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Role of housing in optimization of renewable energy in a Sustainable Positive Energy Neighbourhood in Norway

Increasing the direct usage of on-site produced energy before exporting it to the grid, aiming to decrease the import of energy from the grid

Master's thesis of MSc. Sustainable Architecture

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Abstract

Role of buildings to achieve a sustainable future is undeniable. We are not just striving for energy efficient buildings anymore but for energy conscious neighbourhoods. Beyond the energy conscious neighbourhoods, energy positive projects come into play, which can balance the energy requirements of the projects that are unable to produce enough clean energy for themselves.

Taking a sustainable plus energy neighbourhood (SPEN) from Norwegian context as a case study, this thesis aims to look into the role of housing buildings in a SPEN to decrease the import of electricity from the grid. Even though the neighbourhood inherently produces more energy than it consumes, it is still dependent on grid electricity during times of less or no production. So, along with the energy balance, financial aspect matters,(Rezzonico 1997) in a way that the price of electricity sold to grid is much less compared to price of electricity bought from grid in time of less production on site. (Bøe 2017)

In order to attract masses towards the sustainability, economic factor is quite important. So, from the simulations done in this project, certain strategies are experimented with, which give us insight on how to make SPENs more efficient and attractive to developers. In the selected neighbourhood, only housing buildings are studied in this thesis, so there is plenty of area which needs to be studied further. However, the housing simulations tell us which aspects of these buildings can impact the direct usage of on-site produced energy, resulting in a decline in energy import from grid.

Energy profile of the buildings changes when their construction or energy systems are modified, so results are compared in terms of usage percentage, which tell us from the preliminary analysis that change in thermal mass, ventilation system and/or heating system can easily sway the direct usage of on-site produced energy by 1-6 %, which may not be huge but when applied to large scale projects, can save us a lot of energy emissions. This can act as a steppingstone for further research, as the simulation programs are being improved with time and results from this thesis can provide groundwork for more in-depth research in the future.

Keywords: Energy positive, SPEN, Energy balance, Financial, Energy import

Sammendrag

Vi kan ikke benekte bygningers rolle for en bærekraftig fremtid. Vi strever ikke bare etter energieffektive bygninger, men for energieffektive nabolag. Etter energieffektive nabolag, har vi energi pluss prosjekter. De kan balansere energibehov av prosjekter som ikke kan produsere nok fornybar energi for seg selv.

Denne avhandlingen bruker et bærekraftig pluss nabolag (SPEN) fra Norge som case-studie og fokuserer på rolle av boligbygg i et bærekraftig pluss nabolag for å minske importen av strøm fra energinett. Selv om nabolaget produserer mer energi enn det trenger, er det fortsatt avhengig av energinett når det ikke har nok fornybar energi, for eksempel når det ikke er mye sol eller systemet ikke er helt effektivt. Sammen med energibalansen, er den økonomiske delen viktig, som prisen på strøm når den er solgt til energinett er mye mindre enn prisen på den når vi kjøper energi tilbake fra energinett.

For å tiltrekke folk til bærekraftighet, er den økonomiske delen veldig viktig. Fra simuleringer gjort i denne avhandlingen, ser vi flere strategier som gir oss innsikt i hvordan man kan gjøre SPEN mer effektiv og tiltrekkende for utviklere. I det valgte nabolaget utredes bare boligbygg i denne avhandlingen, så det er flere ting som gir mulighet for etterforskning. Derimot, forklarer boligbyggsimuleringer oss hvilke aspekter kan ha virkning på direkte bruk av fornybar energi på stedet som resulterer i verdifall av energiimport fra energinett.

Energiprofil av bygninger forandrer seg når vi endrer dens konstruksjon eller energi systemer, så resultatene er sammenlignet i prosentdel. En foreløpig analyse forteller oss at endring i termisk masse, ventilasjonssystem og/eller varmesystem kan endre bruk av fornybar energi på stedet veldig enkelt med 1-6%. Det er ikke så mye, men vi ser at i stor skala, det kan la oss unngå mye energi utslipp. Det kan også være et springbrett for mer forskning, siden simuleringsprogrammer blir forbedret med tiden så resultatene fra denne avhandlingen kan gi et grunnlag for mer omfattende forskning i fremtiden.

Nøkkelord: Energi pluss, SPEN, Energibalanse, Økonomisk, Energiimport

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Abbreviations

SPEN	Sustainable Plus Energy Neighbourhood
NDC	Nationally determined contribution
UNFCCC	United Nations Framework Convention on Climate Change
SET	Strategic energy technologies
PED	Positive energy district
PEB	Positive energy building
ZEN	Zero emission neighborhood
ZEB	Zero energy building
nZEB	Nearly zero energy building
DHW	District hot water
PV	Photovoltaic
FF	Flexibility function
GHG	Greenhouse gas
LS	Local storage
ESU	Energy supply unit
IDA ICE	IDA Indoor Climate and Energy
CEA	City Energy Analyst
City BES	City Building Energy Saver
UMI	Urban Modelling Interface
AHU	Air handling unit
SFP	Specific Fan Power

1 Introduction

This chapter briefly explains the theme of the thesis which focuses of Sustainable Plus Energy Neighbourhoods (SPEN) and energy optimization regarding housing in the said neighbourhood, along with motivations and aims for this work and research questions that dictate the flow of the report.

1.1 Literature review

1.1.1 Sustainable/ sustainable positive energy neighborhoods

In a sustainable positive energy neighborhood, there are a lot of things to consider but one of the aspects that makes it a sustainable positive project, is the renewable energy. Hence, it is crucial to optimize the energy production of a Sustainable plus energy neighbourhood (SPEN). There are various ways to do this, for example, decreasing the energy requirement of the buildings and increasing the energy production from renewable sources as in from PV panels are the most common ones. When we talk about the renewable energy in a SPEN, we can look at the two aspects which are, on-site energy production and on-site energy usage.

During the daytime, energy that is produced is higher than the energy that is used and in the nighttime since there is no sun, the energy used by the systems and the buildings is mainly from the stored energy which can be stored in batteries on site or can be bought from the grid, in which case the excess energy during daytime is sold to the grid. In this scenario, the equation of energy gets resolved since we are sending more energy to the grid than we are getting from it however, the energy that is sold to the grid from the neighborhood is much cheaper than the energy that is being bought from the it for the neighborhood usage during the sunless hours.(Rezzonico 1997)

To tackle this problem, we can either have options for energy storage on-site that is produced during the daytime or/and we can try to find out a way in which the amount of energy that is being used during the night, shifts to the daytime and we don't have to use that much energy during the night, in which case we don't need to store it and also we don't need to buy it back from the grid. There is always going to be some energy usage in the nighttime, so, we cannot omit it completely, but we must try to look at the possibility to decrease it even if it is to a small extent.

When we talk about increasing the daytime energy usage and alternately, decreasing the nighttime energy usage, we need to consider load shifting, in which the buildings are made in the way that the energy use during daytime can sustain the building comfort during the nighttime. Along with the load shifting capabilities of the buildings, occupant behavior has an important role too, since in the end the houses and the neighborhoods are for the people and how much energy flexibility works out, is also dependent on the users. In the latter scenario, we cannot control human behavior to improve energy flexibility though, we can only incentivize it, however if there is opportunity of load shifting in building construction and/or building systems, that’s more plausible on a bigger scale for development level.

So, the task at hand takes a sustainable positive energy neighborhood to see the load shifting potential of it, in this case, mainly the housing in the chosen neighbourhood, which in turn, affects the overall neighborhood’s energy profile.

Buildings have a very prominent impact on global emissions, which are increasing every year. Reason for this is the rapid development of cities and the movement of people from local small towns to big cities for employment which in turn causes production of more residential buildings and office buildings in urban areas. Every year, construction industry is responsible for about 35 to 40% of CO2 emissions worldwide (Global CCS 2021) and this number doesn't seem to decrease with the current pace of construction (Figure 1.1). So, one of the solutions to control this progression, if not to stop, is a step towards energy positive architecture. The stage we are at, surpasses the construction of zero energy buildings, instead, we must strive to expand it to neighbourhood scale. In this way, buildings that are not self-sufficient in terms of energy, can be sustained when the excessive energy is produced by the neighborhood. Which leads us to the next step, making energy plus neighborhoods, in which the neighborhood not only produces enough energy to sustain itself but also extra energy to give back to the grid, which can be used for various purposes later and this way we have a reservoir of clean energy produced by our neighborhoods. (Brozovsky, Gustavsen, and Gaitani 2021)

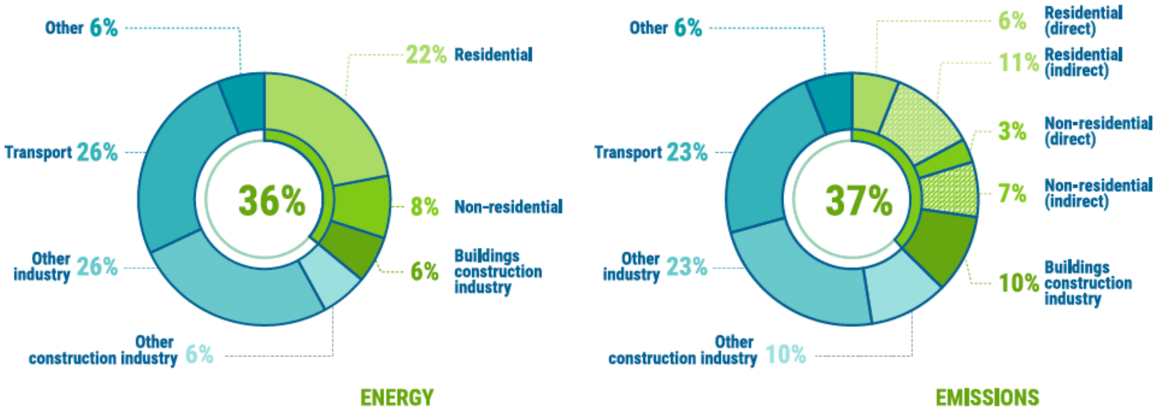


Figure 1.1: Buildings and construction's share of global final energy and energy-related CO2 emissions, 2020

Note: "Buildings construction industry" is the portion (estimated) of overall industry devoted to manufacturing building construction materials such as steel, cement and glass. Indirect emissions are emissions from power generation for electricity and commercial heat.

Source: IEA 2021a. All rights reserved. Adapted from "Tracking Clean Energy Progress"

After the Paris agreement in 2015, carbon emissions did not decrease significantly even though countries were trying to follow certain NDCs (Nationally determined contributions). However, after the pandemic of COVID-19, a significant decrease in these emissions was observed, which was mainly because of shutting down of lot of things because of the pandemic but seeing how the conditions are getting better, that change in emissions does not seem to be permanent or long lasting. It is inevitable that the emissions will rise again and probably even more than before.

Overall emissions rose after Paris agreement, however, because of sustainable housing and sustainable neighborhoods we witnessed some decline in CO2 emissions in certain areas. Investments in sustainable development are increasing, for example, compared to 2015, the investment of $129 billion increased to $180 billion in 2022, even though, most of this is coming from a small set of European countries but at least it is a step towards improvement.(Global CCS 2021)

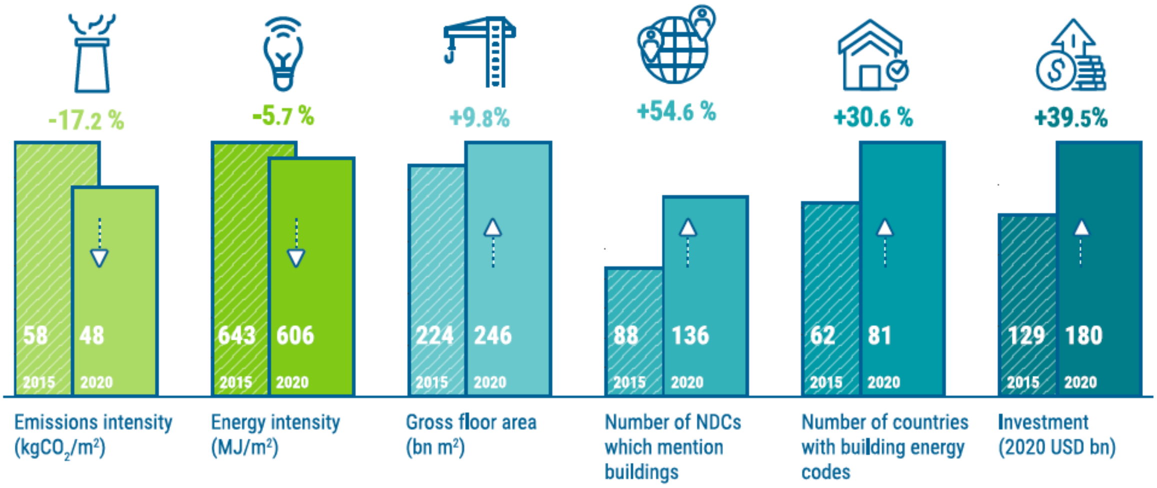


Figure 1.2: Key changes in buildings sector between 2015 and 2020

Source: UNFCCC 2021; Buildings-GSR 2021; IEA 2021a. All rights reserved.

Notes: Emissions intensity is total buildings construction and operations emissions over total floor area, energy intensity is total building operational energy over

When we have look at the construction industry (Figure 1.2), we see that most of the progress that happened recently was during pandemic but there was still some improvement over the years before pandemic and after the Paris agreement for example, investment in building efficiency has increased about 11% while the increase of 13.9% has been observed in building certification. When we exclude the effect of pandemic, the decarbonization level in 2022 was only at 40% of the 2050 reference path to achieve goals of Paris agreement.(Global CCS 2021)

In the framework of strategic energy technologies (SET) plan action 3.2, “Smart cities and Communities”, a project was launched by EU called “Positive Energy Districts and Neighborhoods for Sustainable Urban Development” in 2018. On the agenda of the program, the aim was to launch planning, deployment and replication of about 100 positive energy districts (PED) by 2025 for sustainable urbanization.(SET-Plan Working Group 2018)

When we go through literature, several terms have been used to annotate sustainable neighborhoods and Sustainable plus energy neighbourhoods (SPEN) which include but are not limited to:

- Zero emission neighborhood (ZEN)
- Positive energy district (PED)
- Low carbon district (LCD)
- Nearly zero energy district (nZED)

- Low carbon neighborhood (LCN)
- Net zero energy neighborhood (NZEN)
- Net zero energy district (NZED)
- Nearly Zero Energy Neighbourhood (nZEN),
- Positive Energy Block (PEB),
- Energy Positive Neighbourhood (EPN),
- Low Carbon District Heating (LCDH),
- Zero Energy Neighbourhood (ZEN),
- Plus Energy District (pED),
- Zero Energy District (ZED),
- Positive Energy Precinct,
- Zero Carbon District,
- Zero Carbon Neighbourhood,
- Smart City Eco District,
- Zero Energy Emission District,
- Zero Non-Renewable Energy Neighbourhood,
- Plus Energy Neighbourhood,
- Nearly Zero Energy Settlement,
- Net Zero Exergy District,
- Net Zero Carbon Emission District,
- Low or Zero Emission District Heating,
- Low Carbon Energy District,
- Low Carbon Local Energy Community,
- Net Positive Energy Neighbourhood,
- Energy Positive District,
- Smart Energy Community,
- Net Zero Energy Block,
- Nearly Zero Carbon Neighbourhood,
- Net Zero Energy Settlement,
- Net Zero Energy Campus, and
- Net Zero Energy Community.

(Brozovsky, Gustavsen, and Gaitani 2021)

There are several definitions available for plus energy neighbourhoods, one of them is as following:

> *"A Positive Energy Building produces at least as much renewable energy as it uses in a year, when accounted at the source. Source energy refers to the primary energy used to generate and deliver energy to the site.*
>
> *In a Sustainable Plus Energy Neighbourhood, the geographical boundary is expanded to the entire site of the neighbourhood and includes Local Storage and Energy Supply Units. Users, buildings, and technical systems are all connected via the neighbourhood digital cloud (HUB)"*

Source: synikia.eu

If we approach this definition graphically, Figure 1.3 does a good job of elaborating it with all the aspects included.

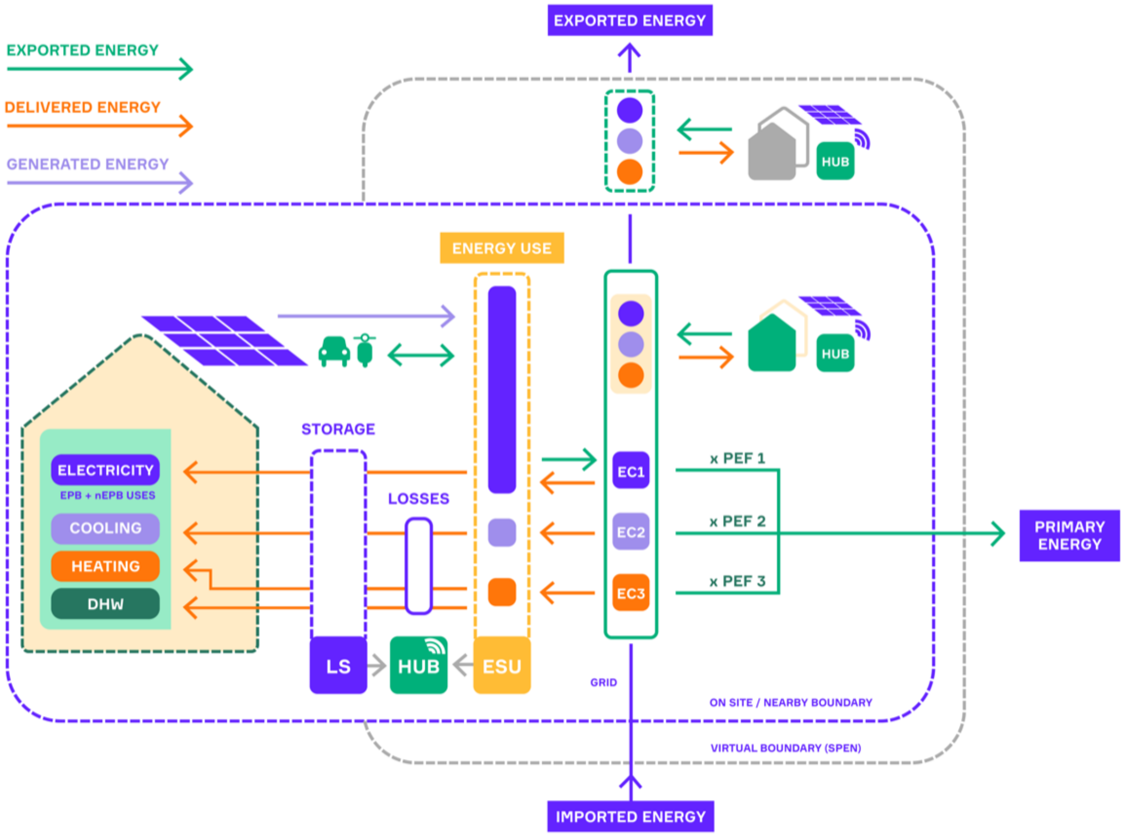


Figure 1.3: Illustration of the concept of sustainable plus energy neighborhood by syn.ikia

Source: synikia.eu

1.1.2 Energy flexibility

When we talk about the power production, systems are generally designed with a central power generation unit or units that are there to meet the demand but in case of renewable energy, this is not the case. In traditional systems, energy is produced to meet the demand since increasing the production means you just use more fuel, however in case of renewable energy, you cannot increase that “fuel” which in this case is the source, like sun, wind or water. Renewable energy is not a constant that we can predict 100% of the times, it varies with weather, for example in case of wind energy, the production of electricity depends on the amount and speed of wind and in case of PV system, it depends on the sun and so on. (Lund and Münster 2006)

In case of renewable energy, potential for flexibility is already there, we just have to explore it, for example, there is the option of heat storage, and we can further improve on that opportunity using model predictive control systems in buildings. These can be centralized or decentralized based on the requirements. In centralized options, there is a grid operator who is in charge of these controls to optimize the flexibility potential of the neighborhood or the project and in decentralized systems, the control systems effect each building separately. In these scenarios, there are different aspects that affect the building control systems ranging from the role that they are required to play to the cost of the systems which means a better system would be more expensive but would have more features and a cheaper system would have limited features as a control system to influence energy flexibility.(Wu et al. 2016)

There are several factors that can influence the energy flexibility of buildings: (Reynders 2015)

- Physical characteristics of building e.g., thermal mass, insulation, architectural layout.
- Technologies used in building e.g., heating, ventilation, storage equipment.
- Control systems e.g., interaction of building systems with external signals.
- Occupant behavior.

We can find the potential of energy flexibility of a project by use of simulation tools or by use of experimental data or by a combination of both by playing with the scale of the project, in which case we need detailed dynamic modeling of energy systems of the project. We can characterize energy flexibility either in domain of frequency or in time. When flexibility is taken as a dynamic function it is titled as flexibility function (FF) in(Junker et al.

2018), which is quite helpful when the state of the system is not very steady which is usually the case when we talk about energy flexibility. Flexibility function is vital when we want to have a quantitative description of energy flexibility, compute flexibility indexes (reaction of a project to penalty signals or control signals imposed by the grid) or to perform ancillary services on a project. (Junker et al. 2018)

1.1.3 Grid electricity

"Norway has the highest share of electricity produced from renewable sources in Europe, and the lowest emissions from the power sector. At the end of 2020, the total installed capacity of the Norwegian power supply system was 37 732 MW, and normal annual production was 153,2 TWh."

Source: energifaktanorge.no

When we use renewable energy systems in buildings, a zero energy building means that it can sustain itself with the energy produced from it without being connected to a grid. However, in case of energy plus buildings, storage for excessive energy needs to be competent enough to store excess energy during high energy production times to be used during the time when the energy cannot be produced because of weather conditions or any other issue. In this scenario, usually a grid connected PV system is preferred instead of having a lot of batteries on site for storage, which are not only an expensive investment but also have their own carbon footprint. Grid connected PV system allows the users to power their buildings with renewable energy during time when the energy is being produced on site and the access energy is sold to the grid, vice versa the opposite happens when there is not enough opportunity to produce sufficient renewable energy on site, electricity from grid is used then. (Dept. of Energy n.d.)

In Norway, most of the energy that is used for heating is electricity which is why electricity prices in winter are the highest in the whole year, which also means in a sustainable positive neighborhood, the excessive energy that is produced during the summer and is sold to the grid is not as expensive as the energy that is bought from the grid during the winter when there is not enough sun to meet the requirement of the building by the PV system on site. (Ministry of Petroleum and Energy 2021) One of the common metering arrangements that happens with grid connected renewable energy systems on site is the net purchase and sale agreement under which two unidirectional meters are installed with one keeping track of electricity drawn from the grid to the building and the other one keeping track of the excess electricity generated by the onsite PV system being sent to the grid. in this scenario, the consumer buys the electricity in time of requirement at retail rates while the grid pays wholesale rates for the excess renewable energy that it buys from the consumer, and the difference between these two rates is usually quite significant.(Dept. of Energy n.d.)

1.1.4 Load shifting

The Concept of load shifting is not new and has been implemented successfully by industrial and several commercial projects for years. Basically, what it does is that it shifts electricity consumption from one time to another, for example, during peak hours of electricity usage, the building reduces its use of electricity and compensates for it when the electricity is cheaper or in other words is abundant in quantity. When we talk about load shifting, one thing that we have to consider always is that we cannot sacrifice occupant comfort or user satisfaction. (Grid beyond 2018)

Load shifting is vital when we talk about energy flexibility of sustainable plus neighborhoods. since these zero energy buildings and zero energy neighborhoods are no longer just active consumers only but they also generate power and can be termed as prosumers (Jensen et al. 2017) so, this concept of load shifting strengthens the dynamics of these prosumer projects and the electricity grid.

In developed countries like Norway, the electricity is not only used to run basic appliances but it's a major part of any functional project as it is used for space heating , heating of domestic hot water , ventilation, and pumps etc. (Le Dréau and Heiselberg 2016) So, considering these aspects, even though we cannot shift the electricity usage for appliances like TV or microwaves mainly since they are user dependent and can make a difference when there are changes in occupant behaviours via certain incentives, however, there are certain areas which can contribute to load shifting when we talk about energy flexibility, particularly the thermal part of energy demand which consists of space heating, ventilation, domestic hot water requirement as well as hot water for washing machines, dishwashers and heat for dryers. These are the aspects in a project which can contribute to energy flexibility without jeopardizing the comfort of the occupants. (Jensen et al. 2017)

In scenarios where we need space heating at a certain time which we can predict, based on weather data and/or user behaviours, we can heat up the space when we have excess of energy so that when the electricity is low in storage, we don't have to use a lot of it to heat up those spaces from scratch (Figure 1.4). Similarly in case of a domestic hot water tank, it can be preheated before the peak hours and can make up for a good way to provide short term flexibility. However, certain phase change material tanks and thermochemical material tanks can offer long term flexibility using similar strategy, where the excess heat can be used for several functions (Finck, Li, and Zeiler 2017)

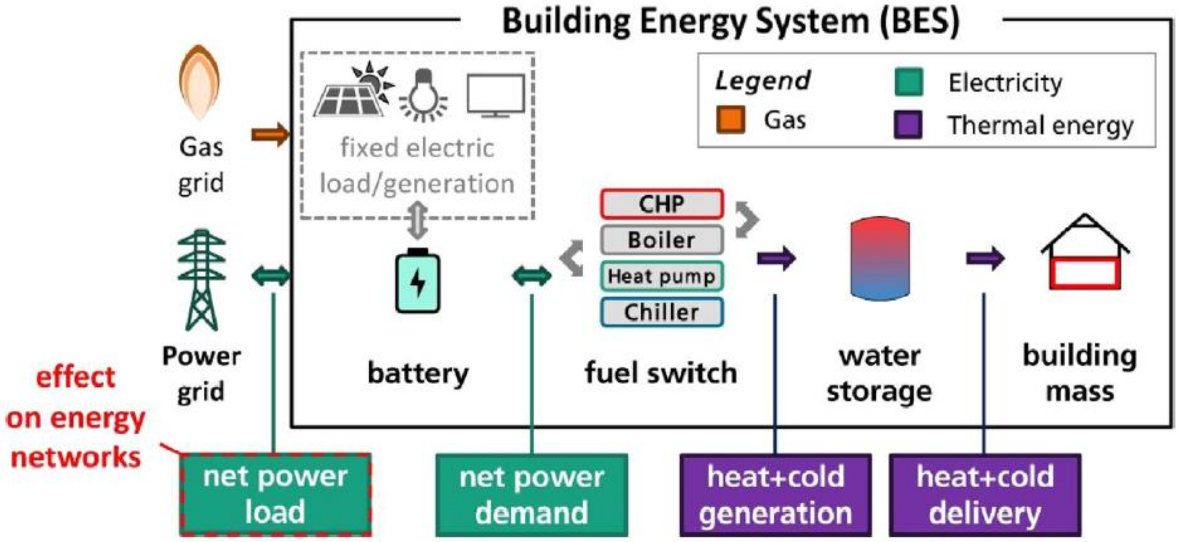


Figure 1.4: Schematic of a building energy system highlighting the different stages where demand and delivery can be decoupled or heat/cold generators can be switched for a specific amount of time, thus providing Energy Flexibility

(Jensen et al. 2017)

In case of load shifting, we need to focus on both energy use and energy generation profiles along with the interconnection with the energy networks which in this case is the connection between the neighborhood’s renewable energy production system and the electricity grid. This can be achieved using smart grid systems where the control systems are not just under user control, but they also learn from the user behaviors and using artificial intelligence and data informed algorithms, they optimize the use of energy in the building. For control systems to be able to do this, building construction should have the capacity to allow this energy flexibility of spaces, and that’s where different constructions combinations based on varying materials and energy systems come in play.

1.2 Motivations

Onsite produced renewable energy is a core point of zero energy buildings and zero energy neighbourhoods, and how we use that energy in relation to storage and grid connection is a crucial part of its overall efficiency in the big picture.

With renewable energy, energy flexibility comes up automatically and it cannot be ignored. While elaborating on the energy balance and energy flexibility, the economic aspect of it in energy positive projects cannot be neglected, since in the end, project developers are concerned with making the most out of their money’s worth, and if we manage to make “sustainability” financially attractive for big and small developers and investors, we can reach people more efficiently.

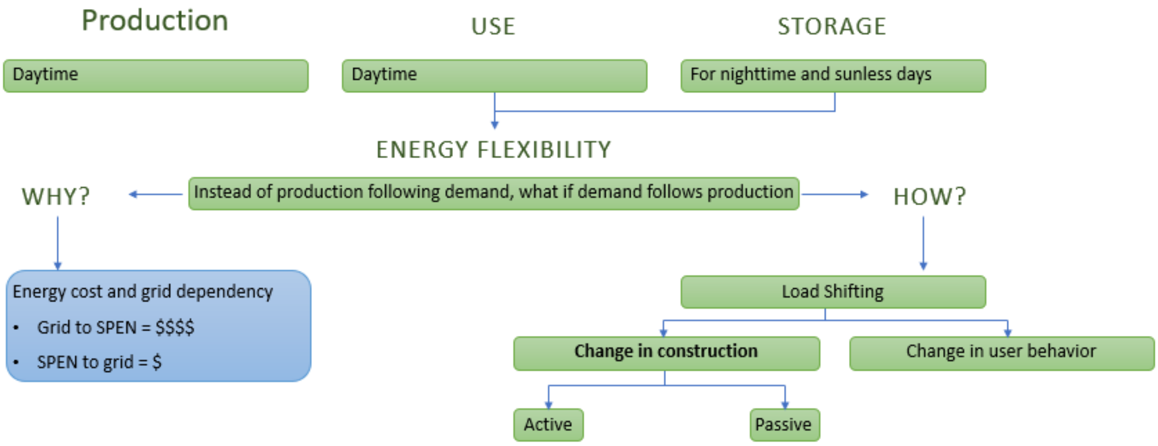


Figure 1.5: Why and how of the thesis

Purpose of this thesis is to explore the financial aspect of the exchanges between grid and neighbourhood in an energy plus neighbourhood, as a way to incentivize these projects further for the project developers and investors. Figure 1.5 briefly shows the how and why of the thesis, and that summarizes is quite well. Based on this, rest of the this is structured to take an example, study, simulate, analyze and see results if there is any possibility to do so without changing the complete course of a project. Project aims to see if there is any possibility which can decrease the import of grid electricity, and then regardless of the amount it imports, it is meant to show that certain strategies work better than other and can be further explored in future.

1.3 Research questions

This thesis has a core question to focus on:

- How to optimize housing in a SPEN to decrease the import of electricity from the grid to the neighbourhood?

And this question is then supplemented by certain sub sections:

- What is the effect of building composition on the energy use of a project?
- How can building systems affect the flow of energy between grid and the neighbourhood?

These questions lead to a selection of a case study, which then needs to be analyzed in a comparative manner to study varying parameters which can affect the optimization of the building in a way which can support this thesis, which in this case means decreasing the import of electricity from the grid in the neighbourhood.

1.4 Research Methodology

This project has three main steps:

- Data collection
- Simulation
- Analysis of the results

The methodology to support these steps focuses on the literature review first and foremost to understand the Why of it all and to see what has been going on in this field. To assess the problems and solution in the area, like onsite energy storage and peak loads are being dealt with charging electric car batteries in such neighbourhoods (Buildings 2020) as a solutions to excess energy production. So, after the literature review, research questions and methodologies are set up for the sake of flow of this report and project.

Methodology of this project can be summarized as following:

- Literature review
- Project to choose case study from
- Reviewing energy modelling tools for the project
- Energy modelling
    - Data collection
    - Data calculation and adjustments

    - Modelling
    - Simulations
    - Data processing to summarize results
- Looking at the impact from building to neighbourhood scale
- Discussion about the impact and outcome of the thesis

2 Syn.ikia

> *"Syn.ikia aims at achieving sustainable plus energy neighbourhoods with more than 100% energy savings, 90% renewable energy generation triggered, 100% GHG emission reduction, and 10% life cycle costs reduction, compared to nZEB levels. This will be achieved while ensuring high quality indoor environment and well-being."*

Source: synikia.eu

Syn.ikia comes from the Greek word "συνοικία", which means neighbourhood:

- Syn: means plus
- Ikia: means house

When these two words are combined, they make the phrase "plus house", which has two meanings, one being a "plus energy house" and the other one being "a neighborhood" as in more than one house. Syn.ikia aspires to increase the share of sustainable neighborhoods with excessive renewable energy in different contexts and climates all around Europe. Between 2020 to 2024, syn.ikia aspires to make four real life sustainable plus energy neighborhoods to demonstrate their functionality to the world.

Syn.ikia makes use of new technologies on a neighborhood scale for energy efficiency and flexibility of buildings to achieve suitable architectural and spatial qualities while promoting sustainable behavior with citizen engagement.

> *"A Positive Energy Building produces at least as much renewable energy as it uses in a year, when accounted at the source, where source refers to the primary energy used to generate and deliver energy to the site.*
>
> *In a Sustainable Plus Energy Neighbourhood, the geographical boundary is expanded to the entire site of the neighbourhood and includes Local Storage (LS) and Energy Supply Units (ESU). Users, buildings, and technical systems are all connected via the neighbourhood digital cloud (HUB)." (Figure 2.1)*

Source: synikia.eu

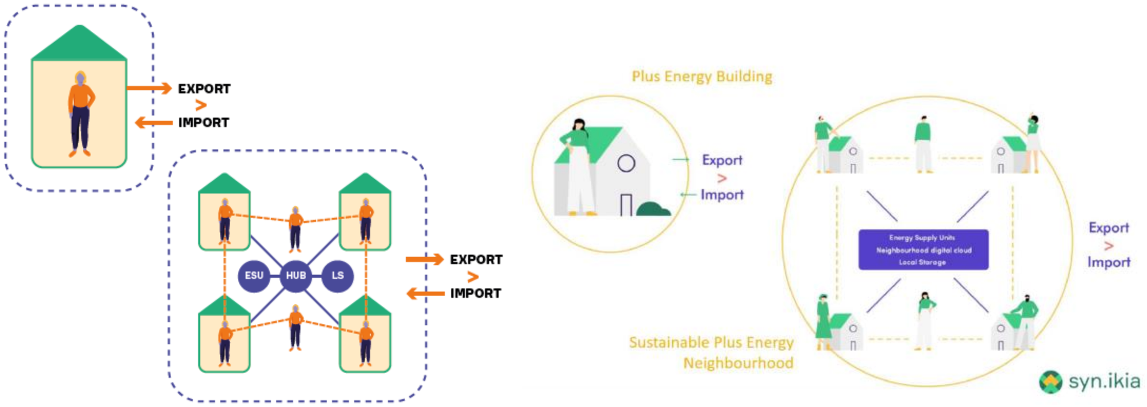


Figure 2.1: Concept of Syn.ikia

LS: Local Storage / ESU: Energy Supply Units HUB: Neighbourhood digital cloud

Source: synikia.eu

It is not always possible for all the buildings to achieve zero energy targets, which can be due to building preservation constraints in renovation projects of protected buildings (ICOMOS n.d.) or sometimes because of insufficient production of renewable energy on site. So, we cannot just focus on individual buildings as it can lead to inefficient solutions due to high power peaks and load fluctuations which often result in failure to achieve synergy between energy use and energy generation. To support this concept, small scale but well distributed renewable energy sources across neighborhoods and responsive buildings, which can act as active nodes of the energy system are a way to go towards energy flexibility. In a neighborhood, the likelihood of energy compensation is more because of auxiliary functions like parking lots community facilities which can strengthen the renewable energy production of neighborhood and solutions like smart charging of electric vehicles etc. ("Niki Gaitani Assoc. Prof. / Project Leader" 2020)

Syn.ikia is going forward with five focus areas and five primary strategies which are as following:

2.1 Syn.ikia's 5D focus areas

- Decentralization: neighbourhoods as flexibility providers that enable more renewable energy sources to enter the grid and allow for flexible management of energy demand and generation
- Democracy: engaged, empowered and conscious users that have access to affordable and high-quality neighbourhoods.

- Decarbonization: climate neutral, highly energy efficient neighbourhoods with a surplus of energy from renewable sources.
- Digitalization: big data-based neighbourhoods and smart networks that provide well-managed housing for the citizens.
- Design: integrated energy, architectural and spatial design that improve attractiveness of energy-efficient housing and its market uptake.

2.2 Syn.ikia’ 5S strategy

- SAVE: reducing the neighbourhood net energy consumption by using solutions based on a total life cycle cost analysis.
- SHAVE: facilitating peak shaving through load shifting, control, and storage thus reducing the size of energy supply installations, increasing self-consumption of renewable energy, and reducing the stress on the grid.
- SHARE: sharing of resources such as energy, infrastructure, and common spaces with neighbors.
- SHINE: ensuring high quality architecture, creating good indoor and outdoor environments, and solutions that make the occupants and the community proud of their neighbourhood.
- SCALE: benefitting from large-scale effects of the neighbourhood scale to replicate the solutions at European level.

Source: synikia.eu

2.3 Sustainable Positive Energy Neighbourhood

The sustainable positive energy neighborhood is defined as a group of interconnected buildings with associated infrastructure, located within both a confined geographical area and a virtual boundary.

SPEN aims to reduce its direct and indirect energy use towards net zero over a complete year and an increased use and production of renewable energy. The neighborhood concept in syn.ikia project refers to (but not limited to) the building portfolio definition within the ISO 52000 that considers a set of buildings and common technical building systems whose energy performance is determined taking into account their mutual interactions (ISO 52000-1:2017(E) 2017)

The geographical boundary for calculating the import and export of energy is the site boundary of the neighborhood, where energy is calculated by taking into account building's operational energy use, domestic hot water heating, space heating/cooling, ventilation and fixed lighting fixtures but excluding plug loads i.e., household appliances.

2.4 Demo projects of Syn.ikia

To execute the sustainable positive neighborhood project of syn.ikia, four climates were chosen where the neighborhoods were supposed to be build, which are as following:

- Subarctic climate
    - Oslo/Fredrikstad, Norway
- Marine climate
    - Uden, Netherlands
- Continental climate
    - Salzburg, Austria
- Mediterranean climate
    - Barcelona, Spain

Location of these neighborhoods can be seen on the Figure 2.2:

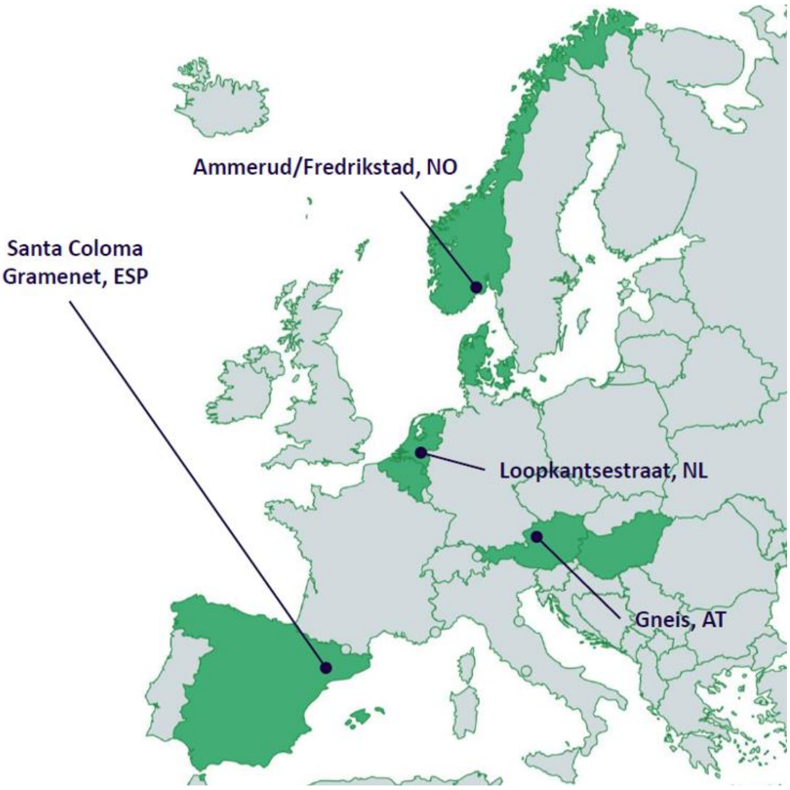


Figure 2.2: Demo neighborhoods by syn.ikia

2.4.1 Demo neighbourhood, Oslo

154 Housing units

- Smart house technology
- Low carbon design
- Recycled materials in construction
- Shared spaces
- Technical IT platform to initiate activities to create a vibrant neighbourhood
- Smart charging of electric vehicles

2.4.2 Demo neighbourhood, Fredrikstad

56 Housing units

- Establishing a neighbourhood energy system
- Architecturally integrated PV
- Smart house technology
- Smart charging of electric vehicles
- Low carbon design, largely wood-based construction, prefab elements
- Use of recycled materials
- Social sustainability with emphasis on shared spaces and IT platform for energy awareness

2.4.3 Demo neighbourhood, Uden

39 Housing units

- Digital twins at neighbourhood scale
- Integrating sensors (HVAC) allowing smart controls and diagnostics
- Load balancing at building and neighbourhood level
- Tenant involvement for enhanced user satisfaction
- Performance guarantee
- Vehicle to Home system
- Social beautiful concept

2.4.4 Demo neighbourhood, Barcelona

38 Housing units

- District heating network

- Energy sharing with the neighbor buildings
- Energy manager and visualization
- Renewable energy generation is beyond the requirements of building code
- Innovative public procurement with sustainable and environmental

2.4.5 Demo neighbourhood Salzburg

230 Housing units

- Energy sharing with the neighbor buildings
- Smart home technology
- Integrated energy systems and low temperature microgrid
- Renovation incentives
- Participatory design
- User behavior assessment

Aim towards all these climates is the same, to achieve energy positive projects with a common goal and desired impact from all the SPEN projects. (Figure 2.3)

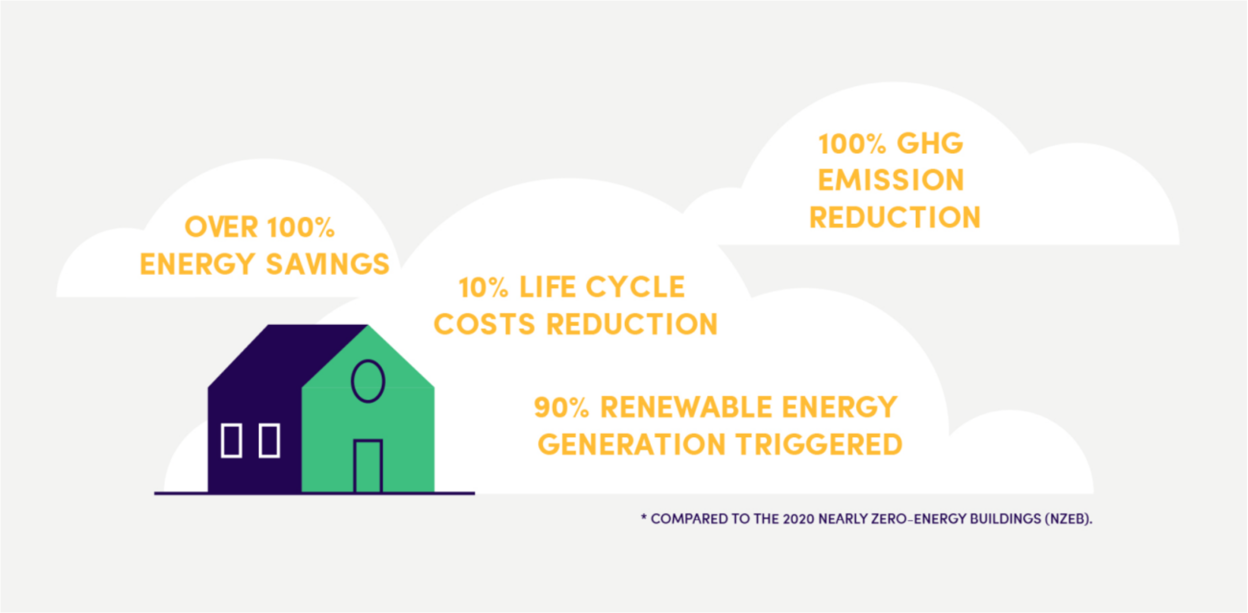


Figure 2.3: Desired impact of SPEN demo projects

(“Niki Gaitani Assoc. Prof. / Project Leader” 2020)

3 Energy modelling tools

This chapter goes through some simulations tools to see which one to be used for the purpose of this thesis. Simulation tools studied in this chapter are of varying scales from building level to neighbourhood level, and are analyzed based on availability, data usage, project relevance and desired output.

3.1 IDA ICE

IDA Indoor Climate and Energy (IDA ICE) is a building level simulation program which gives us the opportunity of combined building, systems and controls modeling; adaptive time steps for fast and high-resolution simulation; BIM import via IFC; interactive 3D with visualization for input as well as results. IDA ICE has a modular structure, with access to the model source code and the possibility to develop our own extensions. (Petersen, n.d.)

The program is not open source, but the developers can issue a student license if you approach them. And since it is not a very new program, there is a lot of helpful material available online to start learning the program, and other then the helping material from internet, the interface is intuitive enough that once you get into it, you end up exploring a lot of features and learn on the go.

IDA ICE was looked into, due to its modular capabilities of separating the information in intuitive interface from which we can take out the desired data. At the end of simulation, the program gives out data in the form of tables, charts, and graphs, but we can further extract the data in the form of an excel sheet to study selective instances in more detail as required.

3.2 Grasshopper

Grasshopper 3D would not be the tool it is without the growing family of Grasshopper plug-ins, a few of the popular ones include Kangaroo – Embeds physical behavior within your model for simulation. Ladybug & Honeybee – Environmental Design tools for the Architect & Engineer. Pufferfish – Shape Blending Tools. Karamba – Structural Engineering Analysis. Octopus - allows the search for many goals at once, producing a range of optimized trade-off solutions between the extremes of each goal, and many other plug-ins.(“Grasshopper 3D - Rhino’s Parametric Modelling Tool - Simply Rhino” n.d.)

Student license is available from NTNU to the students, and it performs almost all the task required by the user. Grasshopper is integrated in the modeling program called

Rhinoceros 7.0 and it performs required tasks depending on the plug-in being used. For the sake of this thesis, honeybee and Ladybug were explored to assess their usability in the context of project at hand.

3.3 CEA-City Energy Analyst

CEA is created by ETH Zurich is an open-source tool made for urban scale simulations in 2015.When we talk about the urban simulation tools, CEA is among the first ones to be successfully used in the area. It builds upon the framework of building simulation tools and increases its scale to evaluate energy efficiency on a neighbourhood scale.

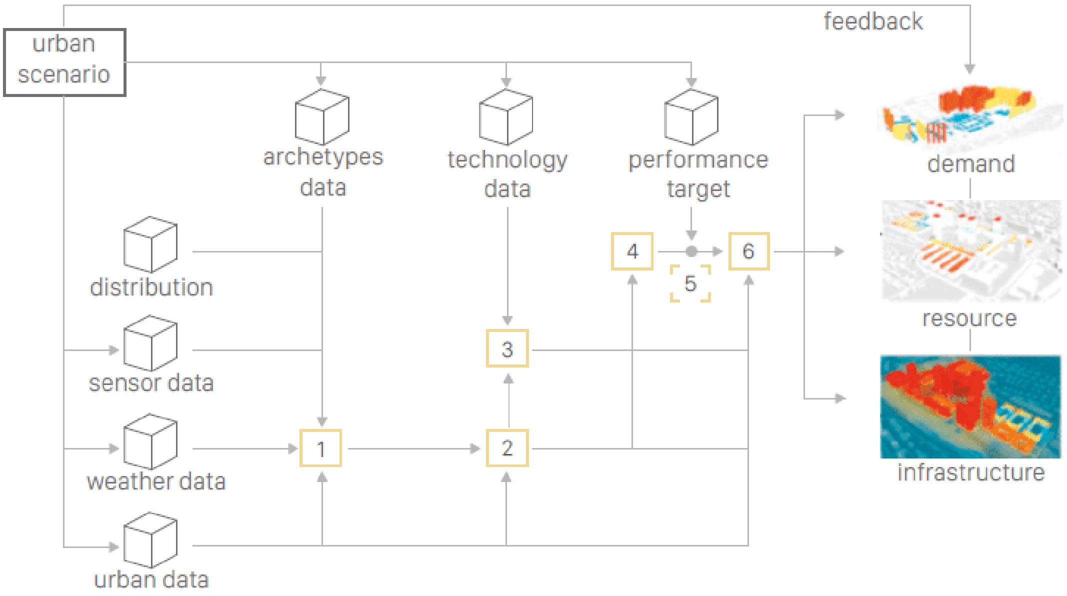


Figure 3.1: Workflow of CEA

(Bianchi 2018) (Robinson et al. 2009)

Database in the program takes the geo referenced building information, infrastructure, topography, and local resources along with weather information. As is evident from the Figure 3.1, simulation in CEA also uses the occupancy information, archetypes and technology data in the model to simulate desired results. (Bianchi 2018)

On one hand, this tool is intuitive to use but in order to use its detailed modules, its dependent on few other programs which ae not open source and require some learning apart from this, which makes the usage a bit complicated in a limited time period.

3.4 City BES

City Building Energy Saver is a web-tool with easy-to-use interface and was released in 2018 by Berkely National Lab, US. It can simulate neighbourhoods of varying sizes quite quickly once the data sets are fed into the system. User can also select certain number of buildings in the neighbourhood and see their results apart from the whole neighbourhood. It can simulate even whole cities to compute the energy efficiency data, however adding the data sets in the beginning requires a lot of background research work, detailed values of each building or aspect of the neighbourhood and the collaboration with the developers of the program to add the data sets in the program, which requires quite a lot of time and manpower to execute. (Figure 3.2)

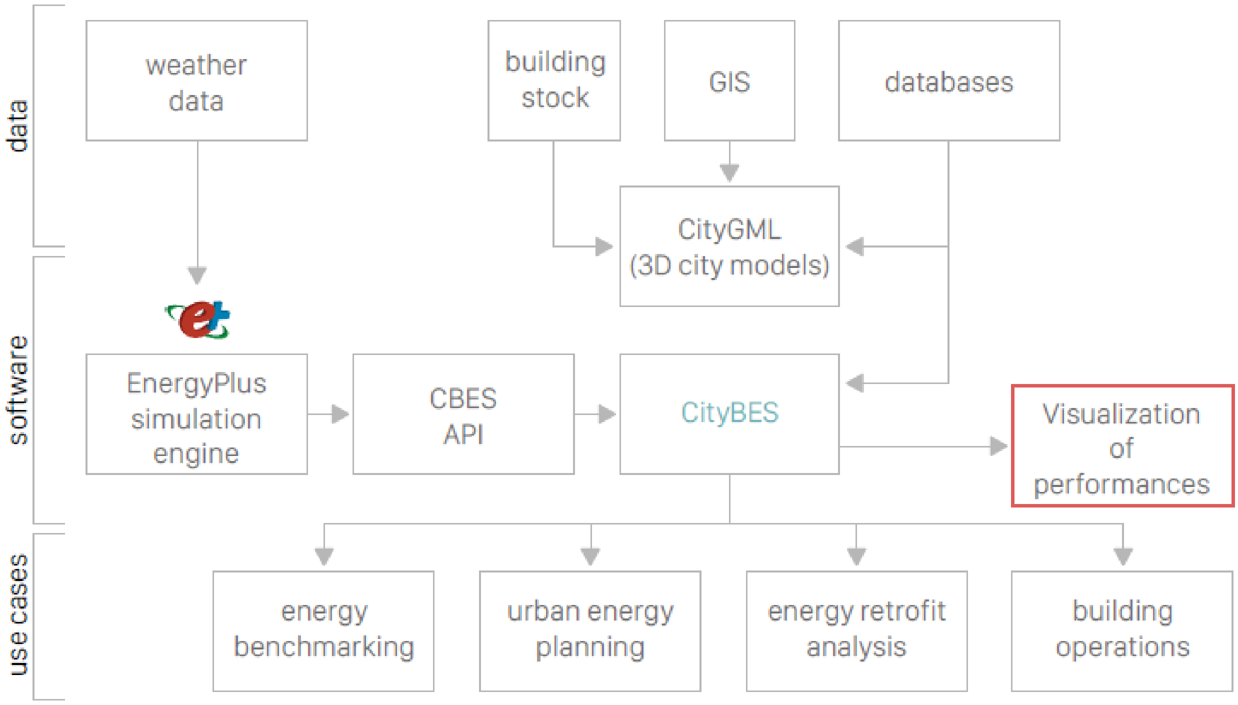


Figure 3.2: City BES workflow

(Bianchi 2018)

3.5 UMI

Urban Modelling Interface (UMI) is based on the modelling program Rhinoceros and is developed by MIT. It uses multiple programs for different results such as Rhinoceros modeler for base model, EnergyPlus for thermal simulation, Python scripts for walkability and Daysim for daylight etc.(Bianchi 2018). On one hand it benefits from this multiple program integration as it advances and the individual programs get improved by developers, however the user need to be familiar with these tools to get the full advantage of UMI.

3.6 Summary of Simulation tools

	Pros	Cons
IDA ICE	Intuitive user interface, learning material available, good support service by developers	Limited to building scale, closed source
Grasshopper	Well-developed program, with a lot of plugin options, Parametric usage	In depth analysis require multiple plugins
CEA	Open source, macro scale simulations, geo-referenced building information	Dependent on multiple programs, time consuming, developer bugs, data availability
CityBES	Micro to macro scale simulation, open source, comparisons with other data sets	Collaboration with program developers, data availability, web tool
UMI	Learning material available, supported by existing programs, open source	Dependent on other programs

Table 3.1: Pros and cons of Selective simulation programs

After carefully assessing these programs (Table 3.1), IDA ICE was chosen for ethe simulations of this project owing to its abilities to simulate building data in detail along with incorporating the use of renewable energy in the simulation model. Its limitation of not simulation bigger scale projects such as complete neighbourhoods pose some challenge, but the purpose of this thesis can work with building simulations and aggregating the data from multiple simulations

4 Project scope

4.1 Scale

After carefully assessing literature on energy flexibility and load shifting in neighbourhoods with renewable energy generation capabilities along with its economic impact, scope of the project was defined along with the simulation tool to be used (IDA ICE 4.99). Project deals with the simulation of two buildings from a neighborhood to do a comparative analysis between their multiple cases by modifying building parameters to study the effect of those parameters on the energy profile of the project in terms of energy consumption of the building from the grid and from the onsite PV panels. Furthermore, calculation of building simulation data is done in order to see the impact on a bigger scale, which in this case targets about 30% of housing in the neighbourhood, to assess the results and effects on the big picture.

4.2 Aim

Purpose of these simulations is to see the opportunity for improvement in the energy positive buildings which can attract more people towards this kind of development. To do that, input values for simulation models are taken from project developer and the values which were not available are assumed based on literature and sets of standards such as passive house values and TEK17. Results are aimed towards the impact of different parameters in terms of building construction and energy systems to maximize the use of onsite produced renewable energy before importing energy from the grid. Using different ventilation strategies and thermal properties of the project, load shifting is studied while maintaining a certain comfort level for users of the project.

4.3 Limitations

Indoor air quality and occupancy are not target parameters in the project, so their assumed values have been used based on the data from TEK17 and building plans, for the sake of simulations. Similarly, thermal comfort is not a point of focus for this thesis, so after making a standard comfort profile in the model using allowed indoor temperatures and air averages, load shifting capabilities of the project are focused on.

4.4 System boundary

System boundary of the project aims to model each apartment in the building as one zone since the building systems such as ground source heat pump and PV system cater to the whole building instead of individual apartments. So, modelling a multi-zone apartment in the building vs a single zone apartment in the building yields similar results in this case, although the former one takes much more time to simulate, hence the decision to move forward with the latter option was made for the sake of comparative analysis of multiple simulated cases.

Project looks at the potential of load shifting on building level using insight in the hourly data over a year, but the results are meant to affect the whole neighbourhood energy dynamic in the long run.

5 Building energy modelling

There are four main steps to building energy modelling, details of which are briefly explained below:

5.1 Data collection

Data collection for energy modeling requires different types of data which includes weather data, energy usage schedules, geometry of the building and the construction documents to assess the construction details of walls and windows to figure out U-values and other such technical aspects. In case of weather data, there are EPW files of several places available in the database and in case we don't have a file of the exact area we have the option to choose the file from the weather station that is closest to our project in order to compute our results. Other data, like geometry of the building and construction details are obtained from the project developers in the form of building drawings, mainly plans, sections, insulation details and the thermal values of the different materials. Once we have this data, we can build the model in a simulation program. Next step takes into account energy systems, to simulate the results based on the information of heating, ventilation and air conditioning technologies used in the project.

In case of renewable energy production on site, we need to know the specifics of the energy production system i.e., type of renewable energy and system parameters. In this case, photovoltaic panels are used on site, so the efficiency percentage of those PV panels, invertor efficiency and the area that they are used on, along with their orientation on the buildings is required to compute the energy production on site.

Once we have this data, we simulate a base case and using the results from it as a reference point, we can pinpoint the areas which have some room for improvement by trial and error method(Meer et al. 2019).

5.2 Reference Building

When we talk about studying a neighborhood through simulations of clusters, it does not necessarily mean to model the whole neighborhood in detail to run the simulations, since that would require a lot of resources in terms of data and time. So, we turn to the method of grouping, which means there are certain buildings in a cluster in a neighborhood which are of similar type in their form, function and/or orientation and using the simulations from one building from the cluster, we can aggregate the results for the whole. For this purpose, the neighborhood is divided into several groups, where each group of buildings can be categorized by similarities such as form, material usage, area and other characteristics that define its energy usage profile and its overall character. Once the grouping is done, a reference building from each group is selected to model and simulate the results, which are then applied to the whole group/cluster. This allows us to do an aggregate of results from different clusters, making up the neighborhood.

In case of a reference building from one of the clusters in the neighborhood, each apartment inside the building is considered as a One zone instead of multiple zones inside each apartment since we are looking at the overall energy usage of the building and not the energy usage or energy profile of each type of room individually. This strategy also assists us to run the simulations more efficiently and providing us the overall result that we want to get from the simulations to analyze add pinpoint target areas for improvement.

5.3 Modelling

After the data collection of buildings and their grouping is done, we move towards the modeling stage. This can differ depending on the scale of the project, for example, if we are analyzing a neighborhood, then the detail on the building level in the project decreases, which means for a neighborhood analysis we won't be modeling every single detail inside a building, instead we will set certain parameters and focus on the macro aspect to compute the results , and on the other hand, if we are analyzing a single building only, then the level of detail in that building increases a lot compared to the level of building detail in the neighborhood analysis. This thesis aims to analyze a part of a neighborhood which means it's bigger than a building but still smaller than a whole neighborhood. In order to do that, one simulation program is not enough, which means one model is not sufficient to compute all the results, leading to models of varying sizes and details, specific to certain analysis.

5.4 Output data

Comprehension of the simulation results poses an important challenge, which means knowing what the relevant results are to focus on, which can affect the specific project. The reliability of the results to the real-world application is then an important discussion, which is a deciding factor of the significance of the simulation program.

Reliability of the simulation programs affects how they influence the future design decisions and what improvements can be made using them in terms of energy usage by the project and consumption of onsite produced renewable energy. Purpose is to use output data of the simulation of a building to study the results for the base case, which becomes an initial reference to which we add additional stimuli to see how the results differ. This helps us to narrow down the target areas to improve the construction of future buildings in the neighborhood.

Range of errors for a building is usually between 7% and to 21%, which are acceptable values when a group of buildings is considered(Bianchi 2018)

6 Case study

Form demo projects of syn.ikia, project in Fredrikstad which is being developed by Arca Nova is chosen for the purpose of this thesis.

6.1 Demo neighbourhood, Fredrikstad – Verksbyen

arcanova.no/Verksbyen

One of the neighborhoods under the project syn.ikia is in Fredrikstad, Norway which has been named as Verksbyen. It is a project being developed by Arca Nova. The neighbourhood is being developed for a while now with 7 sets of different housing zones already planned and opportunity for future expansion provided next to a neighbourhood lake (Figure 6.1). Most of the constructed part is already sold out with smart grid systems introduced to keep track of energy use and production with interactive housing interfaces on digital platforms to assure user comfort while cutting out unnecessary emissions.

In Figure 2.2, demo neighbourhood in the south of Norway based in Fredrikstad is called as Verksbyen. It cater to the Subarctic climate category of the syn.ikia demo projects, with more than 1500 energy plus housing units planned. Buildings in the neighbourhood use passive strategies integrated with energy systems from early design stage to reduce energy needs and then compensate for the rest via renewable energy production on site.

Figure 6.1: Verksbyen

(Source: arcanova.no)

For the sake of this thesis, three sets of housings from this neighborhood were chosen which are Verket Panorama with three building having 64 apartment units in total, Verket

Atrium I and Verket Atrium II with 4 buildings in each (excluding Building D and I), having 226 apartment units in total. That means, 11 apartment buildings with 290 apartment units from the neighbourhood are chosen for the purpose of this thesis (Figure 6.2).

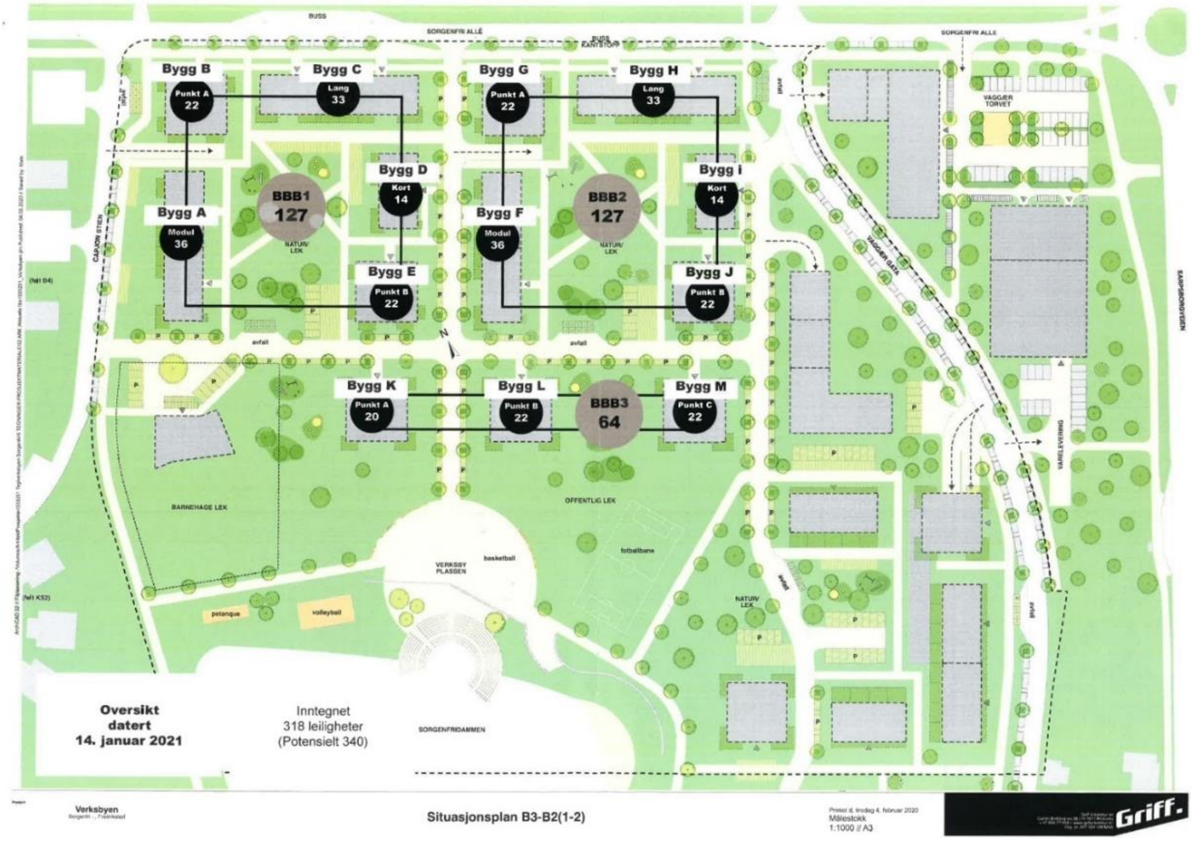


Figure 6.2: Verksbyen Master plan

(Source: Arca Nova)

From now on forward in this report, Verket Atrium I and Verket Atrium II will be termed together as Verket Atrium, making our focus on two clusters, being Verket Panorama and Verket Atrium.

6.2 Verket Panorama

This apartment complex consists of three building with 20-22 apartments each. We can take one building from these three as a reference building to do energy simulations for the analysis. On the plus side, this building type is also repeated four more times in two sets of Verket Atrium buildings. Modelling this building as a reference building means using the construction details such as wall layers including insulations and finishes, along with the details of the energy systems used in the building are modelled for the sake of simulations. In the course of this process, each apartment inside the building is considered a separate zone, while further zones of each room inside each apartment are not in the scope of this project at the moment. For that matter, certain values have been taken as average to be able to apply to the whole apartment in a justifiable manner, such as supply and return air.

Construction details of the building which include wall layers, material layers in floors and ceiling and other details which are pertinent to building performance regarding its construction are taken from drawings made by Arca Nova which can be found in Appendix I. Energy systems used in the project were also given by the project developers but the general systems, and not their details which led to literature-based assumptions when it came to simulations.

6.3 Verket Atrium

Verket Atrium has two sets of apartment buildings comprising of Verket Atrium and Verket Atrium II and having 127 apartments using each in total of 10 apartment buildings. Four of those buildings are similar to building in Verket panorama so they are considered under the reference building mentioned in the previous section i.e., Building K, while Building A from Verket Atrium is chosen as the reference building for the rest of apartments in the category. Building D and Building I, each having 14 apartment units, are not considered for the scope of this study.

Building drawings were provided by Arca Nova(Arca Nova n.d.), while the construction details were taken from Appendix II again. Energy systems are given their parameters from assumptions based on literature from Passive house values and TEK17(TEK17 2022)

7 Simulation

IDA ICE 4.99 is used to model the reference buildings of both clusters to study energy shift in detail on building level by simulating individual building models.

7.1 IDA ICE Simulation Model

Using the information from Verket Panorama and Verket Atrium provided in Appendix I and Appendix II respectively, simulation models were made for reference building K and reference building A respectively.

7.2 Simulation Input Data

To simulate the buildings in detail, some of the core data which was compiled is divided into following categories:

Input parameter	**Unit/detail**
Weather file	IDA ICE weather file/EPW file
Air handling unit	Type, Fan pressures, Coil temperatures, Supply air setpoints
Heating system	Type, No. of units, capacity, power, combinations
PV system details	Area and orientation, Tilt angle, Panel efficiency, Invertor losses,
Architectural drawings	Plans, sections, master plan
Construction details	Detail drawings, material layers, insulation details
Thermal bridges	W/K/ (m^2 envelope)
Infiltration data	Air tightness, pressure difference
Hot water use	No. of liters per occupant per day
Heating/cooling setpoints	^oC
Supply/return air	m^3/h
Occupancy data	Number of people
Lights	Number of units
Equipment	Number of units
Project Average U-value	W/ (m2 K)

Table 7.1: Input parameters for simulation via IDA ICE

There are many other input parameters along with these in the table 7.1, which can be used for detailed load shifting studies of a project, especially to do a neighbourhood scale simulation in programs like UMI, CEA or City BES etc, however, these are some which can be relatively easily acquired/assumed/simulated compared to more confidential real data.

7.3 Simulation model of Verket Panorama Building K

In Verket Panorama, building K was chosen as a reference building to model and simulate results for this cluster and for similar building in other clusters.

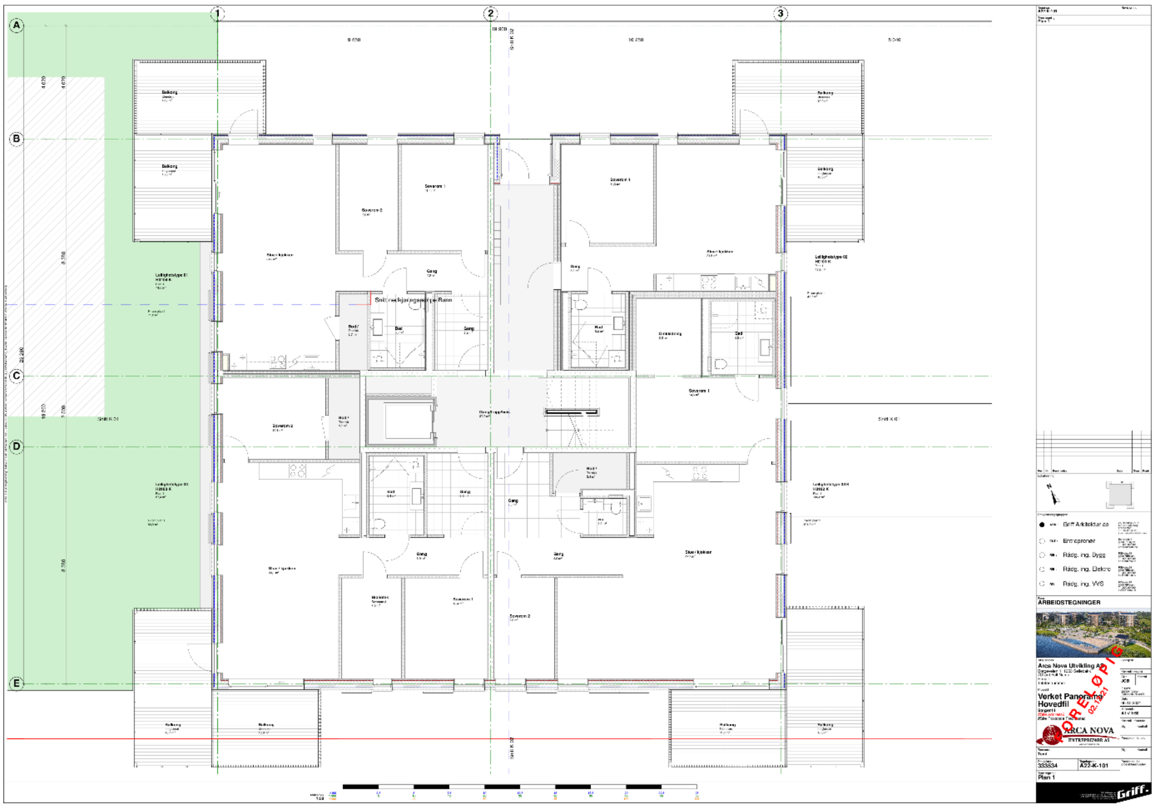


Figure 7.1: Verket Panorama Floor 1 plan-Building K

Verket Panorama is a 6-floor apartment building with three identical building in Panorama cluster and four of the same building in the clusters Atrium I and Atrium II. Figure 7.1 shows the 1st floor plan of the building while rest of the plans and sections can be found in Appendix I. This building has 4 types of apartments which are repeated in all the floors.

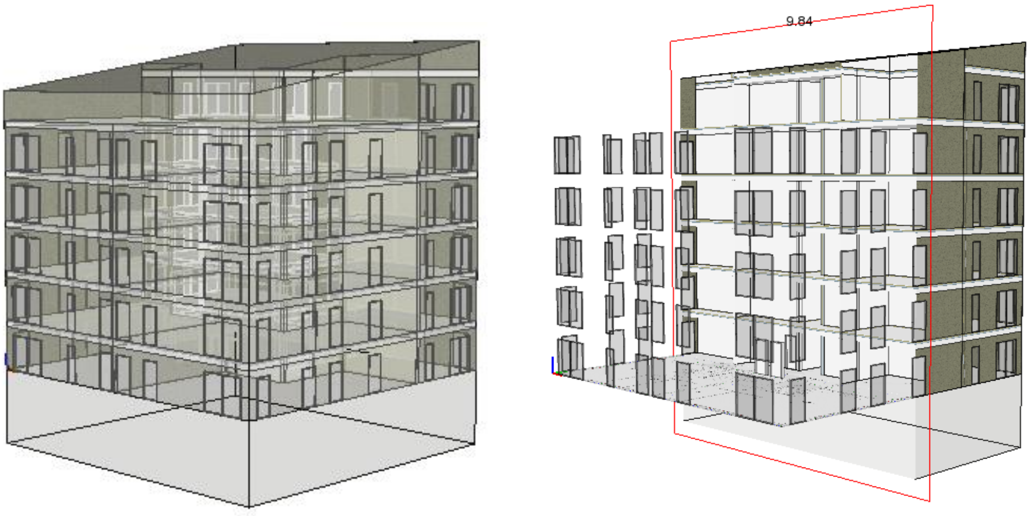


Figure 7.2: Simulation model of Panorama Reference building K

(Modelled in IDA ICE 4.99)

There are certain aspects and characteristics which are kept same in energy modelling of Panorama reference building (Figure 7.2) and Atrium reference building (Figure 7.4) but owing to the area differences, orientation and different apartment types, some input data stays unique between the two types.

7.3.1 Input data for Panorama reference building K

Reference building has 20 apartment units with four on floor 1-5 and two on floor 6. These apartments are all modelled one zone per apartment for the sake of simulation and then we have 6 zones of building circulation zone, making it to be a 28-zone building simulation model.

Zone type Designation	No. of bed/ zone	No. of Zones	Area/ apt, m^2	Supply Air, m^3/h	Return Air, m^3/h	No. of occupants/apt	Lights, W/m^2	Equipment, W/m^2	Exterior Window area
A	2	5	105.0	204	204	3	1.134	4.96	22
B	1	6	45.5	120	120	2	1.641	6.57	12
C	2	5	87.5	163	163	4	1.55	6.03	19
D	2	6	74.5	159	159	3	1.412	5.04	17
E-Circulation	0	6	37.5	26.5	26.5	-	1.198	1.99	0

Table 7.2: Data collection of Panorama reference building K

Building data in Table 7.2, regarding the number of rooms, windows and areas is taken form the plans provided by Arca Nova, however the information about lights, equipment and occupants is assumed, while supply/return air is calculated based on plans and TEK17. Since each apartment is modelled as one zone in the building, supply and return air are taken as equal, and also their values are calculated from different rooms in the apartment and then an average is made from those values which has been used here as one number for the whole apartment zone. Calculation of these values of supply and return air can be found in Appendix I- supply and return air calculation, based on the numbers from TEK 17. One thing that needs to be mentioned here is that the calculation to supply and return air that is done here assumes the usage of space 24/7, however in reality these air flow rates differ based on the fact when the space is being use and when it’s not. This means the results of the simulation will be higher compared to the results we would get if we put different values of air flow for when the space is being use and when it’s not. That being said, purpose of this project is not to decrease the energy usage of the building on its own, it’s supposed to be a comparative analysis of different options with some parameters changed to see their effect in the energy usage and that comparative analysis can still be done if we keep certain values constant in the base case and the test cases, which in this case would be the supply and return air, while increasing our energy usage, their number would remain same in all the test cases.

Other than using constant air flows regarding the use of space, we also disregard the use of forced ventilation for the sake of these simulations, which would definitely increase the use of overall energy of the project, however as mentioned in the previous paragraph, we take this as a constant and can carry on with our comparative analysis without it drastically affecting our results. So, for the sake of this project, forced ventilation is taken out of the scope.

7.4 Simulation model of Verket Atrium Building A

In Verket Atrium, building A has been chosen as a reference building to model and simulate results for this cluster.

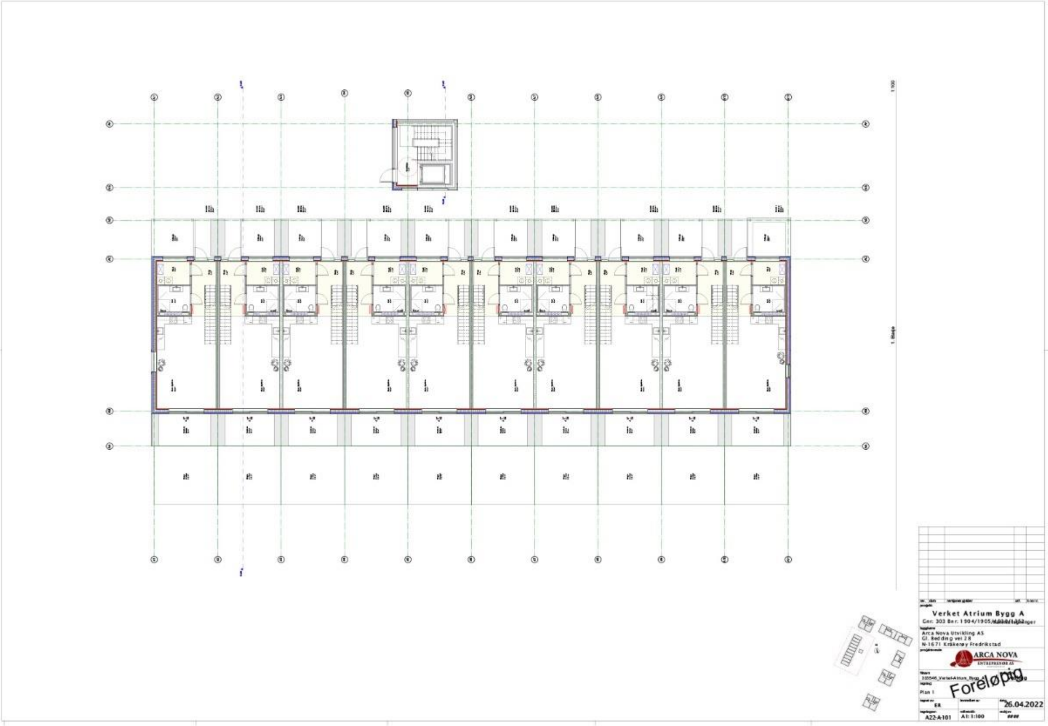


Figure 7.3: Verket Atrium Floor 1 plan-Building A

Verket Atrium I and Atrium II have four building blocks modelled on the floor plan in Figure 7.3, having total height for 6 floor levels, with some apartments being duplexes in them. This cluster also has four building blocks that are modelled on the layout of Verket Panorama buildings. Two more buildings, building D and building I are not considered in simulations for the sake of this project, which have 14 apartment units in each. Figure 7.3 is showing the floor 1 of Building A in Verket Atrium, while rest of the plans and sections can be seen in Appendix II. Energy model based on these plans can be seen in Figure 7.4.

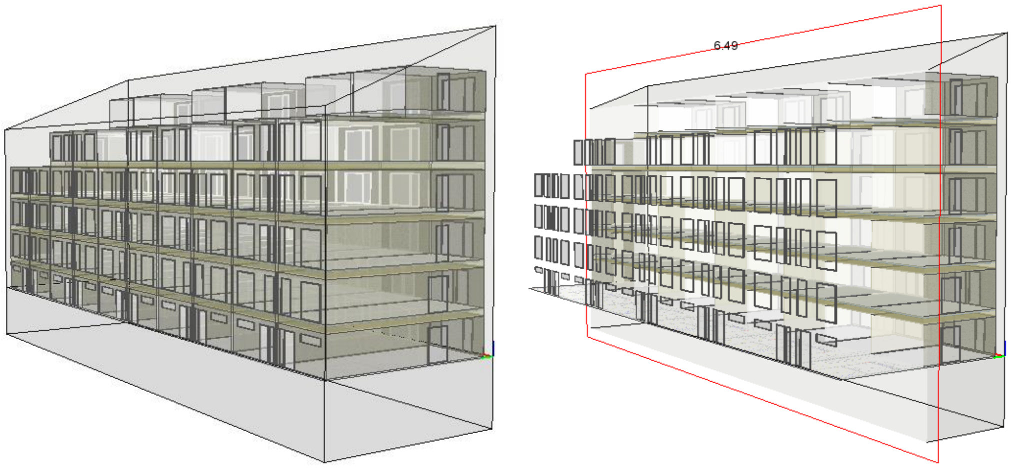


Figure 7.4: Simulation model of Atrium Reference building A

(Modelled in IDA ICE 4.99)

7.4.1 Input data for Atrium reference building A

This building has four types of apartments with two types being duplexes. In those four types, there are various layouts planned by developers so for that reason, each level is modelled in a separate zone, which means that one zones is equal to one apartment unless it's a duplex, in which case, it consists of two zones. Also, the outer segregated circulation core of the building is not modelled for the energy simulations. After all this, simulation model of Building A has 56 zones.

Zone type Designation	No. of bed/ zone	No. of Zones	Area /zone, m^2	Supply Air, m^3/h	Return Air, m^3/h	No. of occupants/apt	Lights, W/m^2	Equipment, W/m^2	Exterior Window area
A	0	10	57.0.	153	153.0.	2	1.58	7.88	8.21-11.73
B	3	10	57.0	142.6	142.6	4	1.84	7.88	10.78-14.3
C	1	23	57.0	130	130.0	1	1.31	6.56	11.44-13.64
D	2	3	57.0	151	151.0	2	1.58	7.88	13.64
E	1	2	30.5	36.5	36.5	2	1.97	7.37	9.46
F	1	8	30.5	63.2	63.2	2	2.46	7.37	9.46-11.65

Table 7.3:Data collection of Atrium reference building A

In Figure 7.3, building data regarding the number of rooms, windows and areas is taken form the plans and sections provided by Arca Nova, however the information about lights, equipment and occupants is assumed. Calculation and application of supply and return air is done as explained earlier in "Section 7.3.1 Input data for Panorama reference building". In table 7.3, we have the values of supply and return air , calculation of which can be found in Appendix II-supply and return air calculation based on the information from TEK 17.(TEK17 2022)

7.5 Input data common between Building K and Building A

Aside from the input data that's already been mentioned previously, there is other relevant data which has been used in both simulation models as input for the base cases.

Starting from the building construction details, wall and floor details are taken from the drawings provided by the project developer, Arca Nova, which can be seen in the Appendix III. These drawings give us the layers of different materials with their thicknesses, arrangement, and u-values for the simulations.

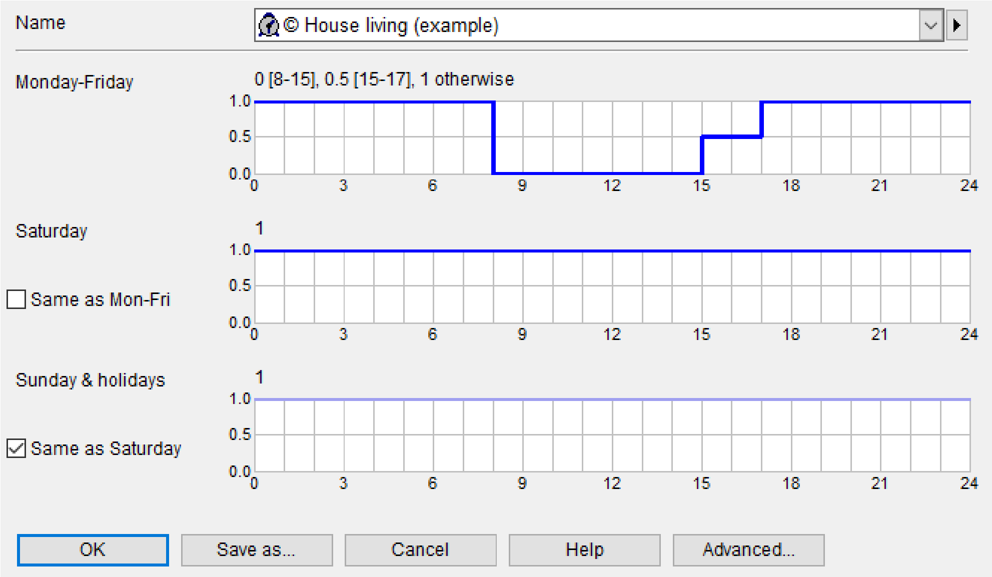
For equipment values, standard equipment unit from the program IDA ICE is used, number of which are assumed based on the floor plans, with 75W heat emitted per unit. In case of lights, each unit of 15W with luminous efficacy of 125lm/W and convective fraction of 0.78 has be used in both models.

Regarding PV systems, photovoltaic panels of 20% efficiency are used to cover the complete roofs of both building with the extents of the panels ranging a bit further than the roof boundary owing to the supporting stands under them. Reference building from the cluster Panorama has PV area on roof of 400m^2 and the other reference building, belonging to the cluster Atrium has PV area of 650m^2 on the roof.

For heating, both buildings use Ground source heat pump, with Brine to water heat pump being used in the simulation model for base heating. Hot tank of 0.76m^3 volume used in simulation model of building K and tank of 1m^3 is used in the model of building A in their respective plants. Ground source borehole loops are used in the ground heat exchange. For top-up heating, generic floor heating is employed, with their heating power ranging from 1475-3394 W in Panorama reference building K and heating power in Atrium reference building A ranging from 805-1650 W, being operated by PI controllers in the simulation model.

Thermal bridges in both buildings for total envelope including roof and ground are taken as 0.03W/K (m^2 envelope). This value is quite optimistic in terms of real-world construction, so this can change depending on the construction quality of the project and there can be differences between simulated results and the real-world results based on the difference between thermal bridges of simulation model on the actual building. For infiltration, air tightness is taken as 0.6 ACH(building) and air pressure difference is take as 50 Pa. Average hot water usage is taken as 40L/occupant/ day in both buildings. (Ivanko, Walnum, and Nord 2020).

For most of the operation systems in the building models, schedule of “House Living” is used where the space under simulation is occupied as can be seen in Figure 7.5.



Name: © House living (example)

Monday-Friday: 0 [8-15], 0.5 [15-17], 1 otherwise

Saturday: 1

☐ Same as Mon-Fri

Sunday & holidays: 1

☑ Same as Saturday

Figure 7.5: House Living (Schedule of usage)

In the base cases of both reference buildings, this schedule is used for lighting, equipment and for occupancy. For window openings, PI temperature controller is used, while the u-value of the windows is taken at 0.8 W/m^{2}K.

Weather file form RYGGE weather station is used for simulations which is the nearest weather station to Fredrikstad (approximately 30km), and which is available in IDA ICE. Wind profile of Suburban areas from ASHRAE 1993 is used along with this weather data.

Aside from these inputs, details about the building surfaces and their placements are taken from architectural drawings of the projects (Appendix I , Appendix II, Appendix III). Some of these details in the form of u-values of the respective overall surface thickness used in the base cases of both buildings can be seen in table 7.4:

Building surface	Thickness (m)	U-value (W/m^{2}K)
External wall	0.39	0.08
Load bearing interior wall-Conc	0.21	2.90
Load bearing interior wall insulated	0.27	0.30
Interior wall with insulation	0.15	0.62
Non load bearing interior wall	0.12	0.32
Floor with ceiling	0.51	0.19

Table 7.4: Building walls and floor data

8 Results and discussion

Models of both reference building were tested five times each with different parameters, to do a comparative analysis of the results to see which case performs better when it comes to energy shift from grid electricity usage to direct on-site produced electricity usage. Result output is taken in the form of hourly data of one whole year, generating the values for 8760 hours for each case. By plotting the results in excel format and comparing side by side, certain aspects became clear as to which case is performing better and by how much.

Results from these simulations are summarized and tabulated for the sake of this report, showing us the definite numbers form each case and differences between them. In case of both reference buildings, one base case is used to study the other cases with modified parameters, to better understand the varying energy use, load shifting and behavior of renewable energy on site.

Schematics of the results generated from IDA ICE simulations can be seen in the Figure 8.1 to better understand the energy dynamic of the project.

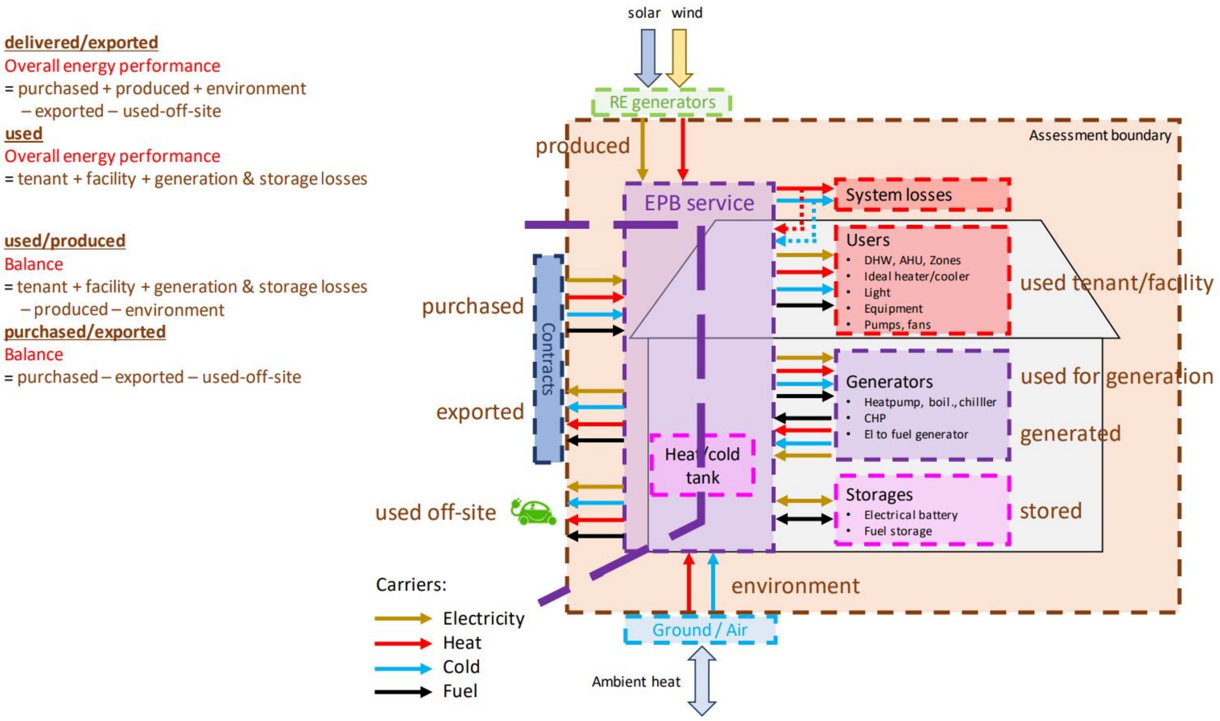


Figure 8.1: Schematic of definitions

(IDA ICE 4.99)

8.1 Choice of test cases

For the purpose of simulation of multiple cases of each reference building, parameters needed to be set for the cases. Choice of parameters for the test cases was made based on factors which would be different enough from each other that they won’t get into the territory of each other, while giving us insight into a whole section of project to explore the future possibilities for improvement, not just a standalone aspect which cannot be explored in detail, or which is just specific to only one project in the world.

So, five categories were devised based on this thought process where one case would become the Base case, which is to be used to compare and study results from other simulation cases.

Second case needed to be construction related, which would affect the decision of composition of materials used in the project. This would affect the design of the project, like wall thicknesses, space sharing, and structural aspects of the project design. This led to increasing the thermal mass for case 02, which in this case turned out to be increasing the using of concrete in the project. As the design was locked, so to keep the wall thicknesses same, amount of insulation was decreased in certain areas and in the results, we can see the impact of that along with the effect of increased concrete usage.

Choice of third case was focused on the heat storage capability of fluid in the project, which meant targeting the water usage in the project. Since water can be heated during the sun hours when the energy is being produced and that heat can be retained for a while to be used in sunless hours to heat up certain spaces, this option came into play naturally and led to the testing of increased number of brine to water pumps and a noticeable increase in the volume of hot water tank used in the project.

After focusing on building composition in terms of material usage and use of water in the project in previous two cases, air flow in the project was chosen to be modified, which meant changing the parameters of air handling unit. This led to trying out an alternate ventilation strategy, i.e., Night ventilation instead of a standard air handling unit. Night ventilation directly affects the air flow in the building, and any stored hot air from the space is replaced by fresh air, so it was coupled with heat recovery of hot exhaust air, which is then used to heat up a liquid to affect the indoor temperatures when required. This strategy meant an impact on the electrical heating load and delay in energy usage in certain times when it would be supported by liquid heat recovery to fulfill the space requirements of general comfort. Detailed effects of this strategy are then studied in the results, supported by simulations.

Final case that was chosen for this study, was aimed at the thermal intake from glazing of the project. Since, we have high performance triple glazed glass used in the project, which is supported by integrated shading, we focus on any external elements that can affect the heat intake from those areas. Which meant adding an external shading device on each window and observing its effect on the energy profile of the project.

To summarize, five study cases were chosen based on the following criterion:

- Case 01 – Base case to compare test results with
- Case 02 – Effect of change in construction composition
- Case 03 – Manipulation of hot water in the project
- Case 04 – Use of air in the project in alternate ways
- Case 05 – Targeting the glazing of the project

8.2 Simulation of Panorama Building K

Reference building K has been simulated 5 times with some parameters changed each time to study their effect on the building's energy profile and changes in the consumption of on-site produced renewable energy.

8.2.1 Case 01- Base case

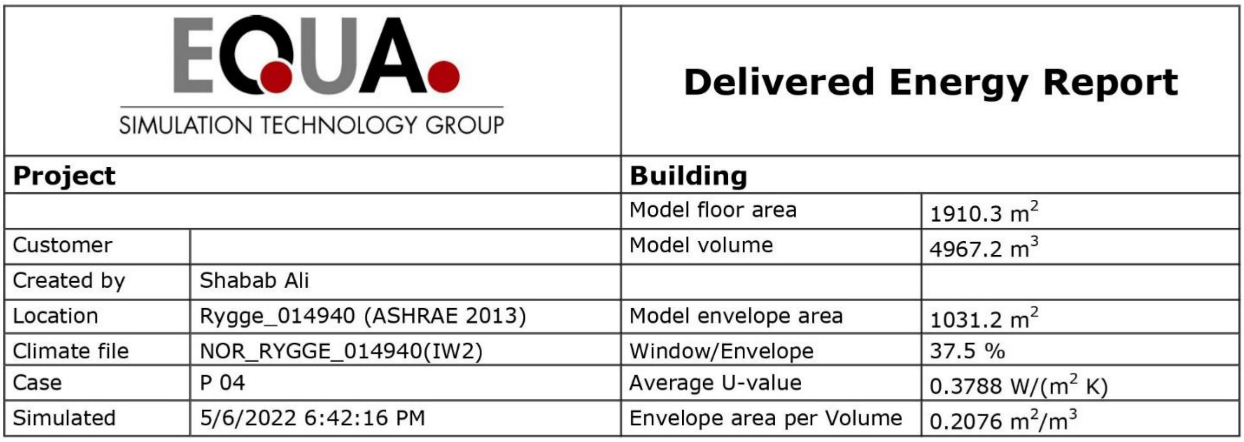
Input data for base case of the Panorama reference building is as follows:

Input parameter	**Unit/detail**
Weather file	NOR_RYGGE_014940_IW2
Air handling unit (AHU)	Standard AHU, SFP=1.5 kW/(m^3/s), Efficiency=0.85, Pressure rise=1275, Heat exchanger effectiveness=0.9, Heating coil=ON, Cooling coil=OFF, Supply air setpoints= Schedule, Operation=House Living schedule
Heating system	Ground source heat pump, Brine set constant=7, No of units=4, Unit capacity=10kW, Volume of Hot tank=0.76m^3, Floor heating power=1475-3394 W
PV system details	Area=400m^2, Orientation=30^o of S, Slope angle=9^o, Efficiency =20%
Architectural drawings	Appendix I

Construction details	Appendix III
Thermal bridges	0.03 W/K/ (m^2 envelope)
Infiltration data	Air tightness=0.6 ACH (building), Pressure difference=50 Pa
Hot water use	40 liters per occupant per day
Heating/cooling setpoints	21°C / 25 °C
Supply/return air	Appendix I
Occupancy data	65 people
Lighting data	175 units
Equipment data	130 units
Project Average U-value	0.38 W/ (m2 K)
Window Shades	Integrated window shading

Table 8.1: Building K Input-Case 01

Using the input mentioned earlier in the report and in the table 8.1, simulation on test case 01 yielded the following energy report:



EQUA SIMULATION TECHNOLOGY GROUP		**Delivered Energy Report**	
Project		**Building**	
		Model floor area	1910.3 m^2
Customer		Model volume	4967.2 m^3
Created by	Shabab Ali		
Location	Rygge_014940 (ASHRAE 2013)	Model envelope area	1031.2 m^2
Climate file	NOR_RYGGE_014940(IW2)	Window/Envelope	37.5 %
Case	P 04	Average U-value	0.3788 W/(m^2 K)
Simulated	5/6/2022 6:42:16 PM	Envelope area per Volume	0.2076 m^2/m^3

Figure 8.2: Delivered energy report of Building K-Case 01

(IDA ICE 4.99) – Appendix IV

Complete energy report can be found in Appendix IV-Verket Panorama reference Building K- Results _ Case 01. However, summary of the report in terms of energy can be seen as following in the Table 8.2:

	Building's energy requirement	Renewable energy produced on site	Renewable energy used on site	Renewable energy sold to grid	Energy bought from grid	Energy balance
kWh/m^2	62.4	34.1	13.8	20.28	48.5	28.3
kWh	119,266.2	65,237.0	26,499	38,738.8	92,767.2	54,029.2
%	100.0	54.7	**22.2**	32.5	77.8	45.3

Table 8.2: Simulation summary of Building K-Case 01

Although the simulation resulted in 8760 instances of data in term of hours in a year, the data is compiled and read as comparison of energy use of each system in the building, giving us the summarized numbers in the table 8.2. Here, the number 100% marks the total energy demand of the project and works as a benchmark to compare other numbers of the project.

8.2.2 Case 02-Increased thermal mass

Input data for case 02:

Input parameter	**Unit/detail**
Air handling unit (AHU)	Standard AHU, SFP=1.5 kW/(m^3/s), Efficiency=0.85, Pressure rise=1275, Heat exchanger effectiveness=0.9, Heating coil=ON, Cooling coil=OFF, Supply air setpoints= Schedule, Operation=House Living schedule
Heating system	Ground source heat pump, Brine set constant=7, No of units=4, Unit capacity=10kW, Volume of Hot tank=0.76m^3, Floor heating power=1475-3394 W
Project Average U-value	0.88 W/ (m2 K)
Window Shades	Integrated window shading

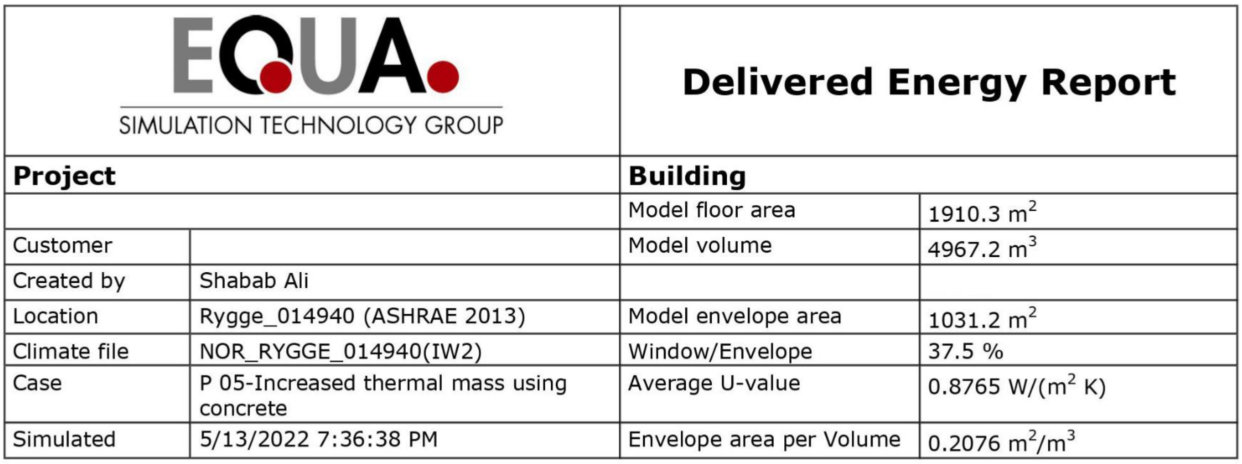
Table 8.3: Building K Input-Case 02

In case 02, thermal mass of the model was increased by increasing the amount of concrete in the project. Details of which can be seen in the table 8.4:

Building surface	Thickness (m)	Base case (Case 01) U-value (W/m^{2}K)	Case 02 U-value (W/m^{2}K)
External wall	0.39	0.08	0.88
Load bearing interior wall-Conc	0.21	2.90	2.90
Load bearing interior wall insulated	0.27	0.30	1.36
Non load bearing interior wall	0.12	0.32	3.04
Floor with ceiling	0.51	0.19	0.55

Table 8.4: Change in thermal mass

Increasing the amount of concrete in the construction resulted in an increase in the thermal mass of the projects, which is done to study any effects of heat storage capabilities of the material which may or may not cause the load shifting from nighttime to daytime to any extent. So, all the input parameters are same except the use of concrete in this simulation case. Simulation report with increased thermal mass can be seen in Figure 8.3:



EQUA
SIMULATION TECHNOLOGY GROUP

Delivered Energy Report

Project		**Building**	
		Model floor area	1910.3 m^2
Customer		Model volume	4967.2 m^3
Created by	Shabab Ali		
Location	Rygge_014940 (ASHRAE 2013)	Model envelope area	1031.2 m^2
Climate file	NOR_RYGGE_014940(IW2)	Window/Envelope	37.5 %
Case	P 05-Increased thermal mass using concrete	Average U-value	0.8765 W/(m^2 K)
Simulated	5/13/2022 7:36:38 PM	Envelope area per Volume	0.2076 m^2/m^3

Figure 8.3: Delivered energy report of Building K-Case 02

(IDA ICE 4.99) – Appendix IV

Complete energy report can be found in Appendix IV-Verket Panorama reference Building K- Results _ Case 02. However, summary of the report in terms of energy can be seen in Table 8.5 below:

	Building's energy requirement	Renewable energy produced on site	Renewable energy used on site	Renewable energy sold to grid	Energy bought from grid	Energy balance
kWh/m^2	73.0	34.1	14.5	19.6	58.5	38.9
kWh	139,539.3	65,243.0	27,746.7	37,496.3	111,792.6	74,296.1
%	100.0	46.7	**19.9**	26.8	80.1	53.3

Table 8.5: Simulation summary of Building K-Case 02

Increasing the thermal mass while keeping the thicknesses of the walls and surfaces same as before, resulted in less insulation in the building, and as a result the overall energy demand of the building increased by a lot. This was expected, but the behavior of the project to consume onsite produced renewable energy was the result for which the simulation was ran, and even though the energy profile of the building increased, thermal mass of the building did not help the systems with energy delay for load shifting, instead we see a decrease in the consumption percentage of onsite produced energy and increase in the grid used energy compared to base case.

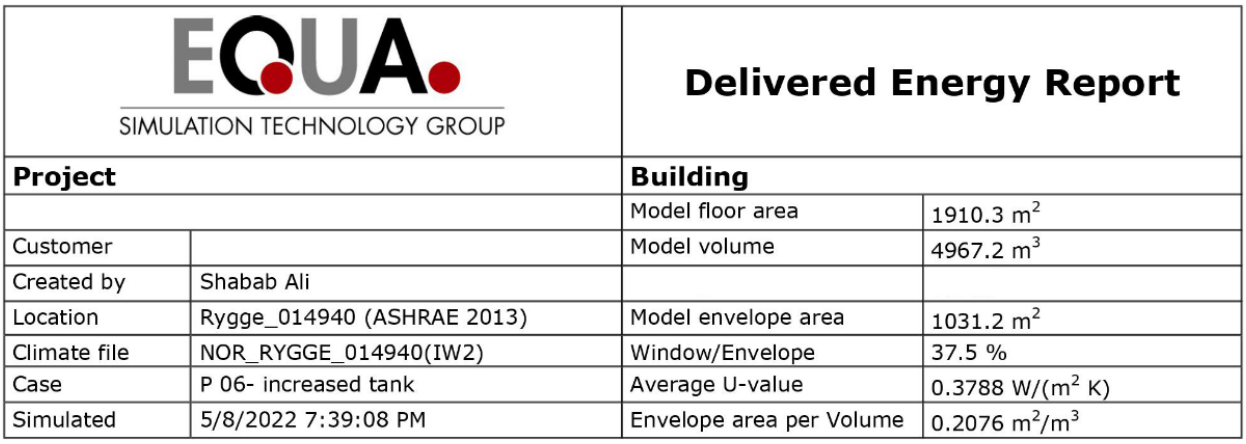
8.2.3 Case 03-Increased volume of water tank

Input data for case 03:

Input parameter	**Unit/detail**
Air handling unit (AHU)	Standard AHU, SFP=1.5 kW/(m^3/s), Efficiency=0.85, Pressure rise=1275, Heat exchanger effectiveness=0.9, Heating coil=ON, Cooling coil=OFF, Supply air setpoints= Schedule, Operation=House Living schedule
Heating system	Ground source heat pump, Brine set constant=7, No of units=5, Unit capacity=10kW, Volume of Hot tank=2.00m^3, Floor heating power=1475-3394 W
Project Average U-value	0.38 W/ (m2 K)
Window Shades	Integrated window shading

Table 8.6: Building K Input-Case 03

Case 03 deals with the increased number of units of Brine to water heat pump, along with bigger volume of hot water tank (Table 8.6). So, an overall increased energy profile was expected from the project, which we can study in the energy report for case 03 in Figure 8.4:



EQUA SIMULATION TECHNOLOGY GROUP

Delivered Energy Report

Project		**Building**	
		Model floor area	1910.3 m^2
Customer		Model volume	4967.2 m^3
Created by	Shabab Ali		
Location	Rygge_014940 (ASHRAE 2013)	Model envelope area	1031.2 m^2
Climate file	NOR_RYGGE_014940(IW2)	Window/Envelope	37.5 %
Case	P 06- increased tank	Average U-value	0.3788 W/(m^2 K)
Simulated	5/8/2022 7:39:08 PM	Envelope area per Volume	0.2076 m^2/m^3

Figure 8.4: Delivered energy report of Building K-Case 03

(IDA ICE 4.99) – Appendix IV

Complete energy report can be found in Appendix IV-Verket Panorama reference Building K- Results _ Case 03. However, summary of the report in terms of energy is presented in Table 8.7.

	Building's energy requirement	Renewable energy produced on site	Renewable energy used on site	Renewable energy sold to grid	Energy bought from grid	Energy balance
kWh/m^2	63.0	34.1	14.3	19.9	48.7	28.8
kWh	120,312.0	65,236.8	27,233.2	38,003.6	93,079	55,075.2
%	100.0	54.3	**22.6**	31.5	77.3	45.7

Table 8.7: Simulation summary of Panorama Case 03

Increasing the size of hot water tank and overall ground source heat system by increasing the number of units was expected to cause an increase in the building's energy demand to some extent, however, along with the overall increase in energy profile of the building, we also see an increase in the percentage of onsite renewable energy consumption compared to the base case, even though the increase is quite small and negligible.

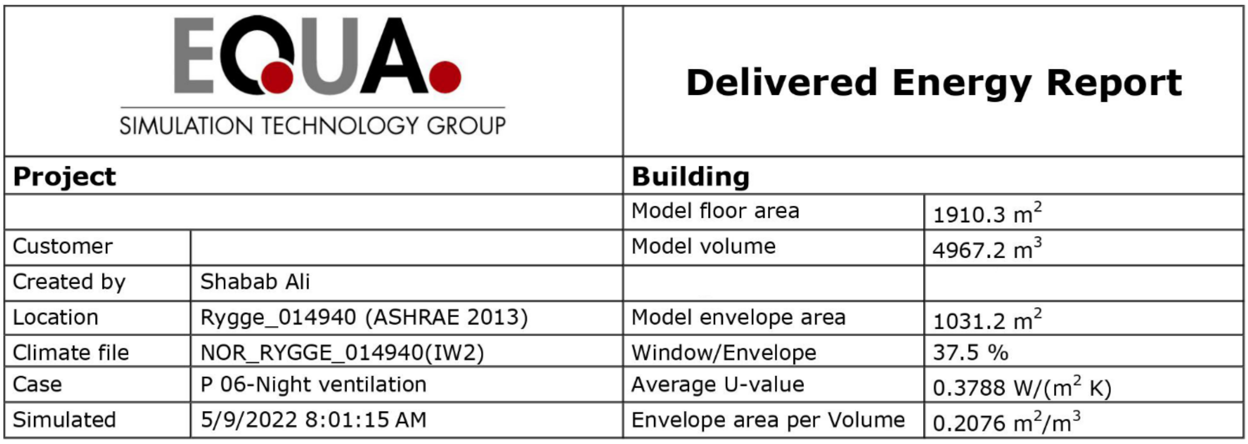
8.2.4 Case 04-Night ventilation and Exhaust air with liquid heat recovery

Input data for case 04:

Input parameter	**Unit/detail**
Air handling unit (AHU)	Night ventilation control + Exhaust air with liquid heat recovery, SFP=1.5 kW/(m^3/s), Efficiency=0.85, Pressure rise=1275, Heat exchanger effectiveness=0.9, Heating coil=ON, Cooling coil=OFF, Supply air setpoints= 17°C, Operation=Always on
Heating system	Ground source heat pump, Brine set constant=7, No of units=4, Unit capacity=10kW, Volume of Hot tank=0.76m^3, Floor heating power=1475-3394 W
Project Average U-value	0.38 W/ (m2 K)
Window Shades	Integrated window shading

Table 8.8: Building K Input-Case 04

Case 04 targets the air handling unit and ventilation systems in the project, where night ventilation is used primarily for the fresh air intake in the project and system of heat recovery is employed with exhaust air (Table 8.8), results of this can be seen in the following energy report (Figure 8.5):



EQUA SIMULATION TECHNOLOGY GROUP		**Delivered Energy Report**	
Project		**Building**	
		Model floor area	1910.3 m^2
Customer		Model volume	4967.2 m^3
Created by	Shabab Ali		
Location	Rygge_014940 (ASHRAE 2013)	Model envelope area	1031.2 m^2
Climate file	NOR_RYGGE_014940(IW2)	Window/Envelope	37.5 %
Case	P 06-Night ventilation	Average U-value	0.3788 W/(m^2 K)
Simulated	5/9/2022 8:01:15 AM	Envelope area per Volume	0.2076 m^2/m^3

Figure 8.5: Delivered energy report of Building K-Case 04

(IDA ICE 4.99) – Appendix IV

Complete energy report can be found in Appendix IV-Verket Panorama reference Building K- Results _ Case 04. However, summary of the report in terms of energy cab be studied in Table 8.9.

	Building's energy requirement	Renewable energy produced on site	Renewable energy used on site	Renewable energy sold to grid	Energy bought from grid	Energy balance
kWh/m^2	55.2	34.1	15.1	19.1	40	21.0
kWh	105,397.4	65,246.3	28,859.3	36,387.0	76,538.1	40,151.0
%	100.0	62.0	**27.4**	34.5	72.6	38.0

Table 8.9: Simulation summary of Building K-Case 04

In this scenario, not only the percentage of direct consumption of the onsite produced renewable energy increases, but the overall energy demand of the project also decreases by a lot.

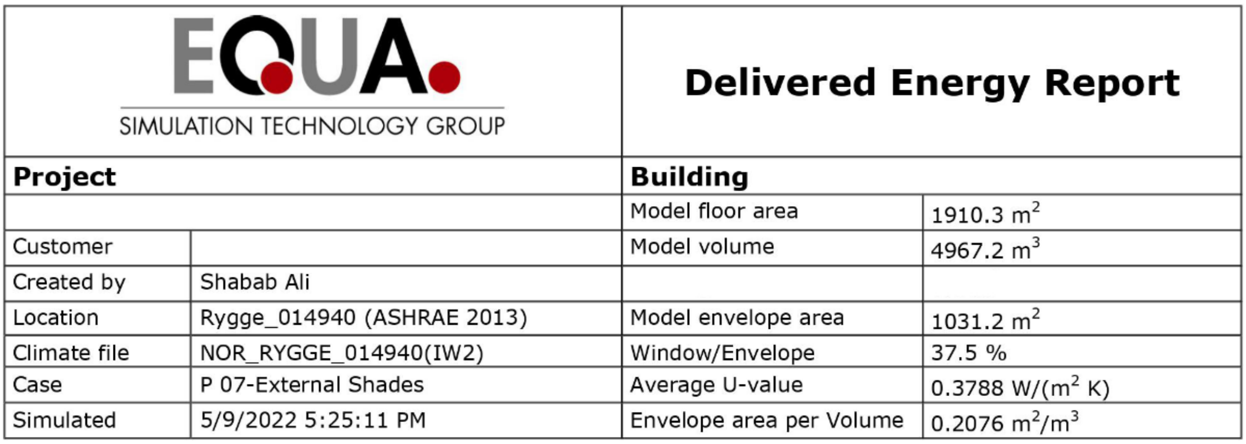
8.2.5 Case 05-External shades on windows

Input data for case 05:

Input parameter	**Unit/detail**
Air handling unit (AHU)	Standard AHU, SFP=1.5 kW/(m^3/s), Efficiency=0.85, Pressure rise=1275, Heat exchanger effectiveness=0.9, Heating coil=ON, Cooling coil=OFF, Supply air setpoints= Schedule, Operation=House Living schedule
Heating system	Ground source heat pump, Brine set constant=7, No of units=4, Unit capacity=10kW, Volume of Hot tank=0.76m^3, Floor heating power=1475-3394 W
Project Average U-value	0.38 W/ (m2 K)
Window Shades	External window shading

Table 8.10: Building K Input-Case 05

In the base case and in all other simulate cases, windows in the project only had integrated shading, however in case 05, all the windows are supplemented with external shading devices (Table 8.10) and the results are shown below in Figure 8.6:



EQUA SIMULATION TECHNOLOGY GROUP		Delivered Energy Report	
Project		**Building**	
		Model floor area	1910.3 m^2
Customer		Model volume	4967.2 m^3
Created by	Shabab Ali		
Location	Rygge_014940 (ASHRAE 2013)	Model envelope area	1031.2 m^2
Climate file	NOR_RYGGE_014940(IW2)	Window/Envelope	37.5 %
Case	P 07-External Shades	Average U-value	0.3788 W/(m^2 K)
Simulated	5/9/2022 5:25:11 PM	Envelope area per Volume	0.2076 m^2/m^3

Figure 8.6: Delivered energy report of Building K-Case 05

(IDA ICE 4.99) – Appendix IV

Complete energy report can be found in Appendix IV-Verket Panorama reference Building K- Results _ Case 05. However, summary of the report in terms of energy can be seen as following:

	Building's energy requirement	Renewable energy produced on site	Renewable energy used on site	Renewable energy sold to grid	Energy bought from grid	Energy balance
kWh/m^2	62.4	34.1	13.9	20.3	48.5	28.2
kWh	119,182.1	65,240.1	26,494.5	38,745.6	92,687.6	53,942.0
%	100.0	54.7	**22.2**	32.5	77.8	45.3

Table 8.11: Simulation summary of Building K-Case 05

Looking at the data in Table 8.11, we can see that in this case, the energy profile of project and the renewable energy consumption stays the same compared to the base case simulation, albeit with negligible differences.

8.3 Simulation of Atrium Building A

Similar to simulation of reference building of Verket Panorama, second reference building, from cluster of Verket Atrium, which is building A, is modelled and simulated five times with varying parameters.

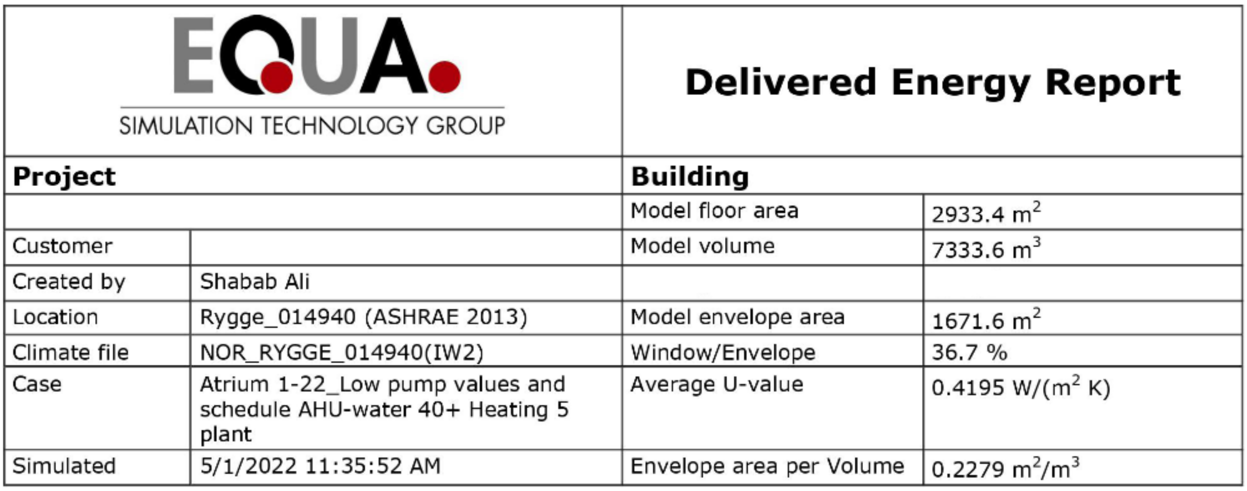
8.3.1 Case 01-Base Case

Input data for base case of the Atrium reference building is as follows:

Input parameter	**Unit/detail**
Weather file	NOR_RYGGE_014940_IW2
Air handling unit (AHU)	Standard AHU, SFP=1.5 kW/(m^3/s), Efficiency=0.85, Pressure rise=1275, Heat exchanger effectiveness=0.9, Heating coil=ON, Cooling coil=OFF, Supply air setpoints= Schedule, Operation=House Living schedule
Heating system	Ground source heat pump, Brine set constant=7, No of units=5 Unit capacity=10kW, Volume of Hot tank=1.00m^3, Floor heating power=805W-1650W
PV system details	Area=650m^2, Orientation=295^o of S, Slope angle=15^o, Efficiency =20%
Architectural drawings	Appendix II
Construction details	Appendix III
Thermal bridges	0.03 W/K/ (m^2 envelope)
Infiltration data	Air tightness=0.6 ACH (building) , Pressure difference=50 Pa
Hot water use	40 liters per occupant per day
Heating/cooling setpoints	21^{o}C / 25 ^{o}C
Supply/return air	Appendix II
Occupancy data	109 people
Lighting data	311 units
Equipment data	283 units
Project Average U-value	0.42 W/ (m2 K)
Window Shades	Integrated window shading

Table 8.12: Building A Input-Case 01

Case 01 or base case (Table 8.12) is simulated to be the benchmark for other cases to be compared with and the result for this case is as following (Figure 8.7):



SIMULATION TECHNOLOGY GROUP

Delivered Energy Report

Project		**Building**	
		Model floor area	2933.4 m^2
Customer		Model volume	7333.6 m^3
Created by	Shabab Ali		
Location	Rygge_014940 (ASHRAE 2013)	Model envelope area	1671.6 m^2
Climate file	NOR_RYGGE_014940(IW2)	Window/Envelope	36.7 %
Case	Atrium 1-22_Low pump values and schedule AHU-water 40+ Heating 5 plant	Average U-value	0.4195 W/(m^2 K)
Simulated	5/1/2022 11:35:52 AM	Envelope area per Volume	0.2279 m^2/m^3

Figure 8.7: Delivered energy report of Building A-Case 01

(IDA ICE 4.99) – Appendix IV

Complete energy report can be found in Appendix IV-Verket Atrium reference Building A- Results _ Case 01. However, summary of the report in terms of energy can be seen in Figure 8.13:

	Building's energy requirement	Renewable energy produced on site	Renewable energy used on site	Renewable energy sold to grid	Energy bought from grid	Energy balance
kWh/m^2	66	36	12.6	23.3	53.4	30.1
kWh	193,463.1	105,293.0	36,954.8	68,338.2	156,508.1	88,170.1
%	100.0	54.4	**19.1**	35.3	80.9	45.6

Table 8.13: Simulation summary of Building A-Case 01

With 19.1% direct usage of onsite produced renewable energy in Table 8.13, this becomes the starting point for comparative analysis of multiple cases of Building A. Where 100% is the building's total energy demand and 19.1% of that demand is being directly fulfilled by onsite produced renewable energy.

8.3.2 Case 02- Increased thermal mass

Input data for case 02 of the Atrium reference building is as follows:

Input parameter	**Unit/detail**
Air handling unit (AHU)	Standard AHU, SFP=1.5 kW/(m^3/s), Efficiency=0.85, Pressure rise=1275, Heat exchanger effectiveness=0.9, Heating coil=ON, Cooling coil=OFF, Supply air setpoints= Schedule, Operation=House Living schedule
Heating system	Ground source heat pump, Brine set constant=7, No of units=5 Unit capacity=10kW, Volume of Hot tank=1.00m^3, Floor heating power=805W-1650W
Project Average U-value	0.87 W/ (m2 K)
Window Shades	Integrated window shading

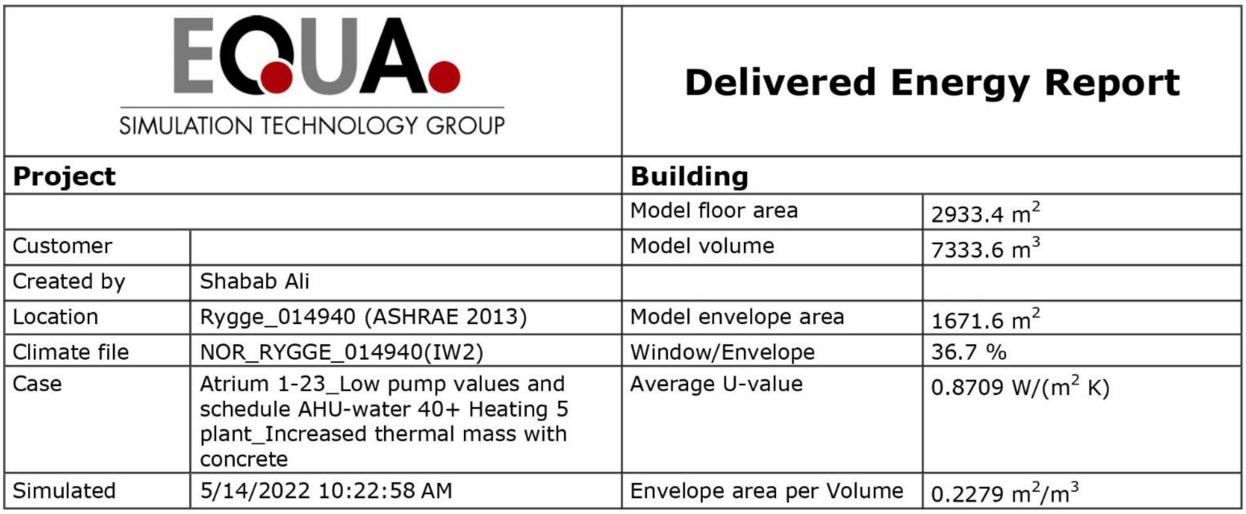
Table 8.14: Building A Input-Case 02

In case 02, thermal mass of the model was increased (Table 8.14) by increasing the amount of concrete in the project, while keeping the wall thickness same. Effect of this on the u-values of surfaces can be seen in the table 8.15:

Building surface	Thickness (m)	Base case (Case 01) U-value (W/m^{2}K)	Case 02 U-value (W/m^{2}K)
External wall	0.39	0.08	0.853
Load bearing interior wall-Conc	0.21	2.90	2.90
Interior wall with insulation	0.15	0.62	2.14
Non load bearing interior wall	0.12	0.32	3.04
Floor with ceiling	0.51	0.19	0.55

Table 8.15: Change in thermal mass

Similar to case 02 of building K, in this case also the thermal mass is increased which resulted in a decrease in building insulation as the wall thickness is kept same. The simulation report in that case can be seen in Figure 8.8:



EQUA SIMULATION TECHNOLOGY GROUP

Delivered Energy Report

Project		**Building**	
		Model floor area	2933.4 m^2
Customer		Model volume	7333.6 m^3
Created by	Shabab Ali		
Location	Rygge_014940 (ASHRAE 2013)	Model envelope area	1671.6 m^2
Climate file	NOR_RYGGE_014940(IW2)	Window/Envelope	36.7 %
Case	Atrium 1-23_Low pump values and schedule AHU-water 40+ Heating 5 plant_Increased thermal mass with concrete	Average U-value	0.8709 W/(m^2 K)
Simulated	5/14/2022 10:22:58 AM	Envelope area per Volume	0.2279 m^2/m^3

Figure 8.8: Delivered energy report of Building A-Case 02

(IDA ICE 4.99) – Appendix IV

Complete energy report can be found in Appendix IV-Verket Atrium reference Building A - Results _ Case 02. However, summary of the report in terms of energy can be seen as following in Table 8.16:

	Building's energy requirement	Renewable energy produced on site	Renewable energy used on site	Renewable energy sold to grid	Energy bought from grid	Energy balance
kWh/m^2	78.4	36	13.6	22.2	64.7	42.5
kWh	229,826.5	105,294.9	40,051.9	65,243.0	189,776.7	124,531.6
%	100.0	45.8	**17.4**	28.4	82.6	54.2

Table 8.16: Simulation summary of Building A-Case 02

We see a decrease in the efficiency of the whole system with overall energy demand rising and direct usage of onsite renewable energy decreasing.

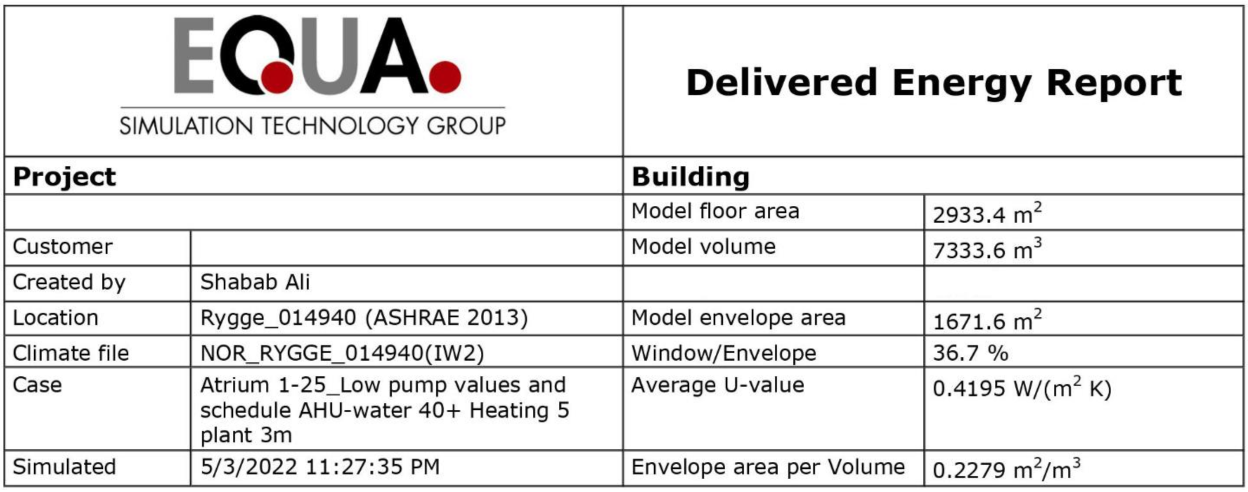
8.3.3 Case 03- Increased volume of water tank

Input data for case 03:

Input parameter	Unit/detail
Air handling unit (AHU)	Standard AHU, SFP=1.5 kW/(m^3/s), Efficiency=0.85, Pressure rise=1275, Heat exchanger effectiveness=0.9, Heating coil=ON, Cooling coil=OFF, Supply air setpoints= Schedule, Operation=House Living schedule
Heating system	Ground source heat pump, Brine set constant=7, No of units=7 Unit capacity=10kW, Volume of Hot tank=3.00m^3, Floor heating power=805W-1650W
Project Average U-value	0.42 W/ (m2 K)
Window Shades	Integrated window shading

Table 8.17: Building A Input-Case 03

Case 03 deals with a bigger water-based heating system in the project (Table 8.17) to see the effect of heat storage capacity of the liquid on the overall energy usage and load shifting in the project. Simulation report for this case can be seen below in Figure 8.9:



EQUA SIMULATION TECHNOLOGY GROUP		**Delivered Energy Report**	
Project		**Building**	
		Model floor area	2933.4 m^2
Customer		Model volume	7333.6 m^3
Created by	Shabab Ali		
Location	Rygge_014940 (ASHRAE 2013)	Model envelope area	1671.6 m^2
Climate file	NOR_RYGGE_014940(IW2)	Window/Envelope	36.7 %
Case	Atrium 1-25_Low pump values and schedule AHU-water 40+ Heating 5 plant 3m	Average U-value	0.4195 W/(m^2 K)
Simulated	5/3/2022 11:27:35 PM	Envelope area per Volume	0.2279 m^2/m^3

Figure 8.9: Delivered energy report of Building A-Case 03

(IDA ICE 4.99) – Appendix IV

Complete energy report can be found in Appendix IV-Verket Atrium reference Building A - Results _ Case 03. However, summary of the report in terms of energy can be seen as following:

	Building's energy requirement	Renewable energy produced on site	Renewable energy used on site	Renewable energy sold to grid	Energy bought from grid	Energy balance
kWh/m^2	66.0	36	13.4	22.5	52.6	30.1
kWh	193,653.0	105,298.4	39,212.6	66,085.8	154,440.3	88,355.0
%	100.0	54.4	**20.25**	34.15	79.75	45.6

Table 8.18 Simulation summary of Building A-Case 03

From the summarized results in Table 8.18, we see a slight increase in the direct usage of onsite produced renewable energy compared the base case. It is not a lot but still enough to tell us about the potential of this strategy to improve on it further.

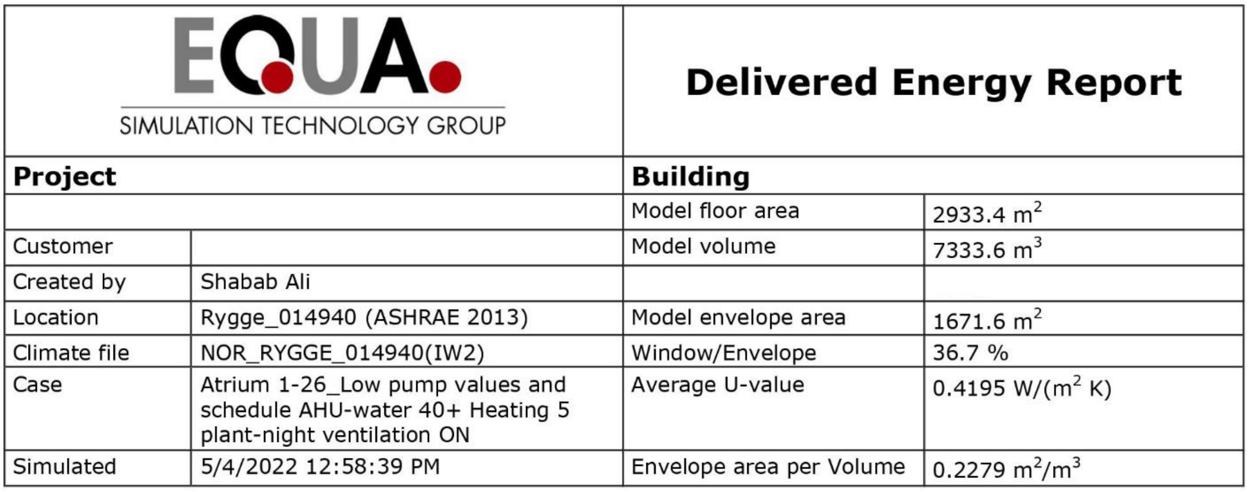
8.3.4 Case 04-Night ventilation and Exhaust air with liquid heat recovery

Input data for case 04:

Input parameter	**Unit/detail**
Air handling unit (AHU)	Night ventilation control + Exhaust air with liquid heat recovery, SFP=1.5 kW/(m^3/s), Efficiency=0.85, Pressure rise=1275, Heat exchanger effectiveness=0.9, Heating coil=ON, Cooling coil=OFF, Supply air setpoints= 17°C, Operation=Always on
Heating system	Ground source heat pump, Brine set constant=7, No of units=5 Unit capacity=10kW, Volume of Hot tank=1.00m^3, Floor heating power=805W-1650W
Project Average U-value	0.42 W/ (m2 K)
Window Shades	Integrated window shading

Table 8.19: Building A Input-Case 04

Replacing a standard air handling unit with a system for night ventilation and heat recovery system (Table 8.19), and modifying the supply air setpoint of the system, we get the following results:



EQUA SIMULATION TECHNOLOGY GROUP		Delivered Energy Report	
Project		**Building**	
		Model floor area	2933.4 m^2
Customer		Model volume	7333.6 m^3
Created by	Shabab Ali		
Location	Rygge_014940 (ASHRAE 2013)	Model envelope area	1671.6 m^2
Climate file	NOR_RYGGE_014940(IW2)	Window/Envelope	36.7 %
Case	Atrium 1-26_Low pump values and schedule AHU-water 40+ Heating 5 plant-night ventilation ON	Average U-value	0.4195 W/(m^2 K)
Simulated	5/4/2022 12:58:39 PM	Envelope area per Volume	0.2279 m^2/m^3

Figure 8.10: Delivered energy report of Building A-Case 04

(IDA ICE 4.99) – Appendix IV

Complete energy report can be found in Appendix IV-Verket Atrium reference Building A- Results _ Case 04. However, summary of the report in terms of energy can be seen in Table 8.20:

	Building's energy requirement	Renewable energy produced on site	Renewable energy used on site	Renewable energy sold to grid	Energy bought from grid	Energy balance
kWh/m^2	56.4	36	14.4	21.5	42.0	20.5
kWh	165,328.0	105,313.2	42,219.2	63,094.0	123,108.8	60,013.9
%	100.0	63.7	**25.5**	38.2	74.5	36.3

Table 8.20: Simulation summary of Building A-Case 04

As expected, because of the results of case 04 of building K, we see a rise in the efficiency of the PV system in this option, with an increase in the direct usage of onsite produced renewable energy, reaching from 19.1% to 25.5%.

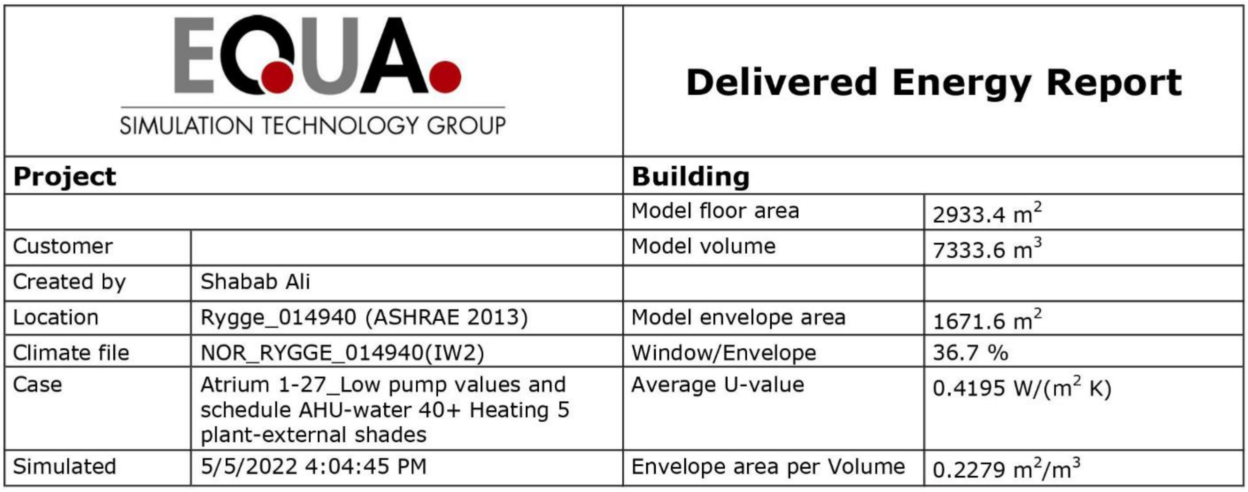
8.3.5 Case 05-External shades on windows

Input data for case 05:

Input parameter	Unit/detail
Air handling unit (AHU)	Standard AHU, SFP=1.5 kW/(m^3/s), Efficiency=0.85, Pressure rise=1275, Heat exchanger effectiveness=0.9, Heating coil=ON, Cooling coil=OFF, Supply air setpoints= Schedule, Operation=House Living schedule
Heating system	Ground source heat pump, Brine set constant=7, No of units=5 Unit capacity=10kW, Volume of Hot tank=1.00m^3, Floor heating power=805W-1650W
Project Average U-value	0.42 W/ (m2 K)
Window Shades	External shaders

Table 8.21: Building A Input-Case 05

In this case(Table 8.21), integrated window shading is replaced with externa shading system and the results of it can be seen in the following report in Figure 8.11:



EQUA SIMULATION TECHNOLOGY GROUP

Delivered Energy Report

Project		**Building**	
		Model floor area	2933.4 m^2
Customer		Model volume	7333.6 m^3
Created by	Shabab Ali		
Location	Rygge_014940 (ASHRAE 2013)	Model envelope area	1671.6 m^2
Climate file	NOR_RYGGE_014940(IW2)	Window/Envelope	36.7 %
Case	Atrium 1-27_Low pump values and schedule AHU-water 40+ Heating 5 plant-external shades	Average U-value	0.4195 W/(m^2 K)
Simulated	5/5/2022 4:04:45 PM	Envelope area per Volume	0.2279 m^2/m^3

Figure 8.11: Delivered energy report of Building A-Case 05

(IDA ICE 4.99) – Appendix IV

Complete energy report can be found in Appendix IV-Verket Atrium reference Building A- Results _ Case 05. However, summary of the report in terms of energy can be seen as following:

	Building’s energy requirement	Renewable energy produced on site	Renewable energy used on site	Renewable energy sold to grid	Energy bought from grid	Energy balance
kWh/m^2	65.9	36	12.6	23.3	53.3	30.0
kWh	193,254.1	105,294.8	36,936.0	68,358.8	156,318.1	87,960.4
%	100.0	54.5	**19.1**	35.4	80.9	45.5

Table 8.22: Simulation summary of Building A-Case 05

Looking at the results from the simulation of this case in Table 8.22, we see no prominent difference in the energy profile of the project compared to the base case of Building A.

8.4 Comparative analysis of simulation results

In total, we end up with 10 simulation results, with five for each building type. While comparing those results, we see that there are differences in energy demand and energy usage in all cases and we cannot directly compare the actual amount of energy in terms of kWh here. Instead, percentages have been assigned to all the values in the simulation results so the results can be put against each other for a comparative analysis, where 100% signifies the total demand of the respective case and sets a benchmark for that particular case to divide the energy numbers in various categories. In this way, we get to see how much “percentage” of energy is being compensated from the PV system, and regardless of different energy demand in each simulation case, we can still compare the efficiency of the system.

Data compiled from the simulations of all cases can be seen in the table 8.23:

	Unit	Verket Panorama Reference building (Building K)					Verket Atrium Reference building (Building A)				
		Case 01	**Case 02**	**Case 03**	**Case 04**	**Case 05**	**Case 01**	**Case 02**	**Case 03**	**Case 04**	**Case 05**
Building’s energy requirement	kWh/m^2	62.4	73.0	63.0	55.2	62.4	66.0	78.4	66.0	56.4	65.9
	kWh	119,266.2	139,539.3	120,312.0	105,397.4	119,182.1	193,463.1	229,826.5	193,653.0	165,328.0	193,254.1
	%	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Renewable energy produced on site	kWh/m^2	34.1	34.1	34.1	34.1	34.1	36.0	36.0.	36.0	36.0	36.0
	kWh	65,237.0	65,243.0	65,236.8	65,246.3	65,240.1	105,293.0	105,294.9	105,298.4	105,313.2	105,294.8
	%	54.7	46.7	54.3	62.0	54.7	54.4	45.8	54.4	63.7	54.5
Renewable energy used on site	kWh/m^2	13.8	14.5	14.3	15.1	13.9	12.6	13.6	13.4	14.4	12.6
	kWh	26,499.0	27,746.7	27,233.2	28,859.3	26,494.5	36,954.8	40,051.9	39,212.6	42,219.2	36,936.0
	%	**22.2**	**19.9**	**22.6**	**27.4**	**22.2**	**19.1**	**17.4**	**20.25**	**25.5**	**19.1**
Renewable energy sold to grid	kWh/m^2	20.3	19.6	19.9	19.1	20.3	23.3	22.2	22.5	21.5	23.3
	kWh	38,738.8	37,496.3	38,003.6	36,387.0	38,745.6	68,338.2	65,243.0	66,085.8	63,094.0	68,358.8
	%	32.5	26.8	31.5	34.5	32.5	35.3	28.4	34.15	38.2	35.4
Energy bought from grid	kWh/m^2	48.5	58.5	48.7	40.0	48.5	53.4	64.7	52.6	42.0	53.3
	kWh	92,767.2	111,792.6	93,079.0	76,538.1	92,687.6	156,508.1	189,776.7	154,440.3	123,108.8	156,318.1
	%	77.8	80.1	77.3	72.6	77.8	80.9	82.6	79.75	74.5	80.9
Energy balance	kWh/m^2	28.3	38.9	28.8	21.0	28.2	30.1	42.5	30.1	20.5	30.0
	kWh	54,029.2	74,296.1	55,075.2	40,151.0	53,942.0	88,170.1	124,531.6	88,355.0	60,013.9	87,960.4
	%	45.3	53.3	45.7	38.0	45.3	45.6	54.2	45.6	36.3	45.5

Table 8.23:Energy simulation data of building A and Building K

In the table 8.23, we have a lot of numbers from all the simulation cases, but our main focus is on the third row from the top, which is “Renewable energy used on site”. This information can be presented in the form of a bar chart for the sake of discussion and to see the comparison more clearly (Figure 8.12).

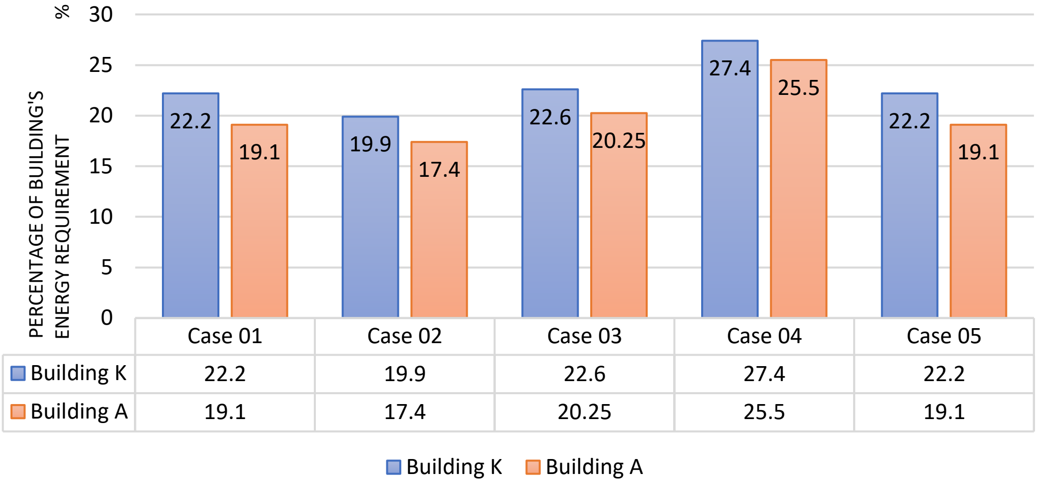


Figure 8.12:Direct usage of on-site produced renewable energy on site
(Where 100% = Building energy demand profile in the respective simulation case**)**

- Case 01 – Base case
- Case 02 – Increased thermal mass
- Case 03 – Increased number and volume of hot water tank
- Case 04 – Night ventilation and Exhaust air with liquid heat recovery
- Case 05 – Window integrated shades replaced with external shades

When we analyze the results from all the simulation cases, we see a similar pattern in both reference buildings. So, from simulations of these two reference buildings, we see the behavior of project’s energy profile changing based on varying parameters.

8.4.1 Effect of increased thermal mass

When we compare all the results and analyze all the cases of two buildings, we see that increasing the thermal mass of the project have a negative effect on the overall project, where we see a rise in the energy demand of the Building K by 17% and Building A by 18.7% compared to their respective base cases. Along with this increased building energy use, we see a decrease in the direct usage of onsite produced renewable energy on site, in Building K the decrease is by 2.3% and in Building A, a decrease of 1.7% is noticed compared to the usage percentage in their respective base cases. When we look at the renewable energy use on site in terms of kWh, we see that in case 02, we have an increase by a about 1200kWh and 3000kWh in building K and A respectively. However, owing to their increased energy demand, this increased usage of the onsite produced energy cannot be taken as a positive thing, that is why we are looking at this usage in terms of percentages here, and from that aspect, we see that Base cases of both buildings are meeting their bigger portion of energy demand directly from onsite produced energy compared to case 02 of both buildings.

8.4.2 Effect of increased hot water capacity

In the next simulation study, case 03, we study the effect of increased hot water capacity in the project and how it affects the energy demand and direct onsite usage of renewable energy. By increasing the number of units in Brine to water heat pump and increasing the volume of hot water tank, we see a positive effect in case of both buildings. Increase in building demand is negligible compared to their respective base cases, being 0.8% and 0.1% for building K and A respectively. On the plus side, we see an increase in the direct usage of onsite produced renewable energy, in building K by 0.4% and by 1.15% in building A. In terms of kWh, the increase in this renewable energy usage by the systems is about 1000kWh and 3000kWh (building K and A respectively), which is similar to case 02 results, but owing to much increased energy demand of case 02, here in case 03, we see a rise in the percentage usage of this energy, even if it is by a very small number.

8.4.3 Effect of night ventilation along with liquid heat recovery system

In the scenario, Case 04, we test the effect of night ventilation along with the liquid heat recovery system in the projects and the result is much better than any other case simulated in this report. For both buildings, we see a decrease in the energy demand and increase in the direct usage of onsite produced renewable energy. With Building K needing 11.6% less and Building A needing 14.5% less energy compared to their respective base cases, while their direct usage of onsite produced renewable energy being increased from 22.2% to 27.4% and from 19.1% to 25.5% respectively, the results make it clear that parameters used in case 04 are very promising both in terms of environmental footprint of energy production by decreasing the energy demand and the economic aspect of selling less energy to grid and instead using it directly on the site without any extra storage facilities.

8.4.4 Effect of external shading devices

In case 05 of both building, we see that using external shading devices instead of integrated window shading isn’t very fruitful as it doesn’t make any noticeable difference in terms of energy demand and usage from the onsite PVs.

8.5 Discussion

From these results, we find out which parameters are effective when it comes to decreasing the import of electricity from the grid in a SPEN. Some cases are more effective than others and some are downright bad for the whole system. In some cases, we see the positive effect is very negligible, like in case of increased hot water capacity (case 03), however, it does open up the channel for further development in the area to achieve more improvements. On the other hand, we see about 10-15% decrease in building energy demand and at the same time, an increase of 5-6% in the use of onsite produced renewable energy, which turned out to be almost 2300kWh and 5200kWh for building K and A respectively, which shows us that by looking into certain aspects while designing energy positive buildings, not only we can make them more energy efficient, we can also optimize the onsite produced renewable energy usage. Which means, it is good for the environment and also good for the project developers and invertors economically.

8.5.1 Certainty of results

Accuracy of these results is dependent on the correlation of similarities between input of the simulation models and the input from the real construction of the project. For example, thermal bridges for simulation are taken as 0.03 W/K/ (m2 envelope), but it can differ depending on the construction quality and material joineries, which can affect the overall results.

However, as the simulations are studied relatively with comparison to a base case, which is simulated in this project also, the results hold their merit and fulfill the purpose of the thesis, which is to look at the possibility of optimizing the use of onsite renewable energy. As the results are discussed in terms of percentages comparing demand and supply of each test case, the results from this study can be used make a criterion which can affect design decisions of a vast spectrum by collecting and analyzing real world data of projects.

9 Building to neighbourhood scale

Since so far, we have dealt with the simulation of individual buildings and not a cluster connected to the whole neighbourhood, where there are a lot of factors in play, like non-residential buildings, parking spaces with energy production capabilities owing to PVs, effect of green spaces in the neighborhood, water bodies and so on. These auxiliary functions, however important they are to a neighbourhood are not included in this these, since for that we need much more data which at this stage of project development by Arca Nova, is simple not accessible for this thesis, which also limits the use of neighbourhood energy simulation tools like UMI or CEA at this stage. However, as mentioned earlier in section 6.2 and 6.3, by making use of the reference buildings chosen form clusters Verket Panorama and Verket Atrium, we can see how much difference in term of energy it makes to the neighbourhood, if we apply the parameters of our best case scenario (Case 04) from all the simulations, to all the buildings in the cluster.

9.1.1 Limitations

When we do this, we multiply the values from one reference building to all similar buildings in category of that reference building, and doing so, we are not considering losses which occur in real world scenario where buildings have different geo-locations and the PV panels on the buildings have varied orientation, despite having same areas. This also does not take into account the energy exchange between any two building in the neighbourhood, which in real life scenario is bound to happen due to it being a neighbourhood where renewable energy is used to cover the needs of all the building of the neighbourhood, regardless of the production capacity of the any building itself., This kind of losses and complex energy exchanges need complex simulation tools which not only see energy exchanges between zones of a building, but also take energy exchange and losses related to it between whole buildings and the auxiliary programs of the neighbourhood.

9.1.2 Neighborhood energy simulation attempt

An attempt to get a preliminary result on neighbourhood scale using Rhino based simulation tool, Grasshopper, produced very different results when compared with detailed results from IDA ICE, and the purpose of this seemed to be the lack of certain information which would complete the simulation script and would take into account all the auxiliary losses in the results. For example, when the energy production on- site from the two programs was compared, the results of produced onsite energy from IDA ICE were almost half of what was being generated in Grasshopper. For that purpose and due to some other errors in simulations because of data problems, neighbourhood level simulation at this stage was not pursued further and more attention was focused on detailed building level simulations with varying parameters, results of which are promising enough to open ways into neighbourhood level simulation work in future.

9.1.3 Manual calculations from results of building simulations

For the purpose of this task, simulated cases of both reference buildings were taken, and a manual calculation is done to do an estimate of how much energy can be optimized in two clusters (Verket Panorama and Verket Atrium) of Verksbyen, setting aside all the limitations mentioned earlier. While doing these calculations, only two cases from each reference building are considered, which are, Base case (Case 01) and best performed case in individual simulations, Case 04.

Reference building K is representing three building in Verket Panorama and four buildings in Verket Atrium, in total being 7 buildings, and for the sake of this study they are all assumed to be identical to reference building, while reference building A represents 4 buildings in Verket Atrium, making a total of 11 apartment building with almost 290 apartment units in them.

Energy production from 11 building = (Building K x 7) + (Building A x 4)

= (65,237 x 7) + (105,293 x 4)

= 877,831.0 kWh

Case 01

Energy demand for 11 buildings = (Building K x 7) + (Building A x 4)

= (119,266.2 x 7) + (193,463.1 x 4)

= 1,608,715.8 kWh

On-site direct use of renewable energy without exporting it to grid = (Building K x 7) + (Building A x 4)

= (26,499 x 7) + (36,954.8 x 4)

= 333,312.2 kWh

Case 04

Energy demand for 11 buildings = (Building K x 7) + (Building A x 4)

= (105,397.4 x 7) + (165,328 x 4)

= 1,399,093.8 kWh

On-site direct use of renewable energy without exporting it to grid = (Building K x 7) + (Building A x 4)

= (28,859.3 x 7) + (42,219.2 x 4)

= 370,891.9 kWh

Energy difference between Case 01 and Case 02

Difference in energy demand = Case 01 demand – Case 04 demand

= 1,608,715.8 - 1,399,093.8

= 209,622.0 kWh

Difference in direct usage of onsite produced energy = Case 04 use – Case 01 use

= 370,891.9 - 333,312.2

= 37,579.7 kWh

9.1.4 Discussion

From this simplified calculation, we see that in Case 01, clusters of Verket Panorama and Verket Atrium were collectively meeting 20.7% of their energy demand from onsite produced energy, without needing to store it somewhere or buying/selling it from the grid. This 20.7% of building demand amounts to 38% of total onsite energy produced, simulated in IDA ICE 4.99. Remaining 62% can be used for balancing the energy use, by considering the buying and selling in cooperation with grid, but economically, that 62% when bought back from the grid, is a financial burden, which can be decreased if we look into load shifting and energy flexibility potential of housing.

In case 04, 26.5% of energy demand of these buildings is being compensated directly from onsite produced energy without having to import energy back from the grid at higher rates. This 5.8% difference amounts to 35,579.7 kWh annually and shows us a way to increase this percentage further by investing into variations of building constructions and energy systems before execution, solely based on overall energy balance.

10 Limitations and discussion

Limitations of each step in this thesis are already explained wherever they came up, but to summarize, the project focuses on energy simulation of two buildings which are taken as reference building from two clusters of a SPEN, which make almost 30% of the neighbourhood housing. Focus is on the renewable energy produced on site, energy demand of buildings and direct usage of onsite produced energy by these buildings, and how to increase that usage percentage. In order to minimize the import of electricity from the grid at high cost, several parameters are tested in these two reference buildings, alternatively to maximize the usage of onsite produced electricity without storing it or exporting it to the grid to buy back later on.

Since the focus is on energy profiles of these buildings, and eventually the cluster they represent, apartments are zoned in single zones inside the apartment buildings to decrease the simulation time and to do multiple scenario simulations in the available time. Certain aspects of the zones are defined based on the necessary limitations such as indoor temperatures, average air flows and general occupancies, however other than that, thermal comfort is not the prime focus of this study.

These buildings are part of a SPEN, so it is safe to assume that all the energy they use, can be produced on site in a year, even though it is not used at the same time and is sold to the grid when excess energy is produced and bought back from the grid when required. However, simulations in this study show that the energy balance is not positive towards onsite produced energy, which may be different for multitude of reasons like efficiency of PV panels, their position differences and/or excess energy generation from other parts of the neighbourhood which compensates the lack of energy production from the buildings in the overall equation. This apparent difference in the energy balance of real SPEN and the simulation cases does not affect the results of this study in a negative way as they are relative to a base case set in this report.

As it is clear that even though, we don’t see complete energy balance from the results of simulation added in this study, where energy demand is more than energy produced, the study is not affected by that. Purpose of the study was to compare similar cases with changing parameters of a base case to study particular aspects and that has been achieved since all the cases have been measured based on a core criterion, where the data results in absence of a total energy balance.

There are some parameters which are not exactly like the parameters used in the real project by Arca Nova, which is because of lack of data availability, so assumptions have been made there. This doesn’t affect the conclusion of the results we have since they are achieved by comparative analysis and their effect, positive or negative, is relative and dependent on the base case defined for this study.

11 Conclusion and Way forward

Sustainable plus energy neighbourhoods or SPENs are a way to approach the effort of decreasing emissions caused by the construction industry when we look at the big picture. So, it is essential that big and small developers alike take interest in it, and it should be attractive for investors.

These neighbourhoods produce more electricity annually than they use, which mean they run on clean energy and even provide excess clean energy to the energy reservoir. This, however, does not mean that neighbourhood is independent from the electricity grid for its energy needs as the sun doesn't shine all the time and the system is not at the full capacity at all times. Which is when the grid sells back the energy it bought from the neighbourhood, albeit on a slightly expensive rate owing to it being a high energy demand time and to dela with the peak, which also factors in the prices that go in maintaining the storage facilities and grid nodes. This expensive rate can be taken as a type of a penalty signal for the neighbourhood users, so they don't overuse energy in these times, regardless it is an economic burden on an otherwise independent project. We cannot get rid of this burden at this point completely unless we have energy storage options on site, which has their own complications, like use of batteries has their own huge carbon footprint but using car batteries from electric vehicles of the neighbourhood to sustain the neighbourhood needs in peak hours is an up and coming alternative though and we need such innovative solutions to address the complexities and inconveniences of energy flexibility regarding onsite renewable energy.

Results of the simulations done for this project and the calculations that are done along with it, including all the assumptions, exceptions and limitations, they show us how we can approach this energy flexibility and the dependency of SPENs on electrical grids. This thesis takes individual buildings as simulations cases so we can study the building in detail and when it comes to implementation in real world, results can be applied from building level to a neighbourhood scale. Once we have some data that supports that an individual building in a neighbourhood can affect the grid import, expanding it on the neighbourhood level becomes relatively streamlined, as neighbourhood has more opportunities to optimize the energy production and usage compared to a single building.

Calculation of the results from building to neighbourhood scale shows us what does a 6% improvement in the building simulation level can mean in terms of energy saving for the neighbourhood. So, although 6% is not a huge margin and in some test case we see less than

1% improvement, but what these improvements show us that how these parameters and strategies affect these behaviours, which answers the supporting questions of the main research question of this report. As to answering the main research question, we see multiple options in the course of this thesis report on how to optimize the housing in a SPEN to decrease the electricity import from the grid.

11.1 Way forward

This 1-6% improvement opens up a path to further research on these strategies to see how far we can push them. In the big picture this small percentage of improvement can mean hundreds and thousands of kWh energy saved as is clear from the building to neighbourhood scale calculations in the report.

Ultimate goal would be that we manage to improve on these results and push these values enough that one day, owing to a combination of a multitude of innovative solutions, we can make SPENs independent from the grid, which doesn't seem possible to do but hope is eternal.

With all the solutions being developed so rapidly, its only about time that the right solutions come together to make it all happen and we achieve a truly independent neighbourhood one day, with no compromises on the way of normal living which has become a standard at this day and age. The results of this thesis have implications on a bigger scale and pave the way for further research in the area.

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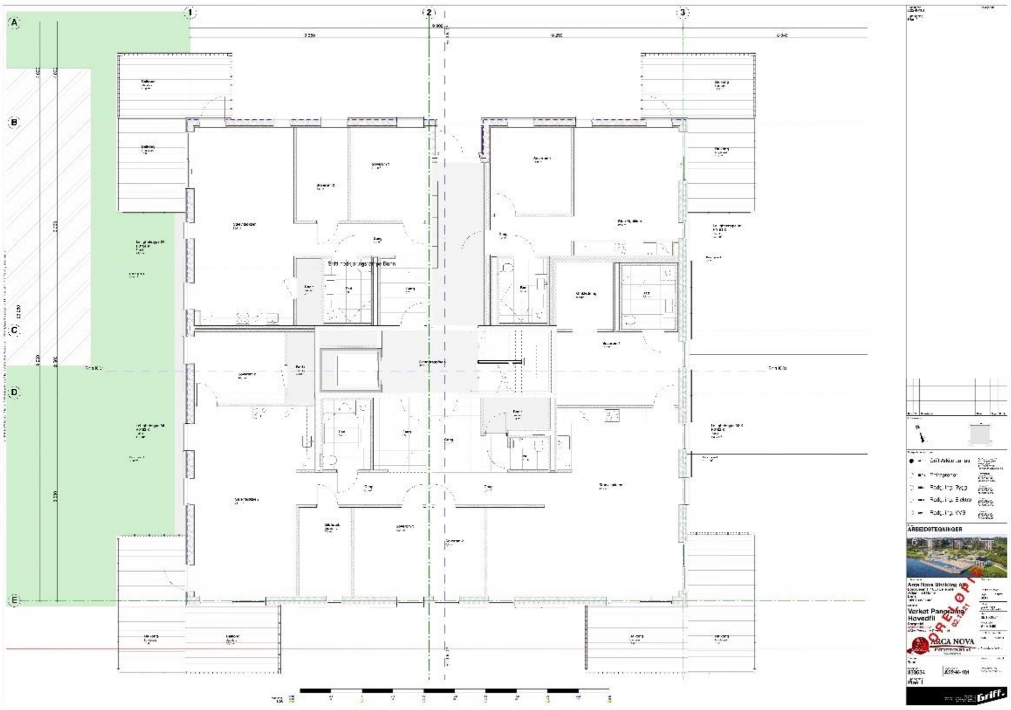
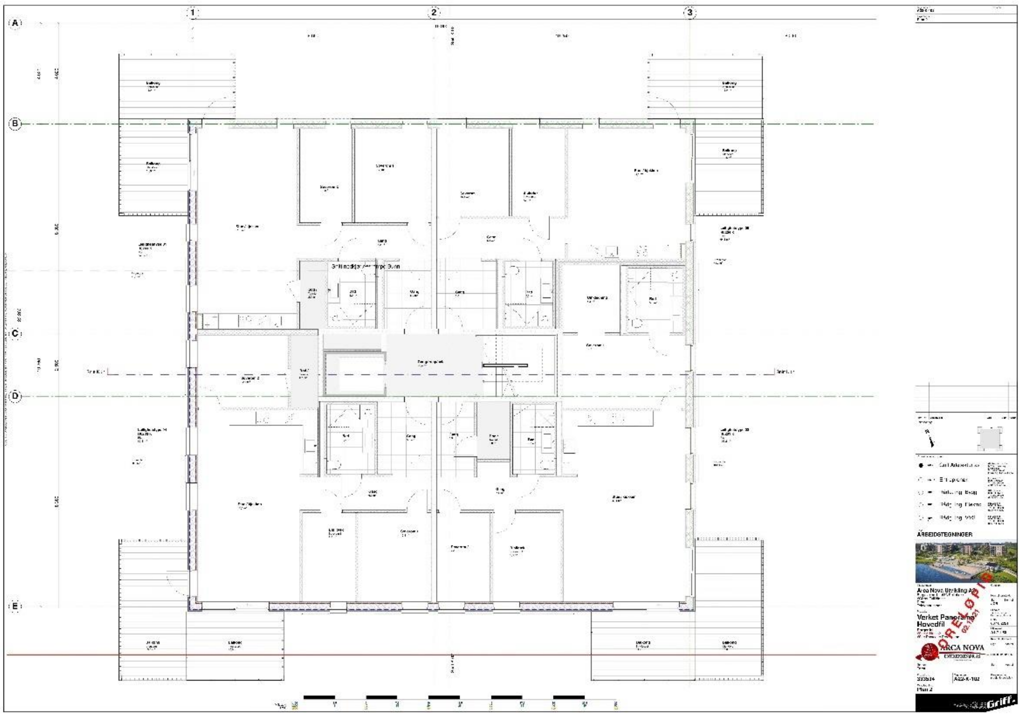
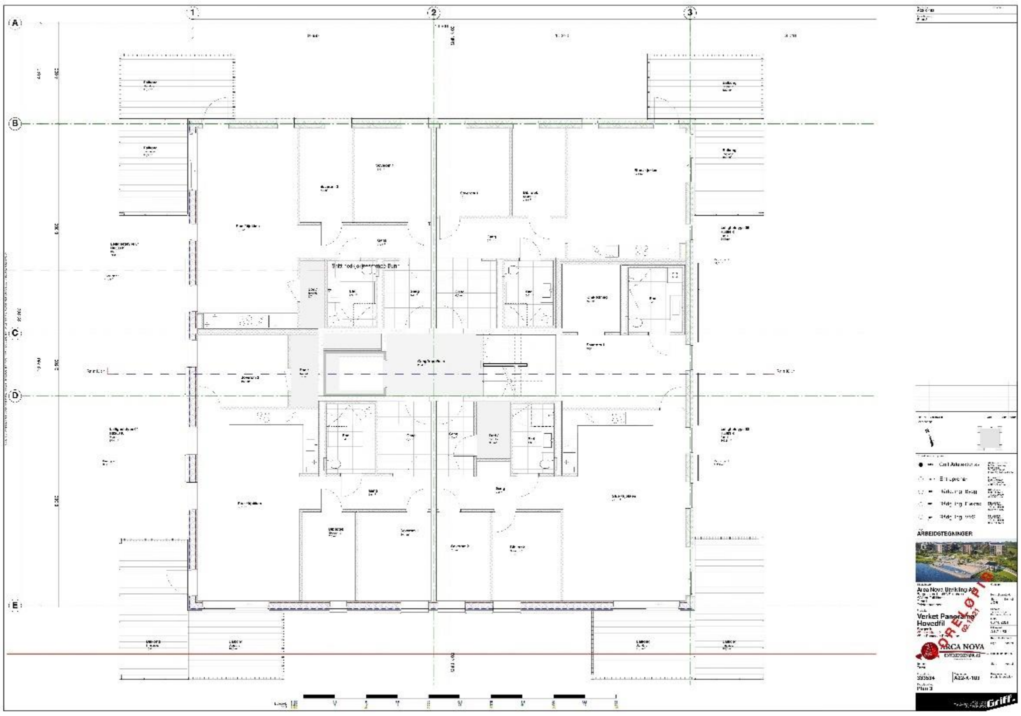
Appendix I-Verket Panorama

Architectural Drawings by Arca Nova



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Arca Nova Utvikling AS
Verket Panorama
Hovedfil
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ARCA NOVA
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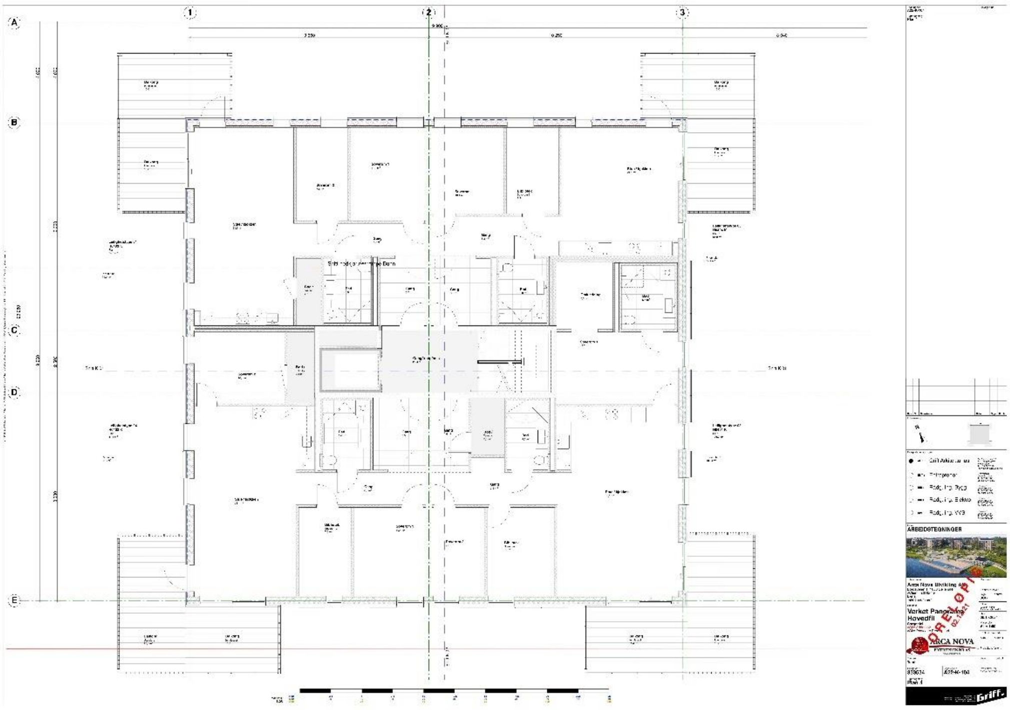
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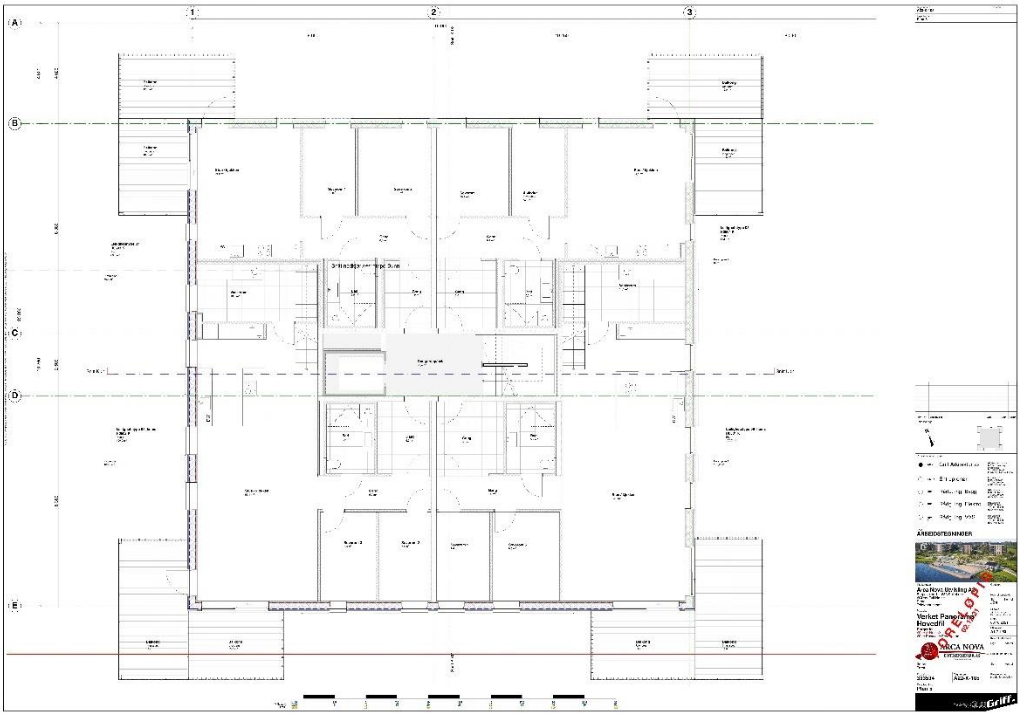
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ENTREPRENØR AS
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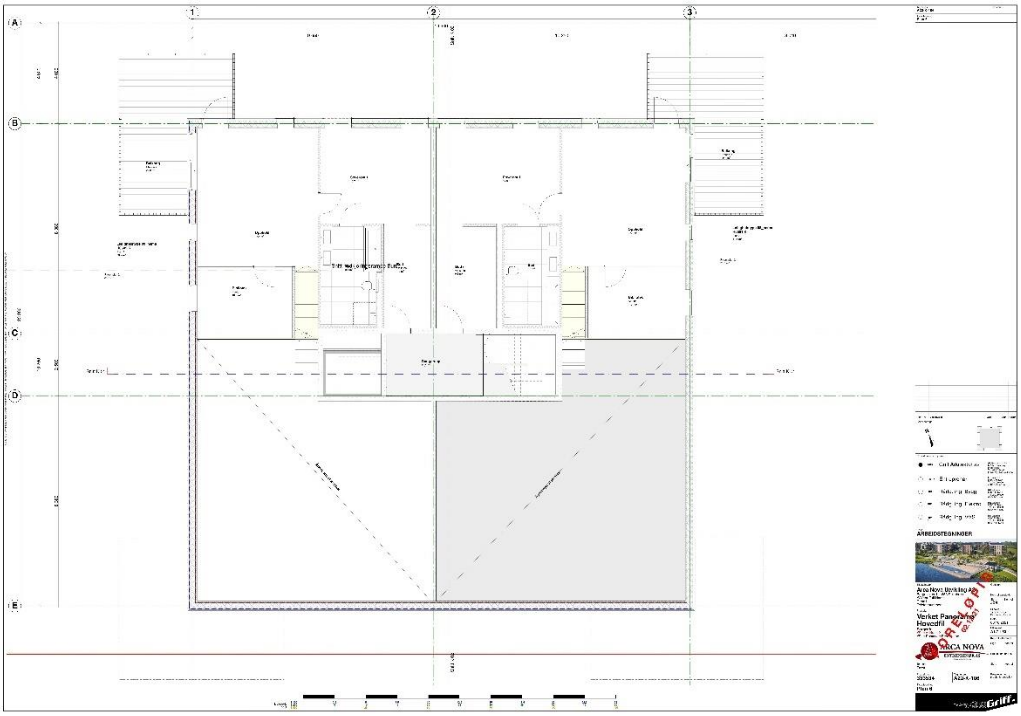
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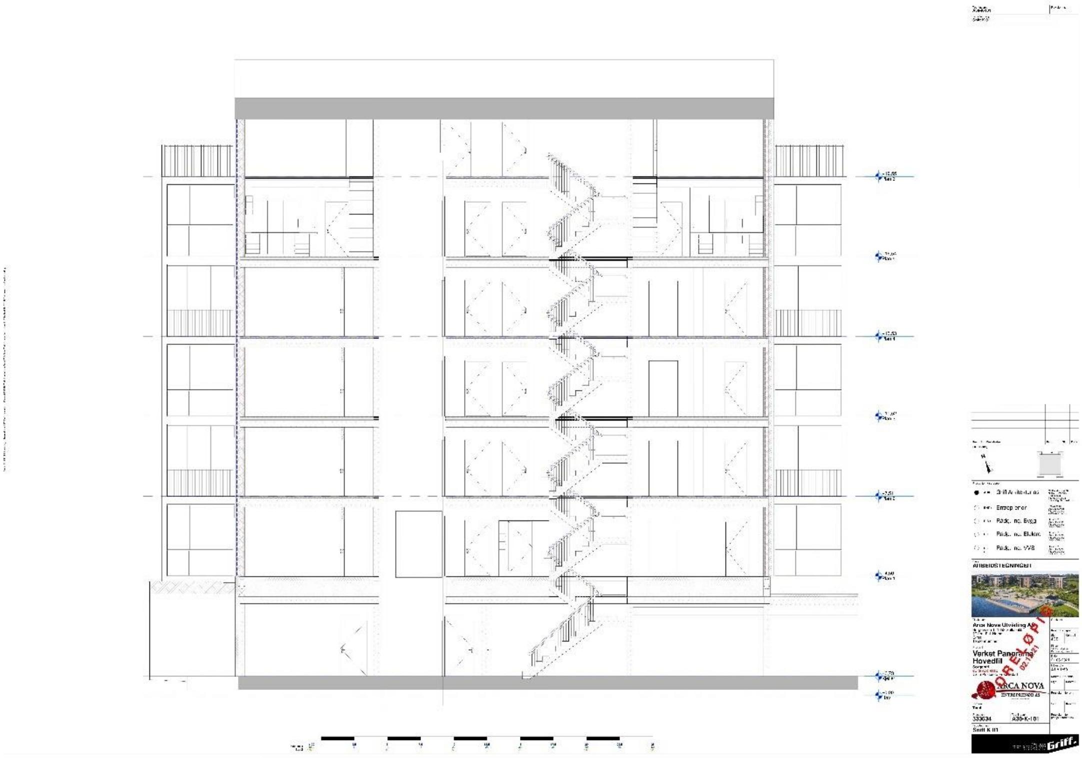
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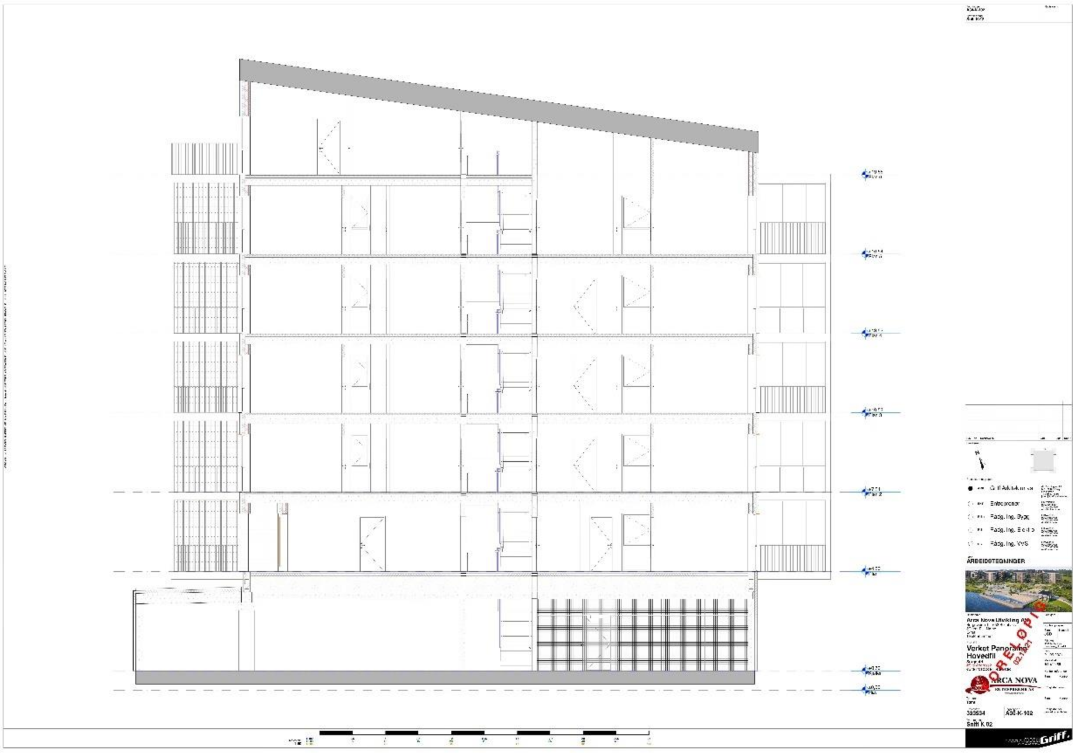
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Verket Panorama
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02.12.21
ARCA NOVA
333634
A30-K-102
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Griff.

Supply and return air calculation

Dwelling units shall have ventilation that ensures an average supply of fresh air at a minimum rate of 1.2 m$_3$ per hour per m$_2$ of floor space when the dwelling unit is occupied. (TEK17 2022)

Bed = 26m^3 per bed

Kitchen = 36m^3/h

Toilet = 36m^3/h

Bath = 54m^3/h

Toilet + Bath = 45m^3/4

Supply Air = *[26x No of beds] + [36x No of Kitchens] + [36xNo of Toilets] + [54xNo of Baths] + [45xNo of (Toilet + Bath)] + [0.7x Remaining area]*

Zone **A** – Supply Air = 26x2 + 36x1 + 36x1 + 54x0 + 45x1 + 0.7x50.5

= 204.0 m3/h

Zone **B** – Supply Air = 26x1 + 36x1 + 36x0 + 54x0 + 45x1 + 0.7x19

= 120.0 m3/h

Zone **C** – Supply Air = 26x2 + 36x1 + 36x0 + 54x0 + 45x1 + 0.7x43.5

= 163.0 m3/h

Zone **D** –Supply Air = 26x 2 36x1 + 36x0 + 54x0 + 45x1 + 0.7x37.5

= 159.0 m3/h

Zone **E** – Supply Air = 26x 0 + 36x0 + 36x0 + 54x0 + 45x0 + 0.7x37.5

= 26.5 m3/h

Occupant, Lighting and Equipment data per zone

Total No. of zones	**Zone designation**	**No. of Occupants**	**Usage**
5	Zone A	3	House living
6	Zone B	2	House living
5	Zone C	4	House living
6	Zone D	3	House living
6	Zone E	-	-

Table 0.1: Panorama reference building K occupancy data (assumed)

Total No. of zones	**Zone designation**	**No. of units/zone**	**Rated input/unit (W)**	**Luminous efficacy/unit (lm/W)**	**Convective fraction/unit (0-1)**	**Usage**
5	Zone A	8	15	125	0.78	House living
6	Zone B	5	15	125	0.78	House living
5	Zone C	9	15	125	0.78	House living
6	Zone D	7	15	125	0.78	House living
6	Zone E	3	15	125	0.78	House living

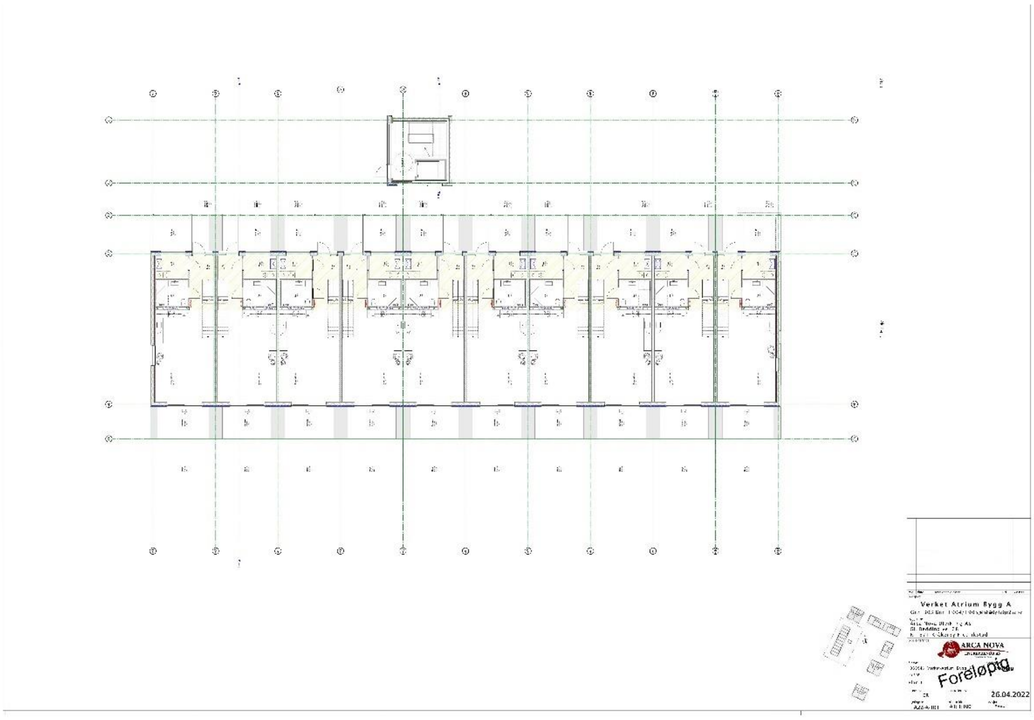
Table 0.2: Panorama reference building K lighting data (assumed)

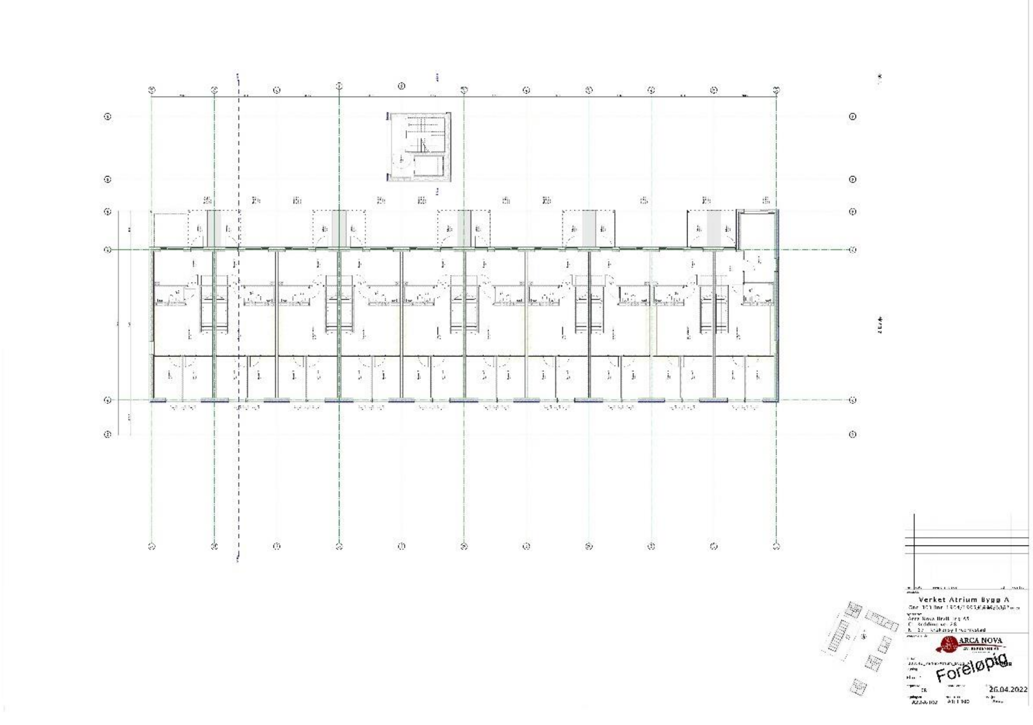
Total No. of zones	**Zone designation**	**No. of units/zone**	**Heat emitted/unit(W)**	**Usage**
5	Zone A	7	75	House living
6	Zone B	4	75	House living
5	Zone C	7	75	House living
6	Zone D	5	75	House living
6	Zone E	1	75	House living

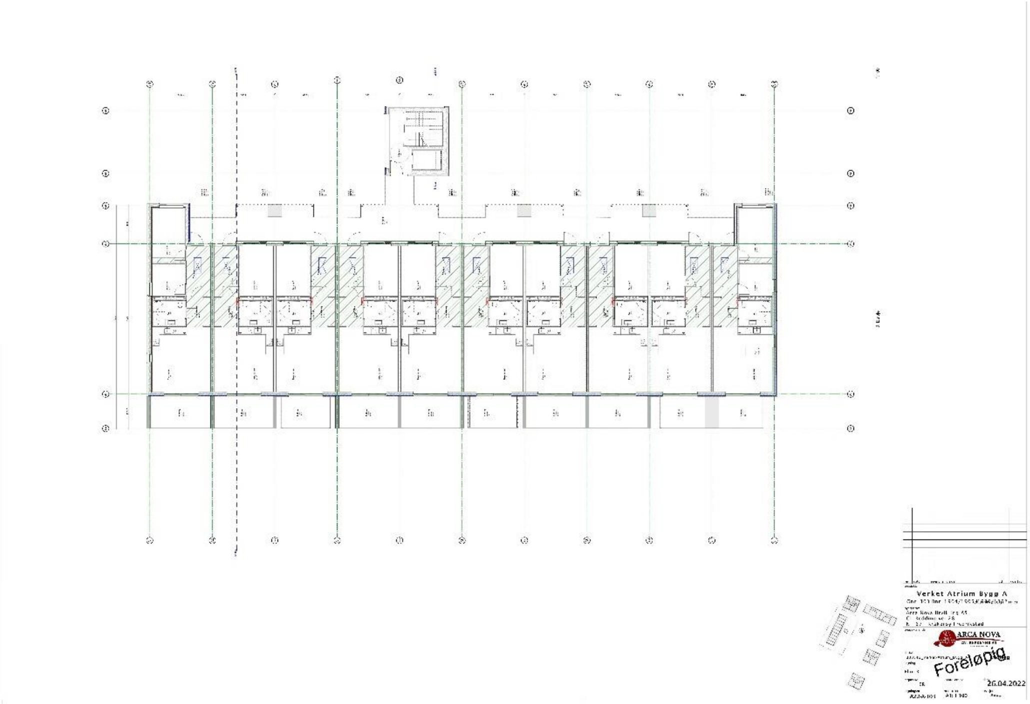
Table 0.3: Panorama reference building K equipment data (assumed)

Appendix II-Verket Atrium

Architectural Drawings by Arca Nova



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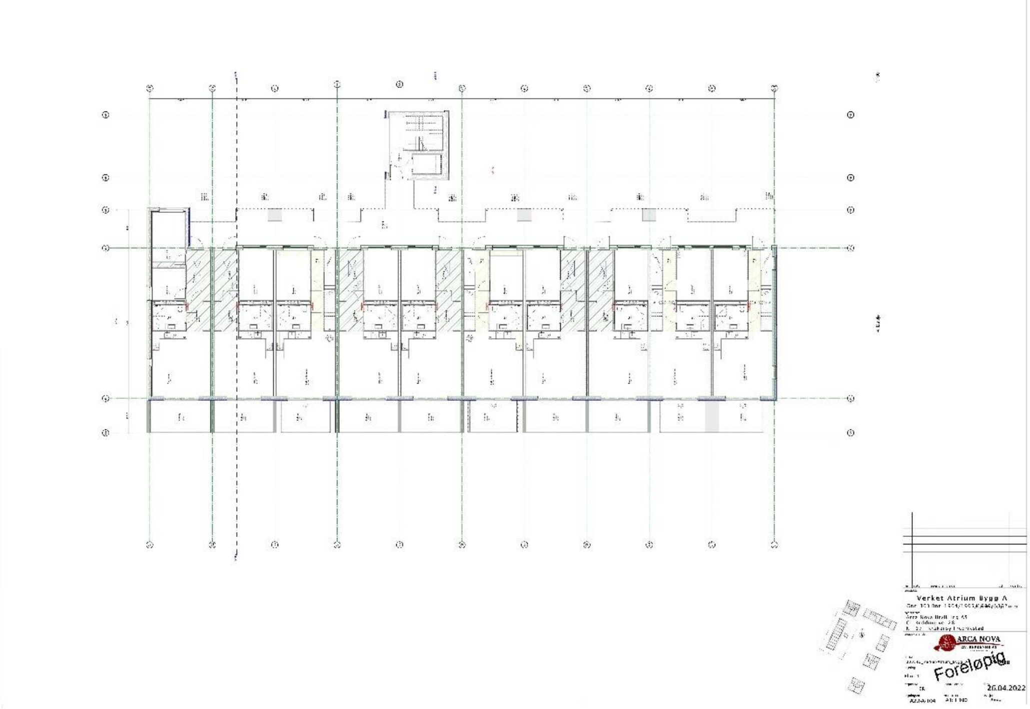
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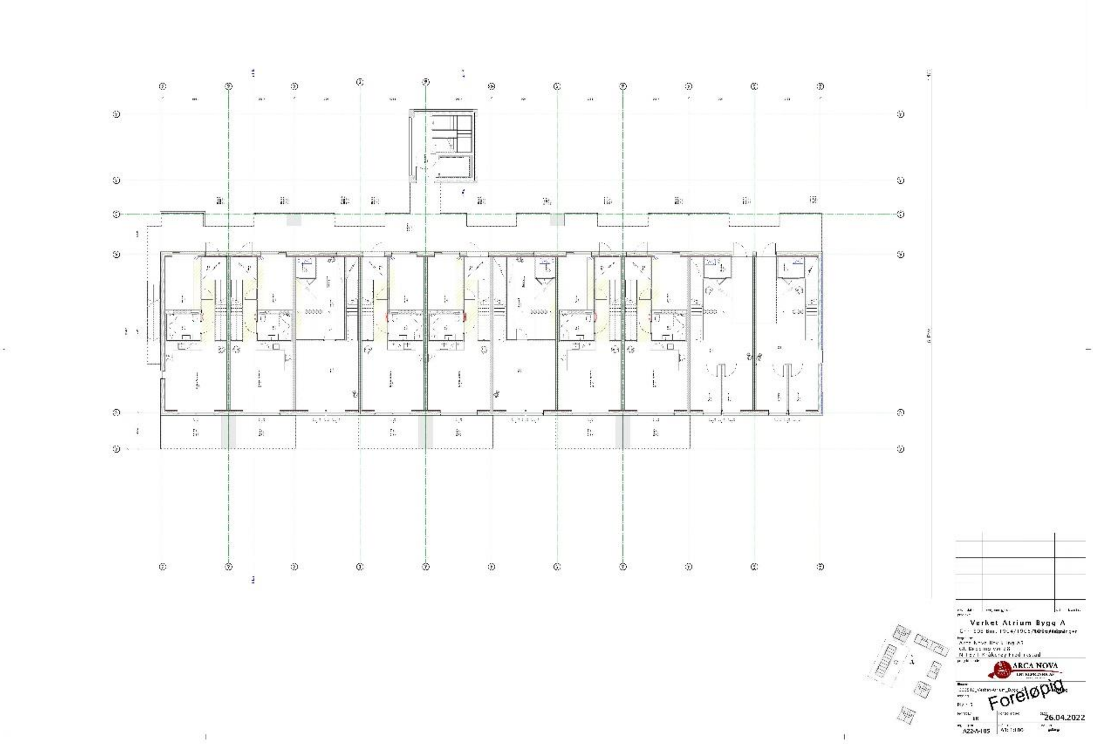
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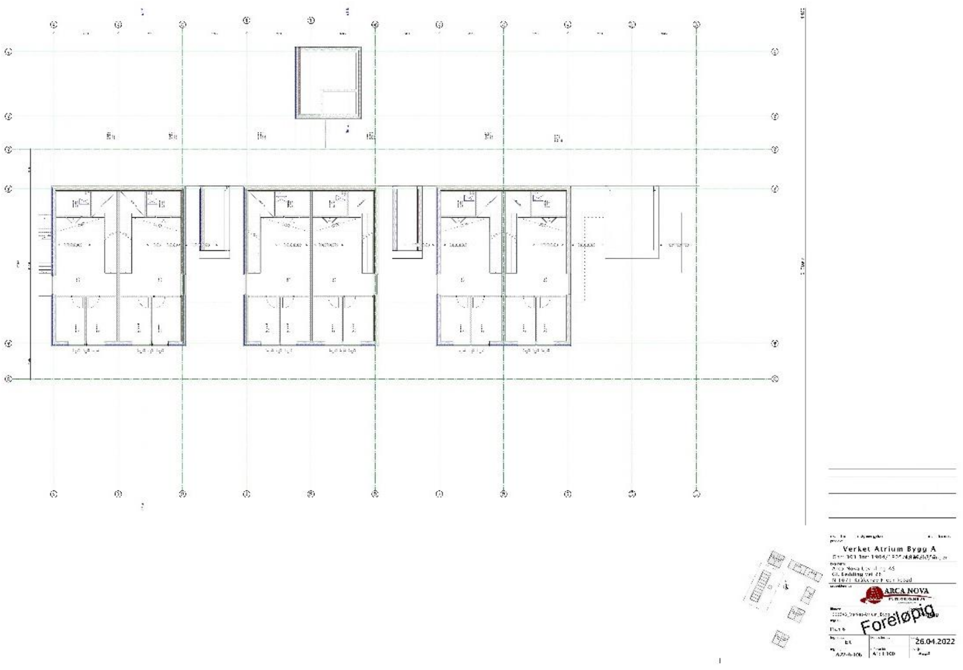
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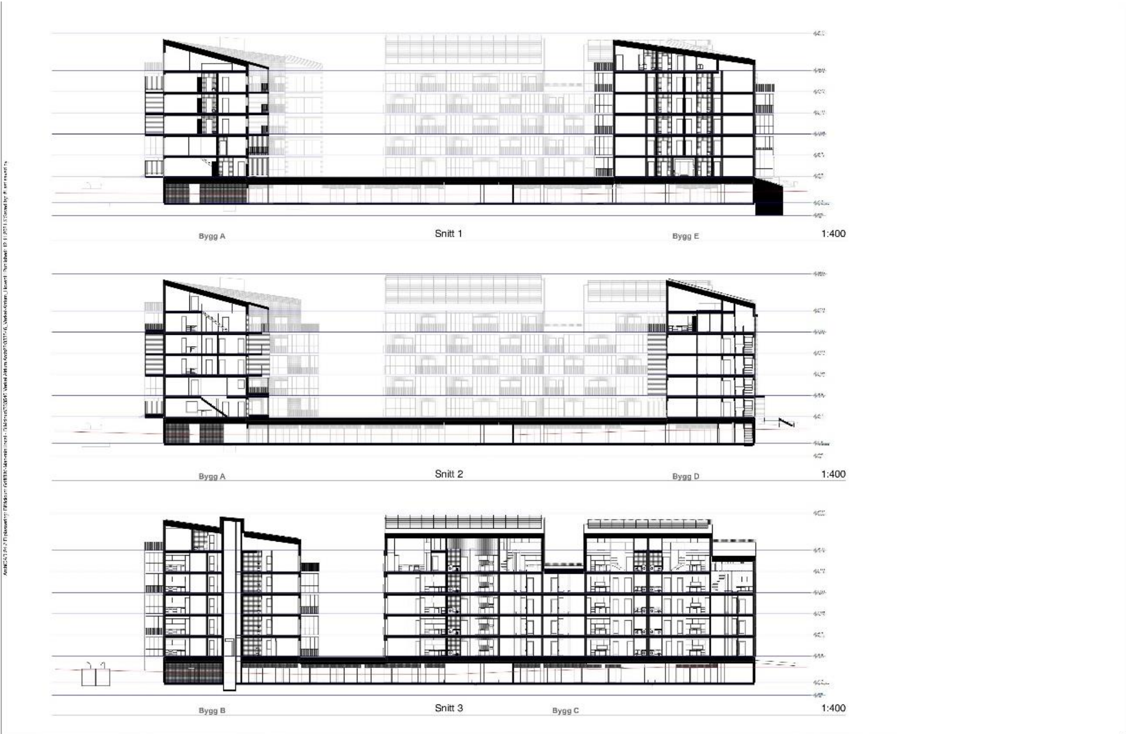

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Arca Nova Utvikling AS
Borgeveien 1 · 1558 Sellebakk

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Tegningstype:

Snitt 1, 2 og 3

Fase:
ARBEIDSTEGNINGER
Tegningsnummer:
A30-S-061

Tegnet av:
MP
Kontroll:

Printet d. fredag 12. november 2021
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Målestokk:
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Tiltakshaver:
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Borgeveien 1 - 1558 Sellebakk

Prosjekt:
Verket Atrium Hovedfil
Sorgenfri - #Site Postcode Fredrikstad
Gnr: 303 Bnr: 1904/1905/1930/1352

Tegningstype:

Snitt 4 og 5

Fase:
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Tegningsnummer:
A30-S-062

Tegnet av:
MP
Kontroll:

Printet d. fredag 12. november 2021
FORELØPIG
Målestokk:
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Supply and return air calculation

Dwelling units shall have ventilation that ensures an average supply of fresh air at a minimum rate of 1.2 m_3 per hour per m_2 of floor space when the dwelling unit is occupied.

Bed = 26m^3 per bed

Kitchen = 36m^3/h

Toilet = 36m^3/h

Bath = 54m^3/h

Toilet+Bath = 45m^3/4

Supply Air = [26x No of beds] + [36x No of Kitchens] + [36xNo of Toilets] + [54xNo of Baths] + [45xNo of (Toilet+Bath)] + [0.7x Remaining area]

Zone **A** – Supply Air = 26x0 + 36x1 + 36x1 + 54x1 + 45x0 + 0.7x38.5

= 153.0 m3/h

Zone **B** – Supply Air = 26x3 + 36x0 + 36x0 + 54x0 + 45x1 + 0.7x28

= 142.6 m3/h

Zone **C** – Supply Air = 26x1 + 36x1 + 36x0 + 54x0 + 45x1 + 0.7x32.8

= 130.0 m3/h

Zone **D** –Supply Air = 26x2 + 36x1 + 36x0 + 54x0 + 45x1 + 0.7x25.6

= 151.0 m3/h

Zone **E** – Supply Air = 26x1 + 36x0 + 36x0 + 54x0 + 45x0 + 0.7x14.9

= 36.5 m3/h

Zone **F** – Supply Air = 26x2 + 36x0 + 36x0 + 54x0 + 45x0 + 0.7x15.9

= 63.2 m3/h

Occupant, Lighting and Equipment data per zone

Total No. of zones	Zone designation	No. of Occupants	Usage
10	Zone A	2	House living
10	Zone B	4	House living
23	Zone C	1	House living
3	Zone D	2	House living
2	Zone E	2	House living
8	Zone F	2	House living

Table 0.1: Atrium reference building A occupancy data (assumed)

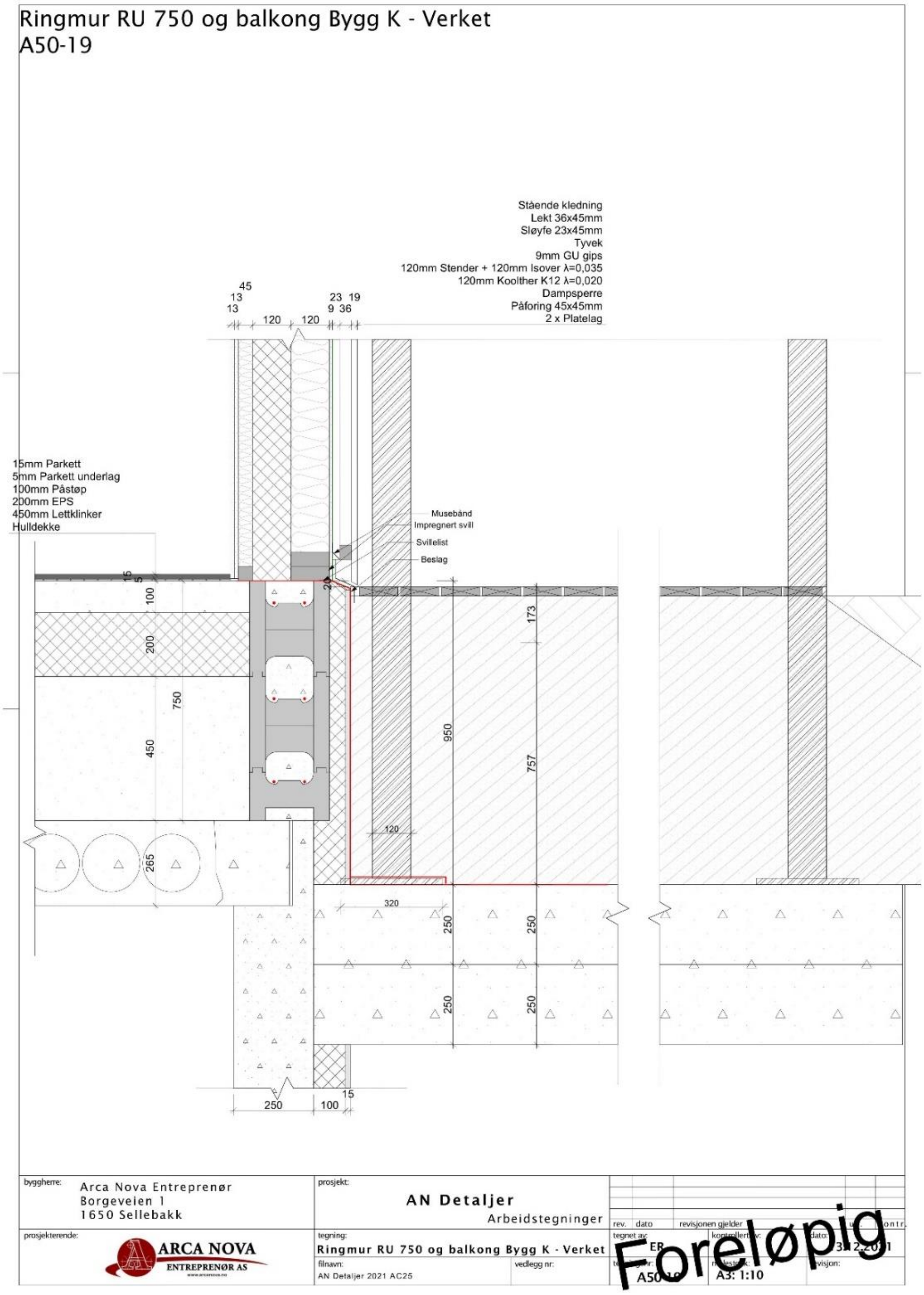
Total No. of zones	Zone designation	No. of units/zone	Rated input/unit (W)	Luminous efficacy/unit (lm/W)	Convective fraction/unit (0-1)	Usage
10	Zone A	6	15	125	0.78	House living
10	Zone B	7	15	125	0.78	House living
23	Zone C	5	15	125	0.78	House living
3	Zone D	6	15	125	0.78	House living
2	Zone E	4	15	125	0.78	House living
8	Zone F	5	15	125	0.78	House living

Table 0.2: Atrium reference building A lighting data (assumed)

Total No. of zones	Zone designation	No. of units/zone	Heat emitted/unit(W)	Usage
10	Zone A	6	75	House living
10	Zone B	6	75	House living
23	Zone C	5	75	House living
3	Zone D	6	75	House living
2	Zone E	3	75	House living
8	Zone F	3	75	House living

Table 0.3:Atrium reference building A equipment data (assumed)

Appendix III-Construction details



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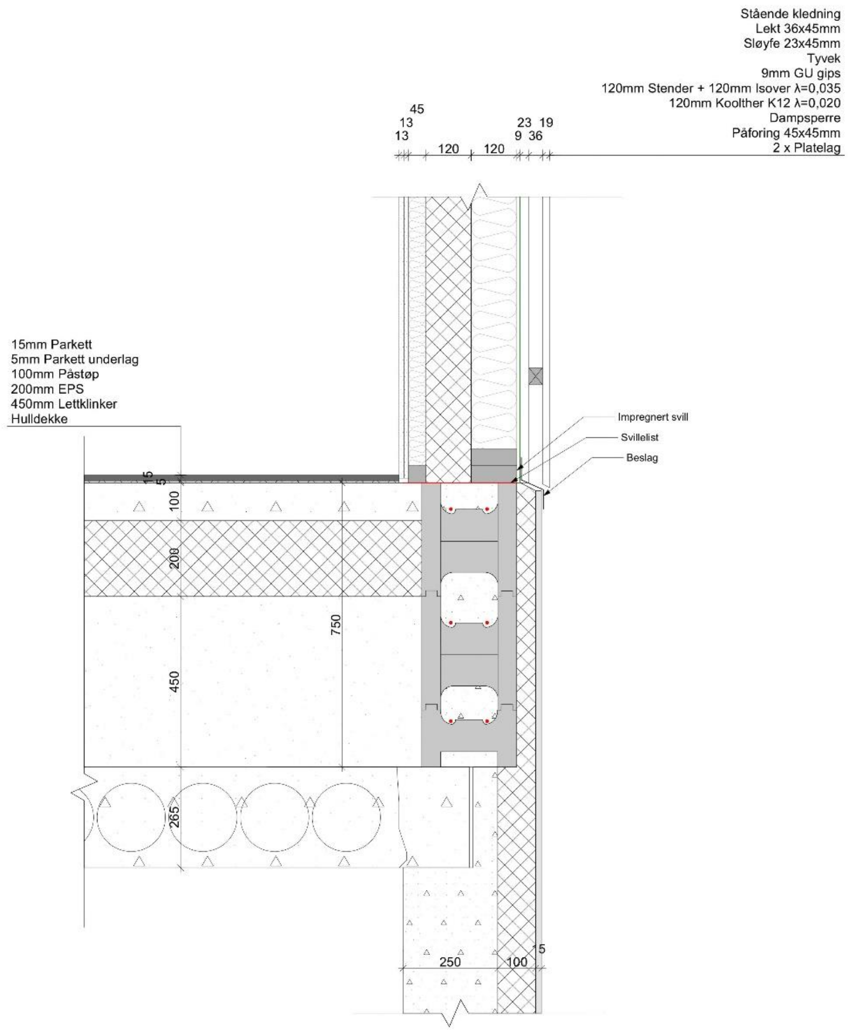

byggherre: Arca Nova Entreprenør
Borgeveien 1
1650 Sellebakk

prosjekt: **AN Detaljer**
Arbeidstegninger

rev.	dato	revisjonen gjelder	utf.	kontr.

prosjekterende: ARCA NOVA ENTREPRENØR AS

tegning: Ringmur RU 750 Bygg K - Verket

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vedlegg nr:

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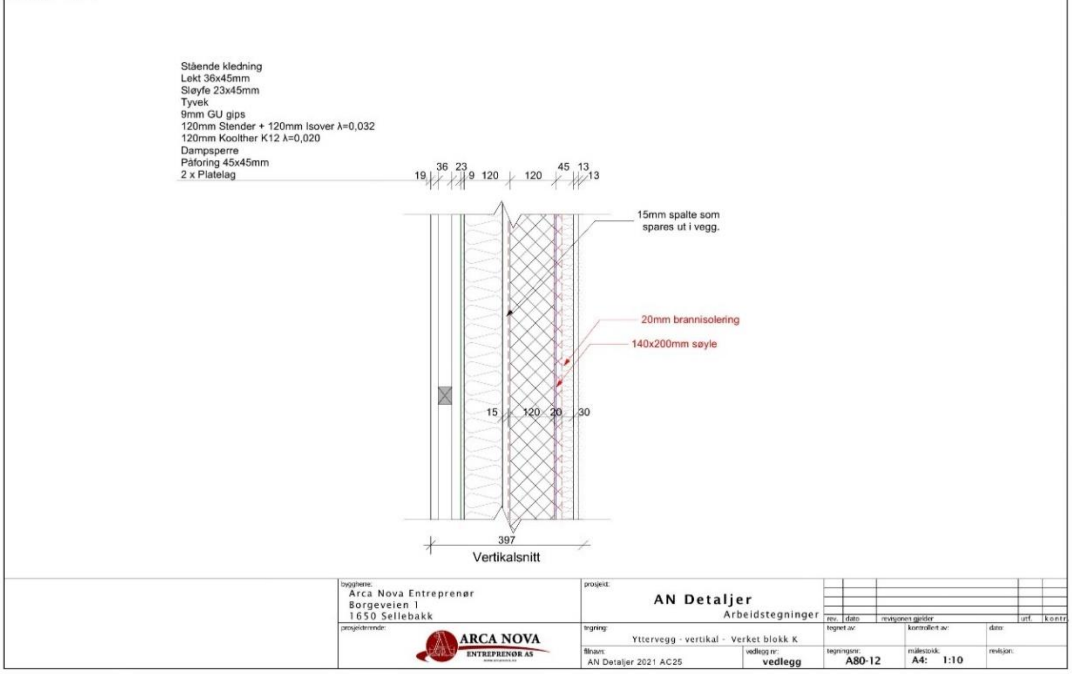

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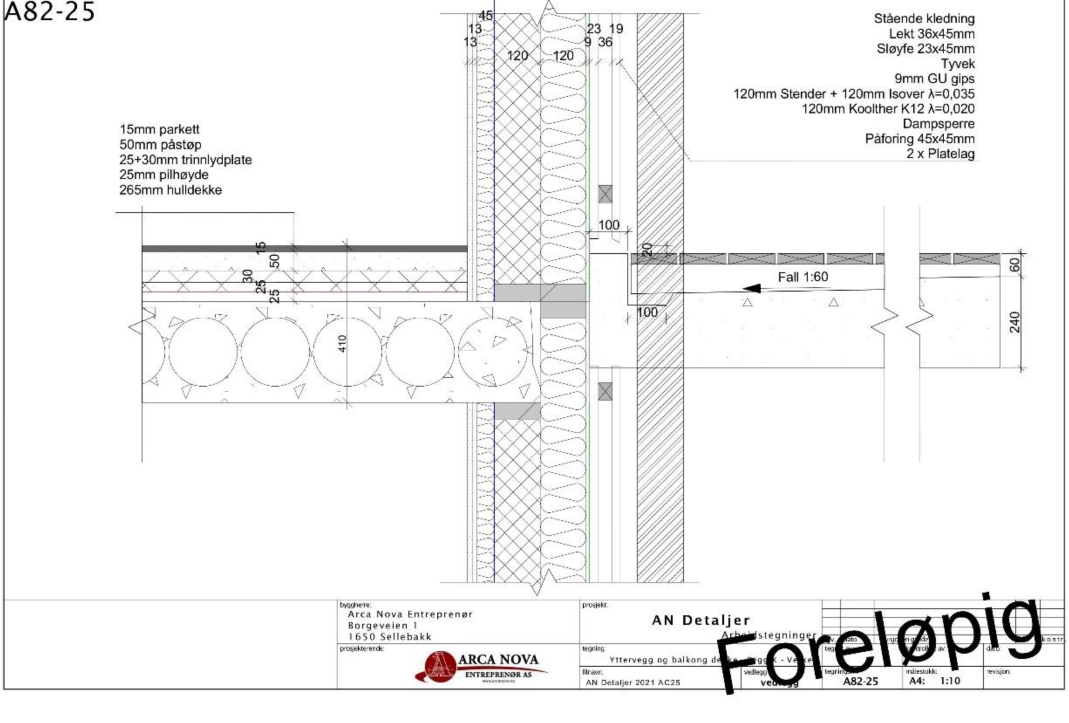

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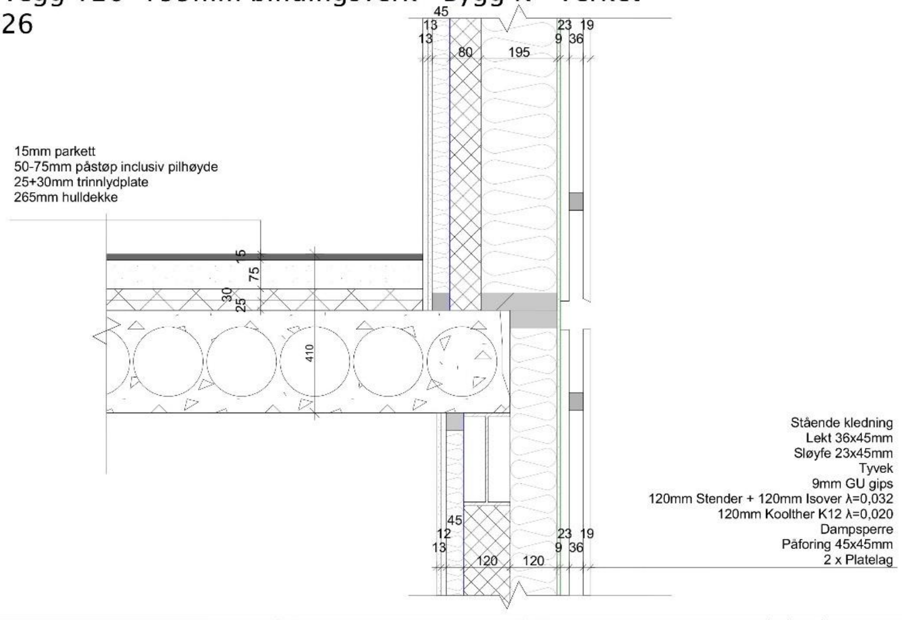

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Borgeveien 1
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AN Detaljer
Arbeidstegninger

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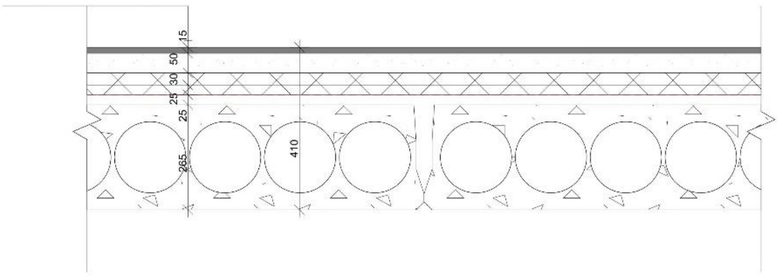

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prosjekt:
AN Detaljer
Arbeidstegninger

rev.	dato	revisjonen gjelder	utf.	kontr.

tegning: Hulldekke - Malt himling med synlig v-fuge - Verket

tegnet av:

kontrollert av:

dato:

filnavn: AN Detaljer 2021 AC25

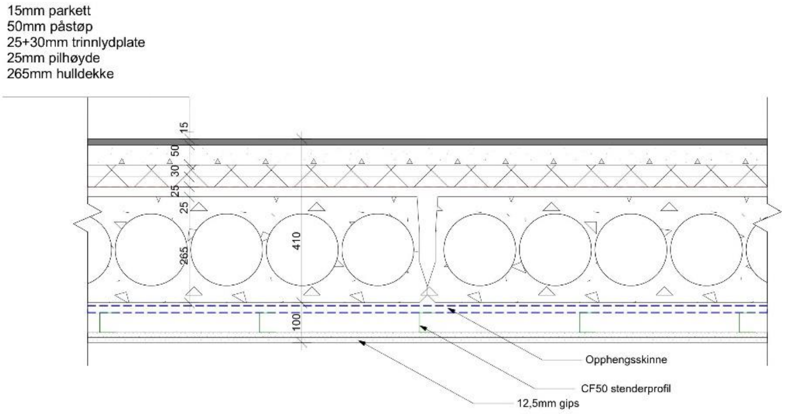
vedlegg nr: vedlegg

tegningsnr.: A94-1

målestokk: A4: 1:10

revisjon:

Hulldekke - Nedsenket himling med sparklet og malt gips - Verket
A94-2



byggherre: Arca Nova Entreprenør
Borgeveien 1
1650 Sellebakk

prosjekt: **AN Detaljer**
Arbeidstegninger

rev. dato revisjonen gjelder utf. kontr.

prosjekterende: ARCA NOVA ENTREPRENØR AS

tegning: Hulldekke - Nedsenket himling med sparklet og malt gips - Verket

tegnet av: kontrollert av: dato:

filnavn: AN Detaljer 2021 AC25

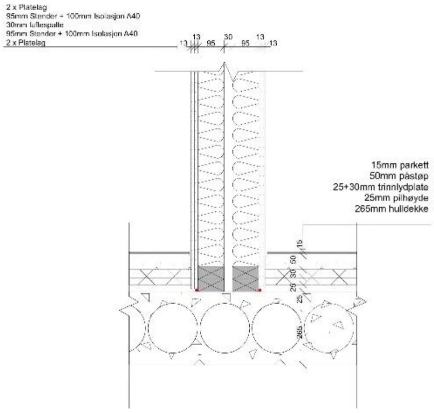
vedlegg nr: **vedlegg**

tegningsnr: **A94-2**

målestokk: **A4: 1:10**

revisjon:

Lydvegg på hulldekke - Verket
A112-4



byggherre: Arca Nova Entreprenør
Borgeveien 1
1650 Sellebakk

prosjekt: **AN Detaljer**
Arbeidstegninger

rev. dato revisjonen gjelder utf. kontr.

prosjekterende: ARCA NOVA ENTREPRENØR AS

tegning: **Lydvegg på hulldekke - Verket**

tegnet av: kontrollert av: dato:

filnavn: AN Detaljer 2021 AC25

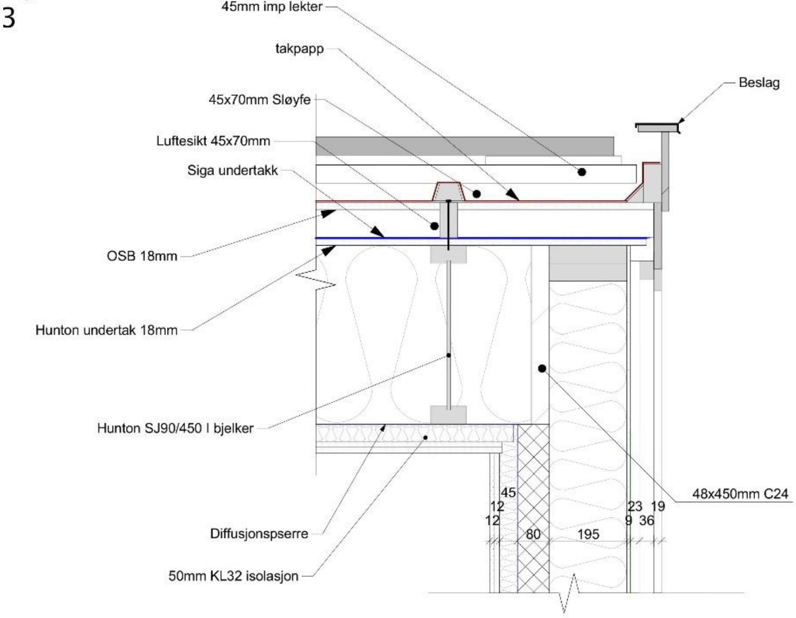
vedlegg nr:

tegningsnr: **A112-4**

målestokk: **A3: 1:10**

revisjon:

Yttertak gavl - 195mm bindingsverk - Verket
A141-23



byggherre:
Arca Nova Entreprenør
Borgeveien 1
1650 Sellebakk

prosjekt:
AN Detaljer
Arbeidstegninger

prosjekterende:
ARCA NOVA
ENTREPRENØR AS

tegning:
Yttertak gavl - 195mm bindingsverk - Verket

filnavn:
AN Detaljer 2021 AC25

vedlegg:
vedlegg

tegning:
A141-23

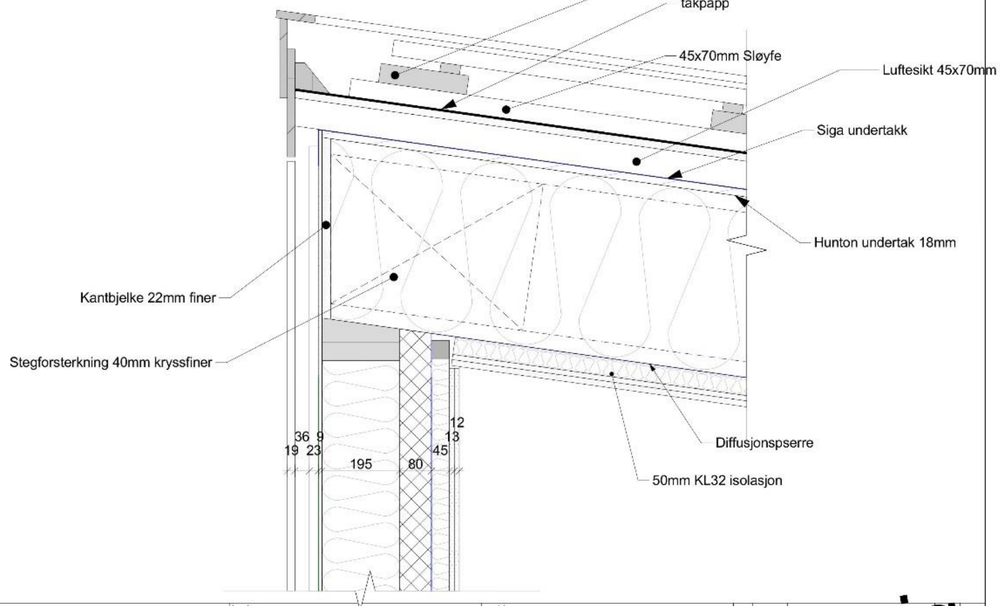
målestokk:
A4: 1:10

revisjon:

dato:

Foreløpig

Yttertak - 195mm bindingsverk - Verket
A141-25



byggherre:
Arca Nova Entreprenør
Borgeveien 1
1650 Sellebakk

prosjekt:
AN Detaljer
Arbeidstegninger

prosjekterende:
ARCA NOVA
ENTREPRENØR AS

tegning:
Yttertak - 195mm bindingsverk - Verket

filnavn:
AN Detaljer 2021 AC25

vedlegg:
vedlegg

tegning:
A141-25

målestokk:
A4: 1:10

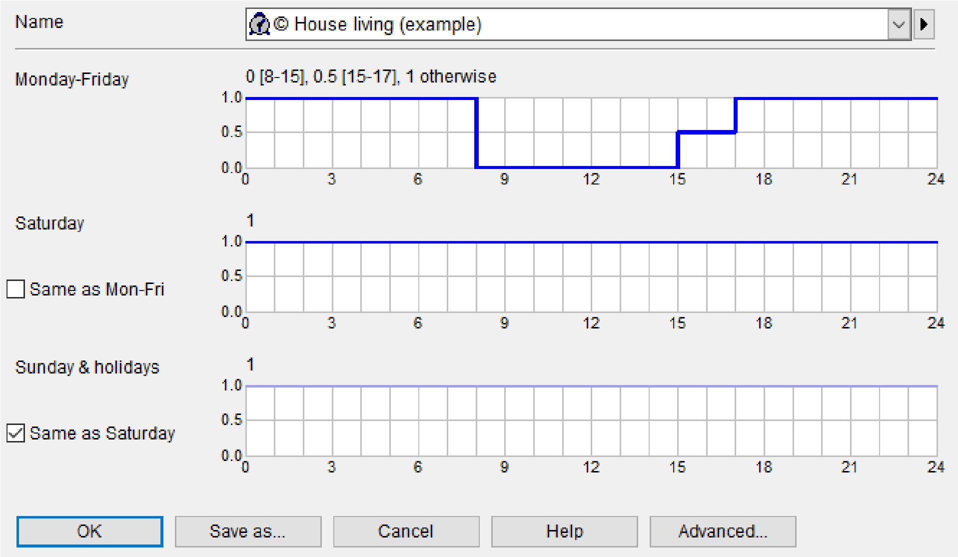
revisjon:

dato:

Foreløpig

Appendix IV-Simulation data

Input data



Name: © House living (example)

Monday-Friday: 0 [8-15], 0.5 [15-17], 1 otherwise

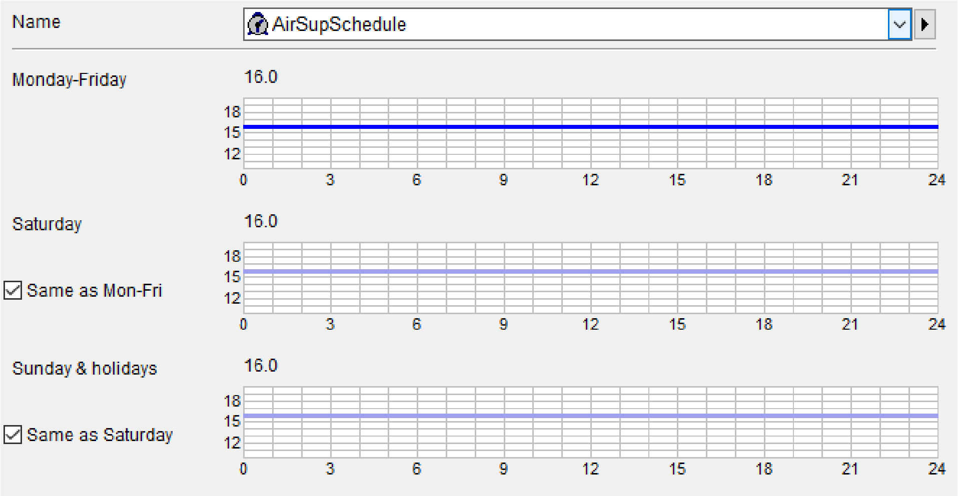
Saturday: 1

☐ Same as Mon-Fri

Sunday & holidays: 1

☑ Same as Saturday

Figure 0.1:House living (schedule of usage)



Name: AirSupSchedule

Monday-Friday: 16.0

Saturday: 16.0

☑ Same as Mon-Fri

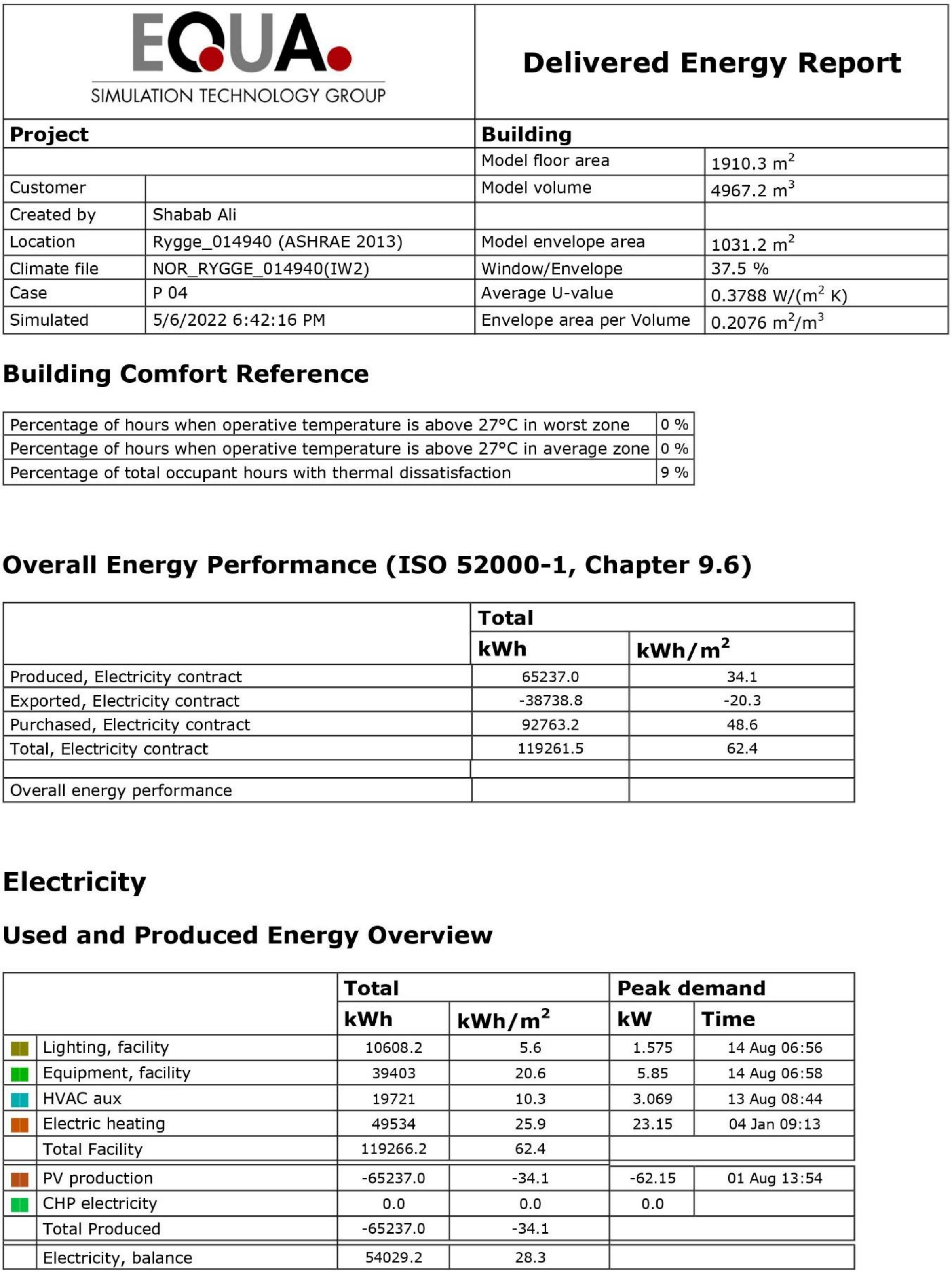
Sunday & holidays: 16.0

☑ Same as Saturday

Figure 0.2: Air supply schedule for AHU

Verket Panorama reference building-Results

Case 01



EQUA
SIMULATION TECHNOLOGY GROUP

Delivered Energy Report

Project		**Building**	
		Model floor area	1910.3 m^2
Customer		Model volume	4967.2 m^3
Created by	Shabab Ali		
Location	Rygge_014940 (ASHRAE 2013)	Model envelope area	1031.2 m^2
Climate file	NOR_RYGGE_014940(IW2)	Window/Envelope	37.5 %
Case	P 04	Average U-value	0.3788 W/(m^2 K)
Simulated	5/6/2022 6:42:16 PM	Envelope area per Volume	0.2076 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	9 %

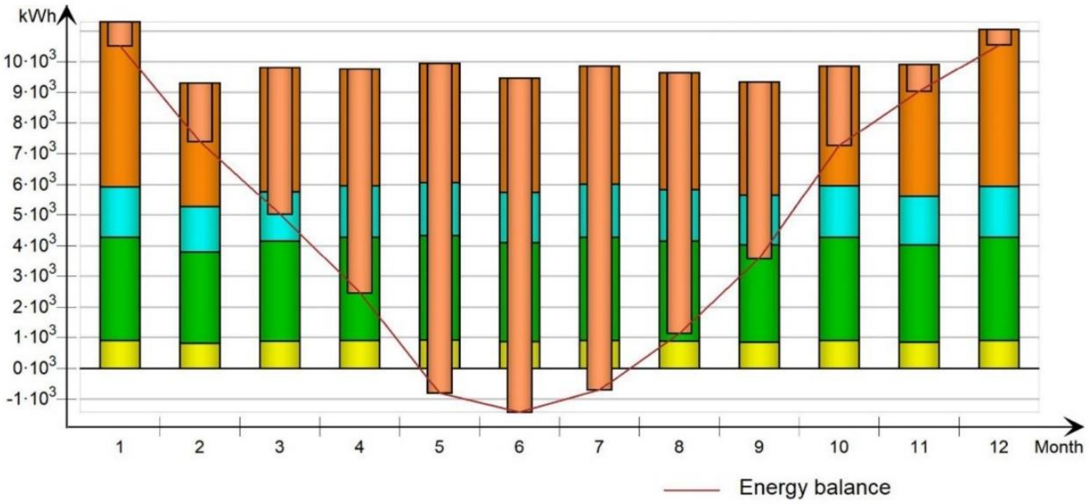
Overall Energy Performance (ISO 52000-1, Chapter 9.6)

	Total	
	kWh	**kWh/m^2**
Produced, Electricity contract	65237.0	34.1
Exported, Electricity contract	-38738.8	-20.3
Purchased, Electricity contract	92763.2	48.6
Total, Electricity contract	119261.5	62.4
Overall energy performance		

Electricity

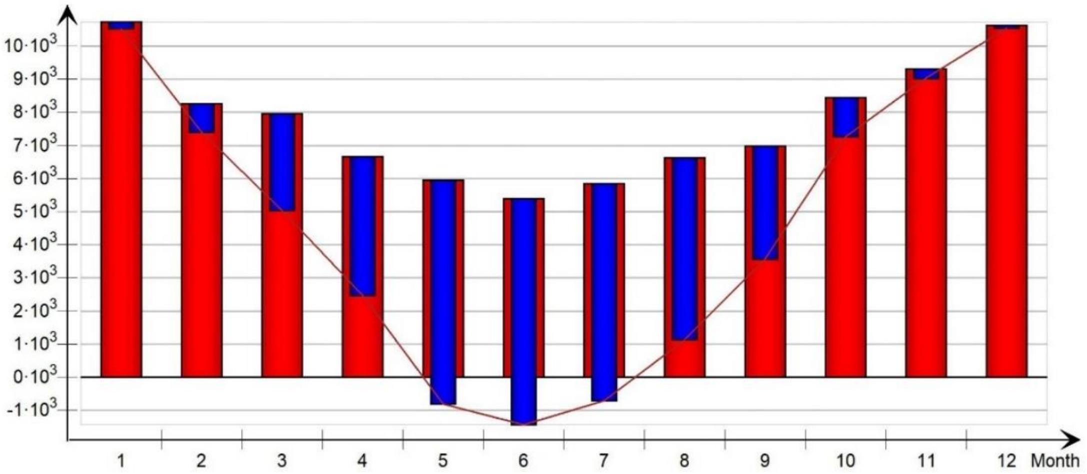
Used and Produced Energy Overview

		Total		**Peak demand**	
		kWh	**kWh/m^2**	**kW**	**Time**
🟨	Lighting, facility	10608.2	5.6	1.575	14 Aug 06:56
🟩	Equipment, facility	39403	20.6	5.85	14 Aug 06:58
🟦	HVAC aux	19721	10.3	3.069	13 Aug 08:44
🟧	Electric heating	49534	25.9	23.15	04 Jan 09:13
	Total Facility	119266.2	62.4		
🟫	PV production	-65237.0	-34.1	-62.15	01 Aug 13:54
🟩	CHP electricity	0.0	0.0	0.0	
	Total Produced	-65237.0	-34.1		
	Electricity, balance	54029.2	28.3		

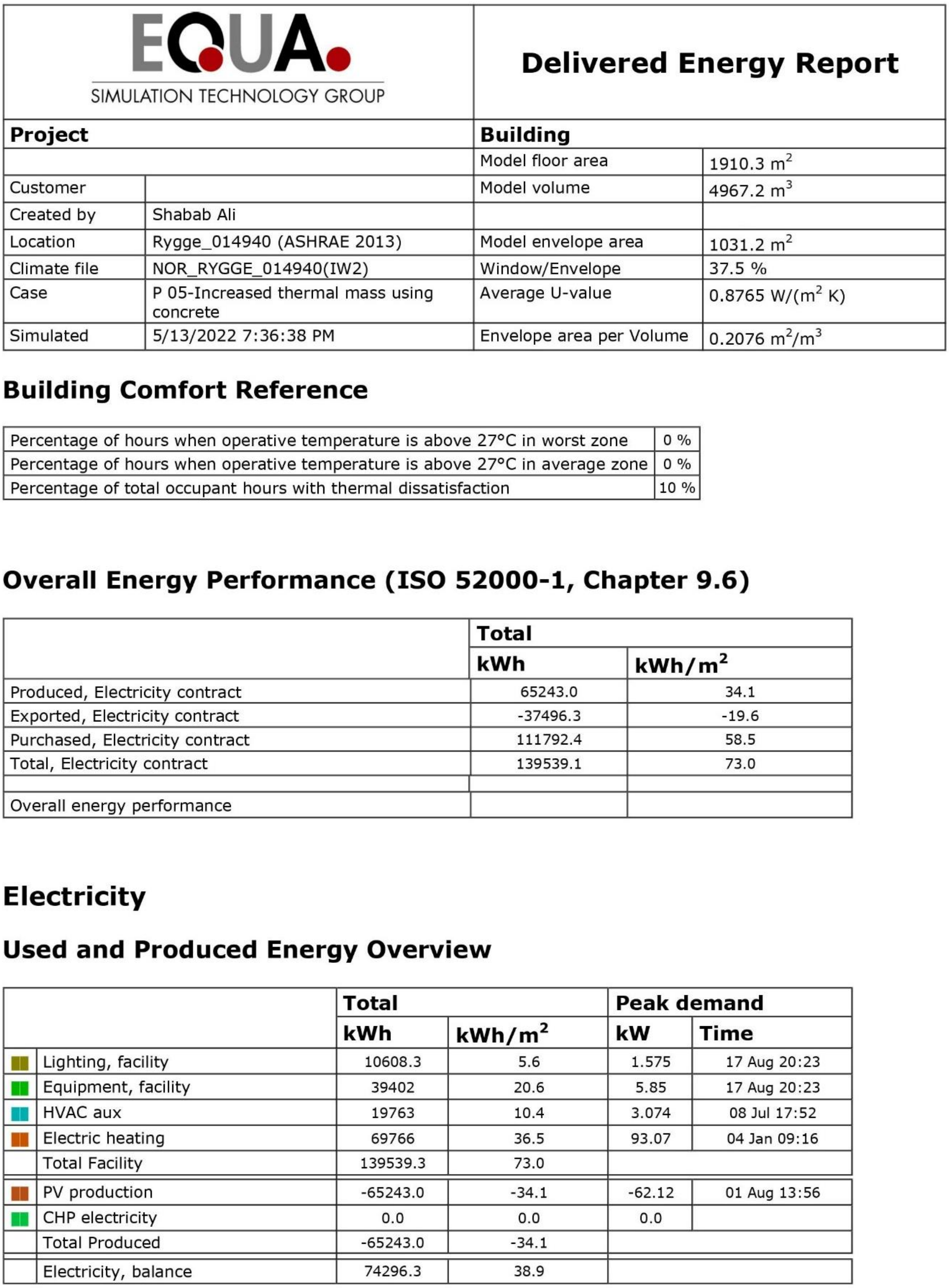


Purchased and Exported Energy Overview

		Total		Peak demand	
		kWh	kWh/m^2	kW	Time
🟥	Purchased, Electricity contract	92763.2	48.6		
🟦	Exported, Electricity contract	-38738.8	-20.3		
	Balance, Electricity contract	54024.4	28.3		
	Electricity, balance	54024.4	28.3		



Case 02



EQUA
SIMULATION TECHNOLOGY GROUP

Delivered Energy Report

Project		**Building**	
		Model floor area	1910.3 m^2
Customer		Model volume	4967.2 m^3
Created by	Shabab Ali		
Location	Rygge_014940 (ASHRAE 2013)	Model envelope area	1031.2 m^2
Climate file	NOR_RYGGE_014940(IW2)	Window/Envelope	37.5 %
Case	P 05-Increased thermal mass using concrete	Average U-value	0.8765 $W/(m^2 K)$
Simulated	5/13/2022 7:36:38 PM	Envelope area per Volume	0.2076 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	10 %

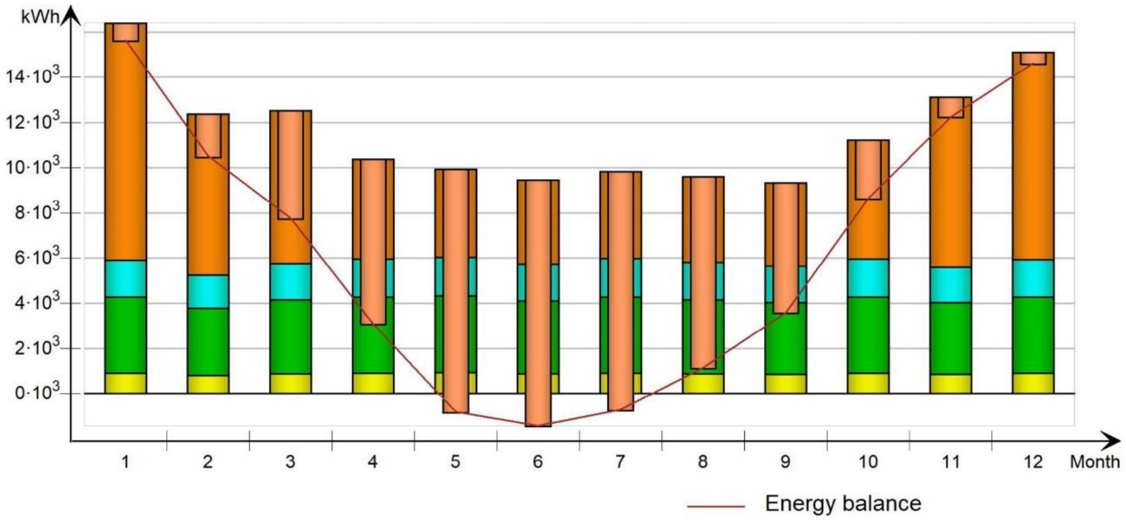
Overall Energy Performance (ISO 52000-1, Chapter 9.6)

	Total	
	kWh	**kWh/m^2**
Produced, Electricity contract	65243.0	34.1
Exported, Electricity contract	-37496.3	-19.6
Purchased, Electricity contract	111792.4	58.5
Total, Electricity contract	139539.1	73.0
Overall energy performance		

Electricity

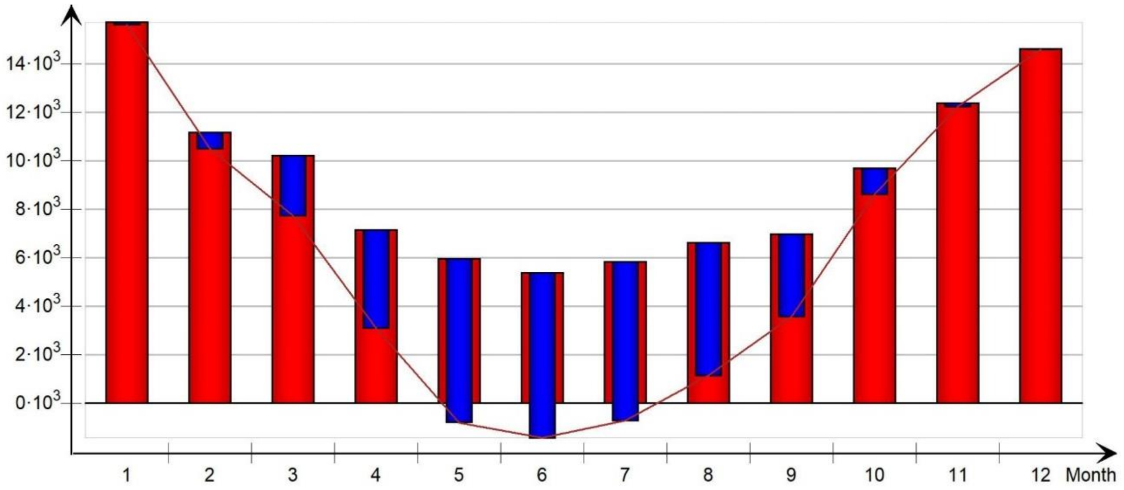
Used and Produced Energy Overview

		Total		**Peak demand**	
		kWh	**kWh/m^2**	**kW**	**Time**
🟫	Lighting, facility	10608.3	5.6	1.575	17 Aug 20:23
🟩	Equipment, facility	39402	20.6	5.85	17 Aug 20:23
🟦	HVAC aux	19763	10.4	3.074	08 Jul 17:52
🟧	Electric heating	69766	36.5	93.07	04 Jan 09:16
	Total Facility	139539.3	73.0		
🟧	PV production	-65243.0	-34.1	-62.12	01 Aug 13:56
🟩	CHP electricity	0.0	0.0	0.0	
	Total Produced	-65243.0	-34.1		
	Electricity, balance	74296.3	38.9		

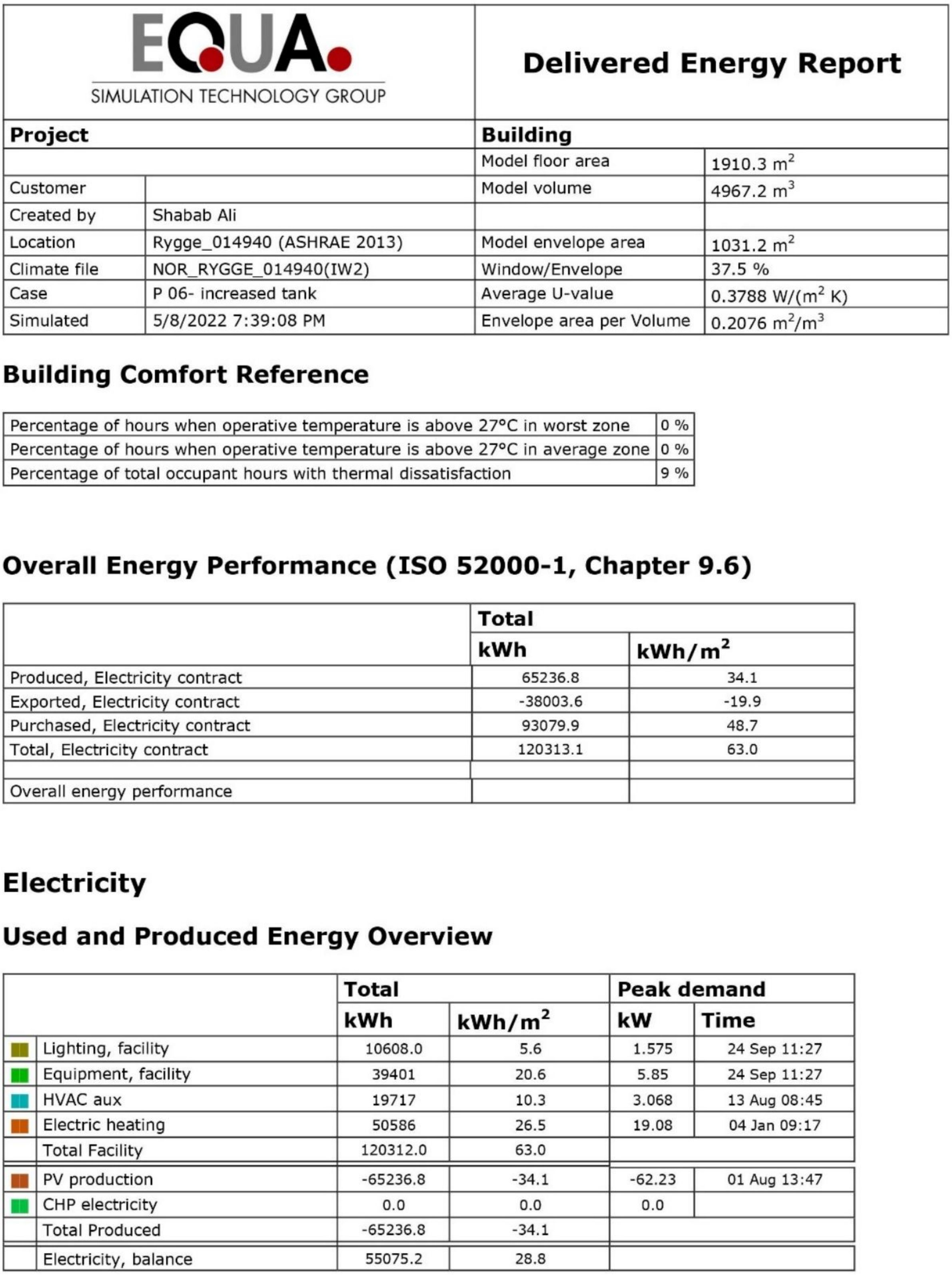


Purchased and Exported Energy Overview

		Total		Peak demand	
		kWh	kWh/m^2	kW	Time
🟥	Purchased, Electricity contract	111792.4	58.5		
🟦	Exported, Electricity contract	-37496.3	-19.6		
	Balance, Electricity contract	74296.1	38.9		
	Electricity, balance	74296.1	38.9		



Case 03



EQUA
SIMULATION TECHNOLOGY GROUP

Delivered Energy Report

Project		**Building**	
		Model floor area	1910.3 m^2
Customer		Model volume	4967.2 m^3
Created by	Shabab Ali		
Location	Rygge_014940 (ASHRAE 2013)	Model envelope area	1031.2 m^2
Climate file	NOR_RYGGE_014940(IW2)	Window/Envelope	37.5 %
Case	P 06- increased tank	Average U-value	0.3788 W/(m^2 K)
Simulated	5/8/2022 7:39:08 PM	Envelope area per Volume	0.2076 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	9 %

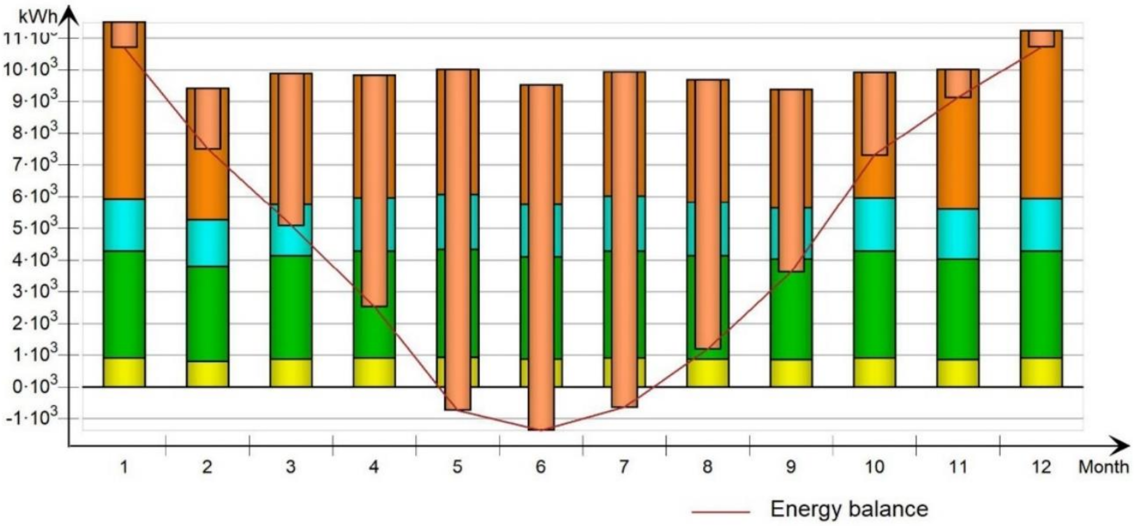
Overall Energy Performance (ISO 52000-1, Chapter 9.6)

	Total	
	kWh	**kWh/m^2**
Produced, Electricity contract	65236.8	34.1
Exported, Electricity contract	-38003.6	-19.9
Purchased, Electricity contract	93079.9	48.7
Total, Electricity contract	120313.1	63.0
Overall energy performance		

Electricity

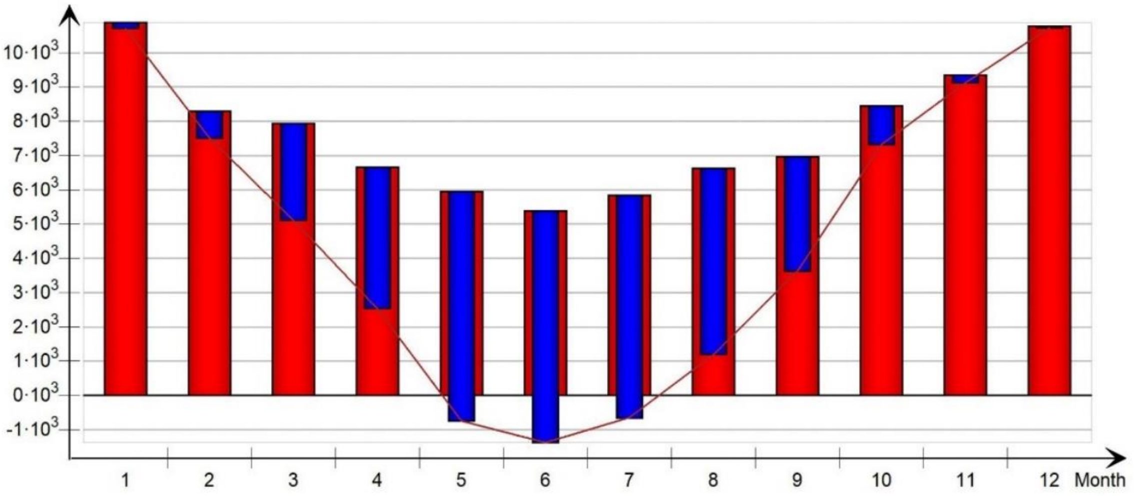
Used and Produced Energy Overview

		Total		**Peak demand**	
		kWh	**kWh/m^2**	**kW**	**Time**
🟨	Lighting, facility	10608.0	5.6	1.575	24 Sep 11:27
🟩	Equipment, facility	39401	20.6	5.85	24 Sep 11:27
🟦	HVAC aux	19717	10.3	3.068	13 Aug 08:45
🟧	Electric heating	50586	26.5	19.08	04 Jan 09:17
	Total Facility	120312.0	63.0		
🟫	PV production	-65236.8	-34.1	-62.23	01 Aug 13:47
🟩	CHP electricity	0.0	0.0	0.0	
	Total Produced	-65236.8	-34.1		
	Electricity, balance	55075.2	28.8		

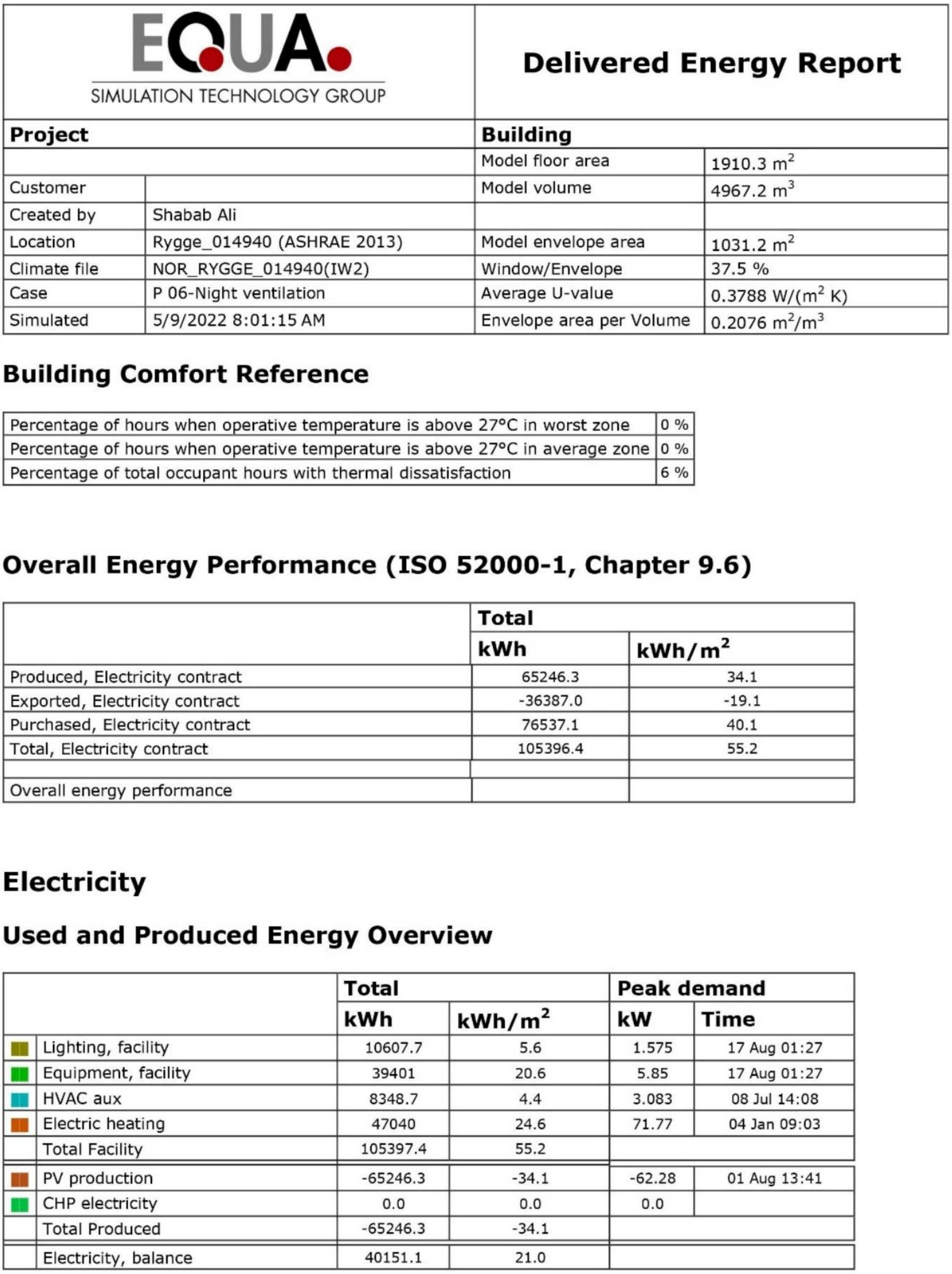


Purchased and Exported Energy Overview

		Total		Peak demand	
		kWh	kWh/m^2	kW	Time
🟥	Purchased, Electricity contract	93079.9	48.7		
🟦	Exported, Electricity contract	-38003.6	-19.9		
	Balance, Electricity contract	55076.3	28.8		
	Electricity, balance	55076.3	28.8		



Case 04



EQUA
SIMULATION TECHNOLOGY GROUP

Delivered Energy Report

Project		**Building**	
		Model floor area	1910.3 m^2
Customer		Model volume	4967.2 m^3
Created by	Shabab Ali		
Location	Rygge_014940 (ASHRAE 2013)	Model envelope area	1031.2 m^2
Climate file	NOR_RYGGE_014940(IW2)	Window/Envelope	37.5 %
Case	P 06-Night ventilation	Average U-value	0.3788 $W/(m^2 K)$
Simulated	5/9/2022 8:01:15 AM	Envelope area per Volume	0.2076 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	6 %

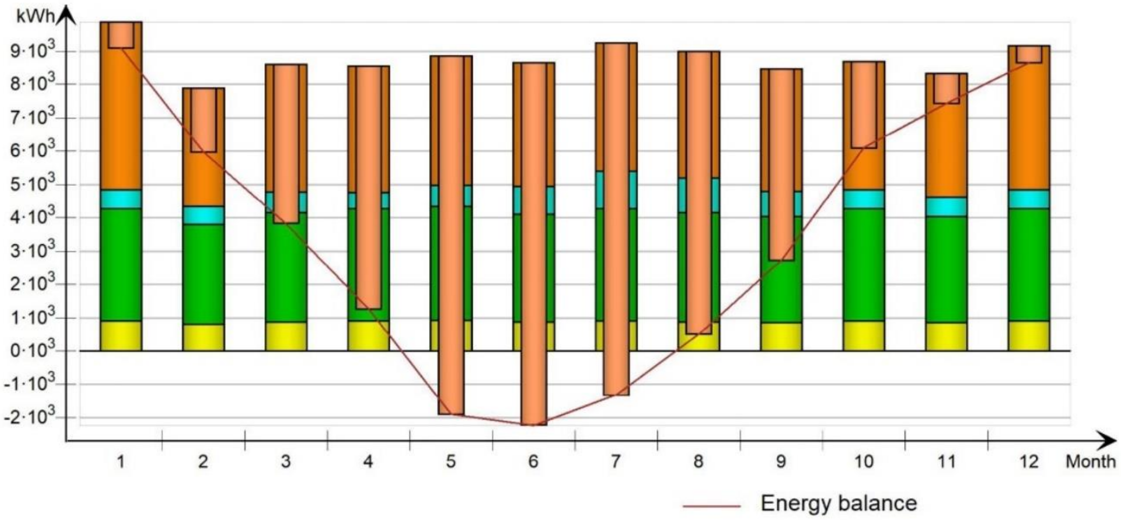
Overall Energy Performance (ISO 52000-1, Chapter 9.6)

	Total	
	kWh	**kWh/m^2**
Produced, Electricity contract	65246.3	34.1
Exported, Electricity contract	-36387.0	-19.1
Purchased, Electricity contract	76537.1	40.1
Total, Electricity contract	105396.4	55.2
Overall energy performance		

Electricity

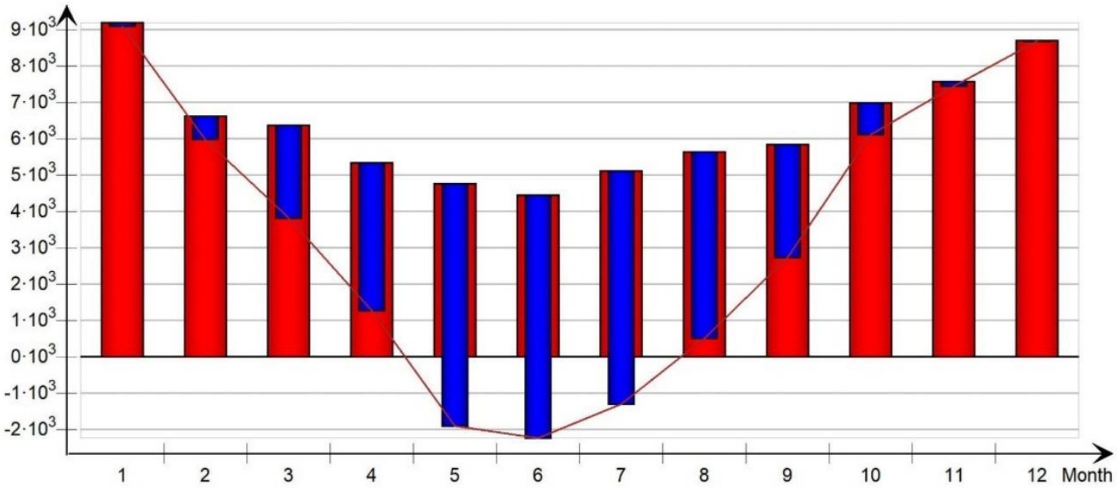
Used and Produced Energy Overview

		Total		**Peak demand**	
		kWh	**kWh/m^2**	**kW**	**Time**
🟨	Lighting, facility	10607.7	5.6	1.575	17 Aug 01:27
🟩	Equipment, facility	39401	20.6	5.85	17 Aug 01:27
🟦	HVAC aux	8348.7	4.4	3.083	08 Jul 14:08
🟧	Electric heating	47040	24.6	71.77	04 Jan 09:03
	Total Facility	105397.4	55.2		
🟫	PV production	-65246.3	-34.1	-62.28	01 Aug 13:41
🟩	CHP electricity	0.0	0.0	0.0	
	Total Produced	-65246.3	-34.1		
	Electricity, balance	40151.1	21.0		

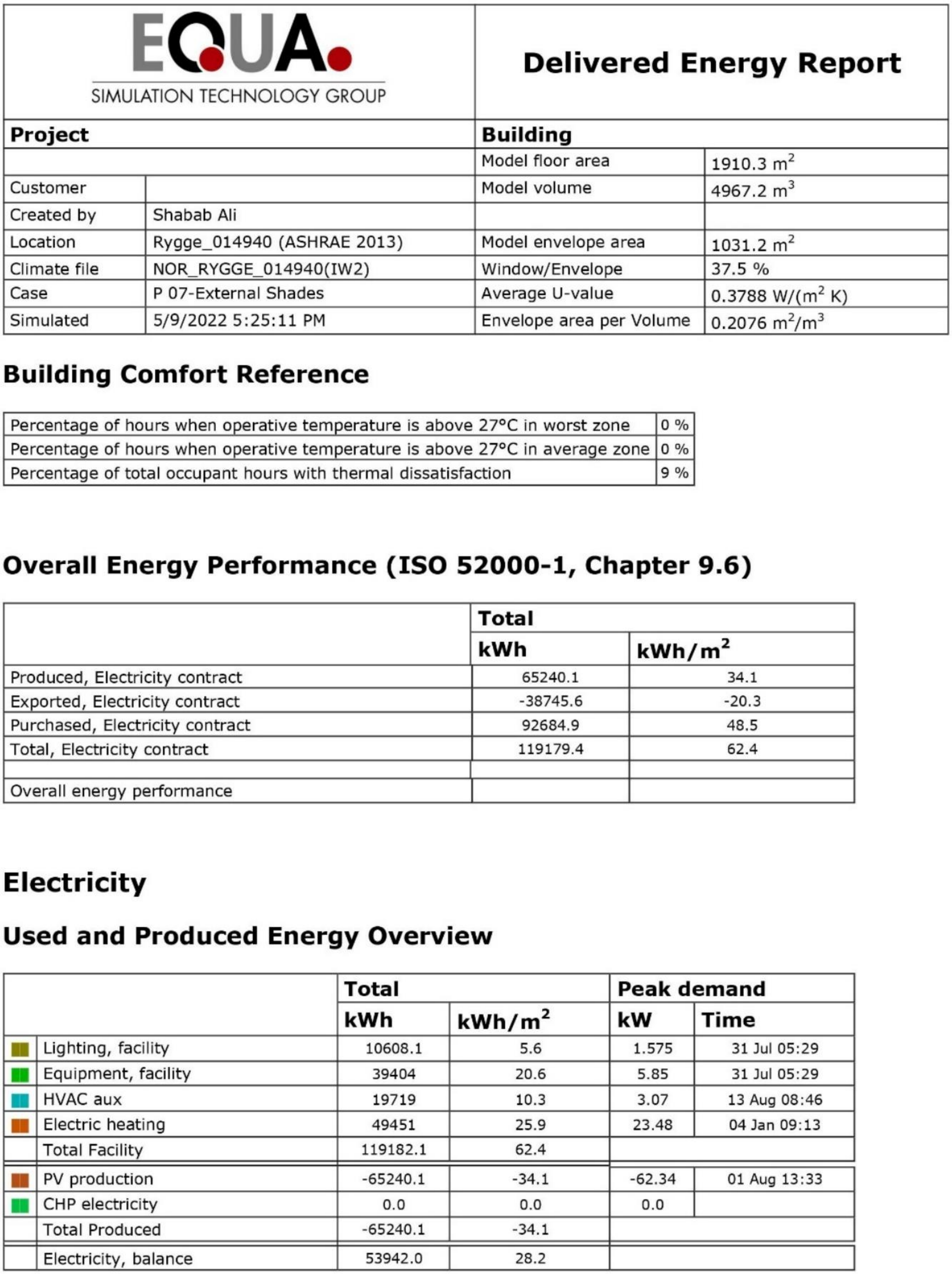


Purchased and Exported Energy Overview

		Total		Peak demand	
		kWh	kWh/m²	kW	Time
🟥	Purchased, Electricity contract	76537.1	40.1		
🟦	Exported, Electricity contract	-36387.0	-19.1		
	Balance, Electricity contract	40150.1	21.0		
	Electricity, balance	40150.1	21.0		



Case 05



EQUA
SIMULATION TECHNOLOGY GROUP

Delivered Energy Report

Project		**Building**	
		Model floor area	1910.3 m^2
Customer		Model volume	4967.2 m^3
Created by	Shabab Ali		
Location	Rygge_014940 (ASHRAE 2013)	Model envelope area	1031.2 m^2
Climate file	NOR_RYGGE_014940(IW2)	Window/Envelope	37.5 %
Case	P 07-External Shades	Average U-value	0.3788 W/(m^2 K)
Simulated	5/9/2022 5:25:11 PM	Envelope area per Volume	0.2076 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	9 %

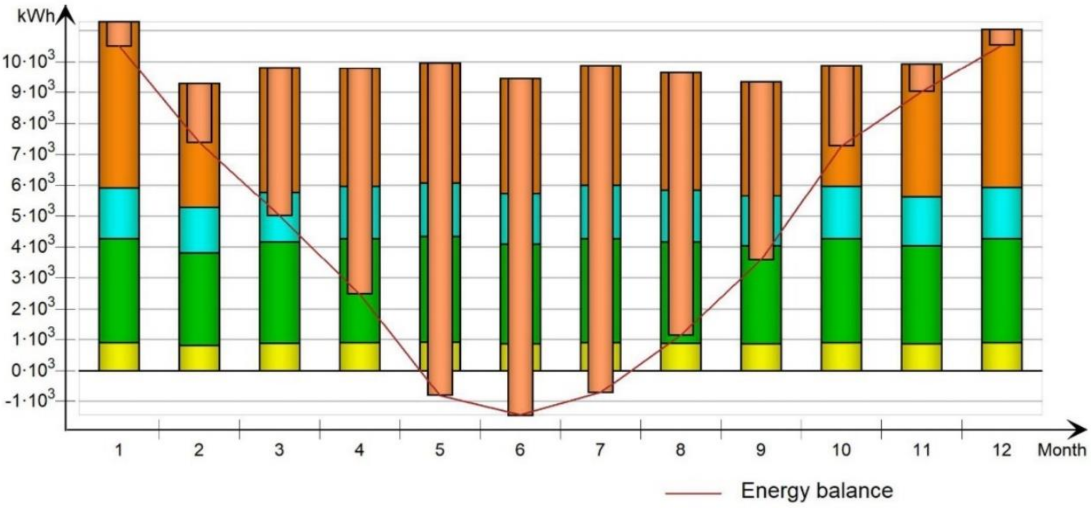
Overall Energy Performance (ISO 52000-1, Chapter 9.6)

	Total	
	kWh	**kWh/m^2**
Produced, Electricity contract	65240.1	34.1
Exported, Electricity contract	-38745.6	-20.3
Purchased, Electricity contract	92684.9	48.5
Total, Electricity contract	119179.4	62.4
Overall energy performance		

Electricity

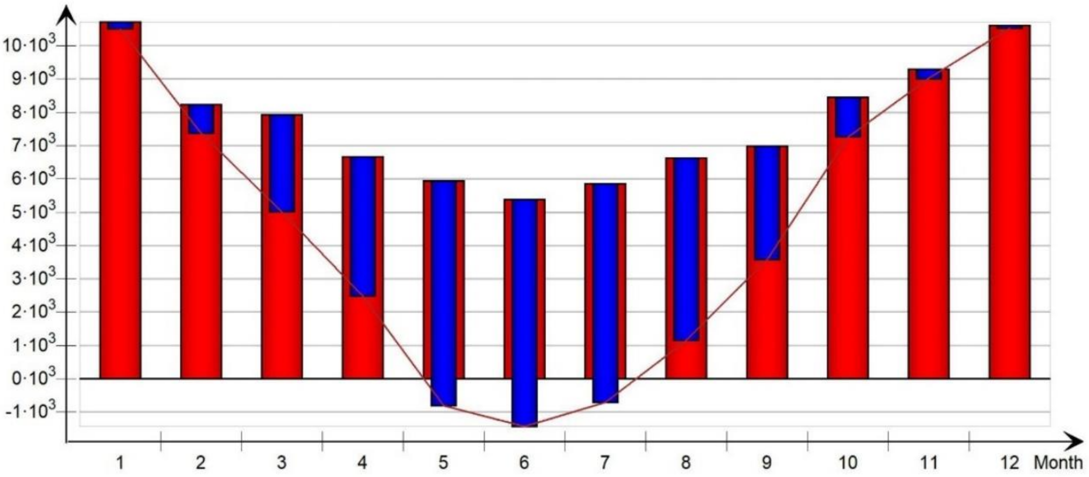
Used and Produced Energy Overview

		Total		**Peak demand**	
		kWh	**kWh/m^2**	**kW**	**Time**
🟨	Lighting, facility	10608.1	5.6	1.575	31 Jul 05:29
🟩	Equipment, facility	39404	20.6	5.85	31 Jul 05:29
🟦	HVAC aux	19719	10.3	3.07	13 Aug 08:46
🟧	Electric heating	49451	25.9	23.48	04 Jan 09:13
	Total Facility	119182.1	62.4		
🟫	PV production	-65240.1	-34.1	-62.34	01 Aug 13:33
🟩	CHP electricity	0.0	0.0	0.0	
	Total Produced	-65240.1	-34.1		
	Electricity, balance	53942.0	28.2		



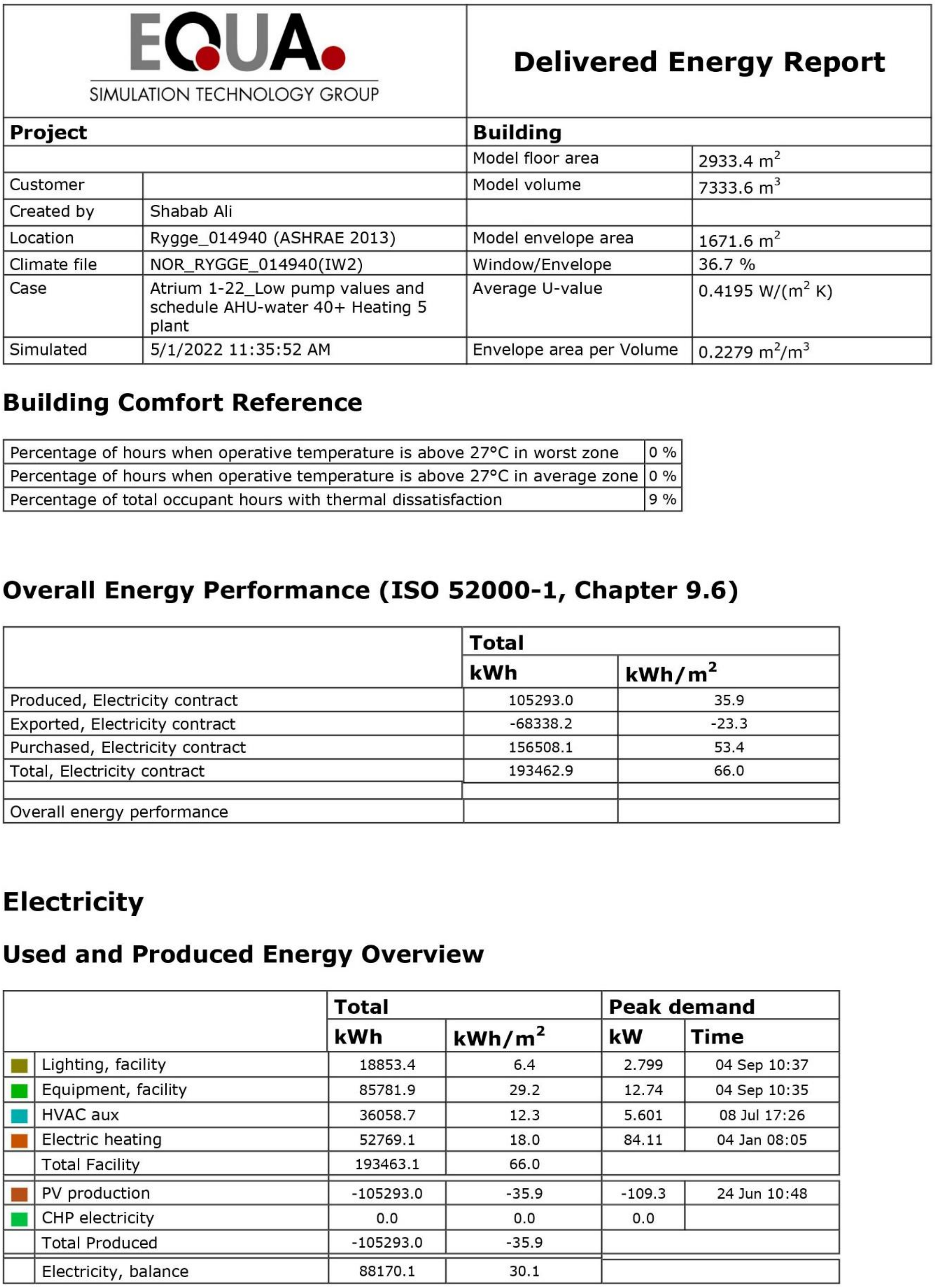
Purchased and Exported Energy Overview

		Total		Peak demand	
		kWh	kWh/m^2	kW	Time
🟥	Purchased, Electricity contract	92684.9	48.5		
🟦	Exported, Electricity contract	-38745.6	-20.3		
	Balance, Electricity contract	53939.3	28.2		
	Electricity, balance	53939.3	28.2		



Verket Atrium reference building-Results

Case 01



Delivered Energy Report

Project		**Building**	
		Model floor area	2933.4 m^2
Customer		Model volume	7333.6 m^3
Created by	Shabab Ali		
Location	Rygge_014940 (ASHRAE 2013)	Model envelope area	1671.6 m^2
Climate file	NOR_RYGGE_014940(IW2)	Window/Envelope	36.7 %
Case	Atrium 1-22_Low pump values and schedule AHU-water 40+ Heating 5 plant	Average U-value	0.4195 W/(m^2 K)
Simulated	5/1/2022 11:35:52 AM	Envelope area per Volume	0.2279 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	9 %

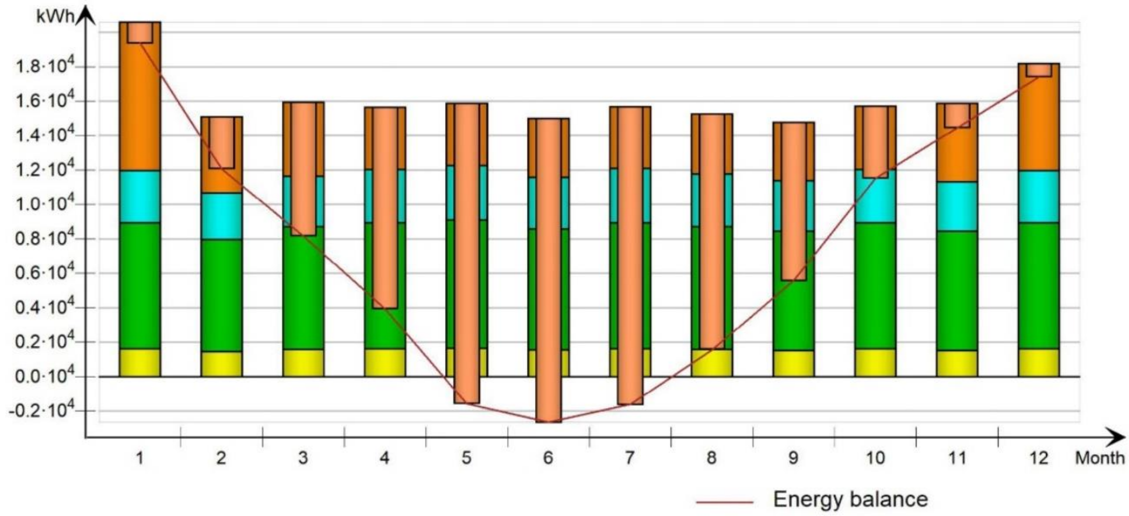
Overall Energy Performance (ISO 52000-1, Chapter 9.6)

	Total	
	kWh	**kWh/m^2**
Produced, Electricity contract	105293.0	35.9
Exported, Electricity contract	-68338.2	-23.3
Purchased, Electricity contract	156508.1	53.4
Total, Electricity contract	193462.9	66.0
Overall energy performance		

Electricity

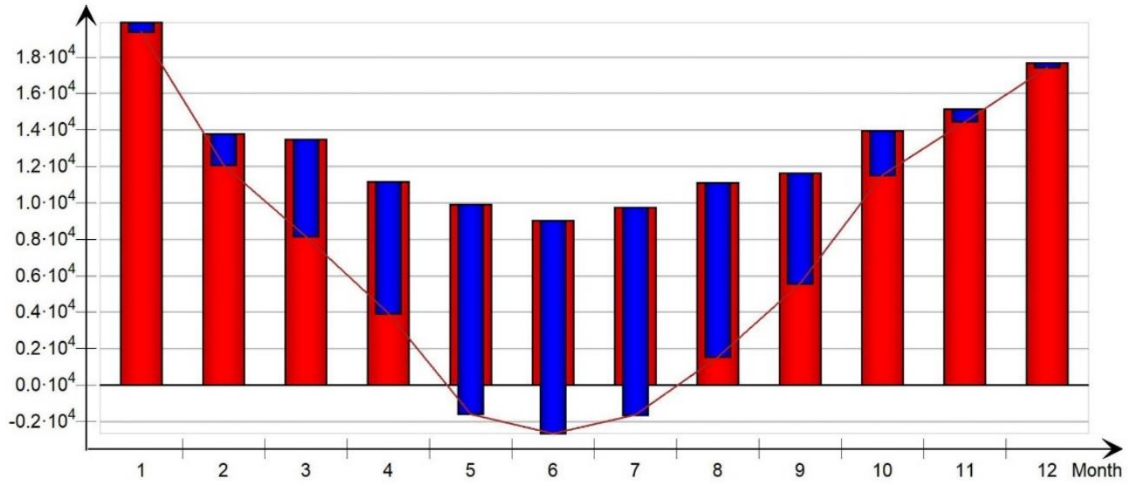
Used and Produced Energy Overview

		Total		**Peak demand**	
		kWh	**kWh/m^2**	**kW**	**Time**
🟨	Lighting, facility	18853.4	6.4	2.799	04 Sep 10:37
🟩	Equipment, facility	85781.9	29.2	12.74	04 Sep 10:35
🟦	HVAC aux	36058.7	12.3	5.601	08 Jul 17:26
🟧	Electric heating	52769.1	18.0	84.11	04 Jan 08:05
	Total Facility	193463.1	66.0		
🟫	PV production	-105293.0	-35.9	-109.3	24 Jun 10:48
🟩	CHP electricity	0.0	0.0	0.0	
	Total Produced	-105293.0	-35.9		
	Electricity, balance	88170.1	30.1		

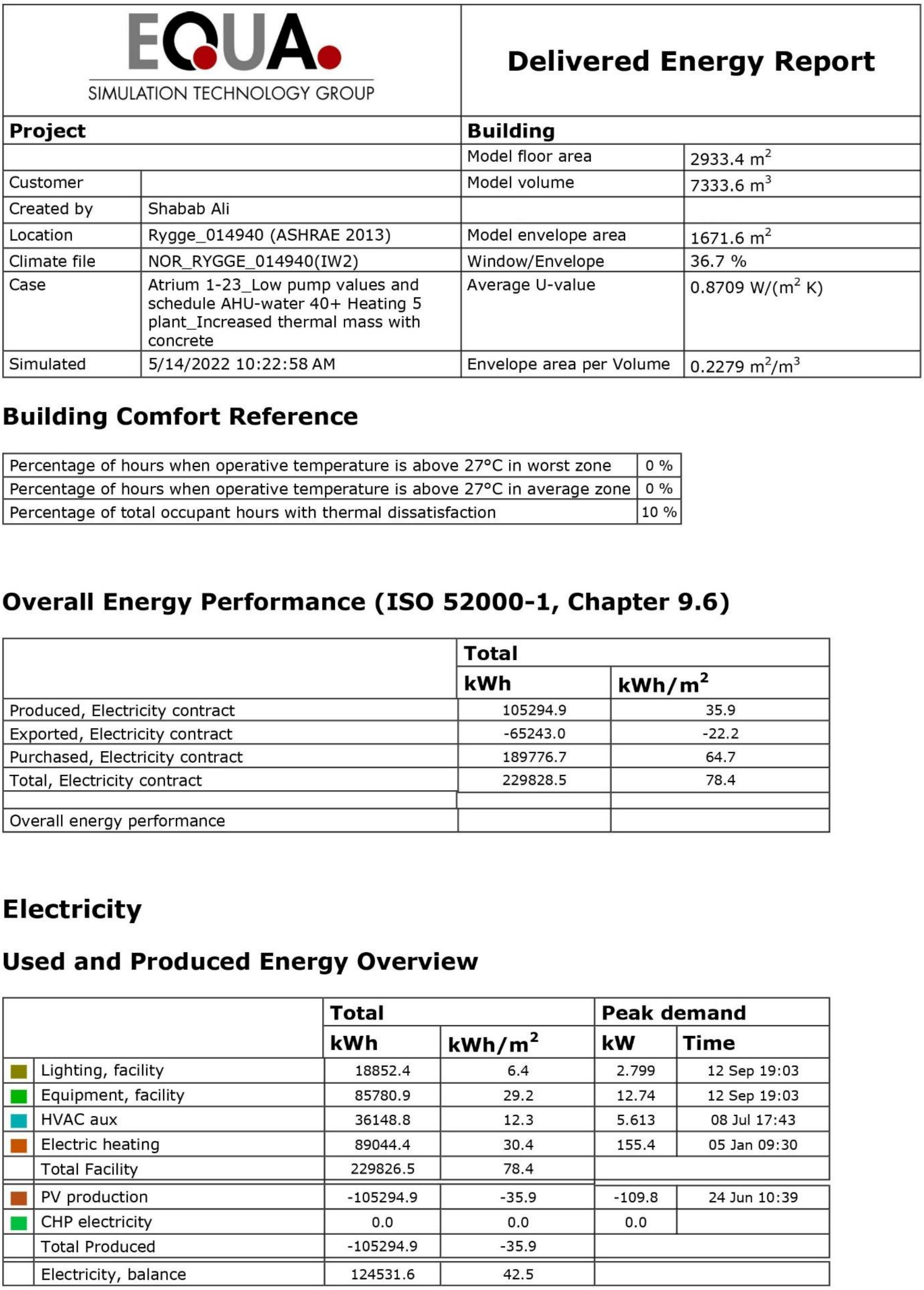


Purchased and Exported Energy Overview

		Total		Peak demand	
		kWh	kWh/m^2	kW	Time
🟥	Purchased, Electricity contract	156508.1	53.4		
🟦	Exported, Electricity contract	-68338.2	-23.3		
	Balance, Electricity contract	88169.9	30.1		
	Electricity, balance	88169.9	30.1		



Case 02



EQUA
SIMULATION TECHNOLOGY GROUP

Delivered Energy Report

Project		**Building**	
		Model floor area	2933.4 m^2
Customer		Model volume	7333.6 m^3
Created by	Shabab Ali		
Location	Rygge_014940 (ASHRAE 2013)	Model envelope area	1671.6 m^2
Climate file	NOR_RYGGE_014940(IW2)	Window/Envelope	36.7 %
Case	Atrium 1-23_Low pump values and schedule AHU-water 40+ Heating 5 plant_Increased thermal mass with concrete	Average U-value	0.8709 W/(m^2 K)
Simulated	5/14/2022 10:22:58 AM	Envelope area per Volume	0.2279 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	10 %

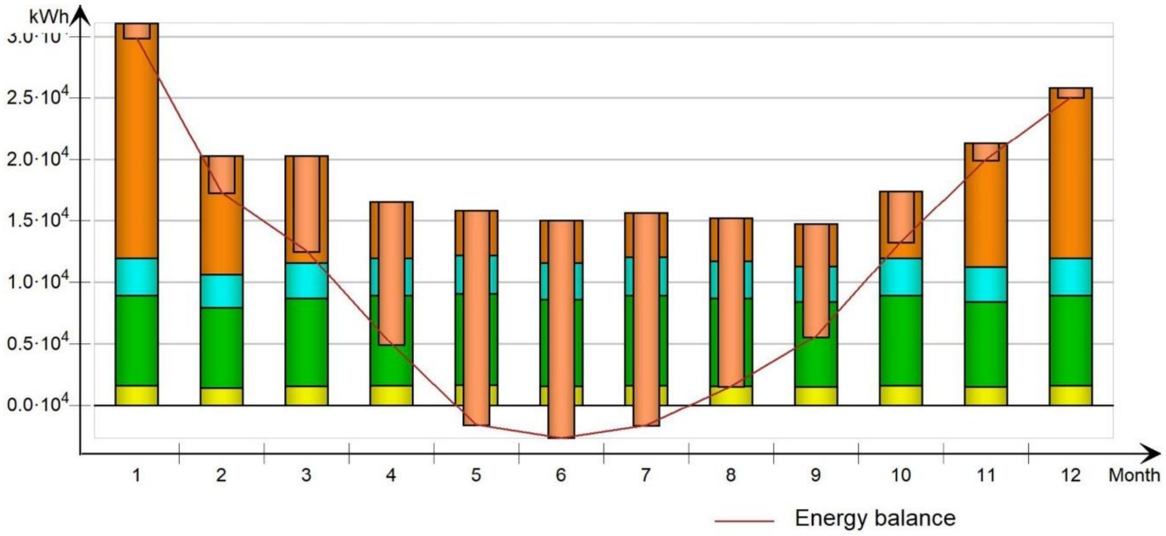
Overall Energy Performance (ISO 52000-1, Chapter 9.6)

	Total	
	kWh	**kWh/m^2**
Produced, Electricity contract	105294.9	35.9
Exported, Electricity contract	-65243.0	-22.2
Purchased, Electricity contract	189776.7	64.7
Total, Electricity contract	229828.5	78.4
Overall energy performance		

Electricity

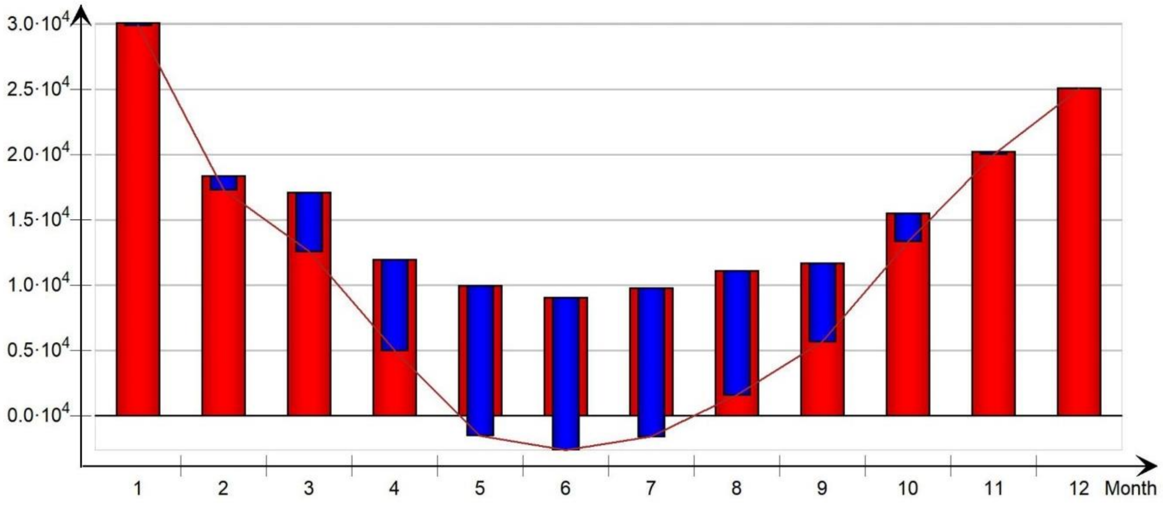
Used and Produced Energy Overview

		Total		**Peak demand**	
		kWh	**kWh/m^2**	**kW**	**Time**
🟨	Lighting, facility	18852.4	6.4	2.799	12 Sep 19:03
🟩	Equipment, facility	85780.9	29.2	12.74	12 Sep 19:03
🟦	HVAC aux	36148.8	12.3	5.613	08 Jul 17:43
🟧	Electric heating	89044.4	30.4	155.4	05 Jan 09:30
	Total Facility	229826.5	78.4		
🟫	PV production	-105294.9	-35.9	-109.8	24 Jun 10:39
🟩	CHP electricity	0.0	0.0	0.0	
	Total Produced	-105294.9	-35.9		
	Electricity, balance	124531.6	42.5		

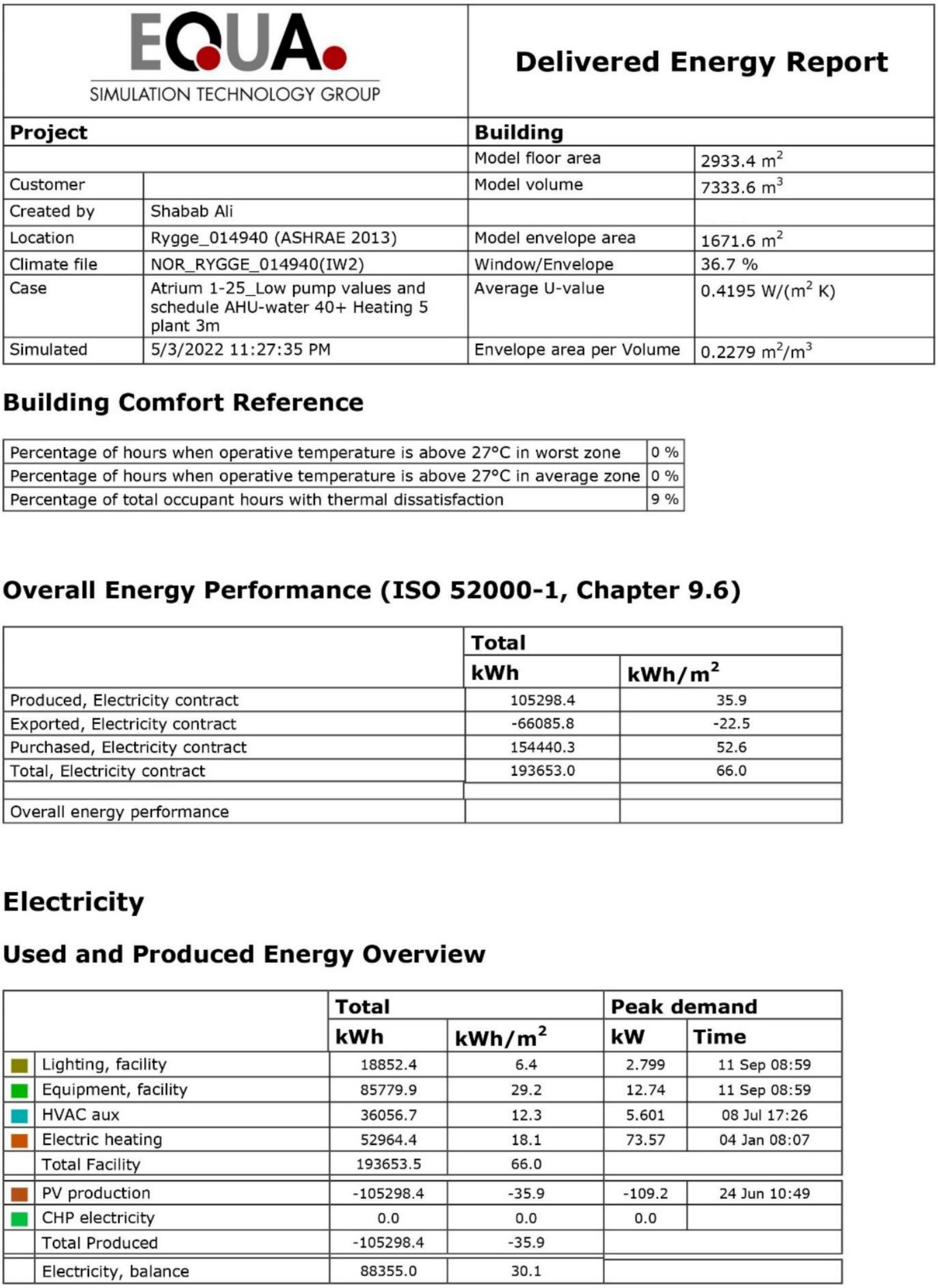


Purchased and Exported Energy Overview

		Total		Peak demand	
		kWh	kWh/m²	kW	Time
🟥	Purchased, Electricity contract	189776.7	64.7		
🟦	Exported, Electricity contract	-65243.0	-22.2		
	Balance, Electricity contract	124533.6	42.5		
	Electricity, balance	124533.6	42.5		



Case 03



EQUA
SIMULATION TECHNOLOGY GROUP

Delivered Energy Report

Project		**Building**	
		Model floor area	2933.4 m^2
Customer		Model volume	7333.6 m^3
Created by	Shabab Ali		
Location	Rygge_014940 (ASHRAE 2013)	Model envelope area	1671.6 m^2
Climate file	NOR_RYGGE_014940(IW2)	Window/Envelope	36.7 %
Case	Atrium 1-25_Low pump values and schedule AHU-water 40+ Heating 5 plant 3m	Average U-value	0.4195 W/(m^2 K)
Simulated	5/3/2022 11:27:35 PM	Envelope area per Volume	0.2279 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	9 %

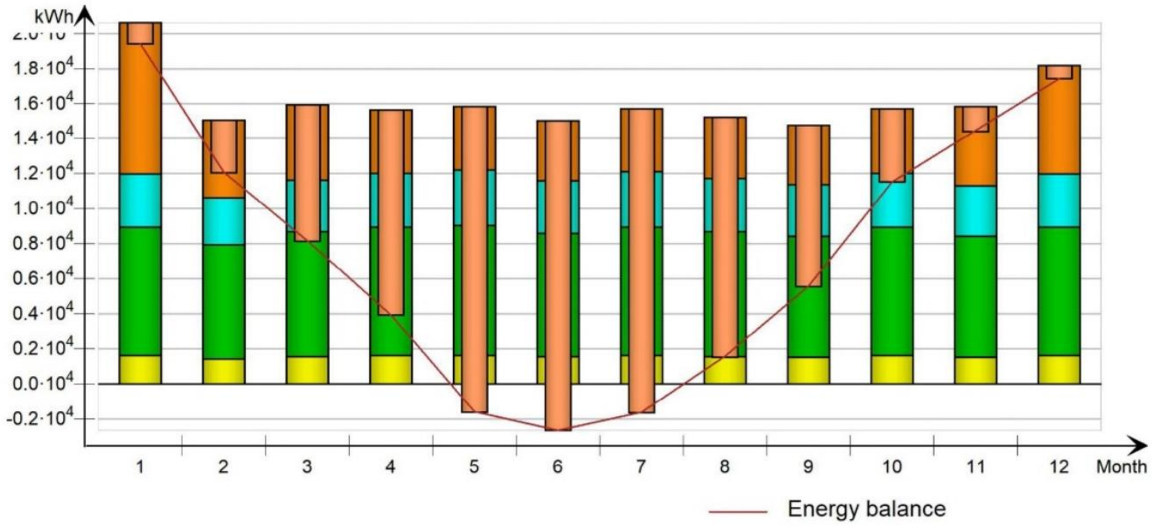
Overall Energy Performance (ISO 52000-1, Chapter 9.6)

	Total	
	kWh	**kWh/m^2**
Produced, Electricity contract	105298.4	35.9
Exported, Electricity contract	-66085.8	-22.5
Purchased, Electricity contract	154440.3	52.6
Total, Electricity contract	193653.0	66.0
Overall energy performance		

Electricity

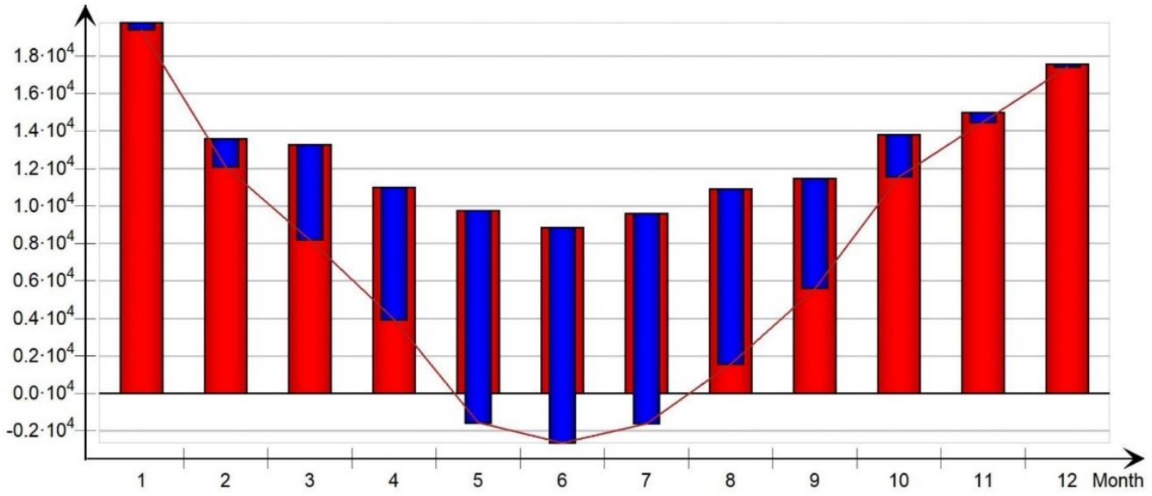
Used and Produced Energy Overview

		Total		**Peak demand**	
		kWh	**kWh/m^2**	**kW**	**Time**
🟨	Lighting, facility	18852.4	6.4	2.799	11 Sep 08:59
🟩	Equipment, facility	85779.9	29.2	12.74	11 Sep 08:59
🟦	HVAC aux	36056.7	12.3	5.601	08 Jul 17:26
🟧	Electric heating	52964.4	18.1	73.57	04 Jan 08:07
	Total Facility	193653.5	66.0		
🟫	PV production	-105298.4	-35.9	-109.2	24 Jun 10:49
🟩	CHP electricity	0.0	0.0	0.0	
	Total Produced	-105298.4	-35.9		
	Electricity, balance	88355.0	30.1		

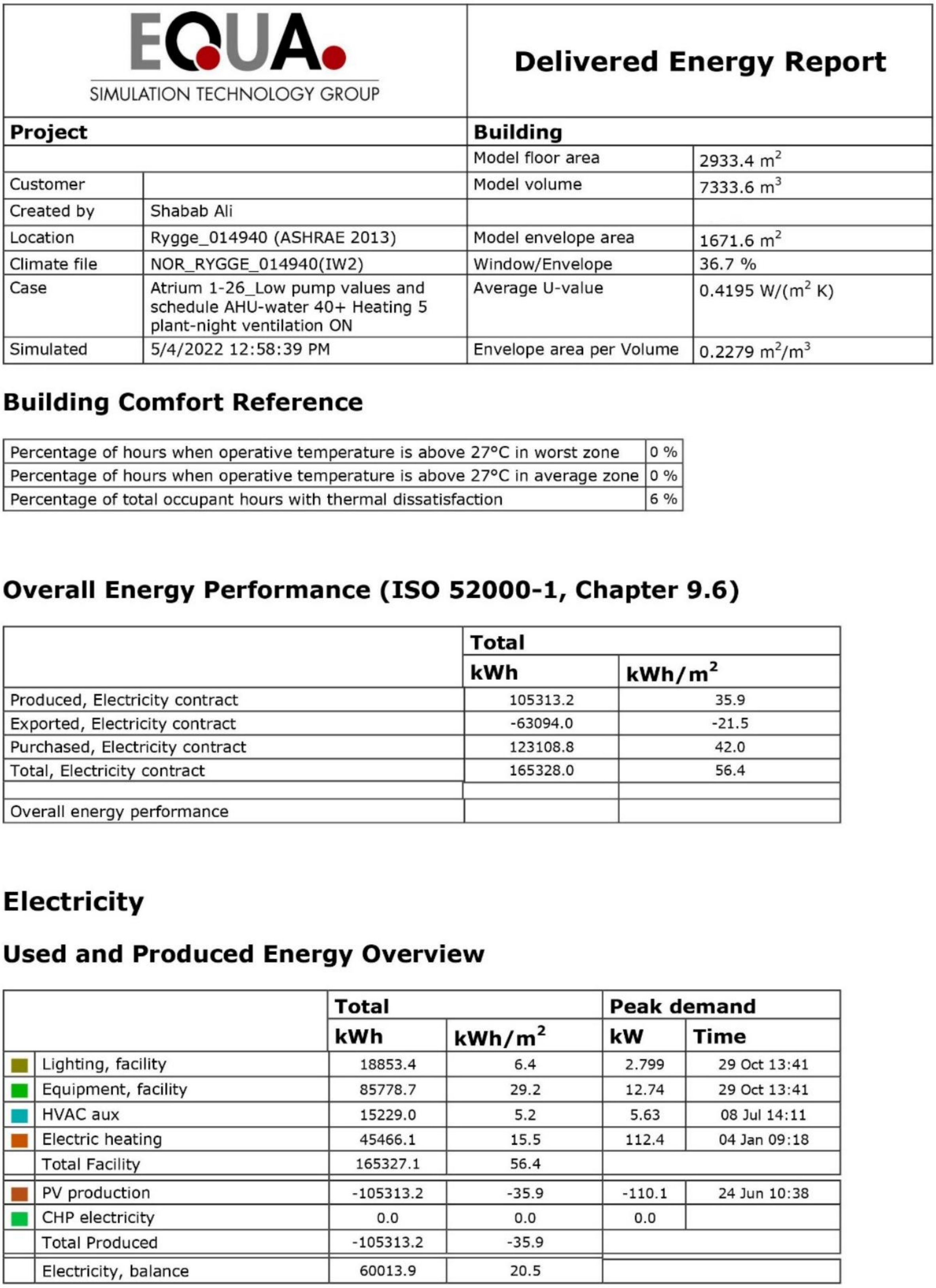


Purchased and Exported Energy Overview

		Total		Peak demand	
		kWh	kWh/m^2	kW	Time
🟥	Purchased, Electricity contract	154440.3	52.6		
🟦	Exported, Electricity contract	-66085.8	-22.5		
	Balance, Electricity contract	88354.5	30.1		
	Electricity, balance	88354.5	30.1		



Case 04



EQUA
SIMULATION TECHNOLOGY GROUP

Delivered Energy Report

Project		**Building**	
		Model floor area	2933.4 m^2
Customer		Model volume	7333.6 m^3
Created by	Shabab Ali		
Location	Rygge_014940 (ASHRAE 2013)	Model envelope area	1671.6 m^2
Climate file	NOR_RYGGE_014940(IW2)	Window/Envelope	36.7 %
Case	Atrium 1-26_Low pump values and schedule AHU-water 40+ Heating 5 plant-night ventilation ON	Average U-value	0.4195 W/(m^2 K)
Simulated	5/4/2022 12:58:39 PM	Envelope area per Volume	0.2279 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	6 %

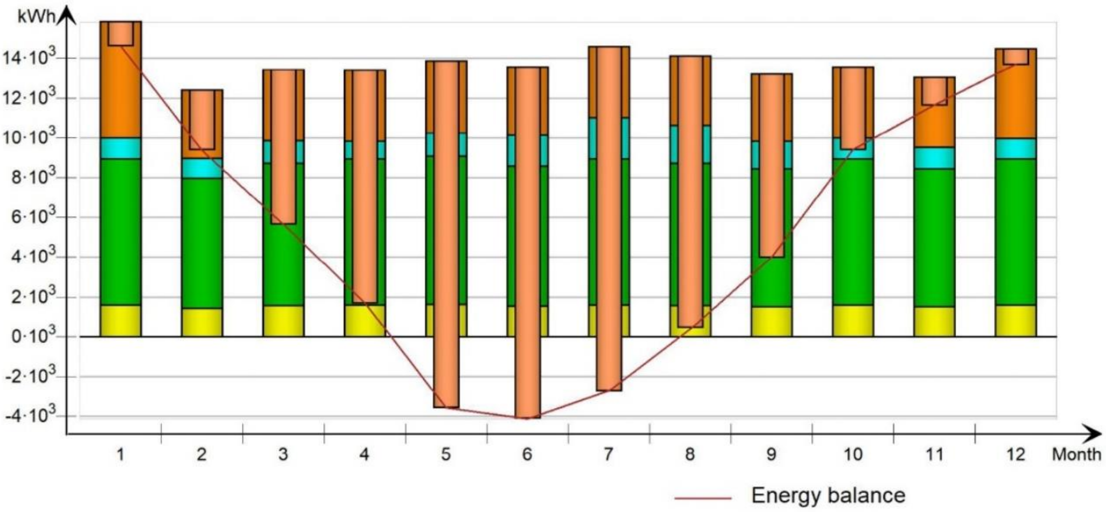
Overall Energy Performance (ISO 52000-1, Chapter 9.6)

	Total	
	kWh	**kWh/m^2**
Produced, Electricity contract	105313.2	35.9
Exported, Electricity contract	-63094.0	-21.5
Purchased, Electricity contract	123108.8	42.0
Total, Electricity contract	165328.0	56.4
Overall energy performance		

Electricity

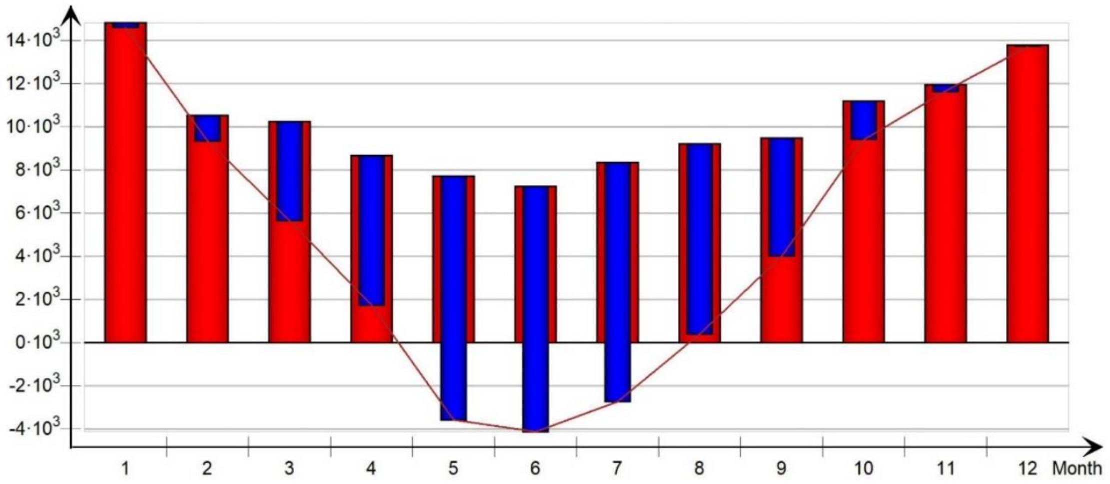
Used and Produced Energy Overview

		Total		**Peak demand**	
		kWh	**kWh/m^2**	**kW**	**Time**
🟫	Lighting, facility	18853.4	6.4	2.799	29 Oct 13:41
🟩	Equipment, facility	85778.7	29.2	12.74	29 Oct 13:41
🟦	HVAC aux	15229.0	5.2	5.63	08 Jul 14:11
🟧	Electric heating	45466.1	15.5	112.4	04 Jan 09:18
	Total Facility	165327.1	56.4		
🟧	PV production	-105313.2	-35.9	-110.1	24 Jun 10:38
🟩	CHP electricity	0.0	0.0	0.0	
	Total Produced	-105313.2	-35.9		
	Electricity, balance	60013.9	20.5		

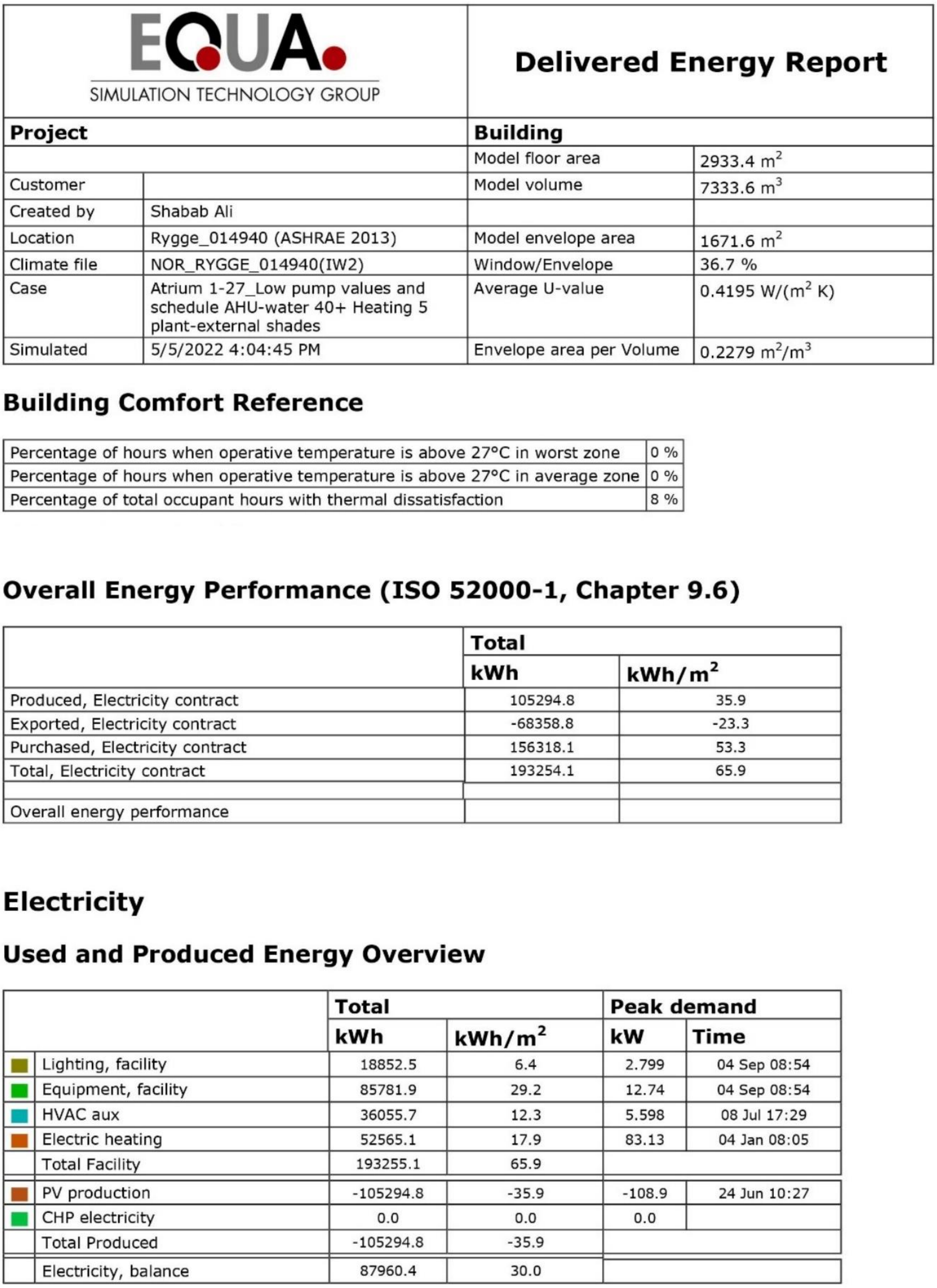


Purchased and Exported Energy Overview

		Total		Peak demand	
		kWh	kWh/m^2	kW	Time
🟥	Purchased, Electricity contract	123108.8	42.0		
🟦	Exported, Electricity contract	-63094.0	-21.5		
	Balance, Electricity contract	60014.8	20.5		
	Electricity, balance	60014.8	20.5		



Case 05



EQUA SIMULATION TECHNOLOGY GROUP

Delivered Energy Report

Project		**Building**	
		Model floor area	2933.4 m^2
Customer		Model volume	7333.6 m^3
Created by	Shabab Ali		
Location	Rygge_014940 (ASHRAE 2013)	Model envelope area	1671.6 m^2
Climate file	NOR_RYGGE_014940(IW2)	Window/Envelope	36.7 %
Case	Atrium 1-27_Low pump values and schedule AHU-water 40+ Heating 5 plant-external shades	Average U-value	0.4195 W/(m^2 K)
Simulated	5/5/2022 4:04:45 PM	Envelope area per Volume	0.2279 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	8 %

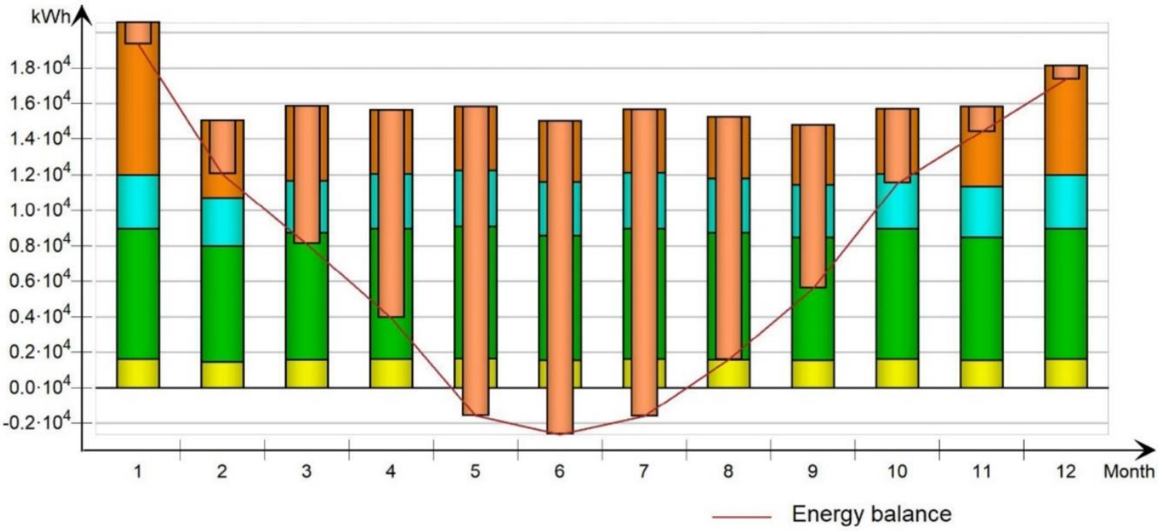
Overall Energy Performance (ISO 52000-1, Chapter 9.6)

	Total	
	kWh	**kWh/m^2**
Produced, Electricity contract	105294.8	35.9
Exported, Electricity contract	-68358.8	-23.3
Purchased, Electricity contract	156318.1	53.3
Total, Electricity contract	193254.1	65.9
Overall energy performance		

Electricity

Used and Produced Energy Overview

		Total		**Peak demand**	
		kWh	**kWh/m^2**	**kW**	**Time**
🟨	Lighting, facility	18852.5	6.4	2.799	04 Sep 08:54
🟩	Equipment, facility	85781.9	29.2	12.74	04 Sep 08:54
🟦	HVAC aux	36055.7	12.3	5.598	08 Jul 17:29
🟧	Electric heating	52565.1	17.9	83.13	04 Jan 08:05
	Total Facility	193255.1	65.9		
🟫	PV production	-105294.8	-35.9	-108.9	24 Jun 10:27
🟩	CHP electricity	0.0	0.0	0.0	
	Total Produced	-105294.8	-35.9		
	Electricity, balance	87960.4	30.0		



Purchased and Exported Energy Overview

		Total		**Peak demand**	
		kWh	**kWh/m^2**	**kW**	**Time**
🟥	Purchased, Electricity contract	156318.1	53.3		
🟦	Exported, Electricity contract	-68358.8	-23.3		
	Balance, Electricity contract	87959.3	30.0		
	Electricity, balance	87959.3	30.0