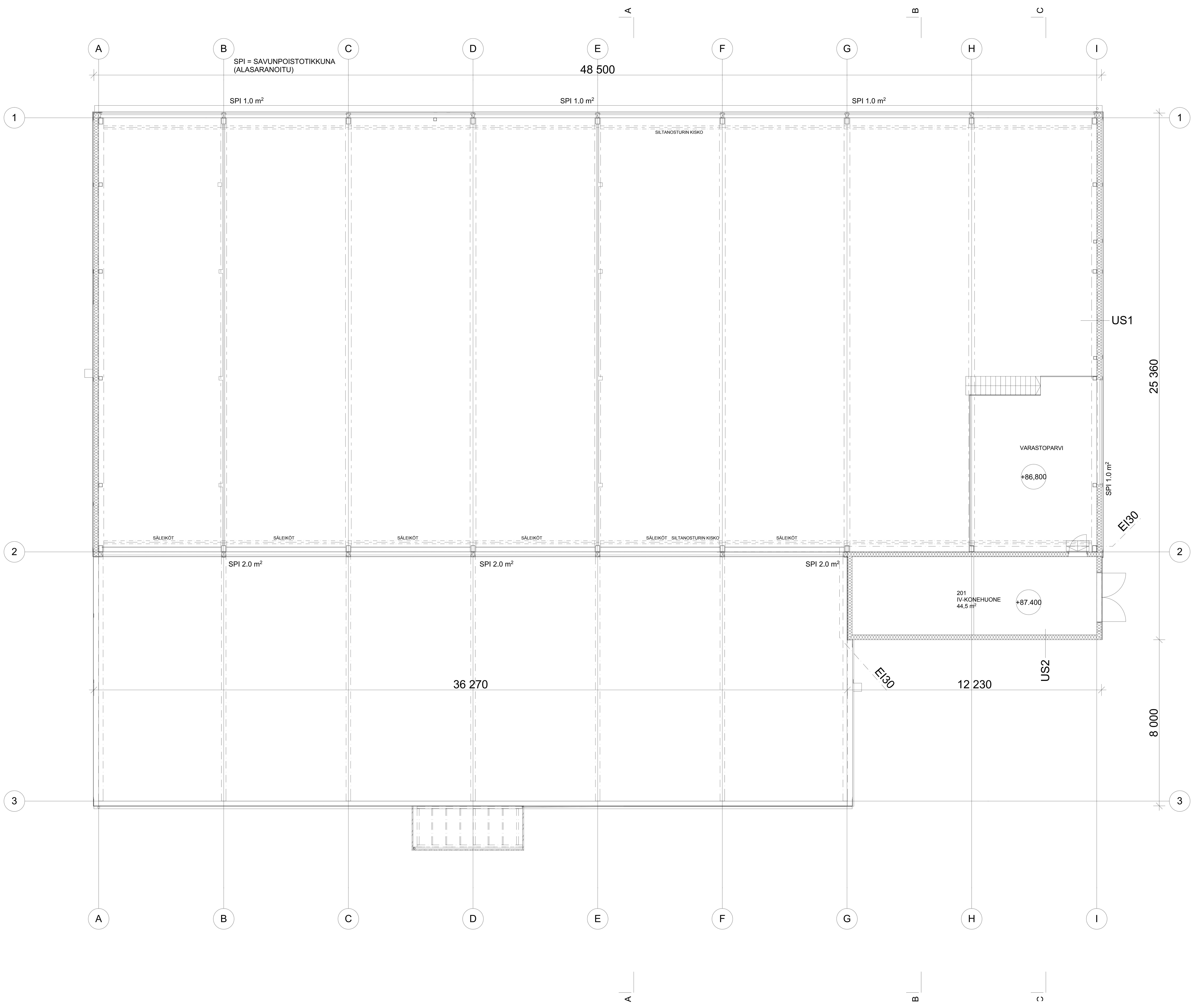
VS 1
Hallin väliseinä
100 Ruukki-seinäelementti

VS 2
Hallin ja tsto-osan väliseinä
230 Ruukki-seinäelementti

VS3
Testihuoneiden väliseinät
Pintakäsittely
13 Kipsilevy EK
92 Teräsranka + min.villa 50
13 Kipsilevy EK
Pintakäsittely
Laatoitetulla alueella kosteussulku-
käsittely ja VTT:n sertifioima veden-

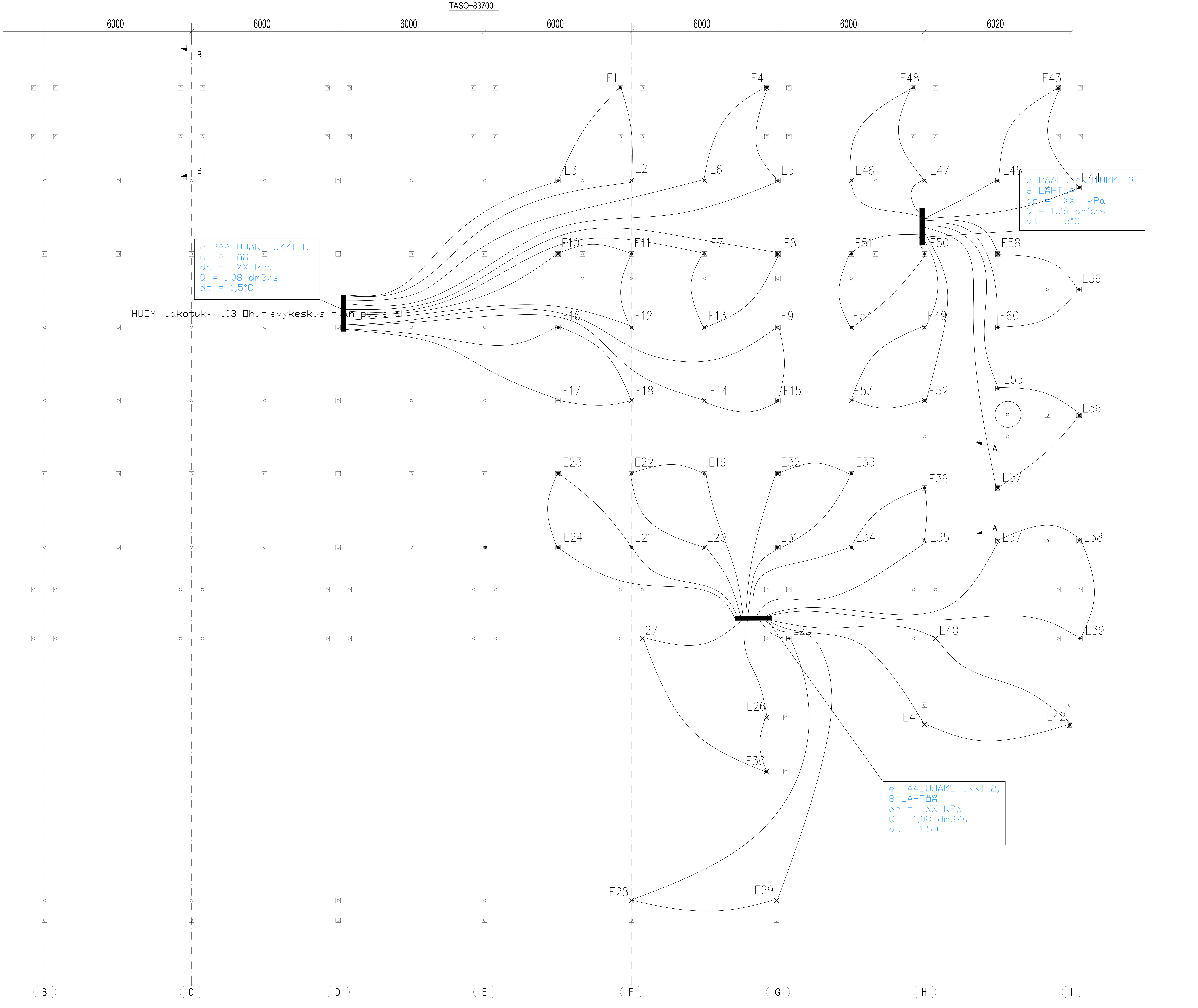
ALUSTAVA!

Kaupunginosa/kylä 109-20	Kortteli/tila 152	Tontti/Rn:o 3	
Rakennustoimenpide Uudisrakennus			Piirustuslaji PÄÄPIIRUSTUS Juoks. nro
Rakennuskohteen nimi ja osoite OHUTLEVYKESKUS Vankanlähde 13 Hämeenlinna 13100			Piirustuksen sisältö POHJAPIIRUSTUS 1. KRS Mittakaavat 1:100
Suunnittelutoimiston tiedot Arkkitehtitoimisto Kaipainen Oy Viipurintie 4A 13200 HML p. 010 239 0010 s. etunimi.sukunimi@kaipainen.fi			
Piirtäjä SL	Suunnittelija Antti Konola, arkkitehti SAFA	Työnumero A0925	
Päiväys	Vastuullinen suunnittelija Asko Kaipainen, arkkitehti SAFA, gsm 0400 318 932		Muutos ARK 2



ALUSTAVA!

Kaupunginosa/kylä 109-20	Kortteli/tila 152	Tontti/Rn:o 3	
Rakennustoimenpide Uudisrakennus			Piirustuslaji PÄÄPIIRUSTUS
Rakennuskohteen nimi ja osoite OHUTLEVYKESKUS Vankanlähde 13 Hämeenlinna 13100			Piirustuksen sisältö POHJAPIIRUSTUS 2. KRS — Mittakaavat 1:100
Suunnittelutoimiston tiedot Arkkitehtitoimisto Kaipainen Oy Viipurintie 4A 13200 HML	p. 010 239 0010 s. etunimi.sukunimi@kaipainen.fi		
Piirtäjä SL	Projektiarkkitehti Antti Konola, arkkitehti SAFA	Työnumero A0925	
Päiväys	Vastuullinen suunnittelija Asko Kaipainen, arkkitehti SAFA, gsm 0400 318 932		Muutos ARK 3



Jakotukki 1	e-paalu nro	e-paalu nro	e-paalu nro
lenkki 1	e3	e1	e3
lenkki 2	e6	e4	e5
lenkki 3	e8	e13	e7
lenkki 4	e10	e11	e12
lenkki 5	e9	e15	e14
lenkki 6	e16	e18	e17

Jakotukki 2	e-paalu nro	e-paalu nro	e-paalu nro
lenkki 1	e26	e30	e27
lenkki 2	e24	e23	e21
lenkki 3	e20	e22	e19
lenkki 4	e31	e32	e33
lenkki 5	e34	e36	e35
lenkki 6	e37	e38	e39
lenkki 7	e40	e42	e41
lenkki 8	e25	e29	e28

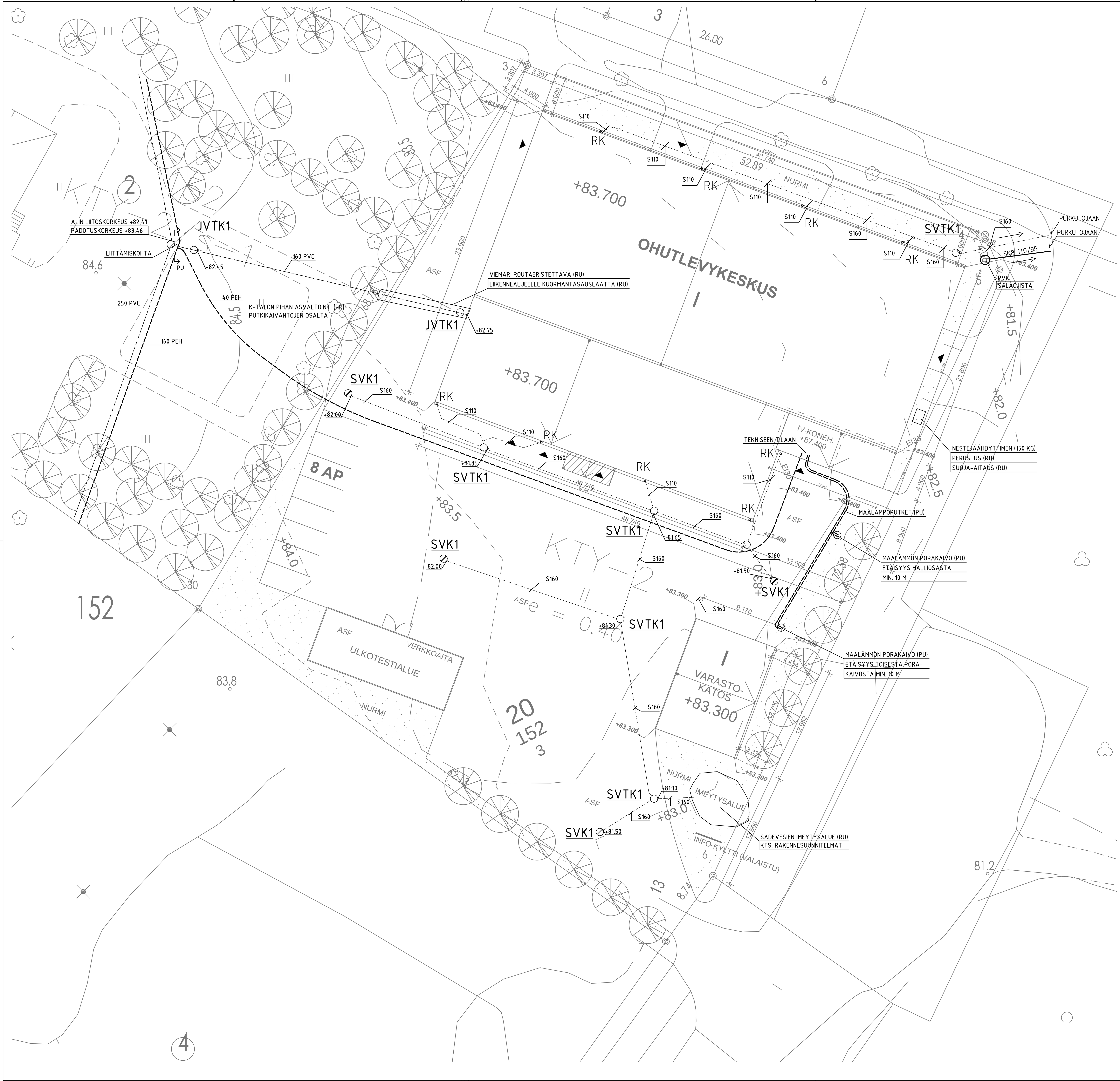
Jakotukki 3	e-paalu nro	e-paalu nro	e-paalu nro
lenkki 1	e46	e48	e47
lenkki 2	e45	e43	e44
lenkki 3	e58	e59	e60
lenkki 4	e55	e56	e57
lenkki 5	e52	e53	e49
lenkki 6	e50	e54	e51

Urakkarajana jakotukkien sulkuventtiilit,

(toimittaa ja asentaa Uponor)

YHDESSÄ LENKISSÄ ON AINA 3 ENERGIAPAALUA
SARJAAN KYTKETKETTYNÄ.

K.OSA 109-20	KORTTELI/TILA 152	TONTTI/RNo 3	RAKENNUSLUVAN TUNNUS		
RAKENNUSTOIMENPIDE UUDISRAKENNUS			PIIRUSTUSLAJI LÄMPÖ		JUOKS.No
RAKENNUSKOHTEEN NIMI JA OSOITE □hutlevykeskus Vankanlähde 13 13100 Hämeenlinna			PIIRUSTUKSEN SISÄLTÖ ENERGIAPAALUT		MITTAKAAVAT 1:50
uponor PAKKASRAITTI 12, 04360 TUUSULA KASKIMÄENKATU 2, 33900 TAMPERE P.020 129 211			SUUN.ALA LVI	TYÍ No 4132397	PIIR.No 1 MUUTOS
			PÄIVÄYS 1.4.2014	YHT.HENK. JJ	PIIRTÄJÄ.



RÄNNIKAIVOT (RK) ASENNETAAN TULEVAN MAANPINNAN TASOON (M.P.).

SADEVESIKAIVOJEN KANNET ASENNETAAN TULEVAN MAANPINNAN TASOON PINNANTASAUSSUUNNITELMAN MUKAAN.

KAIVOJEN TYYPPIPIIRUSTUKSET ON ESITETTY PIIR. 1060.

KTS. RAKENNEPIIRUSTUSLUETTELON MUKAISET PIIRUSTUKSET
- PERUSTUKSET JA SALAOJAT
- UUDET PIHA-ALUEEN KOROT.

URAKKALASKENTAAN

MUUTOS	PVM	SUUNN.	HYVÄKS.	MUUTOKSEN SELITYS

K.OSA/KYLÄ 109-20 · KORTTELI/TILA 152 · TONTTI/RN:O 3	VIRANOMAISTEN ARKISTOINTIMERKINTÖJÄ VARTEN
RAKENNUSTOIMENPIDE UUDISRAKENNUS	PIIRUSTUSLAJI LVI · JUOKS. N:O
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PVM 1.4.2014 · VASTUULLINEN SUUNNITTELIJA JA KOULUTUS HENNA NURMINEN, DI	PIIRUSTUSNUMERO 11415P – 1010_13C · MUUTOS