Martin Tallberg

BIM based iterative simulation - efficient building design

Case study

Master's thesis in Department of Civil and Environmental Engineering
Supervisor: Rolf André Bohne
January 2019

Master's thesis

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Preface

This master thesis is submitted to the Norwegian University of Science and Technology (NTNU) as part of the course TBA 4910 Project Management, Master's Thesis. This course counts for 30 points. The work has been performed at the Department of Civil and Environmental Engineering (IBM) in Trondheim, with the supervision of Professor Rolf André Bohne as the main supervisor.

Summary

The aim of this case study was to evaluate the energy performance of a conceptual apartment building by utilizing materials with different thermal properties. To explore the energy performance, the thesis included building a 3D model of a residential apartment building. The energy loads were calculated using IDA Indoor Climate and Energy 4.8. The energy performance was mapped when shifting the model design and utilizing different energy supply systems to the building.

The scope of the study included designing the apartment building to match the regulations in the Norwegian building codes and perform an annual energy analysis. It was shown that changing the building envelope had a significant effect on the annual energy consumption. The use of electric heating had the lowest energy consumption, compared to the district heating alternative. The study also considered on-site energy production from solar panels and found that the break-even point was not sufficient compared to the grid-connected energy supply.

The limitations of the study were the inherent limitations in the software and the assumptions made for the building model. Therefore, to limit the deviations from expected performance levels, the digital building was made simple to reach realistic performance levels.

Based on the case study and simulations in IDA ICE, several conclusions can be drawn. The design option with the lowest energy demand was found to be the optional building with electric floor heating and an air-to-air non-ducted heat pump. For further research, the thesis finds it expedient to perform an energy analysis on a higher precision level.

Sammendrag

Målet med denne casestudien var å evaluere energibehovet til en konseptuell boligbygning ved å benytte materialer med forskjellige termiske egenskaper. For å kartlegge energibehovet ble det designet en 3-D modell av bygget i modelleringsprogrammet Revit. Energilastene ble beregnet ved hjelp av IDA Indoor Climate and Energy 4.8. Målet var å kartlegge energibruken ved endring av design og ved å utnytte ulike energiforsyningssystemer til bygningen.

Studien omfattet utforming av et leilighetsbygg i henhold til norsk byggestandard og simuleringer av årlig energibruk. Energianalysene viste at tykkere vegger med mer isolasjon og redusert kuldebroeffekt hadde betydelig innvirkning på det årlige energiforbruket. Bruk av elektrisk oppvarming hadde lavest strømforbruk sammenlignet med fjernvarmealternativet. Studien vurderte også elektrisk strømproduksjon fra solcellepaneler. Det ble vist at tilbakebetalingstiden ikke var tilstrekkelig sammenlignet med investeringskostanden for solcelleanlegget.

Begrensningene i studien var bruken av IDA ICE og antagelsene gjort i dette programmet. For å begrense avvikene fra forventede resultater, ble bygget designet med forenklet geometri i vegger, gulv og tak.

Basert på casestudien og simuleringer i IDA ICE, kan flere konklusjoner trekkes. Alternativet med lavest energibehov viste seg å være alternativet med elektrisk gulvvarme og luft-til-luft-varmepumpe. For videre arbeid finner case-studien det hensiktsmessig å utføre energianalyse på et høyere presisjonsnivå.

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Chapter 1

Introduction

In 2015, the residential- and building sector counted for almost 40% of the energy consumption and 40% of the material used in Norway. The energy- and environmental challenges make it necessary to build with quality and aim for regular renewal of the existing building stock. Sustainable quality in private homes, buildings, and built environments reduces environmental impacts and improves quality of life for future generations. In the context of the European Union efforts to reduce the growing energy expenditure, it is widely recognized that the building sector has an important role [26, 58].

Higher energy performance buildings, like ZEB specified buildings, should be economically feasible. Designing minimum energy performance buildings is an arduous challenge. This requires exploring a huge number of design solutions and specifications of each building element. This current study introduces the necessary theory behind sustainable low energy building design and the definitions of ZEB [44].

Directive on the Energy Performance of Building (EPBD) imposes the adoption of measures to improve energy efficiency in buildings, in order to reach the objective of all new be nearly Zero Energy Building (nZEB) by 2020 [21, 26]. It is obvious that the design of a zero-energy building is not yet profitable in terms of costs. The cost of materials and energy consumption will differ from each country and regional areas, the age of the building and its occupancy use.

In present, the results of the BIM-based iterative energy performing simulations from the Autodesk Revit .rvt file in collaboration with the IFC-file from IDA ICE will be targeted, with the aim to establish a procedure for energy-economic optimization. Hence, the aim of the thesis is to evaluate the energy performance of a traditional apartment building. The building was designed using Autodesk Revit and IDA Indoor Climate and Energy 4.8 Edition.

1.1 Research questions

The thesis is divided into two main parts. The first part of the thesis discusses previous work done during the specialization project. This included studying the state of the art of renewable measures for building design, and collecting data about the topic of zero emission buildings. The second part of the study cover performing energy analysis on a conceptual building designed according to the Norwegian TEK-17 standard, compared to the specified thermal properties compiled from the Norwegian research center on zero emission buildings. Hence, the following research is based on previous literature on sustainable building design. The research topics is listed below.

RT1: Assess the energy use of a conceptual building designed according to the Norwegian TEK-17 standard, compared to the ZEB recommended thermal properties

RT2: What is the preferred source of energy for the conceptual apartment building?

1.2 Background

The energy- and environmental challenges make it necessary to build with quality and aim for regular renewal of the existing building stock. Sustainable quality in private homes, buildings and built environments reduces environmental impacts and improves quality of life for future generations. This is an under common fact in a world where traffic and exhaust get more attention [61].

As the population of Norway continues to grow, it is important to plan the urban communities with long term sustainability in mind. This doesn't necessarily include low energy buildings and emission buildings in particular it is just a part of the social transformation [6]. The new-building constructions in Norway count for 1% of the total building mass each year. The energy regulations for construction, set by the government, has continuously tightened the requirements from TEK-10 and TEK-17 to Passive House Standards (NS 3700 and NS3701). Now, there is a demand for nearly zero energy buildings (nZEB) that are scheduled for the end of 2018 for buildings owned by the public, and by the end of 2020 for new buildings [7].

When considering new construction projects, the project owner and investors aim for the highest profit on their investments [66]. Hence, if the concept of Zero Emission Buildings will be able to compete against the standard building, the need for a cost analysis of the total buildings envelop and inventory is crucial [7].

Total power consumption in mainland Norway is expected to increase from 133 TWh in 2016 to 157 TWh in 2035. It is expected increased power consumption in the petroleum industry, data centres and transport, and decline in households and in service industries. In comparison, by 2016, the total building sector in Norway demand 65 TWh an. of the total energy consumption. This means, approximately 48% of the energy consumption are utilized for heating and cooling of buildings to gain a sufficient, inside temperature level. The concept of zero emission buildings aims to reduce this need of energy in residential, commercial and public buildings [62].

1.3 Motivation and goals

This thesis focuses on reviewing the current established nZEB standards and definitions and investigate the primary energy consumption for design apartment buildings located in Oslo, Norway. This is done by designing a fictitious building using BIM and track the energy consumption (kWh/m^2 an.). By improving the air tightness and increasing the insulation in the floor slab, roofs and external walls, the energy performance will be targeted and compared.

A base model of an apartment building consisting of eight 4-levels separate apartments was developed to represent potential future apartment buildings in Norway. The building features were developed based on the Norwegian building standards (TEK-17) and in accordance with the recommendations from ZEN.

The model was designed using Autodesk Revit modelling software. The model was there on exported as a .ifc-file to IDA ICE, to perform whole building energy analysis. The building materials and geometrical characteristics used to evaluate the nZEB potential are described in Chapter 4 Case building.

1.4 Improving the current reference scenario

To achieve low energy targets for the reference scenario, it was imperative to design multiple design options of the building, to comply and evaluate the differences. To reduce energy consumption, design improvements were applied to the model. The suggested solutions implied improving the building fabric by replacing the walls with thicker insulation and better performing windows. The size of the windows and the building orientation was not considered as variables in the building design. The type of windows and technical data is available in Table 2.2.

1.5 Overall limitations of the study

Because the thesis only considers a fictitious apartment building, the results may not be adaptable for the building stock in Norway, as a whole. Hence, the results may not be modified for new use or purpose when considering energy and material costs of other reference buildings.

When considering if zero emission buildings can displace traditional building practice, it is crucial to identify the upfront cost to reach the ZEB specifications. This also includes identifying the life cycle of the different components of the building, both the envelope and the technical specifications for the building, i.e. solar systems (photo voltaic and building integrated photo voltaic), well systems for district geothermal energy supply, hot water tanks and radiator systems. This is an extensive process, which demands high precision and accuracy.

During the buildings life, the real lifespan of these systems will detect the necessary maintenance and replacement costs of the systems. Additionally, due to the market trends in the renewable energy sector, the adjusted prices for energy systems may also differ from the predicted prices used for further work in the master thesis.

Chapter 2

Theory

This chapter includes the underlying motivation behind low energy performing buildings, such as global warming potential and energy consumption of buildings. Further, the building sector in Norway and the state of the art is compiled. The thermo-physical properties of the building envelope, and the supply and demand is also listed in this chapter. In addition, the economic parameters and installation costs of energy supply systems are described. A number of different energy supply systems are listed and presented in detail, even though the district heating system, air-to-air heat pump and photo voltaic were the prefered supply systems for the simulations.

2.1 Global warming potential

Global warming is one of the biggest challenges people face today. Greenhouse gas emissions are the highest in history. It is scientifically proven that human activity is the main contributor to this increase in greenhouse gases, by around 95% probability. Furthermore, it is documented that 40% of all CO_2 emissions come from human activity has come from the last 40 years [26].

The increased temperature levels and rapidly changes in environmental behaviour concerns the national economy [64]. Besides other contributors, extraction of natural resources as building materials itself consume energy, cause environmental degradation and contribute to global warming [47]. Buildings are the largest energy consumers and greenhouse gases emitters [47]. Therefore, rapid changes are required relating to energy saving, emissions control and production of building materials. Immediate suggestion related to use of renewable resources, and to recycling and reuse of building materials is necessary [47].

It is an undergoing fact that the greenhouse gas (GHG) emission from the building sector and built environment needs to be cut drastically by 2050, to meet the Paris Climate Agreement targets. The need to limit GHG emissions have far-reaching implications for business and governments [6].

From 1950 until today, changes in climate and extreme weather have been observed. It has become recorded several colds and hot temperature limits, higher sea level, increased sea temperature and several periods of heavy rain. Extreme weather-related events, such as heat waves, droughts, floods, cyclones, hurricanes, and forest fires have increased in size and frequency. This has a great impact on exposed ecosystems and many man-made systems and constructions [21].

The United Nations (UN) reported in 2007 that the world's cities account for about 75% of total energy consumption and 80% of all greenhouse gas emissions in the world. Figure 2.1 shows baseline scenarios for greenhouse gas emissions distributed over different sectors for 2030, 2050 and 2100 [58]. Other sources say that the building sectors are responsible for over 30% of the total greenhouse gas emissions and around 40% of the total energy consumption in the world [52].

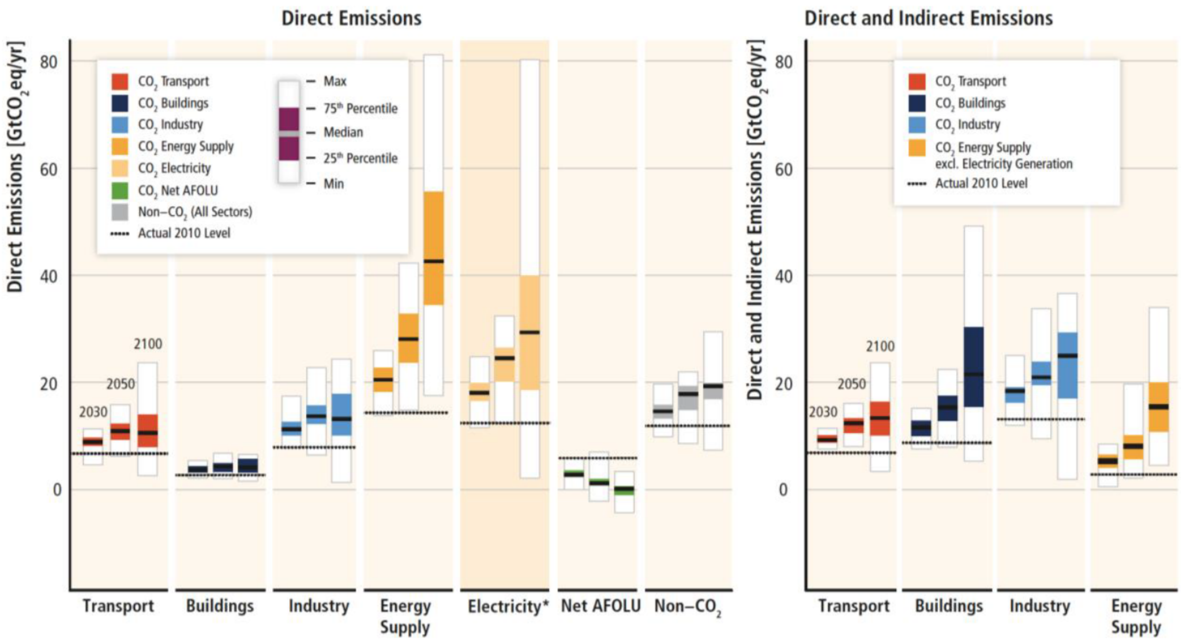


Figure 2.1: Direct- and indirect Gt CO_2-eq emissions (2030, 2050, 2100)

2.2 Global energy consumption

IPCC presented a Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [26]. The report states that the GHG emissions have to be reduced with 40-50% before 2030, to limit global warming to 1.5°C.

The steady state increase in energy consumption needs to be seen in the light of the increased population over time. The increase of energy use in buildings, public offices and occupational areas, is driven by the combination of a growing population and the increasing prosperity. The statistics in Figure 2.2 illustrates the projected global energy consumption (Mtoe) from 1990 to 2040. In 2040, it is estimated that the consumption of energy from renewable energy sources will reach 2.5 billion toe, approximately 14% of the total energy consumption.

The trend of liquid energy consumption will continue with the same steady rate until 2040. This includes oil, gas, bio fuel and other natural resources. The rapidly increased rate of utilizing renewable energy is gained by the use of wind and solar energy systems. Figure 2.2 shows that the use of renewable energy in 1990 was absent, while the trends of today indicate a rapid increase in demand for this energy supply. The predictions indicate a steady increase from today to 2040.

The future trends after 2040 are not included, but the graphical trends may favour the utilization of renewable energy supply, at the expense of oil and gas [16]. Even though, the graphical trends from 2020 and inwards are projections. According to Enova, the projections were made based on a base-case scenario reflecting the likely path from today's vantage point [16].

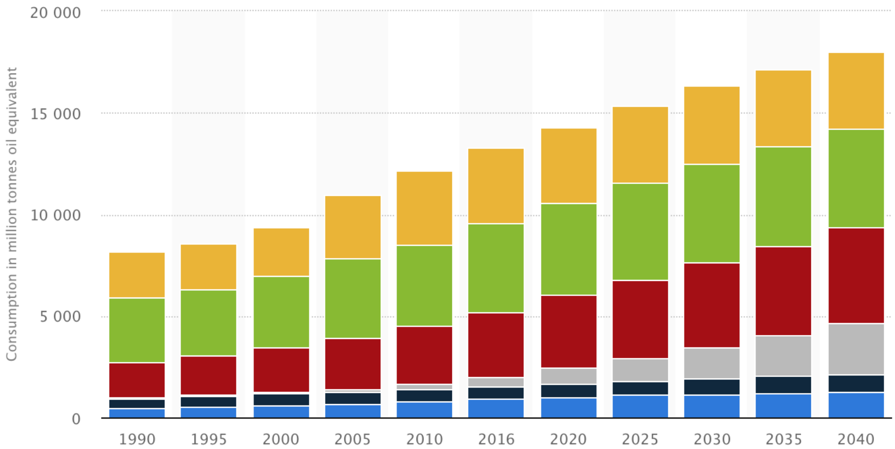


Figure 2.2: Global energy consumption 1990-2040 [52]

2.3 Building sector in Norway

In 2016, the Norwegian government presented a strategy report on Energy Policy until 2030 [37]. The report contains development features, perspectives, and statuses for the domestic energy supply in Norway. One of the priorities, along with wage development of renewable energy and more efficient use of energy, is the business development and value creation through efficient utilization of profitable renewable resources.

In this context, the goal for Norway is to be a pioneer in environmentally friendly energy use and production of renewable energy. This aims to be achieved by reducing energy intensity and energy consumption by 30% by 2030. The government is also working on designing a proposal forbidding the use of fossil fuels for heating in household buildings after 2020 [37].

Buildings are responsible for 40% of energy consumption and 36% of the EUs CO_2 emission. Energy performance of buildings is a key element to achieve the EU climate and energy objectives, namely a 20% reduction of the GHG emissions and 20% primary energy savings by 2020 [6].

Figure 2.3 obtained from Enova, illustrates the energy supply for the total building stock in Norway in 2015. This includes all types of buildings; from kindergarten, hotels, school buildings, residential buildings and so on. The 2015-trends shows that the mean energy consumption for commercial buildings in Norway was 236 kWh/m^2. The school buildings counted for approximately 158 kWh/m^2, and the residential apartment buildings 121 kWh/m^2 [16].

The graph further links the different energy supply carriers. It shows that electricity is the dominant energy supplier independent of the building type. Overall, about 84% of energy consumption is from electricity, 12% from district heating. Furthermore, gas accounted for 1.3%, liquid fuel 1.2%, district cooling 0.8% and biofuels 0.7% [16].

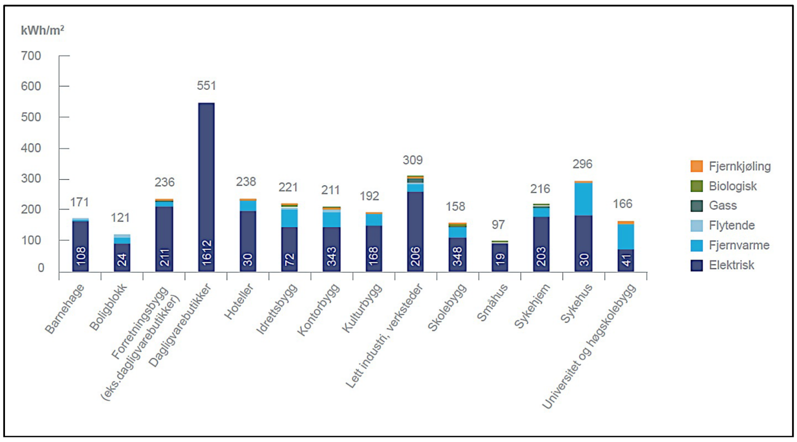


Figure 2.3: Energy supply carriers in Norway [16]

2.4 State of the art

A large proportion of the buildings in 2050 already exist. European Commission indicates that about 35% of the buildings in the EU are 50 years or older. Furthermore, they claim that Europe can reduce total energy consumption by 5-6% and CO_2 emissions by around 5% by building more energy-efficient buildings and renovate existing buildings.

Renovation, renovation, remodelling, culture, lifestyle and behavioural changes are important strategies to reduce greenhouse gas emissions. Lifestyle, culture and other behavioural changes alone can lead to a reduction higher than that available through technology and architecture. In industrialized countries, scenarios indicate that lifestyle and behaviour may decrease energy consumption in buildings by up to 20% short-term and up to 50% by 2050. Furthermore, there is a high probability that developing countries follow the same direction [58]

By using best practices and utilize new technology, it theoretically possible to reduce the energy consumption for heating and cooling existing buildings by 50-75%, and for new buildings by 50-90% [58].

2.5 Low energy building and zero emission buildings

Low energy buildings are characterized by energy-efficient design and technical features which enable to provide high comfort standard with low energy consumption [44]. Low energy buildings may be viewed as examples of sustainable architecture, with both active and passive solar design (i.e. photo voltaic and window orientation), which reduce the energy consumption [44].

The concept of ZEB is to eliminate the net emissions during the lifetime to reach negative emissions [40]. This is illustrated in the figure below. It forces both existing and new buildings to produce enough energy on-site, to compensate for carbon emissions due to the production of materials, construction, transportation, use and operation, disposal and recovery of materials (cradle-to-grave) [40]. The ZEB principle is viewed as a means to reduce carbon emissions and dependence on fossil fuels. Energy is usually harvested on-site through energy producing supply systems like building integrated photo voltaic and panels. Other energy supply systems are district heating systems stored underground.

Figure 2.4 compares the CO_2-eq emission factors for a residential building and a zero emission building. During the construction and production of materials, the emissions are higher because of the utilization of new technology and materials. This is illustrated by the vertical red slopes. The green decline lines show that production of energy on-site can outperform or eliminate the net emissions due to increased construction requirements. The CO_2-eq emissions from a traditional TEK-10 building will not be able to intersect with the x-axis. The emission rates will continue to grow until the demolition.

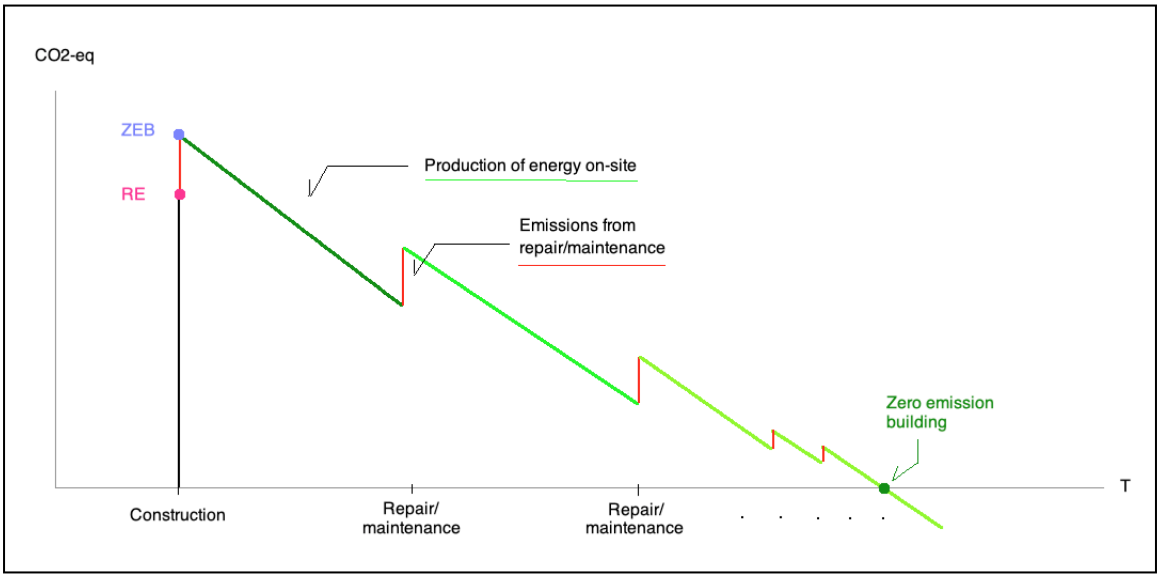


Figure 2.4: CO_2-eq emission

2.5.1 ZEB definitions

Among the different definitions of ZEB, Table 2.1 illustrates the stated ZEB-definitions used in Norway. The definition is based on increased ambition levels. ZEB-COMPLETE is an outstanding ZEB solution.

Table 2.1: ZEB definitions

Definitions	**The building renewable energy production compensate for GHG-emission from**
ZEB-O-EQ	operation of the building, excluding the energy for use of equipment
ZEB-O	operation the building
ZEB-OM	operation the building and production of building materials
ZEB-COM	construction and operation of the building, and production of building materials
ZEB-COMPLETE	cradle to grave

2.5.2 Building body

The innovations of energy efficient materials have been significantly improved by the academic research network, both in Norway and globally, by collecting precise energy performance data on traditional and experimental buildings. According to SINTEF, scientists are working actively to develop building materials which are sustainable, energy effective, multi-functional and intelligent [40].

Table 2.2 illustrates the specified U-values stated in the Norwegian building standard TEK17 and the possible U-values for a ZEB building [59]. Because the policy of making national building codes for ZEB specified buildings is not adopted by 2018, the table illustrates possible ranges of U-values for a ZEB specified building.

Table 2.2: U-values

U-values	**Walls**	**Roof**	**Floor**
TEK17	0.18 W/m^2K	0.13 W/m^2K	0.10 W/m^2K
ZEB	0.10-0.12 W/m^2K	0.07-0.10 W/m^2K	0.06-0.09 W/m^2K

The consecration-first approach to high-performance building starts with advanced building envelope [33]. Guided by physics and building science, advanced building envelopes combine a simple suite of components to manage heat, air, and moisture and deliver superior efficiency, durability, comfort, and occupant health [33].

By controlling the movement of air across building assemblies, the vapour barriers need to control the movements of air and moisture. The barrier should be wrapped continuously, unbroken to prevent heat flowing into the insulation materials.

High-performance buildings employ a ventilated rain screen, a gap between the cladding and wall assembly that not only provides a channel for bulk water to drain away, but also generates air movement across the face of the assembly to dramatically increase drying. A highly thermally resistant wall will have less drying capacity than a conventional wall, so the air movement provided by the ventilated rain screen helps ensure the resilience and durability of high-performance wall assemblies.

To thermally insulate the envelope and to keep sheathing warm and free of condensation, insulation materials have to be placed in all areas of the building envelope exposed for temperature exchanges. Instead of using traditional mineral wool, new insulation materials can provide lower heat loss through the building envelope (Nano insulation, aerogel and vacuum insulated panels). To prevent thermal bridges, it is important to make the thermal layer continuous, with no weak spots allowing thermal energy to escape the inside wall.

Adding a water-resistive barrier between the cladding and wind barrier will minimize the bulk and rainwater to move through the wind barrier and into the insulation. The barrier stops water in its liquid form but allows water in its vapour form to move through, increasing the drying capacity of the assembly.

Table 2.3: Zone energy description

Category	**Description**
Envelope and thermal bridges	Heat gained through external walls, floors, roofs and through thermal bridges.
Internal walls and masses	Heat gained through internal walls, floors, ceilings and internal masses
External walls and solar	Net heat gain through external windows, i.e. through long and short wave radiation as well as via transmission trough pane and frame. Advocated heat through open windows is included in Infiltration and openings
Mechanical supply air	Heat supplied by mechanical ventilation
Infiltration and openings	Heat supplied via air from leaks and openings. For systems with only mechanical exhaust ventilation, all supply air will be accounted for here
Occupants	Heat from people in the zone, excluding heat from perspiration
Equipment	Heat from equipment in the zone, e.g. computers, dishwasher etc.
Lightning	Heat from artificial lighting
Local heating units	Heat from controlled heating units, e.g. radiators, fan coils etc
Local cooling units	Heat from controlled cooling units, e.g. chilled beams, fan coils etc
Net losses	Heat from pipes, ducts etc., the leakage from which has been defined in Extra energy and losses

Source: IDA ICE handbook [18]

Table 2.3 lists the heat balance load categories when tracking the energy performance for the building in this study. This tables is based on the description from IDA ICE Handbook [18], and describes the graphical and tabular results in Chapter 5 Results.

Instead of traditional window technology, new window technology systems, such as electrochromic windows and low-E triple-glazed windows has also paved the way for ZEB to reach the full potential [40]. Electrochromic windows can be used to control solar radiation as the need for daylight and solar heating. The radiation is regulated by applying an electrical voltage. Other materials are so-called phase change materials (PCM), that can absorb or emit heat as needed. Many of these materials and technologies can be combined in different systems, so-called multi-functional and intelligent materials and solutions [11].

Depending on the location of the windows, high-performance windows can be energy positive [33]. In the summer, the solar radiation coming in through the surface in the form of passive solar gain and daylighting can offsets any thermal loss that escapes through them. In the cold seasons, the solar gains can reduce the needs for mechanical heating, but need to be managed during the warmer months to avoid overheating.

2.5.3 Supply and demand

The Net ZEB balance can be represented graphically as in Figure 2.5, plotting the weighted demand on the x-axis and the weighted supply on the energy y-axis. The x- and y-axis can also represent the consumption and production of energy [49]. The red point illustrates the balance between the production of energy and the consumption of energy on-site, or the weighted demand against the weighted supply.

Starting from such a reference case, the pathway to a Net ZEB is given by the balance of two actions: 1: Reduce energy demand (x-axis) by means of energy efficiency measures. 2: Generate electricity as well as thermal energy carriers by means of energy supply 1s to get enough credits (y-axis) to achieve the balance. For a zero emission building, the weighted energy supply-demand is zero because the building produces on-site electricity.

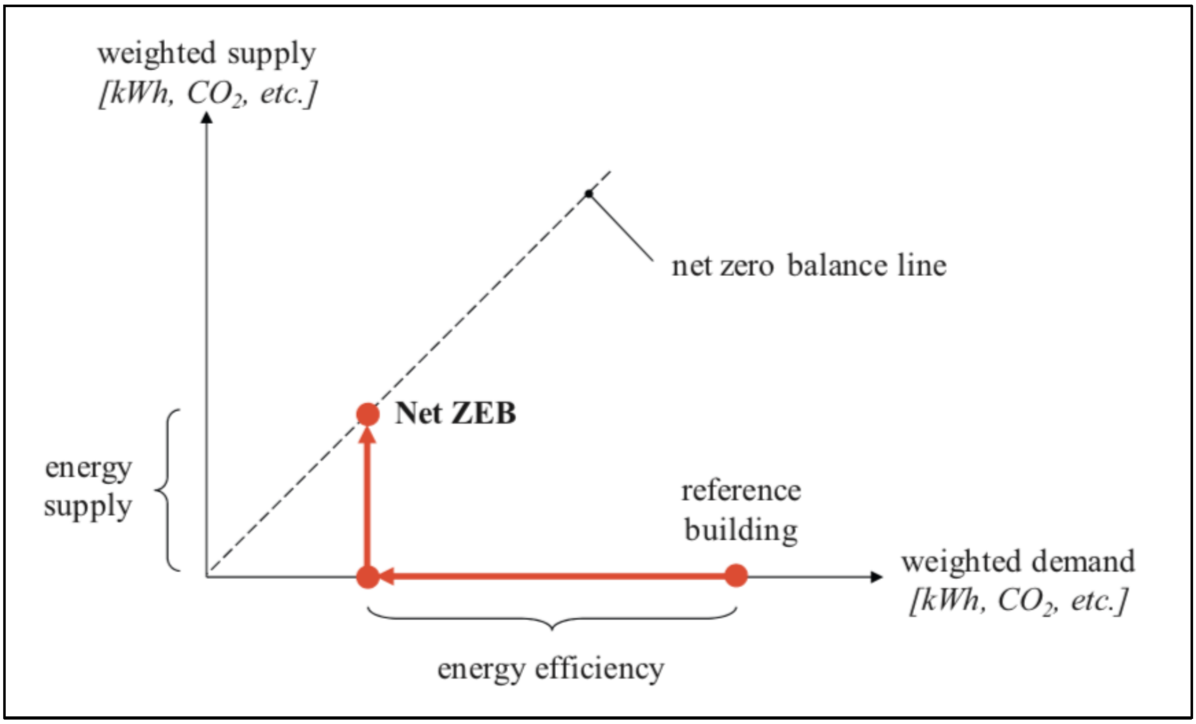


Figure 2.5: Net ZEB balance concept [49]

Net ZEB balance is a condition that is satisfied when weighted supply meets or exceeds weighted demand over a period of time, T. The Net ZEB balance conducted from Sartori et. al. [49] can be calculated as in Equation 2.1.

$$nZEB_{balance} : weighted_{supply} - weighted_{demand} = 0 \tag{2.1}$$

For a strictly ZEB, the ZEB balance equals zero. The building produces/supply the same amount of energy as it consumes/demand over the period, T (i.e. the red point is on the red net zero balance line). For a nearly ZEB, the net ZEB balance < 0. The building produces/supply less energy on-site than it consumes/demand over the time period, T (i.e. the red point is between the x-axis and the red net zero balance line). This is not in accordance with the specifications of ZEB. For a plus energy building, the net ZEB balance > 0. The building produces/supply more energy on-site than it consumes/demand overtime period, T (i.e. the red point is between the y-axis and the red net zero balance line).

2.6 Economic parameters

This section will cover the necessary economic data for the cost analysis. Prices for each energy carrier used in the analysis is needed; both district heating and electricity. Additionally, electric price escalation will be presented.

In a ZEB perspective, the initial investment cost is higher, due to stricter material and energy supply specifications. This includes investments related to the efficiency of the building outlook and envelope to reduce the transmittance of different building elements, low-E windows, and doors, wall insulation etc.

The annual cost target the costs for energy carriers that cover the demand for space heating and cooling, ventilation, domestic hot water, and lightning. They also include operational costs, maintenance costs and costs for periodic replacement. Income from produced energy (e.g. via photo voltaic systems or combined heat and power) can be subtracted from the costs for energy

2.6.1 Installation costs

The case study is considering three different energy supply systems for heating use. From [43] the initial additional installation cost of the district heating system is listed below (Table 2.4). The prices for the photo voltaic and heat pump system is compiled from [8, 13]. The prices for both supply systems consist of installation costs, material costs and labour costs. A value-added tax (VAT) of 25 % were included in the prices. For the underfloor piping system for both waterborne floor heating and electrical heating, the prices assume neglectable, due to the similar additional costs and the small scale price compared to the DH-system and photo voltaic installation system.

Table 2.4: Installation costs

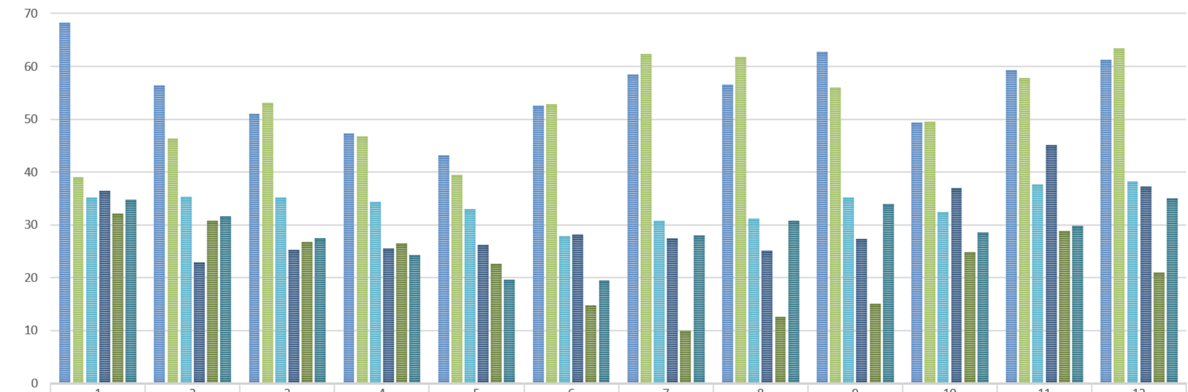
DH system	**Description**	**Cost**
Piping system	30 m	NOK 160 000
Radiator circuits	Heating and domestic hot water	NOK 300 000
Central	From district heating system to plant	NOK 250 000
Total	Installation and labour incl. VAT	NOK 710 000
Total DH cost	Cost each apartment	**NOK 88 750**
PV system		
Panels	30 units	
Grid inverter	SMA Sunny Tripower 10000-TL-20	
Double isolated solar cable	for use between module series and inverter	
MCH cable	Connection between modules and plant	
Incline fuses		
Sunrail	Mountering package	
Installation	Installation costs and labour incl. VAT	NOK 115 290
Enova contribution		NOK -16 860
Total PV cost	Total cost for 30 m^2 panels	**NOK 98 427**
Heat pump		
	Air-to-air non-ducted 6kW, COP=3.2	
	Heat pump cost	NOK 18 700
	Mounting cost	NOK 5 700
	Total installation cost	**NOK 24 400**

2.6.2 Electricity price

Norway has a connected power system. The power section consists of a large number of companies in charge of supply, distribution and power exchange. The electricity is traded between different markets and organized by the Nordic power exchange, Nord Pool Spot. One of the owners, Statnett SF, is the national transmission company of Norway owned by the Norwegian government. Temperature and weather conditions have a strong influential effect on electricity demand and hence the electricity price. The market price varies over time, changing every hour.

Further, the study will consider the electricity production on-site in the nZEB scenario building. The building user will be regarded as a plus consumer. To facilitate the exchange of energy between users and the grid, the Water Resources and Energy Directorate (NVE) published the stated dispensation for plus consumers [38]. This report states that the plus consumers get access to feed their surplus power agile into the grid.

When you produce your own electricity you get the opportunity to sell the profit back to the electricity grid. According to the Norwegian Water Resources and Energy Directorate (NVE), plus customers are end users who have excess power that can be fed into the electricity grid, where the input power does not exceed 100 kW [10] Plus customers are usually private individuals who install solar panels on the roof, but also apply to all other products such as wind, water, biogas and other things. The price you get for the sold electricity depends on which power supplier you enter into an agreement with, but many operate with the spot price, that is the same as the power supplier buys the power for on the Nord Pool Spot power exchange.
The initial electricity price is determined as the spot price in addition to the grid tariff and the government consumption tax of .1583 NOK/kWh. In addition, 0.01 NOK/kWh statutory contribution to the Enova energy fund is also included in the electricity price charged by the consumer. Additional charges should be added, including the Value Added Tax (VAT): 25 % [2, 46]. The data in Figure 2.6 is obtained from [30]. The graph shows that the electricity price in January had a rapid increase, compared to 2018. However, due to the unpredicted electricity trends in March, the future electricity prices was calculated using numerical tools. The electricity price for 2014-2019 is shown in Figure 2.6, with the prices from March to December 2019 consist of predicted electricity prices. The price is listed as the spot price incl. VAT (25%), obtained from [3]. It is determined in 0.01 NOK/kWh.



	1	2	3	4	5	6	7	8	9	10	11	12
2019	68.24	56.44	51.07	47.32	43.16	52.58	58.53	56.59	62.73	49.32	59.26	61.25
2018	39.12	46.3	53.15	46.75	39.46	52.86	62.34	61.85	55.94	49.51	57.77	63.5
2017	35.23	35.27	35.13	34.34	32.95	27.9	30.8	31.22	35.18	32.43	37.62	38.25
2016	36.42	22.92	25.24	25.54	26.28	28.11	27.42	25.15	27.3	36.97	45.11	37.23
2015	32.16	30.77	26.78	26.49	22.67	14.84	9.99	12.66	15.05	24.86	28.81	21
2014	34.82	31.56	27.42	24.27	19.69	19.48	28.08	30.74	33.93	28.53	29.77	35.06

Figure 2.6: Electricity prices incl. VAT

Year 2019	Spot price excl. VAT (25%) imported (0,01NOK/kWh)	Grid tariff (NOK) (0.01NOK/kWh)	Gouvernment fees (NOK) excl. VAT (0.01NOK/kWh)	Total electricity price (0.01NOK/kWh)
January	54.59	33.78	15.83	130.25
Febryary	45.15	33.78	15.83	118.45
March	40.86	33.78	15.83	113.08
April	37.86	33.78	15.83	109.33
May	34.53	33.78	15.83	105.17
June	42.06	33.78	15.83	114.59
July	46.82	33.78	15.83	120.54
August	45.27	33.78	15.83	118.60
September	50.18	33.78	15.83	124.74
October	39.46	33.78	15.83	111.33
November	47.41	33.78	15.83	121.27
December	49.00	33.78	15.83	123.26

Table 2.5: Total electricity prices incl. VAT

Table 2.5 shows the total electricity prices for households in Norway for 2019, with predicted spot prices from March to December. The grid tariff and government fees (excl. VAT) is compiled from [45].

2.6.3 District heating price

The district heating price is subject to the Energy Act and will always be below the electricity price in the area in question [54]. Commercial and private customers have different price models. The power price is the sum of market price/spot price, net lease and public fees. Hence, as a district heating customer, you will not be charged for high hourly rates during the hours when the consumption is high [54]. Monthly averages are an average price for a month where all times are just as much regardless of consumption. In this case, the district heating price will be 5% below the monthly electricity spot price [43].

2.6.4 Price escalation

In this study, four electricity price escalations will be considered. The base case scenario (2.8 %) reflects the EU energy price projections to 2030 and is used as a baseline scenario for the present study [5]. Low scenarios (1.3% an.) are often used in the German national context, including by the Federal Government in the elaboration of energy strategies [5]. The high energy prices scenario (4.3% an). assumes a high energy price rise in the future, similar to the latest years observed rises. Due to a recent study [5], there has been a 5% an. real increase in electricity price from 2000-2010. Hence, this optimistic prediction is also presented in the study.

2.7 Energy supply systems

The thesis distinguishes between off-site and on-site energy supply systems for buildings. An off-site system (centralized system) is the production of energy by a local plant an then distributed to the consumers. The on-site system, distributed energy system, refers to the variety of small technologies located on the building. There is an existing debate nowadays over the choice between centralized or distributed energy supply system for buildings, and which one has a greater benefit in the society. To conduct reasonable values for consumption of electric devices in the two zones: living room/kitchen and bathroom, real values were taken from [15, 39].

In Norway, the current energy distribution infrastructure offers the possibility of relatively low losses during the distribution. High efficiency and reliability in plant production are the strengths of a centralized off-site distribution system. As stated, the nZEB designed model should use on-site energy production based on renewable energies, i.e. the use of distributed energy systems with local production.

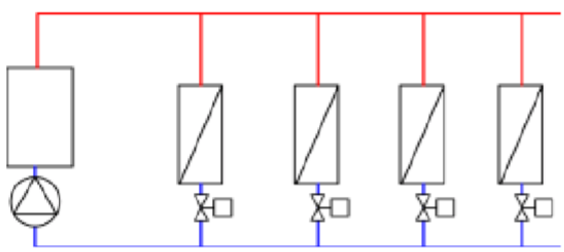
Energy supply technology aims to convert primary energy into other energy carriers more appropriate for demand and distribution of electricity and heat. However, in this study, there are a limited number of energy supply systems that are considered in the case building, due to the complexity to bring out reliable and trustworthy results in IDA ICE. Regardless of this, the different energy supply systems will be discussed in this chapter. All of them should be considered in a real study survey, considering investment costs, complexity, maturity, maintenance and energy potential for each system.

2.7.1 District heating

District heating is a separate energy system that forms a natural part of the energy supply for towns and cities and densely populated areas [53]. The distribution system involves heating of water and is linked to a central heating system what supplies buildings with hot water. Flowing through insulated underground steel pipes, the hot water circulates between the heat production plant and the customer. The pipes are often positioned together with other infrastructures such as telecommunication lines and electricity cables, and experience average heat losses [53].

A number of different energy sources are used to generate district heating. These include waste, bio-fuel, landfill gas, natural gas, propane/butane gas, electricity and fuel oil. Several different energy sources can be used at the same time in a single district heating system. This results in a stable and flexible supply of heat to the customers. If a particular energy source is unavailable for a period of time, another source can be used to heat the water that is distributed to the customers [53]. Figure 2.7 shows a simplification of the distribution system with a plant and four customer substations.

Figure 2.7: Distribution system: district heating



In IDA ICE, district heating can be introduced by setting a top heater with unlimited capacity and an efficiency of 84% when using floor heating (according to NS 3031:2014). The plant is usually a CHP system, a Rankine or Brayton cycle which uses biomass, biofuel, natural gas, oil or coil for the combustion in the boiler [40, 41]. In addition, waste heat from near industries or incineration processes and geothermal energy directly delivered for heat production.

Depending on the production method it can be seen as a complete environmental friendly energy supply technology. Furthermore, the energy output of this kind of systems is also flexible because the CHP machine can deliver heating supply, cooling supply and electricity.

The primary side of the district heating network is the part that connects the customers and which is directly connected to the suppliers' heat exchangers for the production of district heating. The DH system is designed to withstand 110°C but is typically operated at 90°C. For fully expanded district heating networks, the pressure is usually approx. 6-7 bar. However, the net should be able to withstand the operating pressures of 16 bar [51].

Further, the technology is not available in all areas, because of the pipeline network and complexity of the system. It is common in areas with high consumer density, due to the high investment costs implied as well as improvements in the piping network and customer substations [54].

2.7.2 Ground heat exchange

Another heat pump that should be considered is the ground source heat pump. Due to the complexity of designing this on-site energy supply system in IDA ICE, this alternative was not considered in the analysis. However, this alternative requires higher upfront investment cost, due to the construction work and pipe system. This type of heat pump gives a more predictable, stable source temperature.

Ground source heat utilizes thermal energy stored in rock, soil or groundwater [50]. Combining the system with a heat pump, the energy from the ground can be used for both tap water and space heating. The stable temperature of the soil, rock and groundwater over the year provides good operating conditions for the heat pump. The boreholes are usually between 80 and 200 meters deep [50, 48]. The depth of the well depends on the thermal conductivity in the ground, and groundwater flow on site. The placing and design of the borehole system and distance are important parameter's to consider in order to avoid interaction between the pipes itself and ambient sewage infrastructure. The energy that is utilized in the basic plant comes from solar heating combined with energy from radioactivity in rock. There are these basic facilities that are used today for heating of detached houses and smaller commercial buildings.

To prevent the moisture to freeze, a collector hose of plastic is filled with an antifreeze mixture and put penetrated in the borehole pipe. The collector liquid picks up heat from the rock and solid water down the well and emits its heat to a heat pump on the surface. The collector hose usually consists of polyethene or other liquids with a low freezing point. The liquid used in the collector hose is non-toxic and should not contaminate the ground in the event of leakage [34, 50].

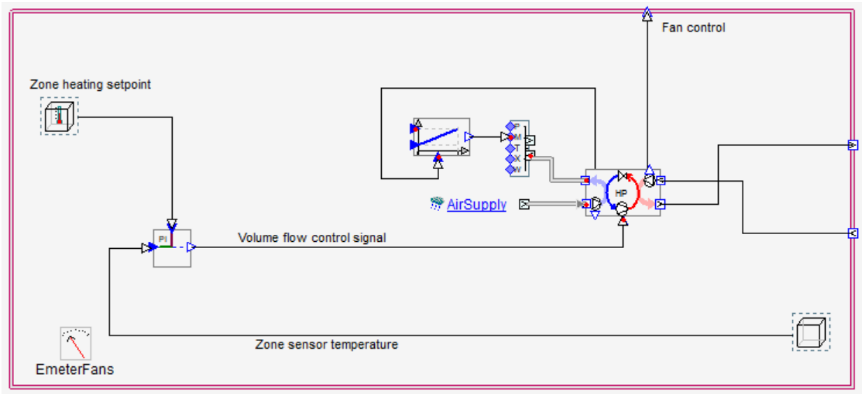
2.7.3 Heat pumps

A heat pump is an electrical device that extracts heat from one place and transfers it to another [32]. The heat pump cycle is fully reversible, and heat pumps can provide year-round climate control for your home heating in winter and cooling and dehumidifying in summer. Since the ground and air outside always contain some heat, a heat pump can supply heat to a house even on cold winter days. In fact, air at 18°C contains about 85% of the heat it contained at 21°C [32].

In this study, the air-to-air heat pump will be considered. The ambient air heat pump requires the lowest investment cost, because of the flexible assembly work for the installation.

In addition, no further construction work is required other than the installation. However, the use of this type is preferably used in mild climate zones, due to the temperature fluctuations during the year. Figure 2.8 illustrates the heat pump setup in IDA ICE.

Figure 2.8: Heat pump



2.7.4 Combined heat and power system

CHP systems generate both electricity and heat from the same energy carrier. This technology differs from a conventional power by capturing the excess heat produced, which otherwise would be wasted. Although it is a well-developed system in large scale plant production, small scale CHPs are still an emerging technology [51].

Because CHP can distribute both heat and electricity, the system has two different efficiencies. Larger scaled CHP units are normally more efficient than micro CHPs. Either of them uses the equations to measure the total efficiency [41]:

$$\eta_{tot} = \frac{P_{el} + Q_{th}}{B} \tag{2.2}$$

$$\eta_{el} = \frac{P_{el}}{B} \tag{2.3}$$

$$\eta_{th} = \frac{Q_{th}}{B} \tag{2.4}$$

, where P_{el} is useful electrical energy, Q_{th} is useful heat and B is the energy fuel source used for the combustion. Micro CHP systems are not common yet in large buildings with simultaneous demand for heat and electricity [60]. However, because of the great potential, this energy source will be considered in this study. The efficiency for both thermal and electric generation are compiled from SN/TS 3031:2016, Table Q.2: Veiledende virkningsgrader for kogenerasjonsenheter [35].

2.7.5 Ambient air to water heat pump

With an air-to-water heat pump, you utilize heat from the air to heat water to radiators, water-borne underfloor heating or to preheat tap water. Heating with such a heat pump results in lower energy consumption than when using electricity. In addition to cutting costs, an air-to-water heat pump will provide a good indoor climate with steady heat throughout the home.

2.7.6 Solar thermal

Solar thermal collectors are devices capturing the incoming solar radiation, converting it into heat energy, and transfer that energy to heat up the water flowing through the collector [28]. The energy collected is delivered to the buildings heating system for direct consumption or to the storage tank from which it can be drawn for use during the night and cloudy days [28]. The system consists of solar collectors installed in the building envelope, pipes, pumps, controllers and storage tank. The efficiency of the solar thermal is defined as the amount of heat supplied from the collector divided by the amount of solar radiation that reaches the collector [31]. The efficiency is defined in the equation below:

$$\eta = \frac{Q_{useful}}{A \times lt} \tag{2.5}$$

Additionally, there are two types of solar collectors: non-concentrating and stationary and concentrating. The stationary collector has the same area for solar interception and absorption, while a concentrating collector has a concave reflecting area that receives solar radiation and focuses the suns beam to a smaller absorption surface [60]. Studies show that solar thermal collectors can be used to complete the operation of a geothermal heat pump: by preheating the domestic hot water, heating dwelling and thermal recharging of the soil during excess solar production periods [60].

2.7.7 Photo voltaic

The solar panels have multiple solar cells made up layers of materials and components [14]. An anti-reflective coating on top helps the cell capture as much light as possible. Beneath is a semiconductor (usually silicone) sandwiched between a negative conductor on top and a positive conductor on the bottom. Once the photons are captured by the solar cell, they begin releasing the outer electrons of atoms within the semiconductor [14]. The negative and positive conductors create a pathway for the electrons and an electric current is created. This electric current is sent to wires that capture the DC electricity. These wires lead to a solar inverter, which then transforms it into the AC electricity used in homes. The more solar cells you install, the more electricity is produced [14].

Building integrated energy devices, such as Building Integrated Photo Voltaic (BIPV) and photo voltaics (PV), is a great energy system to achieve the ZEB standards [11]. By placing the BIPV and PV systems to reach fully solar radiation, the utilization of solar energy can outperform other energy carriers. In the future, it may also be possible to produce solar cells in the form of paint.

However, photo voltaics is complex and is determined on many variables linked together. According to Bjørn Thorud, solar cell expert in Multiconsult, it is three main factors that determine the quality of the panels (Thorud, 2016): 1 - Incorrect mounting that damages the panels. 2 - Damage that occurs during shipping. 3 - The laminating process done by the manufacturer

Two former master's students at NTNU, Kristian Hagen and Torbjørn Lilleheier [22], have examined the loss of efficiency in solar cells. They claim that a number of factors exist that help to reduce the effectiveness of a solar cell. Silicon, which most solar cells are made of, is a shiny material which reflects approx. 30% of all the light shining on it. Solar cells, on the other hand, are equipped with anti-reflective layers which make the reflection considerably smaller. Two layers of silicon monoxide can significantly reduce the reflection percentage so that about 4% of the light is reflected [22]. It is also important to mention that solar cell technology has evolved since then.

Furthermore, they point out that there will be little resistance in the metal contacts in the panels so that some of what could be utilized as power is turned into heat instead. If one considers solar cells at the atomic level, there are also some factors that make efficiency less effective, but this report does not further elaborate on this issue.

Another critical factor in the solar cells is the large temperature differences throughout the year. Tobias Bostrom (professor at the Department of Physics and Technology at UiT) emphasizes that cold has a very great influence on the efficiency of the solar cells. Solar cells always have a leak, a loss of power and voltage. The hotter it is, the greater the leakage [4]. In the cold, on the other hand, the leak is smaller and we get more power for use [4]. Bostrom also claims that if you lower the temperature by 20°, the efficiency of the panels increases by 10%. It is thus very beneficial with solar-coated surfaces on the building with regard to the temperature in Trøndelag [4].

In this case study, the slope of the solar panels is set to is 35° and 40°, using PVGIS and IDA ICE. In a real survey, there is uncertainty as to whether the snow will drain or remain. For the greatest possible effect, clean solar cells are desirable. For utilization of photo voltaic, the thesis finds it appropriate with regular surface washing of the panels.

The installation of the panels is crucial to gain the maximum capacity of the panels. The capacity is reached when the panels are oriented towards the south (on the northern hemisphere) and no shading captures the panels. The type of cell used determines the efficiency of the panels. Today, there is a large variety of cells (flexible thin film, poly crystalline silicon, mono-crystalline) available with different levels of efficiency. Both the temperature and solar radiance are important parameters that determine the efficiency, additionally. Hence, modules have to be installed with an optimum tilt angle, which will depend on the geographical latitude of the location. In this case study, the photo voltaic will be placed on the roof with an optimal tilt angle designed in IDA ICE. Because of the increased efficiency for the panels, and the decreasing price escalation, this technology will be utilized in this study.

From [27], the nominal power is the power given by the manufacturer of the module or system. It is the power output from the module(s) measured at 1.0 kW/m^2 solar irradiance and a module temperature of 25°C). This means that if your modules were 100% efficient, you would need 1 m^2 to get a system with a peak power of 1 kilo Watt. These conditions are known as Standard Test Conditions (STC).

The efficiency is defined as the ratio of electrical power delivered to received light output. The efficiency (η_{nom}) range from 0-1, often given in percent. The general formula for efficiency is; effect out / effect in. For solar cells, this corresponds to the ratio between solar power input (solar radiation) and electrical power output (produced current). A silicon panel normally has an efficiency of 16-20 %. Using other materials, one has been able to produce solar panels which have achieved an efficiency of just over 40% in laboratory experiments, but such panels are very expensive and not economically profitable. The nominal efficiency under STC is defined in the equation below:

$$\eta_{nom} = \frac{P_{out}}{P_{in}} \times 100 \qquad [\%] \tag{2.6}$$

However, the modules are not 100%. I.e., if the panels are 10% efficient modules, it is necessary with need 10m^2 to have a 1kWp system. In other words, if P_{pk} is the nominal peak power and A the area of the module(s), in this case, 30 m^2 each apartment [27]:

$$P_{pk} = A \times \eta_{nom} \qquad [kWp] \tag{2.7}$$

From [27], the following parameters are considered when calculating the P_{total}.

Estimated system losses (cables, inverters):	14.0%
Slope	35° and 40°
Panel size	30 m^2
PV technology	CdTe (Cadmium Telluride)
Estimated losses due to temp. and low irradience:	-0.4%
Estimated losses due to angular reflectance effect:	3.0%
Combined photo voltaic system losses:	16.3%
Peak power [η_{nom} = 16%]:	P_{pk} = 4.8 kWp
Peak power [η_{nom} = 18%]:	P_{pk} = 5.4 kWp
Peak power [η_{nom} = 20%]:	P_{pk} = 6.0 kWp

Additionally, a research article on photo voltaic degradation rates [12] recommends a degradation factor of 0.5% annually. This is also the degradation rates used by Multiconsult and Asplan Viak in their example calculations for commercial buildings. The thesis therefore assumes a reduction of 0.5% an. on total production of solar cells. The formula (2.8) is used to calculate the degradation factor. The total production is given as a repetitive geometric sum of the annual output with a decreasing annual factor r = 0.005.

$$P_{total} = P_{yearly} \times \frac{1-(1+r)^n}{1-(1+r)} \qquad [\%] \tag{2.8}$$

Chapter 3

Method

This chapter discusses the previous work done during the specialization project. Because the theme of the thesis was compiled from the specialization project, the method for collecting reliable and convincing data is included in the thesis. The author found this important due to the recent research on the field in light of sustainable building design. Hence, the method chapter discusses how the collection of research papers and articles on the field were organized, to understand the field of interest. The method also consist of the model setup in IDA ICE and input data.

This method and research design plan were intended to facilitate empirical work for later research during the master thesis. Dalland refers to Vilheim Aubert's formulation of what method is: Method is a course of action, a means of solving problems and developing new knowledge. Any means that serves the purpose belong to the arsenal of methods [36]. Research and scientific questions can be implemented in multiple ways. When choosing a method for data collection, there is a number of things to think about. What collection method we choose will ultimately be determined by the information we need. By using one method we get one type of data, using another we get another type of data [36].

3.1 Quantitative and qualitative orientation

The qualitative method highlights the insight and seeks understanding, while quantitative method highlights overview and seeks the explanations (Tjora, 2017). Qualitative research is primarily exploratory research to gain an understanding of motivations, opinions, and reasons. It can provide insight into a specific problem or ideas for potential qualitative research.

Quantitative methods allow you to study a larger number of units based on a set procedure. This allows the survey to make statistical generating data and sets stricter requirements to the method. It requires discussion and reflection about error sources, deviations, accuracy and variables [36]. Dalland O. [36] represents the following characteristics of quantitative and qualitative orientation. Table 3.1 illustrates the scope of qualitative and quantitative orientation when outsourcing relevant articles and topics.

Table 3.1: Quantitative and qualitative orientation [36]

Quantitative orientation	Qualitative orientation
Precision: gather a wide range of quantitative variation	Sensitivity: get the best possible reproduction of the qualitative variation
Width: collect small units of data about many research parameters	Depth: collect big units of data from small research parameters
The average: get what is common, the representative	The distinctive: get what is special, eventually deviant
Systematic: surveys with a common set of question options. Systematic and structured observations	Flexibility: interviews characterized by flexibility without common question options. Unstructured observations
Parts: data collected is linked to distinct phenomena Explanation: the production aims to negotiate explanations	Entirety: data collected is linked to common context Understanding: the presentation aims to convey understanding
Audience: the researcher sees phenomena from outside, the researcher strives for neutrality and distance	Participant: the researcher sees the phenomena from inside, the researcher acknowledges impact and participation.
Me-it-relationship: researcher and the questionnaire	Me-you-relationship: researcher and the questionnaire
Ex: Survey/questionnaire, correlation research, SWOT	**Ex: One-to-one interviews, group interviews, case study**

Triangulation method facilitates validation of data through cross verification from two or more sources of information [36]. Comparing different perspectives of utilizing ZEB specifications instead of the traditional TEK17 standardized tool, one can reveal different experiences. If the different perspectives point in opposite directions, it may indicate that the ZEB classification system has a bias towards some type of buildings. If two different construction project has the same experience and impact on the material properties utilizing ZEB specified standards, it may indicate that the results have high validity. Hence, triangular research of different contractors will strengthen the credit towards the data collected for the thesis.

3.2 Literature review

The purpose of the literature review was to document the state of the art with respect to the specified topic of interest. This literature review aimed to rapidly map the relevant research material in a field of interest for the master thesis. Hence, the purpose was to gather literature to accumulate as much knowledge as possible for the topics of interest. This required comprehensive and structured searches of the available literature to maximize recall and decrease personal and organizational bias. The search strategy was systematic and transparent. In the early phase of the thesis, the exclusion criteria were flexible because of the inherently limited knowledge of utilizing ZEB specified criteria worldwide and the design specifications.

3.3 Assessment of Method and Research Design

Using a research method, there are some basic standards for how to proceed. Dalland [36] states the following:

- research activities should be cumulative, i.e. existing knowledge and research
- the results must be verifiable
- the researchers understanding must be clarified
- data should be used accurately
- the results must be in accordance with reality
- data must be systematically selected

The process of selecting suitable data for a research project can impact data integrity. It is therefore important to determine the appropriate data type and source, as well as suitable instruments to collect information. When the necessary examinations, observations, and interviews are completed, it is important to evaluate the new information obtained. The motivation and needs for making the thesis as realistic and correct as possible make it crucial to do the assessment of the method used.

Reliability and validity is a criterion for the quality of the research and is about whether the work presented can be relied on [36]. To get reliable knowledge, it is crucial to obtain information from the people in the building industry, and not from outsiders. By interviewing or doing observations of people with a bias towards their own needs (or companies needs), problems will occur.

3.3.1 Search terms

The first approach to include and exclude literature is illustrated in Figure 3.1. The figure shows the flowchart from the inclusion and exclusion process of the scoping study.

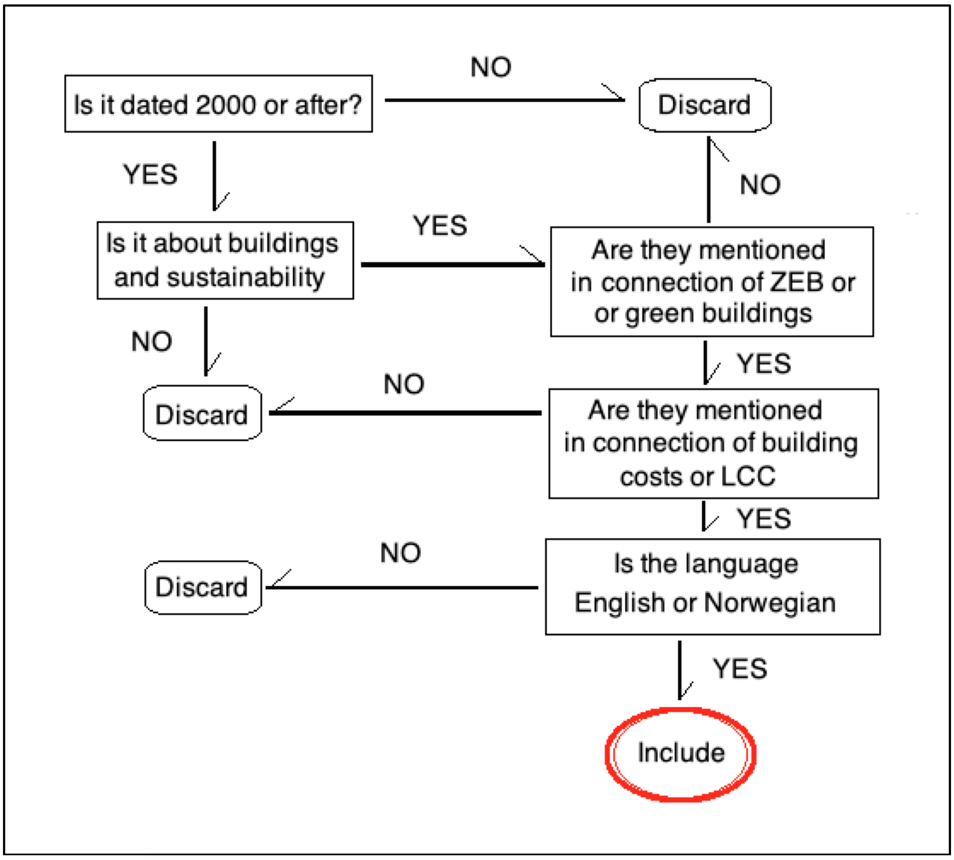


Figure 3.1: Inclusion and exclusion criteria

In addition, because of the huge amount of references gathered, its been used Boolean operators to minimize the redundant articles. The four most common operators in programming use and outsourcing are AND (logical function), OR (logical inclusion), XOR (exclusive OR), and NOT (logical negation). In this review, the search term and operator AND is primarily used because it gave a comprehensive and manageable number of hits [55].

3.3.2 Scoping study

The scoping of the literature was obtained by using different research platforms. In this case, Google Scholar and Oria was the preferred research tool for gathering relevant literature available online. Because of the huge amount of articles available in the online database tools, it was important to check the credibility and performance ratio. This was done by utilizing the ranking system obtained by The Norwegian Register for Scientific Journals, Series and Publishers [20]. The results from outsourcing relevant reviews are discussed. A number of ten different papers, reviews, books, and thesis were gathered to give a wide range of different perspectives on relevant information and topics.

Google Scholar and Oria were used to obtain relevant literature relevant to the research questions. Most of the articles and papers were available literature published on Elsevier, a highly awarded academic publication journal for scientific publications. Osmani M., Reilly [42] stated that the perceived increased costs of achieving high building standards associated with low and zero carbon homes are yet another hurdle restraining house builders from attempting to overcome the existing cultural, design and technical challenges. Several studies revealed that housing developers are reluctant to instigate innovation and achieve high sustainability standards due to the prohibitively perceived or real elevated costs associated with the implementation of such standards [65].

Williams et. al. [65] also concurred that the high cost of certain sustainable measures is a major barrier to low carbon homes when compared to traditional buildings. Moreover, this issue is exacerbated by the uncertainty surrounding the actual cost of achieving the different levels of ZEB. Studies completed to date have shown that the cost of achieving the different levels of the ZEB will vary depending on the economies of scale available to each particular house builder and the construction methods. Cupido A. et al claimed that the upfront costs of sustainable green buildings, like ZEB, are higher due to the technical specifications [9].

The research also found that soft costs are higher than conventional projects due to incremental costs associated with the process of achieving a green building rating. This involves both application costs as well as additional consulting required under the various rating tools. More recent research suggests that by implementing energy efficiency measures commercial buildings can reduce their carbon footprint by 16 % on average, thereby improving green buildings' life cycle cost-effectiveness [29]. To maximize the net savings for a specific building, it is therefore important to utilize an LCC approach for defining the building costs during the lifetime. Because of the stricter requirements for sustainable buildings, and the increased specifications due to more agile and technical properties, financing the new paradigm shift in light of ZEB the built industry were considered. Among the criteria considered by SINTEF and other designers with expertise in sustainable building modelling, the cost is still foremost of others, despite worldwide calls for sustainability and environmental considerations. Table 3.2 illustrates the outsourcing algorithm for retrieving relevant literature.

Table 3.2: Outsourcing material using Boolean operators

Stage	**Search terms**	**Method**	**Hits: Google Scholar**	**Hits: Oria**
Initial search	Zero emission buildings	Bibliometric	1 010 000	26 593
Branching	AND	material Bibliometric + qualitative assessment of title (*)	643 000	15 578
Specification	AND cost	*	565 000	11 107
Specification	AND maintenance	*	58 800	5 806
Specification	Published after 2017	Updated (date)	16 600	1 056
Specification	AND energy	*	6 300	1 034
Specification	AND ZEB	*	834	43
Specification	AND Europe	*	579	64
Selection	Relevant articles selected for further study	Manuel qualitative assessment of titles, keywords and abstract	20	20

To evaluate the literature, the TONE principal tool (English translation: ROAR principal) was preferred. This analyze tool is based on the following criteria; reliability, objective, accuracy and relevance [56].

3.3.3 Choice of Method and Research Design

To answer the research questions, it will be comprehensive to include both qualitative and quantitative method. In many ways, a combination will be useful [1]. It is useful not to look at the different method tools as separate instruments, but rather combine them. This section describes what type of research design is most expedient to answer the research questions of the thesis.

Holme points out three required claims for a good research model. It should be unpredictable, simple and fertile. That said, the model should include exciting elements and not just a continuation of the previous finding. It should not be more complex than strictly necessary to clarify the phenomena dealing with. Last, the model should highlight questions and problems which can open for an extended understanding of the phenomena working on [23].

To conduct real data from relevant projects for the thesis, it was necessary to do a quantitative survey to find a representative and comparable set of existing and new buildings with both TEK-17 and ZEB classified specifications. By studying new ZEB buildings, the findings resulted in unpredictable results, because of the state of the art of constructing ZEB specified buildings.

When the most transparent and similar project had been collected, it was necessary to do qualitative survey to open for an extended understanding of the phenomena working on. For the master thesis, to obtain information and data for the supply chain and material cost for construction projects, this review finds it necessary to do interviews with project managers and supply managers responsible for the construction materials. Figure 3.2 illustrates the triangulation method for the master thesis.

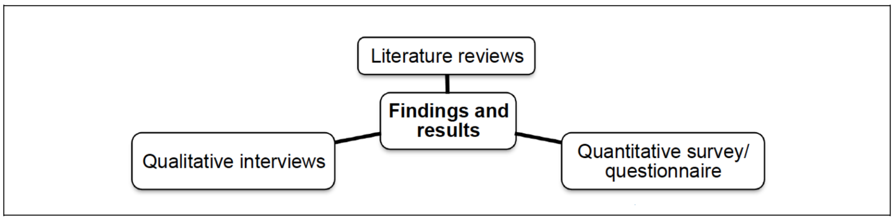


Figure 3.2: Triangulation method for research data

3.4 Rules for calculation

When calculating the energy performance of the different alternatives, the calculations should be performed with validated methods and according to NS 3031, the Norwegian standard for building performance. Institutionally accepted dynamic simulation software, like the one used during this project (IDA ICE), should preferably be the tool for these calculations. Additionally, to obtain reliable results for the energy performance, the simulations shall use local climate conditions and one calculation period consist of a one year study.

3.5 System boundaries

The most important step considering the energy system and performance level is to define the system boundaries. Because the residential building consists of eight similar apartments, the energy performance of one apartment is evaluated. Only the energy flows crossing the apartment system boundary will be considered.

The physical boundary will distinguish between off-site and on-site generation system. When designing the nZEB-system, the renewable energy production system shall be on-site and the heating system can be both. The system boundary is the one that defines which energy uses are taken into account. A combination of both boundaries will be the building system boundary.

To satisfy the energy demand of the building, two types of energy as used: heated water and electricity. Electricity is a high-quality energy that is used for the energy needs of the apartment. The heated water is considered a lower quality energy source depends on the water temperature. This is only considered to cover the heating demand. In the case of analysis, domestic hot water is not considered for each simulation scenario. Hence, for the scenarios in the analysis, both electricity and water heating will be included in the analysis. In the case of nZEB, the exported energy will only include electricity. It is assumed that surplus electricity will be connected to the heating network to export excess heat energy. Further, the analysis considers the exported energy to be lower than the total electricity demand on-site.

3.6 BIM

To be able to track the energy consumption of the case building, the building envelope had to be designed with correct geometry and features. The present sections give the overall feasibility's of the BIM software tools used during the analysis.

3.6.1 Autodesk Revit 2018 edition

Autodesk Revit is building information modelling software for architects, landscape architects, structural engineers, MEP engineers, designers and contractors. Revit Autodesk allows the user to place intelligent elements like walls, doors, and windows. Revit generates floor plans, elevations, sections, schedules, 3D views, and renderings. Optimize building performance early in the design process, run cost estimates, and monitor performance changes over the projects and buildings lifetime. Since Revit is a multidisciplinary BIM platform, you can share model data with engineers and contractors within Revit, reducing coordination tasks [25].

3.6.2 IDA-Indoor Climate and Energy

IDA Indoor Climate and Energy (IDA ICE) offers the balance between solid mathematical modelling and a user-friendly graphical interface [17]. The modelling environment is equation based, providing a possibility to model physical phenomena by simply describing their governing equations, without the need of writing the code that solves those equations [17]. It accurately models the building, its systems, and controllers ensuring the lowest possible energy consumption and the best possible occupant comfort[17].

IDA ICE is an innovative and trusted whole-year detailed and dynamic multi-zone simulation application for the study of thermal indoor climate as well as the energy consumption of the entire building. The physical models of IDA ICE reflect the latest research and best models available, and the computed results compare well with measured data. [17]. While serving a global market, IDA ICE is adapted to local languages and requirements (climate data, standards, special systems, special reports, product and material data)[17].

Further, the BIM export extension Revit 2018 allows to import 3D buildings directly into IDA ICE, using the open and neutral IFC (Industry Foundation Classes) format [19]. The 3D-model was exported as a IFC-file to IDA ICE. The IFC-format, which is commonly used for BIM models, includes the geometrical properties (walls, doors and openings).

3.7 Input data in IDA ICE

3.7.1 Ground properties

In IDA ICE, the ground properties should be chosen carefully. The program calculates the heat resistance of the outermost layer, based on the geometry of the building and the heat conductivity of the outermost layer. Hence, the building body which is connected to the ground is used for the calculation. The input in the ground properties in IDA ICE was concrete will the following properties:

Thermal conductivity:	1.7 W/(m K)
Density:	2 300 kg/m^3
Specific heat:	880 J/(kg K)

For the simulations, Table 3.3 was chosen as the weather file. In IDA ICE the ground properties are computed automatically, and the given temperature is disregarded.

3.7.2 Weather file

Table 3.3: Weather file

	Variables						
	Dry-bulb temperature, Deg-C	Rel humidity of air, %	Direct normal rad, W/m2	Diffuse rad on hor surf, W/m2	Wind speed, x-component, m/s	Wind speed, y-component, m/s	Cloudness, %
January	-7.2	85.3	59.0	9.0	0.1	-0.4	56.3
February	-4.9	81.0	103.7	24.2	0.5	-0.3	57.6
March	-1.8	77.1	154.3	51.1	0.1	1.2	55.2
April	2.8	73.6	133.3	87.8	-0.5	-0.3	63.1
May	10.7	56.9	201.1	115.2	0.1	-0.8	59.1
June	13.2	65.0	183.2	133.6	0.2	0.6	64.5
July	15.6	67.6	185.5	125.4	0.2	-1.0	60.8
August	14.8	74.4	152.8	100.7	-0.6	-0.6	64.7
September	9.8	77.0	121.1	65.3	-0.2	0.5	62.7
October	4.9	85.8	101.2	32.8	-0.4	0.9	59.0
November	0.7	87.7	63.2	13.4	-0.3	1.4	63.1
December	-3.2	93.5	37.4	6.3	0.0	0.3	60.5
mean	4.7	77.1	124.8	63.9	-0.1	0.1	60.5
mean*8760.0 h	40988.4	674985.5	1093392.0	560120.0	-693.7	1047.9	530300.0
min	-7.2	56.9	37.4	6.3	-0.6	-1.0	55.2
max	15.6	93.5	201.1	133.6	0.5	1.4	64.7

3.7.3 User loads, occupancy, lightning and equipment

User-specific loads impact the energy balance of the building model. For the early design phase, the thesis finds it generally desirable to keep the user loads simple. Figure 3.3 illustrates the user load schedules for each room. The occupancy heat gain varies with activity level. For reference, the occupancy density for apartments (NS:3031:2014) is a constant 1.5 W/$m^2$2. The occupancy is set by the number of people in IDA ICE. By default, a density of 10 $m^2$2 equals the load from one person.

In IDA ICE it is optional to control lightning by a scheduling unit in the zone for each room. The lightning is set like the occupancy schedule in IDA ICE. The desired variables in the software allow for documenting total rated input per unit (W). The default is 5 W/m^{2}2 all year. The luminous efficiency is considered with the default value 12 lm/W, by simplicity for the early design.

Equipment is also another input variable to consider. This is considered as appliances like dishwasher, cloth washer and dryer. These values are considered as the total emitted heat per unit (only this consumers energy). The values are set to 75 W for living room/kitchen and 40 W for the bathroom. The equipment for both bedrooms is considered negligible.

Figure 3.3: Occupancy (Bathroom, bedrooms and living room)

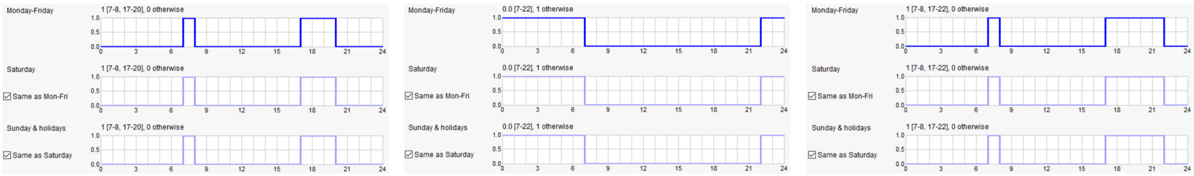
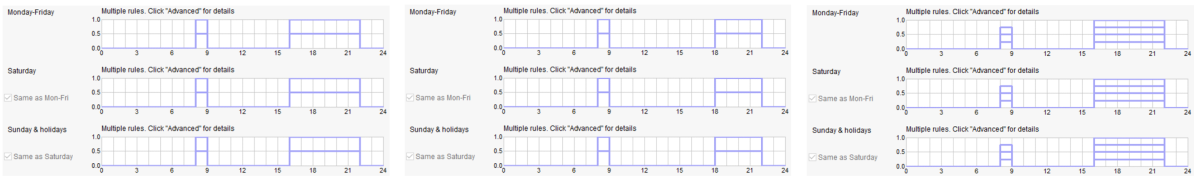


Figure 3.4: Lightning (Bathroom, bedrooms and living room)



3.7.4 Air handling unit (AHU)

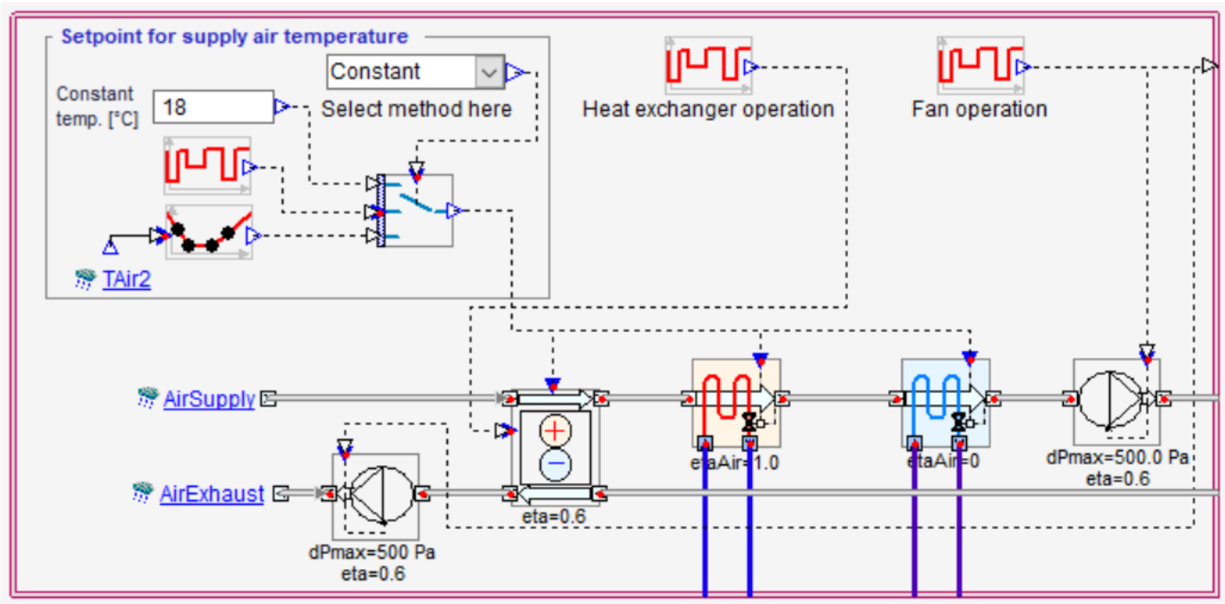
Ventilation is necessary to remove excess heat, supply heat for spacing and remain good indoor quality. Figure 3.5 shows the main structure of the AHU: heat exchanger, fans, heating and cooling coil (not included in this analysis). The supply air temperature, specific fan power and supply and extract fans, and heat recovery efficiency are central parameters. By default, the AHU is of unlimited capacity. Then the ESBO plant is enabled, the ability to provide fresh air will be affected the efficiency of the system. Because the cooling coil is set to 0, the supply air in the summer will not be cooled.

The efficiency of the heat exchanger is set to 60% [1]. The heat exchanger is scheduled to always on, and the fan operator is set to 07-08 17-20 every day. By simplicity, the thesis considers a constant air volume (CAV) system for the apartment building(s). The supplied air is set to 18 °C throughout the year. Because the case does not consider cooling in the summer season, the supply air temperature can exceed 18 °C. In IDA ICE, algorithmic schedule objects are set for both heat exchanger and fan operator. Leap years and daylight saving time (DST) are handled correctly. Discontinuities are handled, both for midnight, and when jumps occur with double time coordinates.

Fan operator

Pressure rise:	500 Pa
Efficiency (electr. to air):	0.6
SFP (specific fan power):	0.833 $kW/m^3/s$
Heating coil	
Air side effictiveness:	1 (on)
Liq. side temp. drop:	20°
Cooling coil	
Air side effectiveness:	0 (off)

Figure 3.5: Air handling unit in IDA ICE



3.8 Room units

The rooms in the IDA ICE building is initially equipped with idealized room units for heating and cooling, called Generic units. These will heat and cool the rooms to maintain temperatures within requirements but are not connected to the water-based central system that is described on the Building tab. This unit provides heating and cooling to the rooms by directly converting electricity to heating. Because of the Norwegian climate, this analysis excludes the consumption of cooling devices in each room. Hence, only heating devices will be considered to maintain the rooms- and zone temperatures of the apartment building. As the effect of this, overheating will occur in the summertime, but will be maintained by opening windows. To eliminate heat gain through transmission, external shading devices was designed into the model. Figure 3.6 illustrates the external shading setup in IDA ICE.

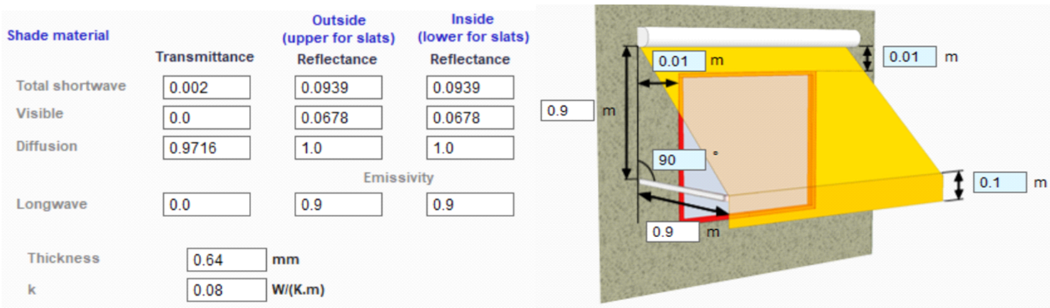


Figure 3.6: Shading setup (IDA ICE)

3.9 Plant model in IDA ICE

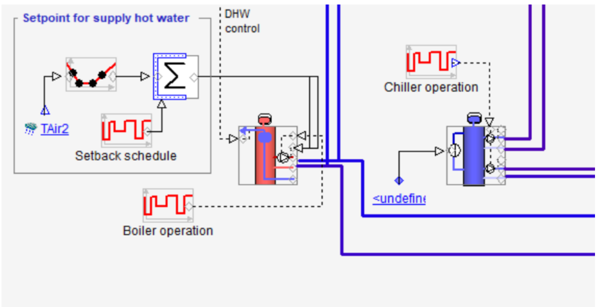


Figure 3.7: Standard plant

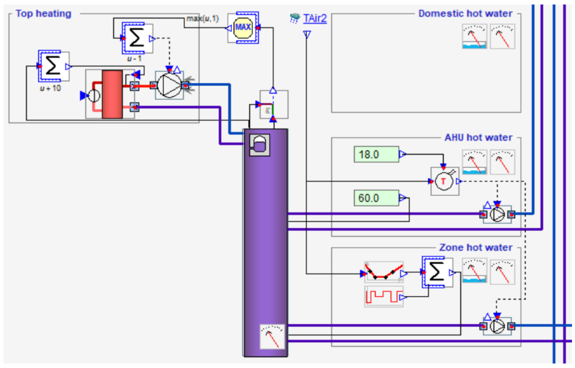


Figure 3.8: ESBO plant

The simulation of electric and district heating required two different plant model. The HVAC plant for the electric heating system is shown in Figure 3.7, and was set as default. For the district heating plant, ESBO Plant model in IDA ICE was chosen for the second alternative (Figure 3.8). The plant model is organized around two water tanks; both heating and cooling tanks. Domestic hot water (DHW) (if desirable) is drawn from the hot tank, which has a mass flow signal into it that gives the required DHW mass flow. Each client circuit, including this one, feeds a temperature set point into the tank. In this case, the temperature set point was set to 55°C.

AHU hot water circuit, connected through a pump, provides with heated water at given pressure and temperature. A temperature set point of 60°C informs the tank about the temperature that is required by the users. Also in the AHU box is an on-off controller for turning off the hot water circulation to both AHU and zones when the ambient temperature is higher than 18°C [63]. The Zone hot water circuit is similar, but has a more elaborate arrangement for the calculation of the temperature set point, allowing it to be a function of ambient temperature as well as an of a night set back schedule [63].

AHU cold water and Zone cold water circuits connected to the cold tank are found in the lower right corner. They have in this example simple fixed set points, 5°C and 14°C, respectively, throughout the year [63].The photo voltaic production circuit is also located in the plant model. It is not connected to the plant system and will appear as a negative energy contribution in the simulation results. Both the location, tilt and area of the panels, along with the panel type can be easily monitored to reach realistic values.

The Top heating circuit is the backup for keeping the top of the tank at the maximal required client temperature. It feeds directly into the tank water, and since expansion vessels are included in the tanks, only a pump is required in this circuit. The control circuit measures the top level water temperature and asks the top up the heater to heat if the Base heating is already fully engaged [63]. Below the top heater is the Base heating circuit, where the condenser of the brine to water heat pump feeds into the tank directly. The heat pump and the condenser circuit pump are controlled by a PI controller which attempts to keep the fill ratio of the tank at a constant. The fill ratio is defined as the degree at which the tank is filled with water at the highest required set point, i.e. if all water is heated to the highest set point, the fill ratio is 1, while if the whole tank holds the ambient temperature (20°C), the fill ratio is zero[63].

Base heating heat pumps will have a speed limit of the condenser pump circuit that will be active when the heat pump should prioritize hot water production, i.e. the top heating circuit is engaged only when the base heating is already running at full capacity. The heat pump is connected to the Brine circuit. The brine circuit has a more complex design. The basic idea is that all free heat and cold sources are connected in parallel to a single brine circuit. The circuit will alternate to feed units that require heat, such as the present heat pump and domestic hot water.

Chapter 4

Case building

This chapter describes the designed case building in question and how it has been calibrated. This includes a description of the building envelope, model set up and calibration in Revit 2018 and IDA ICE 4.8. Model retrofit, rules for the calculation of energy performance and system boundaries of the apartment building is also included in this chapter.

The investigated building is a low energy building which passive parameters are optimized and validated according to TEK-17 and ZEB standardications. The model is a residential building composed of four similar floor levels. Each floor is divided into two apartments, as shown in Figure 4.3. The buildings net area (excluding balconies and non-conditioned spaces) is 464 m^2. All building rooms are modelled in the IDA ICE-zone model, as shown in Figure 4.3. The thermo-physical characteristics of the buildings envelope are represented in Table 4.1.

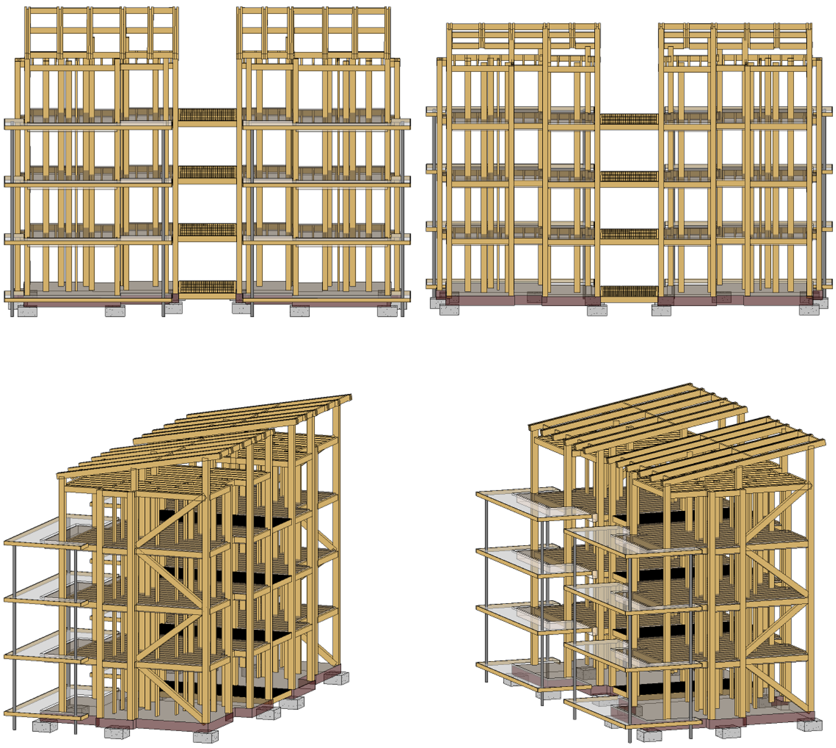


Figure 4.1: Building structure

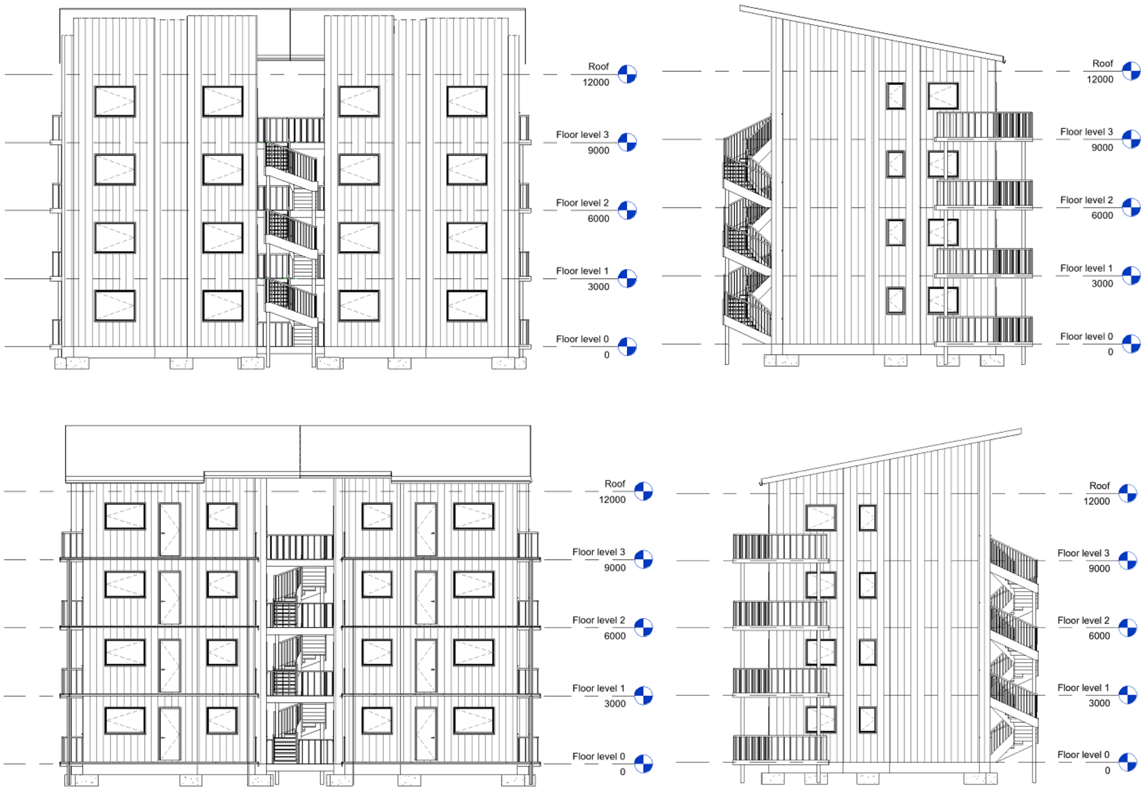


Figure 4.2: Building envelope: detailed

Figure 4.3: Building envelope: level allocation

4.1 Building model

The object of analysis is a four-storey eight units apartment building with an intended location in Oslo, Norway. The apartments have the same design and size, with a total of 464 m^2 combined (58 m^2 each). Each apartment consisted of two separate bedrooms, one bathroom and an entry, living room and kitchen area. Figure 4.1, 4.2 and 4.3 shows the building structure, envelope and level allocation of the designed building using Autodesk Revit 2018 edition.

The model in question was intended to be designed in accordance with the TEK-17 standard. This was referred to as the calibration baseline model. After the creating of the model, the outcomes were thoroughly double checked to the minimum criteria for a residential apartment building designed after TEK-17 standard. Afterwards, it was calibrated with respect to measured energy data. As this project aims to analyse the difference in energy performance comparing the construction in accordance with TEK-17 standard and nZEB, a high-performance building must be obtained.

4.1.1 Building design

The envelope design is made as simplistic as possible, by improving the building envelope, introducing a heat pump with floor heating distribution system and adding a ventilation system. For reducing the U-values in each occupant room and space, all the external walls were designed after both TEK17 standard, and the nZEB classification. For windows and doors, the retrofit is less trivial. As glass surfaces are highly important for external energy gains, it is important to evaluate the performance of the different window and door types. Choosing proper glass surfaces for the baseline model and nZEB model is therefore of great importance. The baseline model was designed with a commercially available window frame and glazing unit with a U-value of 0.8 W/m^2K. For internal heat, the heat gains from occupants, equipment and lightning were designed in a similar manner for both of the design scenarios. Figure 4.4 shows the building facades of the designed building using Autodesk Revit 2018 edition. Figure 4.6 shows the apartment design facades of the designed building using IDA ICE 4.8 edition.

The structural construction of the building is timber, even though this had no impact on the exportation file from Revit to IDA ICE. For structural performance and serviceability, proper connection details are important. Careful consideration of moisture-related expansion and contraction characteristics of wood is essential in detailing glulam connections, to prevent induced tension perpendicular to grain stresses [57]. Connections must be designed to transfer design loads to and from a structural glulam member, without causing localized stress concentrations beyond the capacity of either the connector or the timber member [57].

In Regulations on requirements for construction works and products for construction works, a new thermal bridge concept, normalized thermal bridge value, was introduced. It is this value that is required in the new regulations. A recent project have used the recommended value for normalized thermal bridges [59] of 0.015 W/m^2K. Hence, in this case, the study assumes that this value is durable for the apartment building. For the nZEB case, normalized thermal bridge value is therfore set to 0.015 W/m^2K.

4.1.2 Building envelope

Room boundaries and spaces were required in order to simulate the impact of the variation of each parameter in IDA ICE. The volume computation for space was based on its room- bounding components and was calculated as the area of its base multiplied by the height of the space. The height was set to 2.6 meters, in accordance with the requirements for minimum height (TEK-17). The resulting parameter and default settings for heating setpoint, supply air and indoor humidity for each room are shown in Table 4.2. Additionally, Table 4.2 illustrates the lightning setting for each room (bedrooms, bathroom, living room and kitchen.

Table 4.1: Building design envelope

		TEK-17	**nZEB**
Roof		U-value: 0.13 W/m^2K	U-value: 0.07 W/m^2K
Function	Materials	Thickness (mm)	Thickness (mm)
Finish (external)	roof tiles (11 tilt)	-	-
Membran layer	EPDM Membrane	20	20
Thermal/air layer	air infiltrating barrier	-	-
Structure	timber (90x315)	315	315
Insulation	mineral wool	260	500
Membran layer	vapor retarder	-	-
Finish (internal)	Gypsum	-	-
External walls		U-value: 0.18 W/m^{2}K	U-value: 0.095 W/m^2K
Function	Materials	Thickness (mm)	Thickness (mm)
Finish (external)	horizontal wood panels	-	-
Membran layer	EPDM Membrane	20	20
Thermal/air layer	air infiltrating barrier	-	-
Structure	timber (90x315)	315	315
Insulation	Mineral wool	175	350
Membran layer	vapor retarder	-	-
Finish (internal)	Gypsum	-	-
Floor		U-value: 0.09 W/m^{2}K	U-value: 0.069 W/m^{2}K
Function	Materials	Thickness (mm)	Thickness (mm)
Finish (floor)	wood flooring	-	-
Membran layer	vapor retarder	-	-
Insulation	mineral wool	350	500
Structure	concrete (24.1 mPa)	125	125
Thermal/air layer	damp profing	-	-
Membran layer	randon membrane	-	-
Substrate 1	Concrete (24.1 mPa)	300	300
Substrate 2	hardcore	100	100
Windows	WWR 6.6%		
TEK-17	SHGC and ST	U-value	Internal/external emissivity
	0.15 and 0.1	0.6	0.837 (default)
Windows	WWR 6.6%		
nZEB	SHGC and ST	U-value	Internal/external emissivity
	0.15 and 0.1	0.8	0.837 (default)
Insulation	**Thermal conductivity**	**Density**	**Specific heat**
Mineral wool	0.036 W/m K	20 kg/m^3	750 J/kg K

Figure 4.4: Building facades (Revit Autodesk)

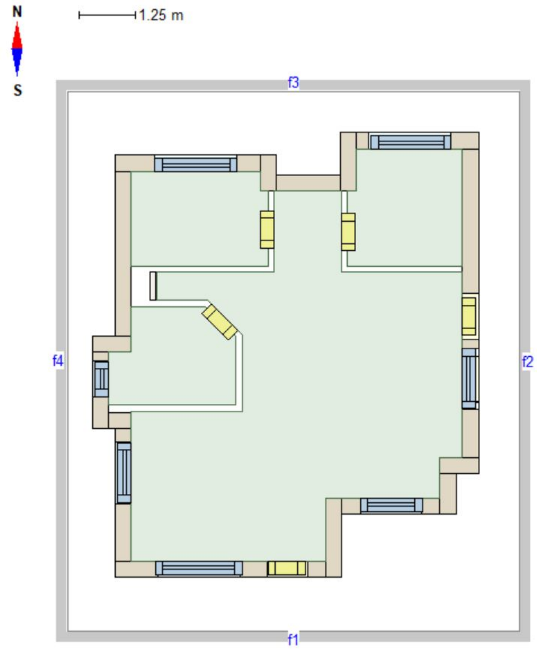


Figure 4.5: Room and space allocation (IDA ICE)

Table 4.2: Room and space data

Zones	**People**	**Lightning***	**Equipment***	**Occupancy**	**Lightning**	**Equipment**
Main area	2	100 W	3100 W	07-09 17-22	07-09 17-22	07-09 17-22
Bathroom	1	100 W	1750 W	Never present	Always off	07-09 17-22
Bedroom 1	1	40 W	50 W	21-07	Always off	21-07
Bedroom 2	1	40 W	50 W	21-07	Always off	21-07
Zones	**Height**	**Heating**	**Cooling**	**Ventilation**	**ACH**	**Supply air**
All zones	2.6m	21	25	AHU CAV	0.5	2 L/sm^2

*Effect (Watt) for equipment and lightning is obtained from [39]

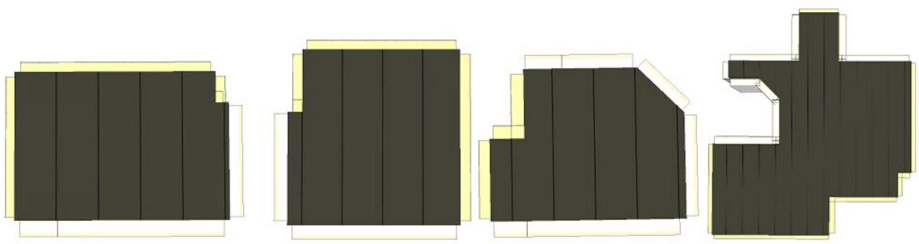


Figure 4.6: Room allocation (IDA ICE)

Chapter 5

Results

This chapter discusses the simulated results for each simulation and compares the energy consumption and cost. The results are based on the energy balance and delivered energy to the building to reach acceptable temperatures and indoor climate. For the sustainable design, photo voltaic electricity generation on-site is also included in the results. The photo voltaic production is simulated using two different calculation tool: IDA ICE and PVGIS. The resulting performance (kWh) from IDA-ICE and PVGIS differed 28%, which had a significant influence.

Initially, the reference scenario was modelled and analyzed. Secondly, different parameters were changed in the system design for mapping the impact on the annual energy use. Lastly, the economic parameters and investment costs are discussed. Sensitivity analysis, with respect to the electricity escalation, is carried out based on the simulated annual energy use in the building. The results show the sensible heat balance for the living room and kitchen main area and the total annual energy consumption for the one apartment. The data is presented in two section (5.1 and 5.2). Each section contain simulating data for both TEK-17 and ZEB specified envelope, obtained from Table 4.1.

The control volume in the zones is inside the walls, ceiling and the floor surface. However, in the case of embedded heating and cooling, the control volume includes the activated layer and significant thermal mass. Because the comparable results are based on the same building model with similar geometry, there was no need for changing anything in the IDA ICE building zone model for each system. The simulation was performed dynamically with periodic start 1st of January 2019 using ASHRAE IWEC climate file for Oslo, Norway. The figures and tables are labelled as Simulation 1-4, by simplicity:

Simulation	**Description**
Simulation 1:	Electric floor heating with air-to-air heat pump COP 3.2 (TEK-17 design)
Simulation 2:	Electric floor heating with air-to-air heat pump COP 3.2 (ZEB design)
Simulation 3:	Water borne underfloor heating (TEK-17 design)
Simulation 4:	Water borne underfloor heating (ZEB design)

5.1 Electric floor heating with air-to-air heat pump

5.1.1 Mean air and operative temperature (electric heating)

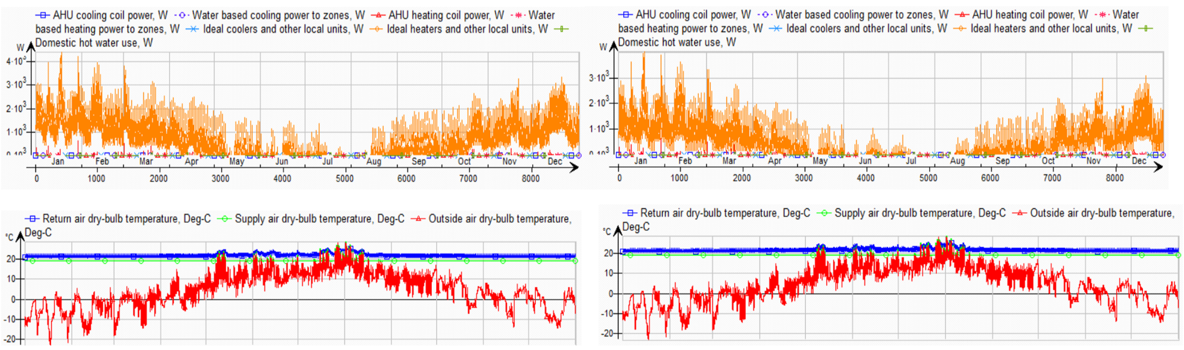
Table 5.1: Mean air and operative temperature (electric heating)

	Variables	
	Mean air temperature, Deg-C	Operative temperature, Deg-C
January	21.0	20.72
February	21.0	20.72
March	21.01	20.74
April	21.04	20.79
May	21.32	21.2
June	21.51	21.46
July	22.17	22.15
August	21.99	21.94
September	21.1	20.91
October	21.04	20.79
November	21.01	20.73
December	21.01	20.72
mean	21.27	21.08
mean*8760.0 h	186335.5	184641.1
min	21.0	20.72
max	22.17	22.15

Table 5.2: Temperature dissatisfaction (electric heating)

Percentage of hours when operative temperature is above 27°C in worst zone	**1 %**
Percentage of hours when operative temperature is above 27°C in average zone	**0 %**
Percentage of total occupant hours with thermal dissatisfaction	**10 %**

Figure 5.1: Design temperatures in main area (electric heating)



From Table 5.1 the mean and operative temperatures are mapped annually in the main area of the apartment (kitchen and living room). Table 5.2 illustrates the temperature dissatisfaction in the whole building. The maximum temperatures occur in the bathroom, due to the equipment loads in combination with the solar heat gain through the E/W facing windows. The solution to reducing the overheating in this area was to schedule the windows with an hourly opening in the summer months, to allow fresh air into the zones in combination with the HVAC-system.

From Figure 5.1, the main heating is electric heating and the air-to-air-heat pump. The floor heating is based on traditional underfloor electrical heating, with an emitted power of 70 W/m^2 in the living room, 60 W/m^2 in the bathroom and 40 W/m^2 in the bedrooms. Due to overheating and thermal comfort, and the size of the building, the only supply heat is placed in the living room area. It consists of an air-to-air heat pump. The total heat power is 6.0kW w/ COP 3.2.

5.1.2 Simulation 1 and 2

Month	Walls	Roof	Floor	Windows	Doors	Thermal bridges
1	-318.5	-174.9	-19.0	-232.7	-78.3	-126.7
2	-255.6	-147.2	-16.3	-194.1	-62.6	-105.2
3	-228.9	-146.6	-16.9	-190.9	-55.6	-102.8
4	-158.6	-116.6	-15.3	-148.8	-37.5	-79.5
5	-59.3	-80.0	-13.2	-95.2	-12.5	-48.1
6	-27.4	-63.5	-13.2	-74.0	-4.3	-36.8
7	-14.3	-55.9	-14.5	-63.1	-1.4	-30.3
8	-32.2	-57.0	-9.7	-67.5	-7.0	-33.1
9	-95.9	-78.0	-7.9	-96.1	-22.9	-49.4
10	-170.1	-106.8	-10.5	-137.2	-41.7	-72.6
11	-223.2	-126.0	-11.4	-164.8	-54.7	-88.7
12	-276.6	-151.2	-13.8	-200.6	-68.0	-108.6
Total	-1860.5	-1303.6	-161.7	-1665.0	-446.5	-881.9
During heating	-1723.3	-1145.2	-76.3	-1527.3	-421.9	-809.5
During cooling	-9.7	-23.5	-33.4	-17.0	1.2	-7.7
Rest of time	-127.5	-134.9	-52.0	-120.6	-25.8	-64.7

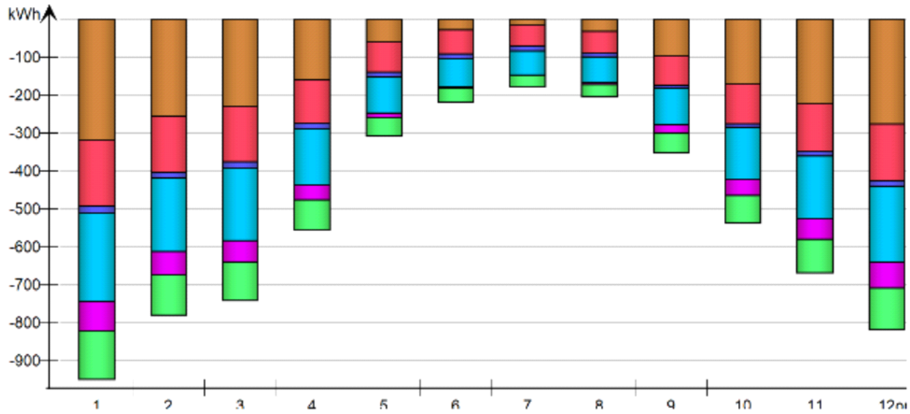


Figure 5.2:
Envelope transmission: simulation 1

		Purchased energy		Peak demand
		kWh	kWh/m^2	kW
	Lighting, facility	308	5.3	0.17
	Equipment, facility	1061	18.3	1.9
	HVAC aux	272	4.7	0.19
	Electric heating	3226	55.7	2.68
	Total, Facility electric	4867	84.1	
	Total	4867	84.1	

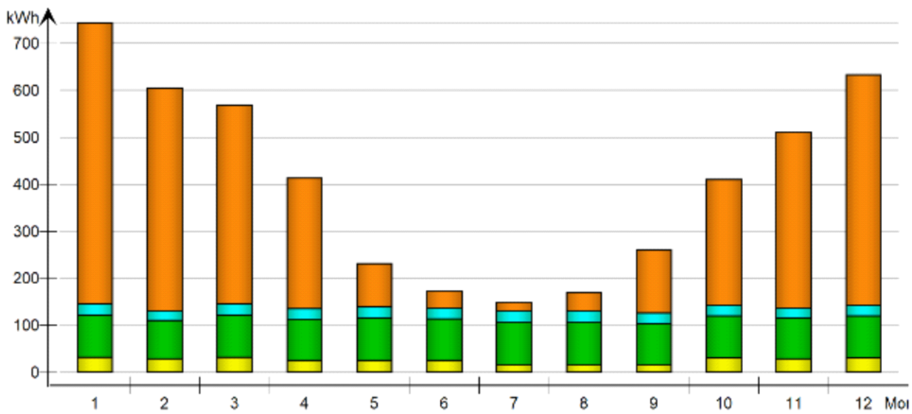


Figure 5.3:
Energy use: simulation 1

Month	Envelope & Thermal bridges	Internal Walls and Masses	Window & Solar	Mech. supply air	Infiltra-tion & Openings	Occu-pants	Equip-ment	Lighting	Local heating units	Local cooling units
1	-708.5	-0.3	-224.7	-196.8	0.0	44.8	90.0	34.2	960.8	0.0
2	-579.5	-0.2	-181.7	-154.8	0.0	40.6	81.5	30.9	762.7	0.0
3	-542.9	-0.1	-165.7	-144.1	0.0	45.2	90.2	34.2	682.3	0.0
4	-399.6	-0.4	-112.3	-101.6	0.0	44.3	87.2	27.2	454.6	0.0
5	-211.4	-1.1	-44.6	-58.5	-0.1	46.4	90.1	28.2	151.3	0.0
6	-145.0	-1.4	-20.4	-52.5	-0.3	45.9	87.2	27.2	59.8	0.0
7	-117.0	-1.1	-10.2	-45.1	-10.1	48.3	90.2	15.7	30.0	0.0
8	-138.0	0.9	-24.5	-48.4	-11.2	48.3	90.1	15.8	66.4	0.0
9	-250.1	-1.0	-66.6	-57.6	0.0	45.9	87.3	15.2	226.8	0.0
10	-393.5	-0.1	-117.9	-95.7	0.0	46.7	90.2	31.4	438.7	0.0
11	-496.2	-0.2	-152.2	-126.1	0.0	44.4	87.3	30.4	612.0	0.0
12	-611.5	-0.1	-194.2	-158.6	0.0	45.4	90.2	31.4	797.2	0.0
Total	-4593.2	-5.2	-1314.9	-1239.8	-21.5	546.2	1061.3	321.8	5242.7	0.0
During heating (MIXED h)	-4309.5	90.8	-1266.6	-1069.8	124.3	429.7	492.4	241.9	5243.1	0.0
During cooling (MIXED h)	-58.4	-34.2	-8.1	-24.1	-56.4	31.0	143.0	16.0	0.1	0.0
Rest of time	-225.3	-61.8	-40.2	-145.9	-89.4	85.5	425.9	63.9	-0.5	0.0

Figure 5.4: Energy balance: simulation 1

Month	Walls	Roof	Floor	Windows	Doors	Thermal bridges
1	-204.2	-171.9	-8.9	-179.6	-80.2	-62.5
2	-164.2	-144.6	-9.3	-149.9	-63.9	-52.0
3	-147.0	-143.8	-11.4	-147.6	-56.4	-50.9
4	-102.8	-114.1	-11.9	-115.1	-37.5	-39.6
5	-40.5	-79.3	-14.0	-73.9	-12.2	-24.1
6	-21.0	-63.5	-14.4	-58.0	-4.2	-18.6
7	-12.8	-56.7	-15.7	-50.3	-1.7	-15.6
8	-22.7	-57.5	-10.5	-53.5	-7.1	-17.0
9	-62.6	-76.9	-7.7	-74.4	-22.6	-24.7
10	-108.6	-104.6	-6.9	-106.1	-41.8	-36.1
11	-143.0	-123.5	-6.9	-127.4	-55.2	-44.0
12	-177.5	-148.6	-7.8	-155.0	-69.2	-53.7
Total	-1206.9	-1285.0	-125.3	-1290.9	-451.9	-438.7
During heating	-1150.3	-1166.9	-43.8	-1197.5	-446.1	-409.4
During cooling	-8.4	-23.2	-26.9	-16.8	0.8	-4.7
Rest of time	-48.2	-94.9	-54.6	-76.6	-6.6	-24.6

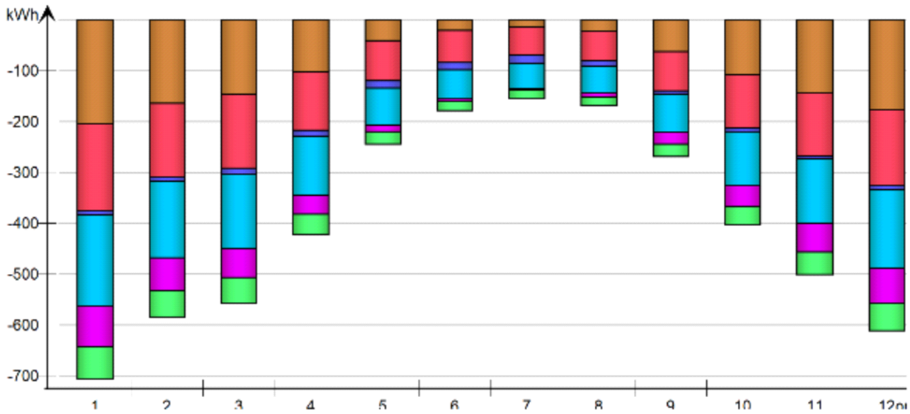


Figure 5.5: Envelope transmission: simulation 2

		Purchased energy		Peak demand
		kWh	kWh/m^2	kW
	Lighting, facility	308	5.3	0.17
	Equipment, facility	1062	18.3	1.9
	HVAC aux	272	4.7	0.19
	Electric heating	2150	37.1	2.28
	Total, Facility electric	3792	65.5	
	Total	3792	65.5	

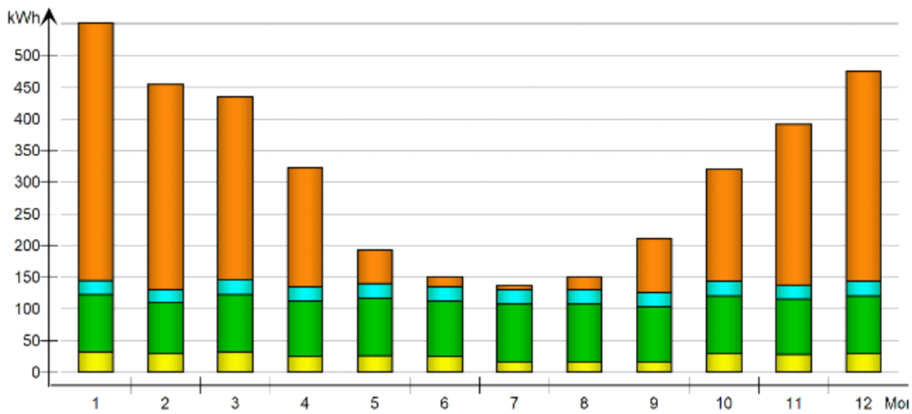


Figure 5.6: Energy use: simulation 2

Month	Envelope & Thermal bridges	Internal Walls and Masses	Window & Solar	Mech. supply air	Infiltration & Openings	Occupants	Equipment	Lighting	Local heating units	Local cooling units
1	-527.8	0.0	-169.8	-196.7	0.0	39.6	90.1	32.4	731.8	0.0
2	-433.9	-0.2	-136.1	-155.0	0.0	35.9	81.5	29.2	578.4	0.0
3	-409.4	-0.1	-121.6	-144.4	0.0	40.0	90.2	32.3	512.8	0.0
4	-305.9	-0.5	-78.6	-101.7	0.0	39.1	87.2	25.4	335.1	0.0
5	-170.0	-1.1	-24.1	-58.4	-0.1	40.9	90.2	26.3	97.1	0.0
6	-121.7	-1.3	-5.0	-52.9	-0.4	40.5	87.3	25.4	28.8	0.0
7	-102.6	-1.2	2.2	-47.2	-11.4	42.5	90.2	16.5	11.7	0.0
8	-114.8	0.9	-10.9	-50.4	-12.1	42.6	90.2	16.5	37.5	0.0
9	-194.5	-1.1	-45.4	-57.9	0.0	40.5	87.4	16.0	155.6	0.0
10	-298.0	-0.1	-87.0	-95.9	0.0	41.2	90.1	29.5	320.4	0.0
11	-372.6	-0.1	-114.3	-126.2	0.0	39.2	87.3	28.6	458.1	0.0
12	-456.8	0.1	-147.3	-158.5	0.0	40.2	90.1	29.5	602.5	0.0
Total	-3507.8	-4.6	-937.9	-1245.4	-23.9	482.2	1061.7	307.7	3869.7	0.0
During heating (MIXED h)	-3216.2	91.6	-902.1	-1065.0	132.6	360.9	487.3	222.3	3869.5	0.0
During cooling (MIXED h)	-62.5	-33.3	-5.0	-28.5	-61.3	31.3	149.1	17.7	0.1	0.0
Rest of time	-229.1	-62.9	-30.8	-151.9	-95.2	90.0	425.3	67.7	0.1	0.0

Figure 5.7: Energy balance: simulation 2

The first simulation was constructed according to the Norwegian TEK-17 standard. The envelope and window set up was designed in accordance with the requirements described in Table 4.1, with normalized thermal bridge value was set to 0.03 W/m^{2}K. From Figure 5.3, the simulations calculated 84.1 kWh/m^2 an. energy consumption to reach the comfort levels throughout the year.

The second resulting simulation was constructed according to the Norwegian nZEB specifications. The envelope and window set up was designed in accordance with the requirements described in Table 4.1, with normalized thermal bridge value was set to 0.015 W/m^{2}K. From Figure 5.6, the simulations calculated 65.5 kWh/m^2 an. energy consumption to reach the comfort levels throughout the year.

Figure 5.2 and Figure 5.5 illustrates the envelope transmittance through the building. It indicates that the walls and windows caused major heat loss through the building. The heat loss from the floor had less significance, because of the electric underfloor heating in the slab. Figure 5.3 and Figure 5.6 shows the monthly delivered energy to the apartment building. It indicates that the majority of the energy was used as electric heating of the apartment building.

Figure 5.4 and Figure 5.7 shows the annual energy balance. In addition, net losses, mechanical air supply and heat losses through windows, thermal bridges and envelope are mapped. The table also includes the total energy balance for each month. As expected, the major contributor to the heat losses was through the envelope and thermal bridges. The results also show that heat from equipment had a significant impact on the energy balance.

5.2 Water borne underfloor heating

5.2.1 Mean air and operative temperature (district heating)

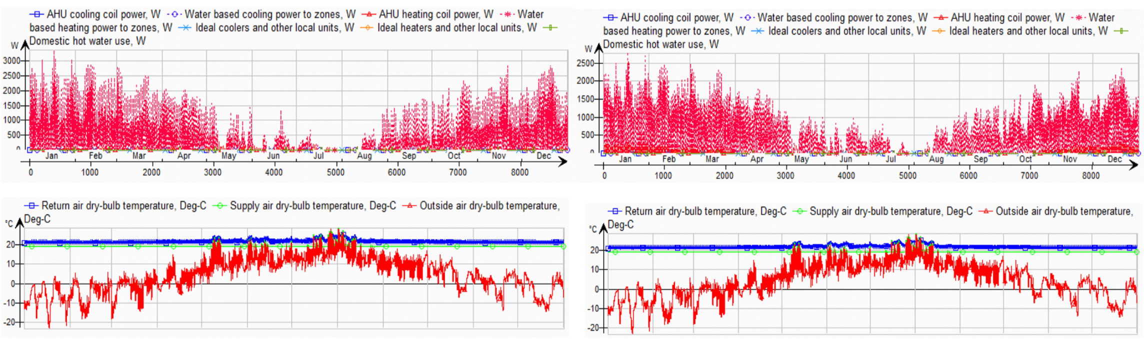
Table 5.3: Mean air and operative temperature (district heating)

	Variables	
	Mean air temperature, Deg-C	Operative temperature, Deg-C
January	21.07	21.06
February	21.08	21.07
March	21.1	21.09
April	21.13	21.13
May	21.42	21.44
June	21.62	21.64
July	22.25	22.27
August	22.06	22.08
September	21.15	21.16
October	21.11	21.11
November	21.09	21.09
December	21.08	21.07
mean	21.35	21.35
mean*8760.0 h	187006.0	187054.9
min	21.07	21.06
max	22.25	22.27

Table 5.4: Temperature dissatisfaction (district heating)

Percentage of hours when operative temperature is above 27°C in worst zone	1 %
Percentage of hours when operative temperature is above 27°C in average zone	0 %
Percentage of total occupant hours with thermal dissatisfaction	10 %

Figure 5.8: Design temperatures in main area (district heating)



From Table 5.3 the mean and operative temperatures are mapped annually in the main area of the apartment (kitchen and living room). Table 5.4 illustrates the temperature dissatisfaction in the whole building. The maximum temperatures occur in the bathroom, due to the equipment loads in combination with the solar heat gain through the E/W facing windows. The solution to reducing the overheating in this area was to schedule the windows with an hourly opening in the summer months, to allow fresh air into space.

Due to the stable underfloor water heating, no additional heating was necessary from the simulation, i.e., the simulation gave polite and reasonable results without using an air-to-air heat pump. The design power and temperature differences were used to calculate supply mass flow for ideal floor heating. The emitted power from the water radiator was set to 40W/m^2 (as a standard setting in IDA ICE). The actual emitted power may become smaller if the heat resistance in the floor construction is too large. As a default setting in IDA ICE, the coil mass flow temperature control (3-way valve) was set to 3°C. The floor heat coil system was located 0.02m under the slab surface and becomes a tempered layer at the given depth in the floor construction.

The heat transfer is normally set to 6 W/m^{2}K for aluminum fins in a wooden construction and to 30 W/m^2 for pipes immersed in concrete. Because the floor construction is a concrete slab, the value was set to 10 W/m^{2}K. This was done as an assumption because the value had an insignificant effect on energy performance. However, the total heat transfer in normally largely determined by the resistance in the floor construction above and the coil, in which case this parameter becomes less important.

When considering the use of district heating as the main energy carrier to the building, the results from IDA ICE gave higher energy performing results than expected. Because the insulated piping system is not 100% insulated, heat losses thought the piping system occurred and gave higher energy demand.

5.2.2 Simulation 3 and 4

Month	Walls	Roof	Floor	Windows	Doors	Thermal bridges
1	-316.8	-173.4	-11.6	-234.7	-80.5	-126.1
2	-253.7	-145.6	-11.2	-195.5	-64.1	-104.7
3	-226.2	-144.6	-13.1	-191.7	-56.6	-102.3
4	-155.4	-114.3	-13.0	-148.8	-37.7	-79.2
5	-57.5	-78.8	-14.4	-94.4	-12.0	-47.8
6	-25.9	-62.6	-14.6	-73.1	-3.8	-36.4
7	-13.2	-55.3	-16.1	-62.5	-1.1	-30.1
8	-31.1	-56.2	-10.2	-67.0	-6.6	-32.9
9	-94.7	-76.9	-6.7	-95.7	-22.7	-49.3
10	-167.5	-104.8	-7.0	-137.3	-41.9	-72.4
11	-220.6	-124.0	-7.7	-165.3	-55.4	-88.3
12	-274.6	-149.6	-9.7	-202.0	-69.5	-108.2
Total	-1837.3	-1286.1	-135.3	-1668.0	-451.9	-877.7
During heating	-1793.0	-1190.0	-51.8	-1580.5	-448.9	-834.9
During cooling	-3.3	-18.6	-28.4	-14.8	1.0	-6.4
Rest of time	-41.0	-77.5	-55.1	-72.7	-4.0	-36.4

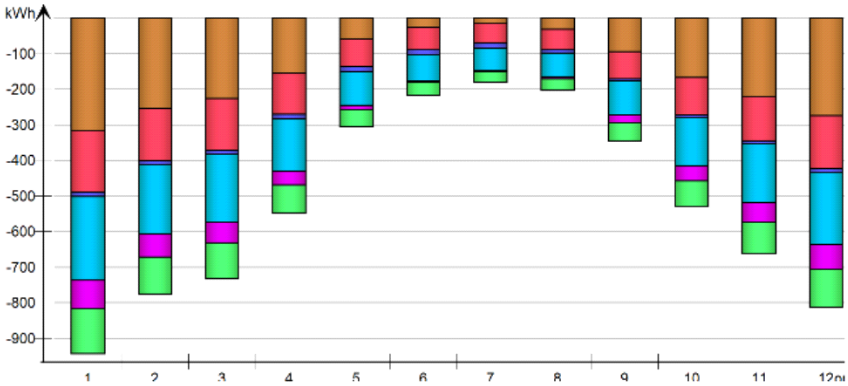


Figure 5.9: Envelope transmission: simulation 3

	Used energy		Purchased energy		Peak demand
	kWh	kWh/m^2	kWh	kWh/m^2	kW
Lighting, facility	308	5.3	308	5.3	0.17
Equipment, facility	1062	18.3	1062	18.3	1.9
HVAC aux	278	4.8	278	4.8	0.19
Total, Facility electric	1648	28.5	1648	28.5	
District heating	5377	92.9	5377	92.9	5.5
Total, Facility district	5377	92.9	5377	92.9	
Total	7025	121.3	7025	121.3	
	Generated energy		Sold energy		Peak generated
CHP electricity	0	0.0	0	0.0	0.0
Total, Produced electric	0	0.0	0	0.0	
Grand total	7025	121.3	7025	121.3	

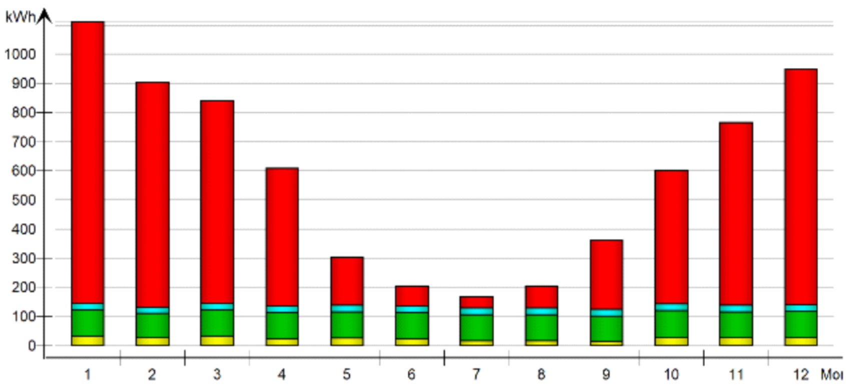


Figure 5.10: Energy use: simulation 3

Month	Envelope & Thermal bridges	Internal Walls and Masses	Window & Solar	Mech. supply air	Infiltration & Openings	Occupants	Equipment	Lighting	Local heating units	Local cooling units
1	-717.3	-0.3	-222.8	-41.2	-0.0	39.5	90.2	32.3	820.9	-0.0
2	-586.9	-0.5	-180.2	-37.5	-0.0	35.8	81.5	29.2	659.8	-0.0
3	-550.9	-0.7	-164.9	-42.8	-0.0	39.9	90.2	32.3	597.9	-0.0
4	-407.5	-1.4	-112.3	-43.0	-0.0	39.1	87.4	25.4	413.4	-0.0
5	-213.1	-0.9	-45.2	-44.9	-0.1	40.9	90.1	26.3	147.1	-0.1
6	-145.1	-1.1	-20.7	-47.8	-0.3	40.5	87.3	25.4	62.8	-0.1
7	-116.5	-1.1	-10.5	-43.7	-9.5	42.6	90.2	16.5	33.2	-0.2
8	-138.9	0.9	-24.7	-44.7	-10.6	42.6	90.1	16.5	68.4	-0.1
9	-254.1	-0.5	-67.0	-44.3	0.0	40.5	87.2	16.0	222.3	-0.0
10	-401.7	-0.9	-117.9	-43.6	0.0	41.2	90.4	29.5	404.4	-0.0
11	-503.8	-0.8	-151.7	-41.4	-0.0	39.2	87.4	28.6	543.4	-0.0
12	-618.3	-0.4	-192.8	-41.8	-0.0	40.1	90.3	29.5	694.9	-0.0
Total	-4654.1	-7.9	-1310.7	-516.7	-20.5	482.1	1062.4	307.5	4668.5	-0.6
During heating (MIXED h)	-4175.0	136.6	-1223.7	-279.0	138.5	351.5	212.7	191.5	4669.5	0.0
During cooling (MIXED h)	-73.2	-53.0	-12.4	-32.5	-82.8	32.0	211.7	22.4	0.0	-0.6
Rest of time	-405.9	-91.5	-74.6	-205.2	-76.2	98.6	638.0	93.6	-0.9	-0.0

Figure 5.11: Energy balance: simulation 3

Month	Walls	Roof	Floor	Windows	Doors	Thermal bridges
1	-209.7	-176.1	-12.5	-181.4	-78.5	-63.6
2	-168.9	-148.1	-11.6	-151.3	-62.7	-52.8
3	-151.5	-147.5	-12.8	-148.9	-55.8	-51.6
4	-106.5	-117.1	-12.2	-116.1	-37.6	-39.9
5	-42.4	-80.8	-11.7	-75.1	-12.8	-24.4
6	-22.2	-64.4	-12.1	-58.9	-4.6	-18.9
7	-13.6	-57.3	-13.6	-50.9	-1.9	-15.8
8	-23.8	-58.4	-9.2	-54.2	-7.5	-17.2
9	-64.1	-78.4	-7.4	-75.4	-23.0	-24.9
10	-112.2	-107.5	-9.5	-107.2	-41.8	-36.5
11	-147.1	-126.9	-10.2	-128.6	-54.7	-44.5
12	-182.4	-152.4	-12.3	-156.5	-68.1	-54.5
Total	-1244.4	-1314.9	-135.0	-1304.5	-448.9	-444.7
During heating	-1093.7	-1117.3	-45.4	-1161.1	-418.1	-396.1
During cooling	-17.8	-31.9	-33.0	-21.1	0.9	-6.3
Rest of time	-132.9	-165.7	-56.6	-122.3	-31.7	-42.3

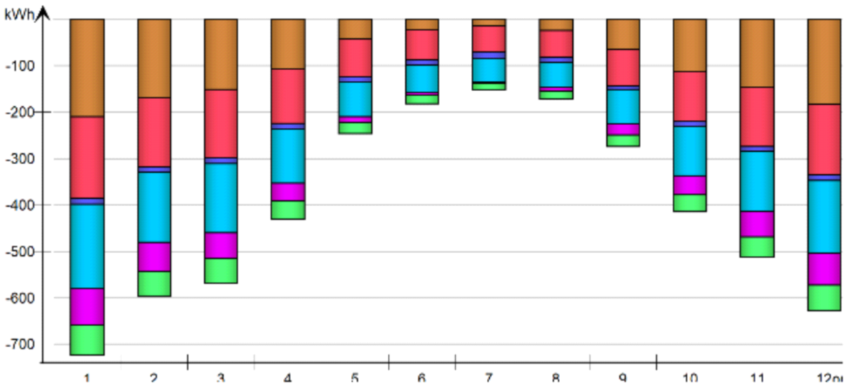


Figure 5.12: Envelope transmission: simulation 4

	Used energy		Purchased energy		Peak demand
	kWh	kWh/m^2	kWh	kWh/m^2	kW
Lighting, facility	307	5.3	307	5.3	0.17
Equipment, facility	1063	18.4	1063	18.4	1.9
HVAC aux	275	4.8	275	4.8	0.19
Total, Facility electric	1645	28.4	1645	28.4	
District heating	3967	68.5	3967	68.5	6.01
Total, Facility district	3967	68.5	3967	68.5	
Total	5612	96.9	5612	96.9	
	Generated energy		Sold energy		Peak generated
CHP electricity	0	0.0	0	0.0	0.0
Total, Produced electric	0	0.0	0	0.0	
Grand total	5612	96.9	5612	96.9	

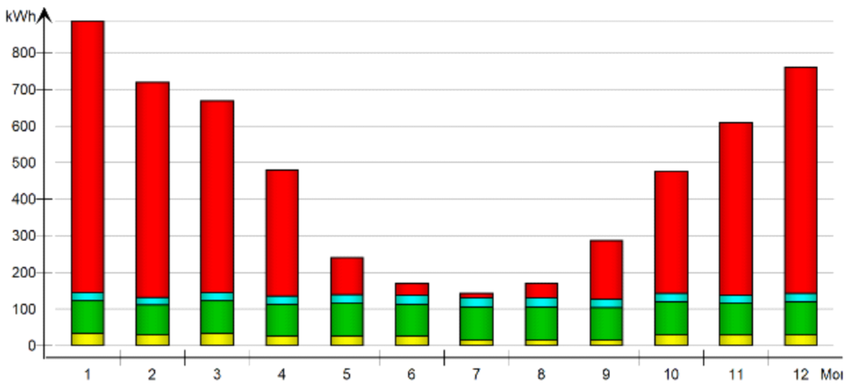


Figure 5.13: Energy use: simulation 4

Month	Envelope & Thermal bridges	Internal Walls and Masses	Window & Solar	Mech. supply air	Infiltra-tion & Openings	Occu-pants	Equip-ment	Lighting	Local heating units	Local cooling units
1	-540.2	-1.6	-171.5	-44.9	-0.0	39.5	90.5	32.3	599.0	0.0
2	-444.1	-1.6	-137.5	-40.7	-0.0	35.8	81.7	29.2	479.4	0.0
3	-419.1	-1.7	-123.0	-45.1	-0.0	39.9	90.3	32.3	428.2	0.0
4	-313.3	-1.9	-79.7	-44.3	-0.0	39.1	87.4	25.4	288.7	0.0
5	-172.2	-1.0	-25.3	-46.1	-0.2	40.9	90.1	26.3	88.1	-0.0
6	-122.2	-1.1	-5.8	-49.6	-0.5	40.5	87.2	25.4	27.0	-0.0
7	-102.2	-1.2	1.6	-46.7	-12.7	42.5	90.2	16.5	12.8	-0.0
8	-116.1	0.9	-11.6	-47.6	-13.6	42.6	90.0	16.5	38.1	-0.0
9	-197.8	-0.6	-46.3	-45.1	0.0	40.5	87.1	15.9	146.7	0.0
10	-307.6	-1.5	-88.0	-45.4	-0.0	41.2	90.2	29.5	283.3	0.0
11	-383.4	-1.7	-115.4	-43.8	-0.0	39.2	87.4	28.6	391.2	0.0
12	-469.7	-1.9	-148.7	-44.9	-0.0	40.1	90.5	29.5	508.1	0.0
Total	-3588.0	-14.8	-951.3	-544.1	-27.1	481.6	1062.6	307.3	3290.8	-0.0
During heating (MIXED h)	-3070.3	136.0	-876.9	-281.9	132.8	324.9	188.2	180.3	3280.5	0.0
During cooling (MIXED h)	-88.0	-60.1	-12.8	-42.6	-103.6	40.4	249.3	27.6	3.2	0.0
Rest of time	-429.7	-90.7	-61.6	-219.6	-56.3	116.3	625.1	99.4	7.1	-0.0

Figure 5.14: Energy balance: simulation 4

The third simulation was constructed according to the Norwegian TEK-17 standard. The envelope and window set up was designed in accordance with the requirements described in Table 4.1, with normalized thermal bridge value was set to 0.03 W/m^2K. From Figure 5.10, the simulations calculated 121.3 kWh/m^2 an. energy consumption to reach the comfort levels throughout the year.

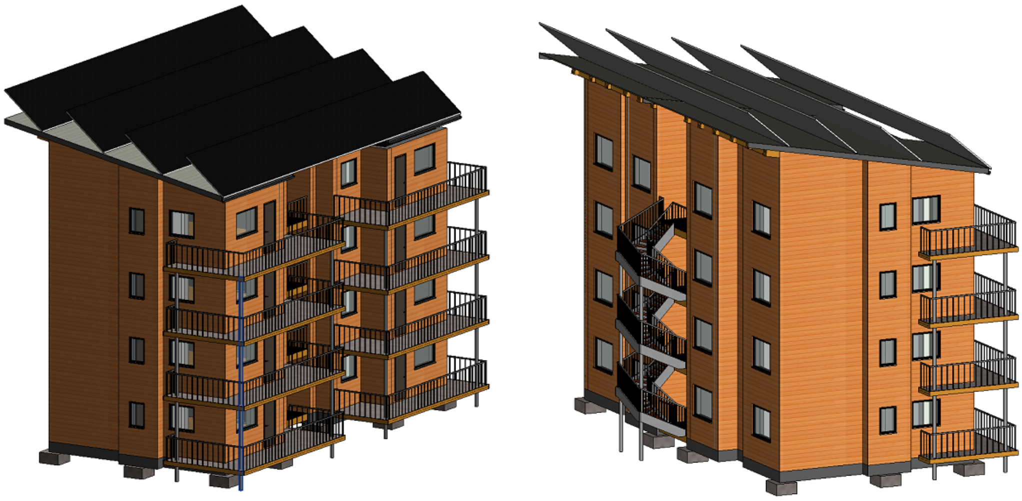
The fourth simulation was constructed according to the Norwegian nZEB specifications. The envelope and window set up was designed in accordance with the requirements described in Table 4.1, with normalized thermal bridge value was set to 0.015 W/m^2K. From Figure 5.13, the simulations calculated 85.3 kWh/m^2 an. energy consumption to reach the comfort levels throughout the year.

Figure 5.9 and Figure 5.12 illustrates the envelope transmittance through the building. It indicates that the walls and windows caused major heat loss through the building. The heat loss from the floor was less significant, because of the water heating in the slab. Figure 5.10 and Figure 5.13 shows the monthly delivered energy to the apartment building. It indicates that the majority of the energy was used as underfloor water heating of the apartment building.

Figure 5.11 and Figure 5.14 shows the annual energy balance. In addition, net losses, mechanical air supply and heat losses through windows, thermal bridges and envelope are mapped. The table also includes the total energy balance for each month. As expected, the major contributor to the heat losses was through the envelope and thermal bridges. The results also show that heat from equipment had a significant impact on the energy balance.

5.3 Photo voltaic optimization

Figure 5.15: Photo voltaic visualization



Adding photovoltaic systems to the model also gave good results, even though IDA ICE especially gave a simplified view of the PV system. The program gave an optimum tilt of the panels of 55°. In the model, the optimal PV-installation was intended to be four rows of the 60 m^2 PV-panels connected together. Because the self-shading between panels, the tilt was set to 40° using IDA ICE and 35° using PVGIS. Partial shading between panels could cause major mismatch for the generated energy from the panels, which is not included when simulating the generated electricity from the panels. The models in IDA ICE are connected in series, and the electrical mismatching would probably lowering the energy output from the panels. Other obstacles, like other building and surrounding topography, is also another factor not included in the generated energy.

Applying photo voltaic to the roof, enabled the building to achieve zero energy standards lower than 50 kWh/m^2 an. To check the simulated photovoltaic energy production, the results were coupled with the results using PVGIS [27]. The data obtained from PVGIS contained a more detailed set of variables that affects the power production from the panels. The assumed input variables were used for the calculations. Table 5.5 illustrates the annual production from the photo voltaic system from both the in-built photo voltaic tool in IDA ICE and PVGIS. The sensitivity analysis then the price escalation of the total energy increases, was also included in the results. A high energy price development corresponds to a increased net present value of future costs.

Simulation tool	Efficiency	Month											
		January	February	March	April	May	June	July	August	September	October	November	December
IDA-ICE kWh	16%	142	277.3	507.2	537.2	810.4	779.1	823.8	713.8	519.5	364.2	163.2	82.2
	18%	166.3	319.5	575.9	606.5	905.3	868.8	916.7	794.7	581.9	412.7	188.8	97.5
	20%	190.9	361.6	644.4	675.8	1000.5	958.6	1009.9	875.4	644.1	461.1	214.5	122.9

Simulation tool	Efficiency	Month											
		January	February	March	April	May	June	July	August	September	October	November	December
PVGIS kWh	16%	66.9	201	387	511	604	608	571	474	333	207	94.8	26.5
	18%	75.3	226	435	575	680	684	643	533	375	233	107	29.8
	20%	83.6	252	484	638	755	760	714	593	416	259	119	33.2

Table 5.5: Annual electricity production

Figure 5.16: Photo voltaic payback time (IDA ICE)

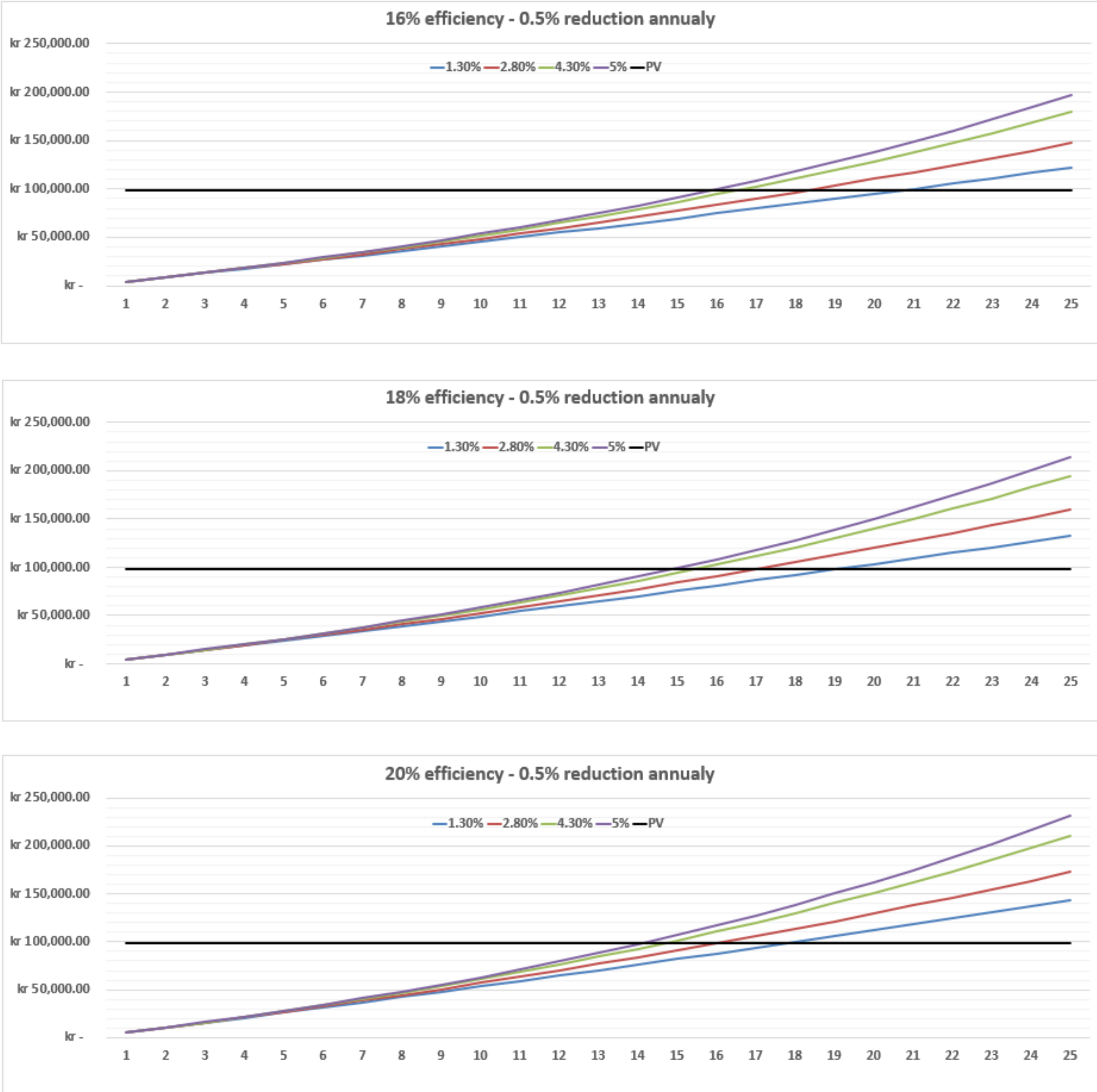


Table 5.6: Break even (IDA ICE)

IDA-ICE												
Efficiency	16%				18%				20%			
Escalation	1.30%	2.80%	4.30%	5.00%	1.30%	2.80%	4.30%	5.00%	1.30%	2.80%	4.30%	5.00%
Break even	20.9	18.3	16.5	15.8	19.1	17	15.4	14.8	17.8	15.9	14.7	14

Figure 5.17: Photo voltaic payback time (PVGIS)

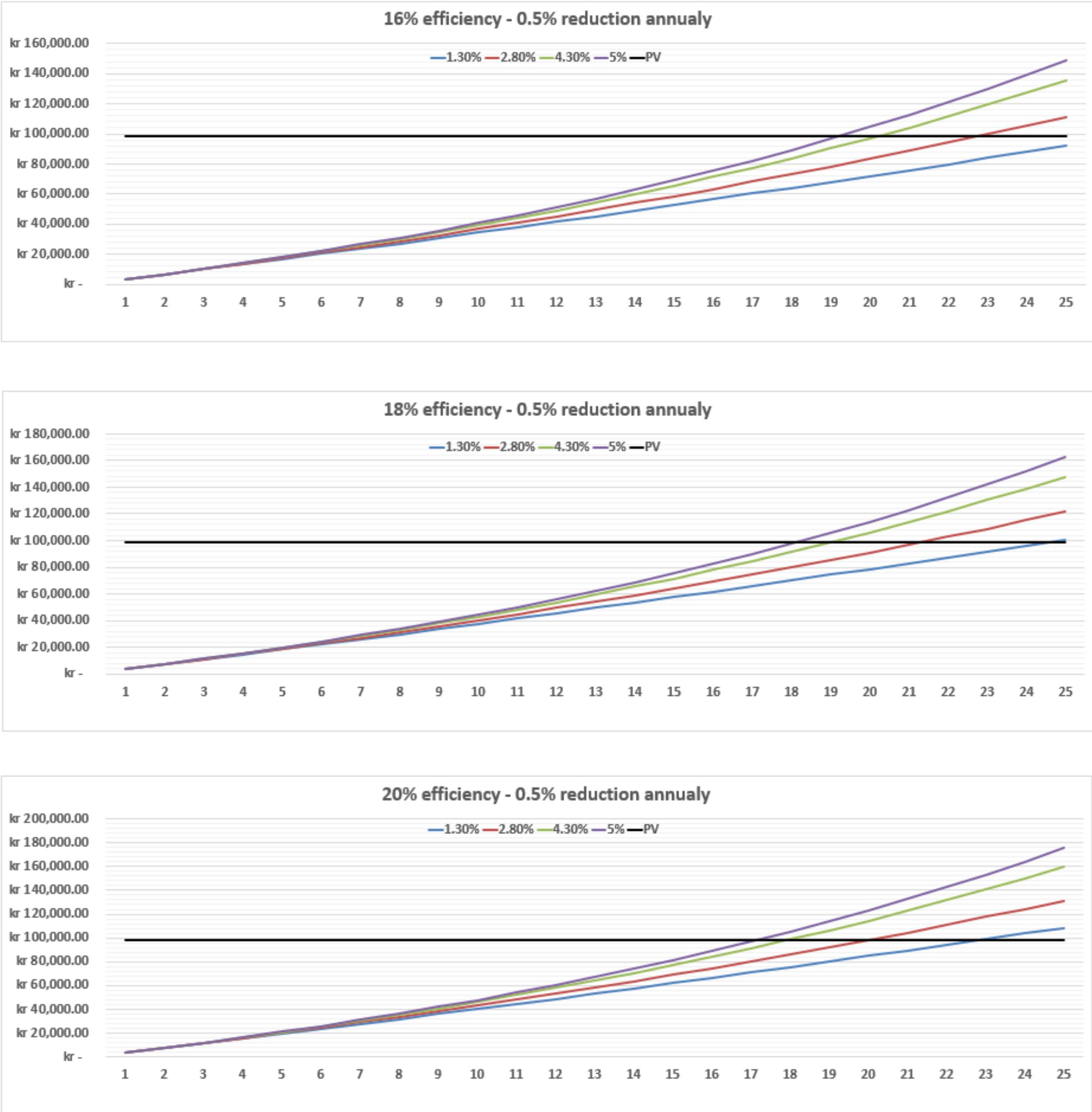


Table 5.7: Break even (PVGIS)

	PVGIS											
Efficiency	16%				18%				20%			
Escalation	1.30%	2.80%	4.30%	5.00%	1.30%	2.80%	4.30%	5.00%	1.30%	2.80%	4.30%	5.00%
Break even	26	22.8	20.2	19	24.6	21.2	19	18.2	22.9	20	17.9	17

Chapter 6

Discussion

6.1 Feedback IDA ICE

The costs of electricity from the grid and district heating are based on predicted price escalations, energy consumption of the building and the size of the building. Because the thesis aimed to find the cost premium of implementing renewable energy supply systems on-site, and use of district heating, it was therefore vital to use a program that gave reliable results. Hence, IDA ICE was proven to give sufficient results when calculating energy performance and energy consumption of the building. For the first to simulations with basic floor heating systems and air-to-air heat pump, the results gave reliable results, and the software worked fine.

Implementing a digital 3D-model and performing energy analysis, require collaboration in-between many different contractors and levels of professionals and disciplines. To evaluate a model properly, the plant temperature levels, combinations of energy systems, detailed sub-system efficiency's and part loads are just a sample of different factors that should be included in the scope. Availability of district heating infrastructure, underground heat sources and solar irradiance are other factors that need to be considered in a real survey.

The time it takes to model a building, largely depends on the complexity of the building retrofit. However, when modelling even more complex building with irregular geometry and largely different room and space with various areas of use, the accuracy may demand time-consuming calculations and resources. Hence, when working in the early design phases, it is important to find sufficient detail levels. In IDA ICE, this may include combining thermal zones, simplify the geometry and merging nearby windows connected to the same zone and room units within the buildings.

6.2 Simulation results

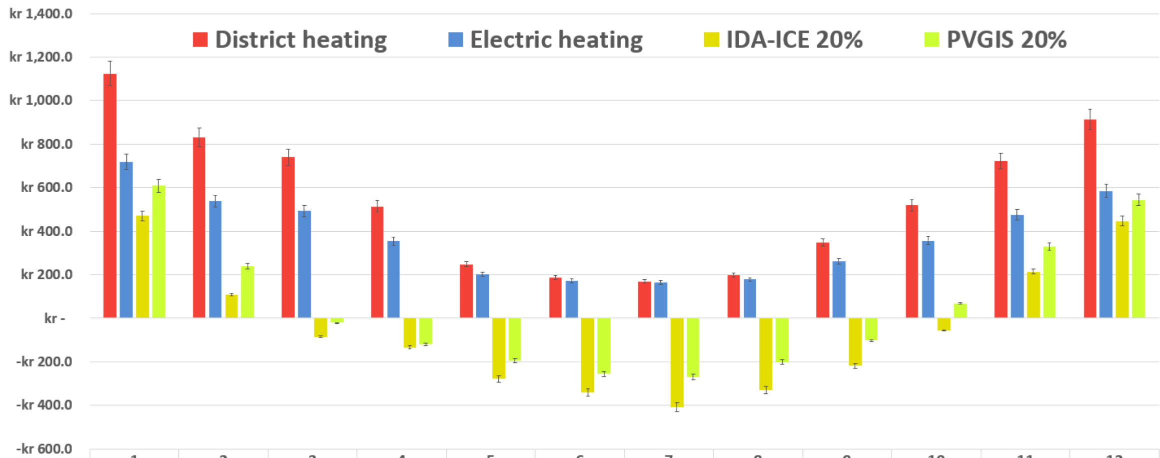
In this thesis, the performance of the low energy apartment building has been presented in terms of energy use, indoor air temperature as well as thermal comfort. IDA Indoor Climate and Energy was used to simulate the energy performance of the early-design building. By designing the building according to the nZEB-specifications rather than TEK-17, the energy consumption was reduced by 18.6 kWh/m^2 (electric heating and air-to-air non-ducted heat pump) and 24.4 kWh/m^2 (underfloor district heating). The results assumed no distribution losses for electric heating. However, for the district heating setup, an efficiency of 84% was chosen. In a real study, the extra energy and losses due to domestic hot water, heating and cooling units should be considered.

The suggested improvements included increasing the insulation to ZEB-standard, and use electric floor heating combined with air-to-air heat pump. The results showed significant improvement in building energy performance, compared to the district heating alternative. However, the lifespan of a heat pump can not outlive the district heating system. The component life span depend on the production and operations and maintenance. For the heat pump, it is necessary with regular maintenance, in addition to service performed by an authorized dealer.

The district heating system is also a great alternative as heating supply system. Even though the performance results from IDA ICE indicated a slightly higher energy performance, the district underfloor heating can be combined with waste water from the drain and spill hot water in the building.

District energy supply system offers flexibility to the energy system in several ways. This means that district heating plants are easier to use than renewable energy sources, such as solar and ambient heat (from sewage, sea, rock, soil by heat pump technology), although these alone cannot deliver all the necessary effects. Until 2020 and 2030, when we enter large amounts of uncontrollable power (power and power) into the power system, coupled with the massive population growth of cities, the need for new flexibility to stabilize power system fluctuations will be more important.

6.3 Annual heating prices



	1	2	3	4	5	6	7	8	9	10	11	12
District heating	kr 1,124.	kr 831.5	kr 740.0	kr 513.8	kr 248.7	kr 186.9	kr 169.6	kr 197.3	kr 348.0	kr 519.0	kr 722.3	kr 913.9
Electric heating	kr 718.6	kr 538.2	kr 492.2	kr 353.8	kr 202.7	kr 172.2	kr 164.2	kr 177.9	kr 262.6	kr 356.6	kr 475.0	kr 585.3
IDA-ICE 20%	469.9	109.9	-85.4	-133.3	-278.9	-340	-409.1	-328.4	-217.6	-55.6	214.9	446.1
PVGIS 20%	609.7	239.7	-19.9	-119	-194.2	-256.5	-270.5	-200.6	-103.1	68.2	330.7	544.3

Table 6.1: Price comparison: Error bars 5%

From Table 6.1, the electric floor heating and air-to-air non-ducted heat pump (6kW) was the favoured cost-optimal energy supply system for the apartment building. The simulating results from PVGIS and IDA ICE for the photo voltaic production, illustrates that the months of surplus production reach the highest values in June. Even though the the photo voltaic system lowers the needs for off-site energy supply from the grid, the surplus production and a low annual energy demand, do not outreach the need for energy production. From the slopes in Table 6.1, the simulation from IDA ICE gave a total electricity cost premium of NOK +600 annually. However, the more reliable and credible results were obtained from PVGIS. The results from this simulation tool gave an electric cost of NOK 600. The annual exported energy was estimated to NOK 1 700 and NOK 1 160, respectively.

The highly developed hydro power infrastructure in Norway contributes uncover the necessity of local energy production. The increased development of hydro plant stations, has a potential consequences of the future electricity prices. Increased production capacity contributes to the total supply of power. At the same time, climate change will help to influence the demand and supply of water to the power plants. Warmer weather will result in less demand for electricity for heating needs, while it may lead to increased snow supply and rainfall. The combination of increased supply and reduced demand may indicate that prices will decrease in the future, but there are many factors that will affect the final outcome.

Further, according to recent studies, the record high electricity price must be viewed in light of increased gas and coal prices and the significant price of CO_2 quotes in EU. The increased costs of power in Europa influences the power prices through import and export. In conclusion, for low energy buildings like the one constructed in this research, small scale photo voltaic system can not compare economically with low-cost grid supply electricity available.

6.4 Simulation comparison

The possibility for existing building to balance their own energy consumption is clear. However, achieving this would require very large solar photo voltaic system. Requiring buildings to comply with zero emission definitions, the potentially significant cost and technical feasibility issues come into play. New buildings can be designed in energy efficient manner to minimize the need for renewable energy, while existing buildings are constrained because of the constructional limitations.

From the resulting electricity production from both IDA ICE and PVGIS, the surplus energy reached high values during the warmer months, as expected. This strengthen the fact that energy efficient requirements lead to the installation of oversized energy systems. Table 6.1 also illustrates that on-site electricity demand and supply do not match temporally. Electricity is drawn from the grid when needed and fed back into the grid when there is excess, achieving zero import over a specified time period.

There is a balance between improvements of the building envelope and reliance on on-site electricity generation. Pursuing energy efficiency and renovation of the existing envelope, seems to be cost-effective for buildings. This specially in Norway, and other countries with high deviating temperature levels. I.e, the point at which it becomes cost-effective to turn to renewable energy will be different, as the upfront cost for adding more insulation and changing the envelope design is lower, compared to retrofit for energy efficient installation, like photo voltaic.

The energy-savings measures were applied to both the building envelope and the heating system. This included the impact of insulation, glazing and normalized thermal bridges. Insulation measures was taken for the floor, facade and roof. The insulation thickness varied from 260mm to 500mm for the roof and 175mm to 350mm for the facade walls. The insulation in the floor slab varied from 350mm to 500mm. The windows U-value was set to 0.8 W/m^2 for the base simulations, and 0.6 W/m^2 for the improved design. The normalized thermal bridge values were

0.03 W/mK and 0.015 W/mK, respectively.

As described in the theory, the concept of low energy building and zero energy buildings is to eliminate the net emissions during the lifetime to reach negative emissions. It forces both existing and new buildings to produce enough energy on-site, to compensate for carbon emissions due to the production of materials, construction, transportation, use and operation, disposal and recovery of materials. However, for low energy buildings with an initial low energy demand, this concept may not be feasible.

This study aimed to compare the energy performance of a conceptual building designed according to the Norwegian TEK-17 standard, and the proposed zero emission building standard. By investigating the energy performance using software, the reduction potential was compared.

Based on the case study and simulations in IDA ICE, several conclusions can be drawn. The design option with the lowest energy demand was found to be the optional concept building with electric floor heating and a air-to-air heat pump designed according to the ZEB specifications. By retrofitting the design from TEK-17 standard to nZEB, the energy demand reduction was found to be 22% for the electric heating option and 29.7% for the district heating alternative. The cost of retrofitting was found to be neglectable, compared to the cost of energy efficient measures, like the photo voltaic system. Furthermore, experimental verification of the demonstrated energy demand potential is recommended.

Conclusion

In conclusion, the object of analysis was a four-storey eight units apartment building with an intended location in Oslo, Norway. The apartments have the same design and size, with a total of 464 m^2 combined (58 m^2 each). From the results, it is clear that the investment of photo voltaic systems for producing electricity on such a small-scale is not a way to approach sustainable design. Due to the inherent emissions of producing photo voltaic and extraction of raw materials, the need of energy should be greater than the electricity for heating, lighting and domestic hot water in residential apartment buildings. However, photo voltaic is a great substitute for renewable electricity for huge plants and industrial premises that demand huge amounts of electricity.

By simplicity, technologies and agile construction due to daylight control, thermal insulation, low-emissivity windows and on-site production of energy can contribute well to decreased energy use in new commercial buildings.

Further, the upfront costs of sustainable green buildings, like ZEB, are higher due to the technical specifications. The research found that green building soft costs are higher than conventional projects due to incremental costs associated with the process of achieving a green building rating. This involves both application costs as well as additional consulting required under the various rating tools. The soft costs include architectural, structural engineering, legal fees, and other pre- and post-construction expenses. Other studies considered the component costs of ZEB. When researching the cost incentives associated with sustainable materials, many research papers found that although ZEB constructions have higher initial costs, the added expense is not severe if the life cycle cost (LCC) is considered.

Because of the newly adapted ZEB specifications, there is not enough literature available to claim that ZEB can displace traditional building practice. The same conclusion was drawn from the simulations. Reconciling theory and practice of additional costs for ZEB buildings remains a limited approach to account for the broader environmental and social costs associated with buildings. The cost savings associated with the construction of green buildings should be factored in along with operating benefits such as lower energy and water consumption. By implementing energy efficient measures, buildings can reduce their carbon footprint, thereby improving green buildings' life cycle cost effectiveness.

From the literature and the simulations, retrofitting the envelope design in combination with proper underfloor heating is a low-cost alternative to reduce the heating demand of the building and other residential apartment buildings. Even though retrofitting demand higher initial capital than constructing a low energy building from scratch, the retrofitting is a great alternative to reach sustainability, rather than installation of energy supply systems on site. By imploring architects and engineers to be innovative and daring by considering the use of salvaged building materials and types of equipment, the researches found the possibility to lower both embodied energy and initial cost.

Further work

When optimizing the energy use of buildings, it is important to apply a life cycle perspective to both the buildings and the energy supply systems. As stated, the building industry today already stands for a significant part of the total energy demand in the world. Designing new buildings with on-site producing energy supply systems may be a substitution that will contribute to a even greater share of this.

However, the photo voltaic solar panels in combination with electric space heating did achieve the lowest primary energy use. Because of the initial low space heating demand, this results are in contrast to recommendations of not using electricity as heating for passive houses and is important in the discussion on a possible conflict between low-energy construction and district heating.

The thesis found that the primary energy varied depending on the energy supply system. However, a significant part of the energy use may be demanded by domestic hot water. This should be considered for further research on sustainable building design.

For further analysis, the thesis finds it expedient to consider a broader range of energy supply systems. In IDA ICE, models for Ground source heat pump (GSHP) and Air-to-Water Heat Pump (AWHP) are included. Even though this option was not considered in the analysis, it is a proper environmentally friendly energy supply alternative. In IDA ICE, it is also possible to choose the type of heat exchanges, for example, a borehole for the GSHP option. From [24], the depth per kW installed capacity should be 20 metres (5 kW GSHP-system would require a 100 metres deep borehole). The plant model is constructed from a number of numerical codes and testings and should be consulted by professionals.

Input parameters in IDA ICE should be defined according to consulting and professionals. The mass flow is set to 1 litre/s brine flow per hole. The input setting for ground source borehole loop is described below:

Physical properties	**Description**
Ground	
CPGRD	Mass heat capacity of ground J/(Kg K)
LAMBGRD	Heat conductivity of ground W/(m K)
RHOGRD	density of ground kg/m^3
Grout	
CPGROUT	Mass heat capacity of grout J/(Kg K)
LAMBGROUT	Heat conductivity of grout W/(m K)
RHOGROUT	Density of grout kg/m^3
Pipe	
RPIPE	Radius pipe (m)
THICKPIPE	Thickness pipe (m)
CPPIPE	Mass heat capacity of pipe wall material J/(kg K)
LAMBPIPE	Heat conductivity of pipe wall material W/(m K)
Liquid	
LiqType	Ethyleneglycol (default)
TFREEZE	Liquid freezing point temperature Deg-C
LAMBLIQ	Heat conductivity of liquid W/(m K)

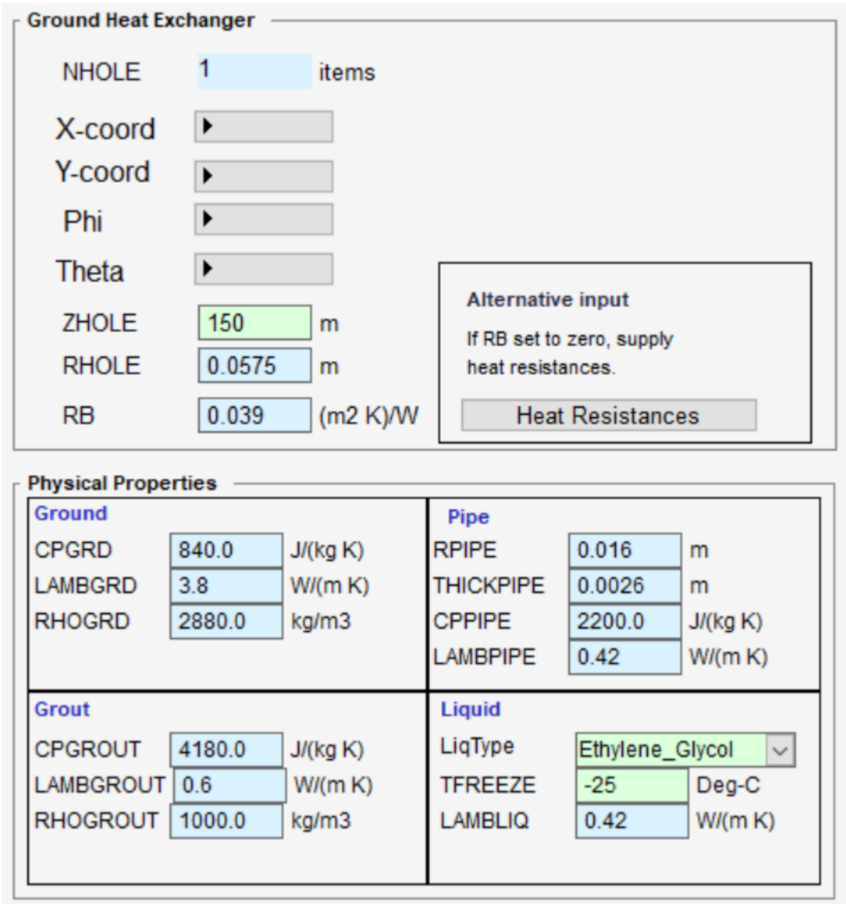


Figure 6.1: Input parameters

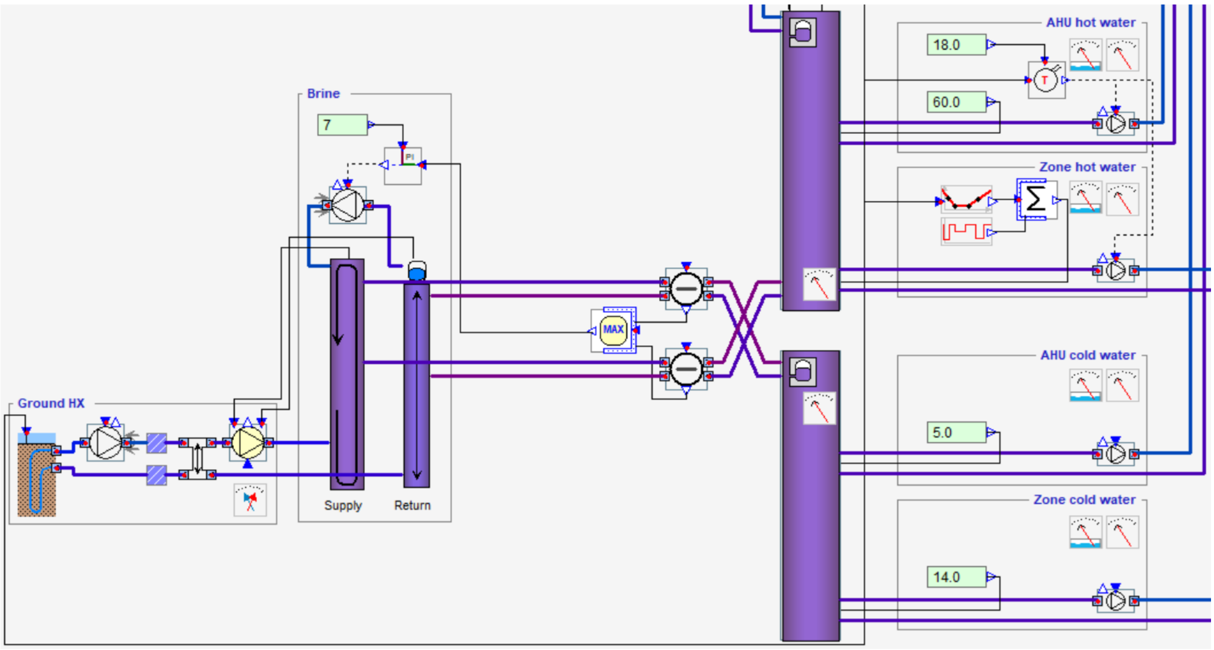


Figure 6.2: Ground source borehole loop
ESBO Plant model in IDA ICE

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Appendix

This appendix includes the paper submitted to the SBE19 Graz Conferance: Transition Towards a Net Zero Carbon Built Environment 11 - 14 September 2019
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BIM based iterative simulation - efficient building design: a case study

Martin Tallberg and Rolf André Bohne

Norwegian University of Science and Technology

E-mail: `martita@stud.ntnu.no`

Abstract. The aim of this case study was to evaluate the energy performance of utilizing different external materials reaching sustainable targets. Buildings are responsible for 40 percent of energy consumption and energy performance of buildings is a key element to achieving the European Unions goals. The EU has pledged to cut its consumption by 20 percent by 2020.

The main objective of this research was to explore the suitability of BIM for sustainability analysis at the conceptual design process. The procedure included analysis and discussion of the results for the lowest energy performance of materials. It was shown that changing the building envelope had a significant effect on the annual energy performance of the case building.

The limitations of the study was the limitations in the software. For further research, the paper finds it expedient to perform a even more detailed simuation analysis on the building design with other energy supply systems.

The value of the paper is to highlight the utilization of BIM to evaluate the material solutions to reach sustainable construction in the future, focusing on the need for lowering the energy consumption of tomorrows buildings.

1. Introduction

In 2015, the residential- and building sector counted for almost 40 percent of the energy consumption and 40 percent of the material use in Norway [4]. The energy- and environmental challenges make it necessarily to build with quality and aim for regular renewal of the existing building stock [3]. Sustainable quality in private homes, buildings, and built environments reduces environmental impacts and improves quality of life for future generations [4]

In the context of the European Union efforts to reduce the growing energy expenditure, it is widely recognized that the building sector has an important role [1]. Directive on the Energy Performance of Building (EPBD) imposes the adoption of measures to improve energy efficiency in buildings, in order to reach the objective of all new buildings to be nearly Zero Energy Building (nZEB) by 2020 [1]. It is obvious that the design of a zero-energy building is not yet profitable in terms of costs [2]. The cost of materials and energy consumption will differ from each country and regional areas, the age of the building and it occupancy use.

The present article will present the results of the BIM based iterative energy performing simulations performed in IDA-ICE, with aim to establish a procedure for techno-economic optimization. Hence, the aim of this paper was to evaluate the energy performance of a traditional apartment building designed for the norwegian TEK-17 standard, compared to the recommended thermal properties compiled by the reseach center on zero emission buildings. The building was designed using Autodesk Revit 2018 edition and exported as a IFC-file to IDA-ICE 4.8.

2. Theoretical framework

The design of low energy buildings involves two strategies minimizing the need for energy use in buildings through energy-efficient measures (EEM) and adopting renewable energy and other technologies (RET) [5]. RET represents photo voltaic (PV) or building-integrated photo voltaic (BIPV), wind turbines, solar thermal (solar water heaters) and heat pumps. EEMs include building services systems, internal conditions and building envelopes. These include life-cycle cost and environmental impacts, climate change and social policy issues [5, 6].

The consecration-first approach to high performance building starts with advanced building envelope [3]. Guided by physics and building science, advanced building envelopes combine a simple suite of components to manage heat, air, and moisture and deliver superior efficiency, durability, comfort, and occupant health [2]. By controlling the movement of air across building assemblies, stabilizes the temperature and comfort in the building. The vapor barrier should be wrapped continuously, unbroken to prevent heat and moisture flowing into the insulation materials. High-performance buildings employ a ventilated rain screen, a gap between the cladding and wall assembly that not only provides a channel for bulk water to drain away, but also generates air movement across the face of the assembly to dramatically increase drying [2]. A highly thermally resistant wall will have less drying capacity than a conventional wall, so the air movement provided by the ventilated rain screen helps ensure the resilience and durability of high performance wall assemblies [2].

3. Methodology

The envelope design was made as simplistic as possible, by improving the building envelope, simulating a air-to-air heat pump in combination with electric floor heating. For reducing the U-values in each occupant room and space, all the external walls were designed as both TEK-17 standard, and the nZEB standard classification. As glass surfaces are highly important for external energy gains, it was important to evaluate the performance of the different window and door types. The baseline model was designed with a commercially available window frame and glazing unit with a U-value of 0.8 W/m2K. For internal heat, the heat gains from occupants, equipment and lightning were had the same default settings for both of the design scenarios. Figure 1 shows the building facades of the designed building using Autodesk Revit 2018 edition. Figure 2 shows the apartment design facades of the designed building using IDA-ICE 4.8 edition.

4. Case building

This chapter describes the designed case building in question and how it has been calibrated. This includes a description of the building envelope, model set up and calibration in Revit 2018 and IDA-ICE 4.8.

The investigated building was a conceptual low energy building which passive parameters are optimized and validated according to TEK-17 and ZEB standardization. The model was a residential building composed of four similar floor levels. Each floor level was divided into two apartments. The buildings net area (excluding balconies and non-conditioned spaces) was 464 m^2. All building rooms was modelled in the IDA-ICE-zone model. The physical characteristics

Figure 1. Building facades (Revit 2018)

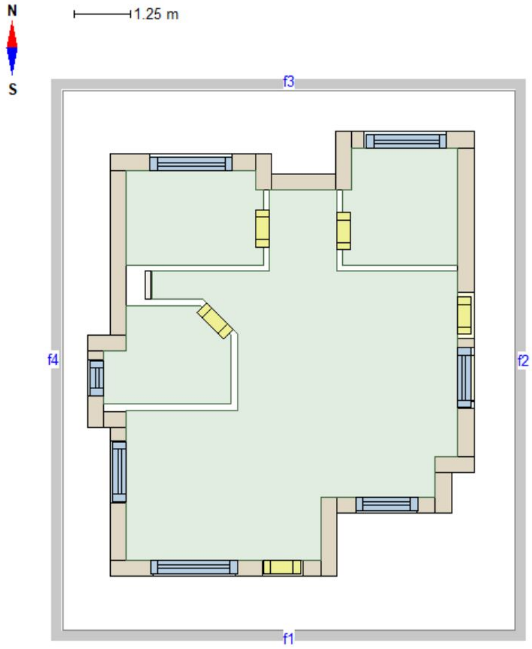


Figure 2. Room and space allocation (IDA-ICE 4.8)

of the buildings envelope are represented below.

From the Norwegian TEK.17 standard, heat loss through thermal bridges can be considered satisfactory if the normalized thermal bridge value calculated does not exceed 0.03 W/m^2K for single-family houses. In this case, the study assumes that this value was durable for the apartment building. For the nZEB case, normalized thermal bridge value was set to 0.015 W/m^2K.

Room boundaries and spaces were required in order to simulate the impact of the variation of each parameter in IDA-ICE. The volume computation for space was based on its room- bounding components and was calculated as the area of its base multiplied by the height of the space. The height was set to 2.6 meters, in accordance with the requirements for minimum height (TEK-17).

5. Results

This chapter discusses the simulated results for each simulation and compares the energy consumption. The results was based on the energy balance and delivered energy to the building to reach acceptable temperatures and indoor climate. For the sustainable design, photo voltaic electricity generation on-site was also included in the results. The photo voltaic production was simulated using PVGIS.

Initially, the reference scenario was modelled and analyzed. Secondly, different parameters were changed in the system design for mapping the impact on the annual energy use. Lastly, the economic break even for the photo voltaic systems were described. Sensitivity analysis, with respect to the electricity escalation, was carried out based on the simulated annual energy use in the building. The results show the sensible heat balance for the living room and kitchen main area and the total annual energy consumption for the one apartment.

Table 1. Building design envelope

		TEK-17	nZEB
Roof		U-value: 0.13 W/m^2K	U-value: 0.07 W/m^2K
Function	Materials	Thickness (mm)	Thickness (mm)
Finish (external)	roof tiles (11 tilt)	-	-
Membran layer	EPDM Membrane	20	20
Thermal/air layer	air infiltrating barrier	-	-
Structure	timber (90x315)	315	315
Insulation	mineral wool	260	500
Membran layer	vapor retarder	-	-
Finish (internal)	Gypsum	-	-
External walls		U-value: 0.18 W/m^{2}K	U-value: 0.095 W/m^2K
Function	Materials	Thickness (mm)	Thickness (mm)
Finish (external)	horizontal wood panels	-	-
Membran layer	EPDM Membrane	20	20
Thermal/air layer	air infiltrating barrier	-	-
Structure	timber (90x315)	315	315
Insulation	Mineral wool	175	350
Membran layer	vapor retarder	-	-
Finish (internal)	Gypsum	-	-
Floor		U-value: 0.09 W/m^{2}K	U-value: 0.069 W/m^{2}K
Function	Materials	Thickness (mm)	Thickness (mm)
Finish (floor)	wood flooring	-	-
Membran layer	vapor retarder	-	-
Insulation	mineral wool	350	500
Structure	concrete (24.1 mPa)	125	125
Thermal/air layer	damp profing	-	-
Membran layer	randon membrane	-	-
Substrate 1	Concrete (24.1 mPa)	300	300
Substrate 2	hardcore	100	100
Windows	WWR 6.6%		
TEK-17	SHGC and ST	U-value	Internal/external emissivity
	0.15 and 0.1	0.6	0.837 (default)
Windows	WWR 6.6%		
nZEB	SHGC and ST	U-value	Internal/external emissivity
	0.15 and 0.1	0.8	0.837 (default)
Insulation	**Thermal conductivity**	**Density)**	**Specific heat**
Mineral wool	0.036 W/(mK)	20 kg/m^3	750 J/(kg K)

Table 2. Room and space data

Zones	People	Lightning	Equipment	Occupancy	Lightning	Equipment
Main area	2	100 W	3100 W	07-09 17-22	07-09 17-22	07-09 17-22
Bathroom	1	100 W	1750 W	Never present	Always off	07-09 17-22
Bedroom 1	1	40 W	50 W	21-07	Always off	21-07
Bedroom 2	1	40 W	50 W	21-07	Always off	21-07
Zones	**Height**	**Heating**	**Cooling**	**Ventilation**	**ACH**	**Supply air**
All zones	2.6m	21	25	AHU CAV	0.5	2 L/sm^2 height

Month	Walls	Roof	Floor	Windows	Doors	Thermal bridges
1	-318.5	-174.9	-19.0	-232.7	-78.3	-126.7
2	-255.6	-147.2	-16.3	-194.1	-62.6	-105.2
3	-228.9	-146.6	-16.9	-190.9	-55.6	-102.8
4	-158.6	-116.6	-15.3	-148.8	-37.5	-79.5
5	-59.3	-80.0	-13.2	-95.2	-12.5	-48.1
6	-27.4	-63.5	-13.2	-74.0	-4.3	-36.8
7	-14.3	-55.9	-14.5	-63.1	-1.4	-30.3
8	-32.2	-57.0	-9.7	-67.5	-7.0	-33.1
9	-95.9	-78.0	-7.9	-96.1	-22.9	-49.4
10	-170.1	-106.8	-10.5	-137.2	-41.7	-72.6
11	-223.2	-126.0	-11.4	-164.8	-54.7	-88.7
12	-276.6	-151.2	-13.8	-200.6	-68.0	-108.6
Total	-1860.5	-1303.6	-161.7	-1665.0	-446.5	-881.9
During heating	-1723.3	-1145.2	-76.3	-1527.3	-421.9	-809.5
During cooling	-9.7	-23.5	-33.4	-17.0	1.2	-7.7
Rest of time	-127.5	-134.9	-52.0	-120.6	-25.8	-64.7

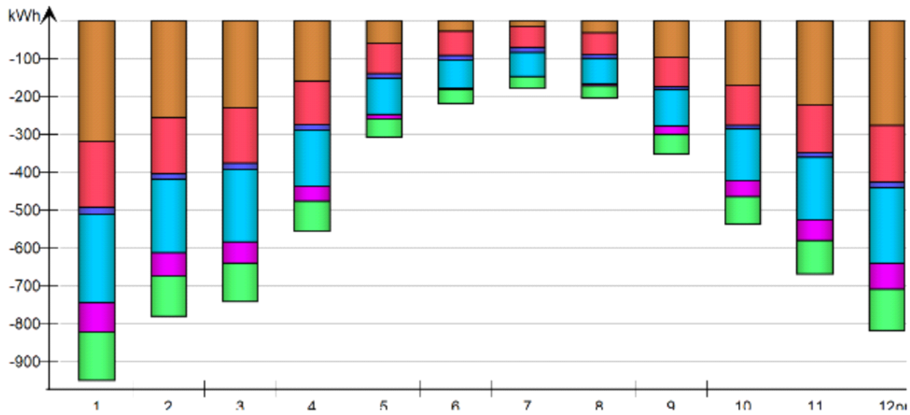


Figure 3. Envelope transmission: Norwegian TEK-17 standard

	Purchased energy		Peak demand
	kWh	kWh/m^2	kW
Lighting, facility	308	5.3	0.17
Equipment, facility	1061	18.3	1.9
HVAC aux	272	4.7	0.19
Electric heating	3226	55.7	2.68
Total, Facility electric	4867	84.1	
Total	4867	84.1	

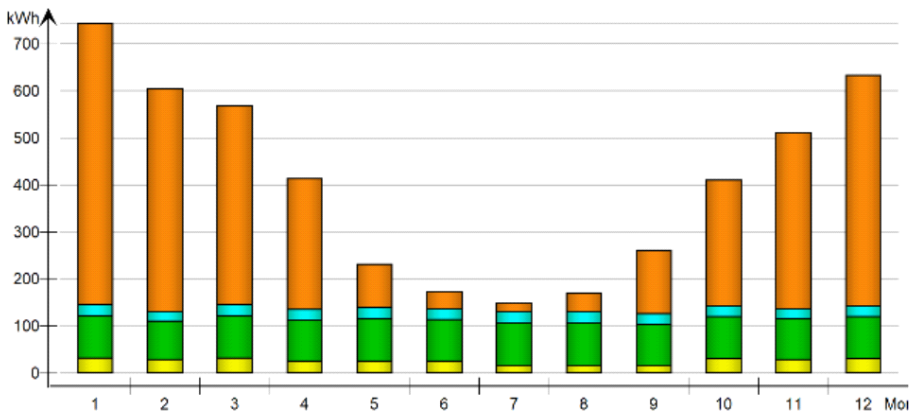


Figure 4. Energy use: Norwegian TEK-17 standard

Month	Walls	Roof	Floor	Windows	Doors	Thermal bridges
1	-204.2	-171.9	-8.9	-179.6	-80.2	-62.5
2	-164.2	-144.6	-9.3	-149.9	-63.9	-52.0
3	-147.0	-143.8	-11.4	-147.6	-56.4	-50.9
4	-102.8	-114.1	-11.9	-115.1	-37.5	-39.6
5	-40.5	-79.3	-14.0	-73.9	-12.2	-24.1
6	-21.0	-63.5	-14.4	-58.0	-4.2	-18.6
7	-12.8	-56.7	-15.7	-50.3	-1.7	-15.6
8	-22.7	-57.5	-10.5	-53.5	-7.1	-17.0
9	-62.6	-76.9	-7.7	-74.4	-22.6	-24.7
10	-108.6	-104.6	-6.9	-106.1	-41.8	-36.1
11	-143.0	-123.5	-6.9	-127.4	-55.2	-44.0
12	-177.5	-148.6	-7.8	-155.0	-69.2	-53.7
Total	-1206.9	-1285.0	-125.3	-1290.9	-451.9	-438.7
During heating	-1150.3	-1166.9	-43.8	-1197.5	-446.1	-409.4
During cooling	-8.4	-23.2	-26.9	-16.8	0.8	-4.7
Rest of time	-48.2	-94.9	-54.6	-76.6	-6.6	-24.6

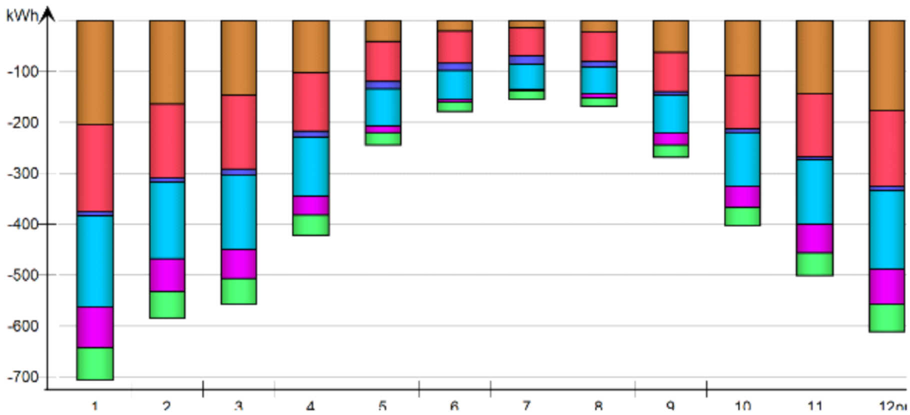


Figure 5. Envelope transmission: ZEB recommendations

	Purchased energy		Peak demand
	kWh	kWh/m^2	kW
Lighting, facility	308	5.3	0.17
Equipment, facility	1062	18.3	1.9
HVAC aux	272	4.7	0.19
Electric heating	2150	37.1	2.28
Total, Facility electric	3792	65.5	
Total	3792	65.5	

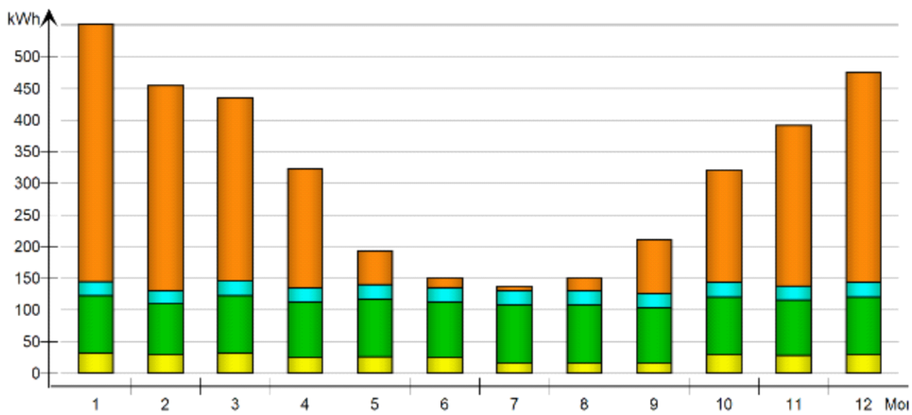


Figure 6. Energy use: ZEB recommendations

Table 3. Mean air and operative temperature (electric heating)

	Variables	
	Mean air temperature, Deg-C	Operative temperature, Deg-C
January	21.0	20.72
February	21.0	20.72
March	21.01	20.74
April	21.04	20.79
May	21.32	21.2
June	21.51	21.46
July	22.17	22.15
August	21.99	21.94
September	21.1	20.91
October	21.04	20.79
November	21.01	20.73
December	21.01	20.72
mean	21.27	21.08
mean*8760.0 h	186335.5	184641.1
min	21.0	20.72
max	22.17	22.15

Table 4. Temperature dissatisfaction (electric heating)

Percentage of hours when operative temperature is above 27°C in worst zone	**1 %**
Percentage of hours when operative temperature is above 27°C in average zone	**0 %**
Percentage of total occupant hours with thermal dissatisfaction	**10 %**

The mean and operative temperatures was mapped annually in the main area of the apartment (kitchen and living room). The maximum temperatures occur in the bathroom, due to the equipment loads in combination with the solar heat gain through the E/W facing windows. The solution to reducing the overheating in this area was to schedule the windows with an hourly opening in the summer months, to allow fresh air into the zones in combination with the HVAC-system.

The floor heating was based on traditional underfloor electrical heating, with an emitted power of 70 W/m^2 in the living room, 60 W/m^2 in the bathroom and 40 W/m^2 in the bedrooms. Due to overheating and thermal comfort, and the size of the building, the only supply heat was placed in the living room area. It consists of an air-to-air heat pump. The total heat power was 6.0kW w/ COP=3.2.

6. Discussion and conclusion

In this study, four electricity price escalations was be considered. The base case scenario (2.8 %) reflects the EU energy price projections to 2030 and was used as a baseline scenario for the present study. Low scenarios (1.3% an.) are often used in the German national context, including by the Federal Government in the elaboration of energy strategies. The high energy prices scenario (4.3% an. assumes a high energy price rise in the future, similar to the latest

Figure 7. Design temperatures in main area (electric heating)

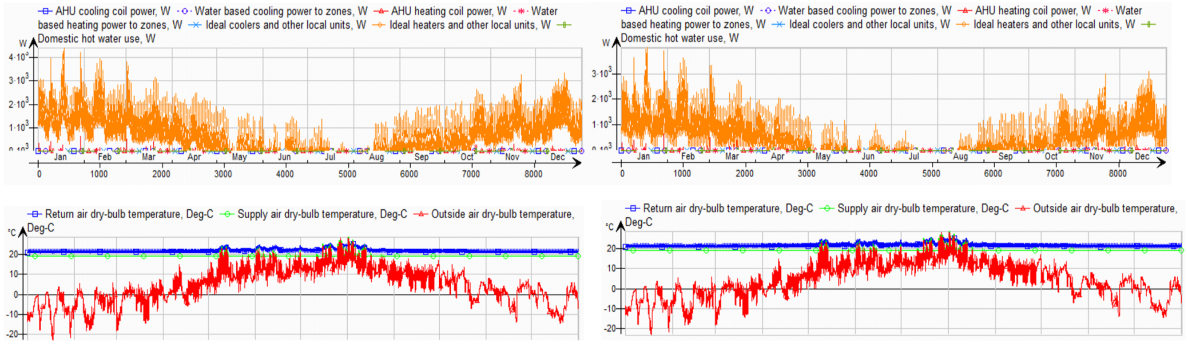


Table 5. Break even (PVGIS)

PVGIS												
Efficiency	16%				18%				20%			
Escalation	1.30%	2.80%	4.30%	5.00%	1.30%	2.80%	4.30%	5.00%	1.30%	2.80%	4.30%	5.00%
Break even	26	22.8	20.2	19	24.6	21.2	19	18.2	22.9	20	17.9	17

years observed rises. Due to resent research, there has been a 5% an. real increase in electricity price from 2000-2010. Hence, this optimistic prediction was also presented in the study.

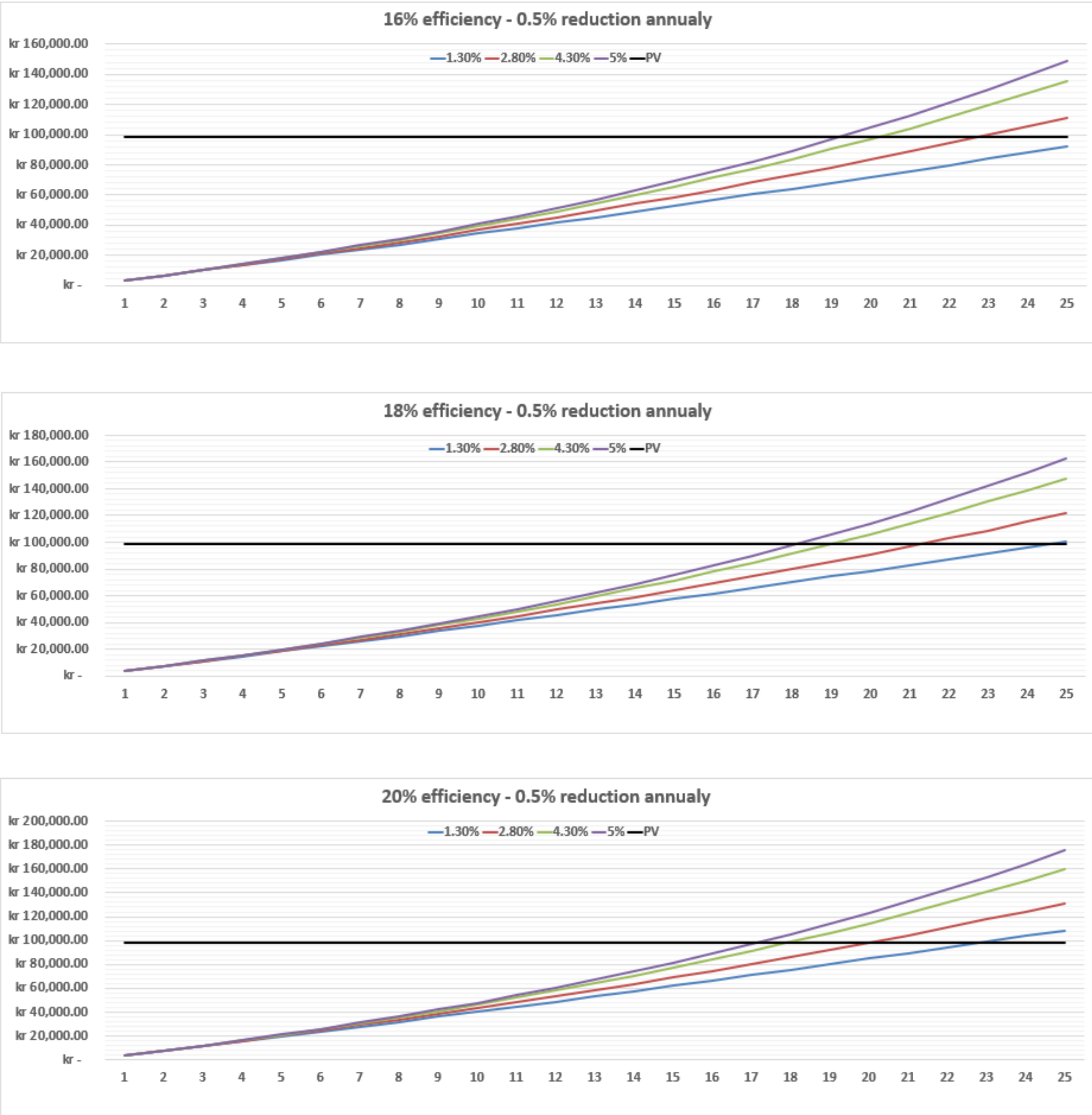
Energy efficiency technologies such as daylight control, thermal insulation, low-emissivity windows and on-site production of energy can be used to decrease energy use in new commercial buildings. Although the increased energy efficiency usually increases the upfront construction costs of a building, the energy savings over the service life of the building often offset these initial higher costs. The results gave a significant reduction in energy demend, from 84.1 65.5 kWh/m^2. When considering the displacement from traditional buildings to ZEB, the building type, climate, and study period impact the financial benefits from energy efficiency improvements. The longer the study period, the greater the energy savings for the building.

Furthermore, the adaptation of early stage BIM simulation is not a trivial task. This paper finds it prudent to investigate other software tools to evaluate the energy performance of different building components. Further research is needed in the areas of software tool integration and selection for establishment of integrated design procedures and optimal criteria.

The results shows that by investing photo voltaic panels in addition to improved building envelope, the building performance reached high levels of performance. However, for the Norwegian climate, it is clear that the cost of 22.8 years payback is a high initial investment cost, which was the break even point from the simulations in PVGIS (assuming a 2.8% electricity price escalation). Based on the assumption of escalating electricity prices, specially in Norway, the paper did not find it recommended from a economical point of view.

Based on the case study and simulations in IDA-ICE, several conclusions can be drawn. The design option with the lowest energy demand was found to be the optional concept building with electric floor heating and a air-to-air heat pump designed according to the ZEB specifications. By retrofitting the design from TEK-17 standard to nZEB, the energy demand reduction was found to be 22%. The cost of retrofitting was found to be neglect able, compared to the cost of energy efficient measures, like the photo voltaic system. Furthermore, experimental verification of the demonstrated energy demand potential is recommended.

Figure 8. Photo voltaic payback time (PVGIS)



In conclusion, this was a case study of a digital case study building. The work done attempted to establish a fast and precise procedure for optimization of the building envelope using building performance software, which could be applied to different case-studies. For further research, this papers finds it necessary to scale the study quantity of different building types to be considered in terms of sensitivity analysis based on variation of climatic locations, electricity cost escalation and product costs.

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Martin Tallberg

NTNU
Norwegian University of
Science and Technology