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BIM based iterative simulation - efficient building design: a case study

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BIM based iterative simulation - efficient building design: a case study

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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 an even more detailed simulation 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 tomorrow's 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 necessary 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 its 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 opti



mization. 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- le 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-e cient 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- rst 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 e ciency, 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 owing 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 oor 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 ex-ternal energy gains, it was important to evaluate the performance of the di erent 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 oor levels. Each oor level was divided into two apartments. The buildings net area (excluding balconies and non-conditioned spaces) was 464 m². All building rooms was modelled in the IDA-ICE-zone model. The thermo-physical



Figure 1. Building facades (Revit 2018)

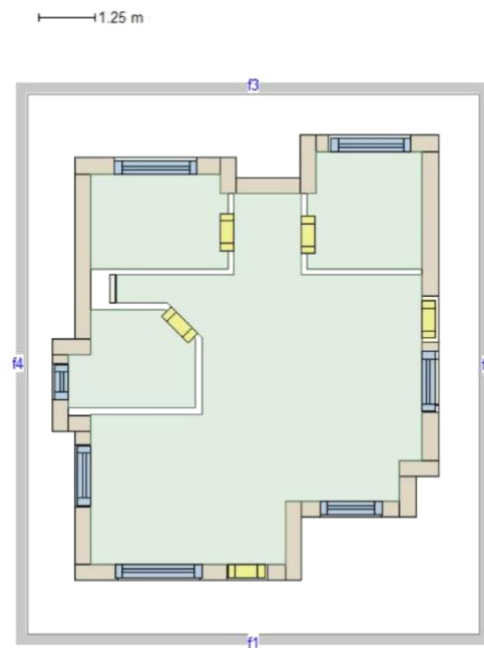


Figure 2. Room and space allocation (IDA-ICE 4.8)

characteristics of the buildings envelope are represented in Table 1.

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 $0.03 \text{ W/m}^2\text{K}$ 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 $0.015 \text{ W/m}^2\text{K}$.

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. The data is presented in

Table 1. Building design envelope

		TEK-17	nZEB
Roof Function	Materials	U-value: 0.13 W/m ² K Thickness (mm)	U-value: 0.07 W/m ² K Thickness (mm)
Finish (external)	roof tiles (11 tilt)	-	-
Membran layer	EPDM Membrane	20	20
Thermal/air layer	air in ltrating barrier	-	-
Structure	timber (90x315)	315	315
Insulation	mineral wool	260	500
Membran layer	vapor retarder	-	-
Finish (internal)	Gypsum	-	-
		U-value: 0.18 W/m ² K Thickness (mm)	U-value: 0.095 W/m ² K Thickness (mm)
External walls Function	Materials		
Finish (external)	horizontal wood panels	-	-
Membran layer	EPDM Membrane	20	20
Thermal/air layer	air in ltrating barrier	-	-
Structure	timber (90x315)	315	315
Insulation	Mineral wool	175	350
Membran layer	vapor retarder	-	-
Finish (internal)	Gypsum	-	-
		U-value: 0.09 W/m ² K Thickness (mm)	U-value: 0.069 W/m ² K Thickness (mm)
Floor Function	Materials		
Finish (oor)	wood ooring	-	-
Membran layer	vapor retarder	-	-
Insulation	mineral wool	350	500
Structure	concrete (24.1 mPa)	125	125
Thermal/air layer	damp pro ng	-	-
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)	Speci c 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 o	07-09 17-22
Bedroom 1	1	40 W	50 W	21-07	Always o	21-07
Bedroom 2	1	40 W	50 W	21-07	Always o	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

*Effect (Watt) for equipment and lightning was obtained from [?]

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	-69.0	-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

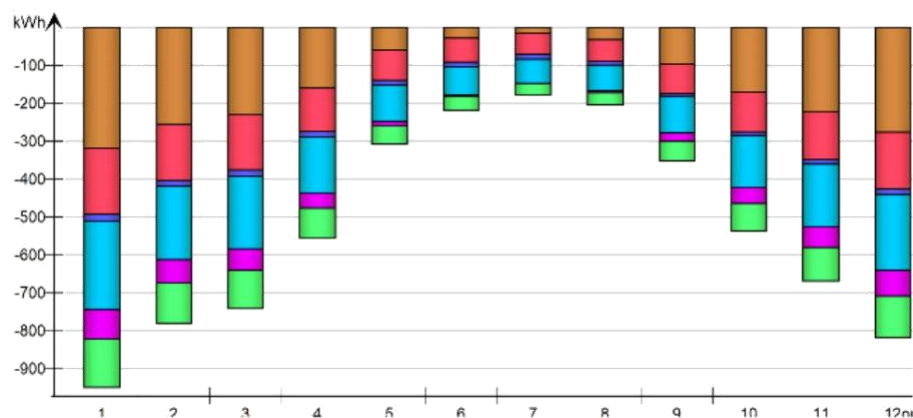


Figure 3. Envelope transmission: Norwegian TEK-17 standard

	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	

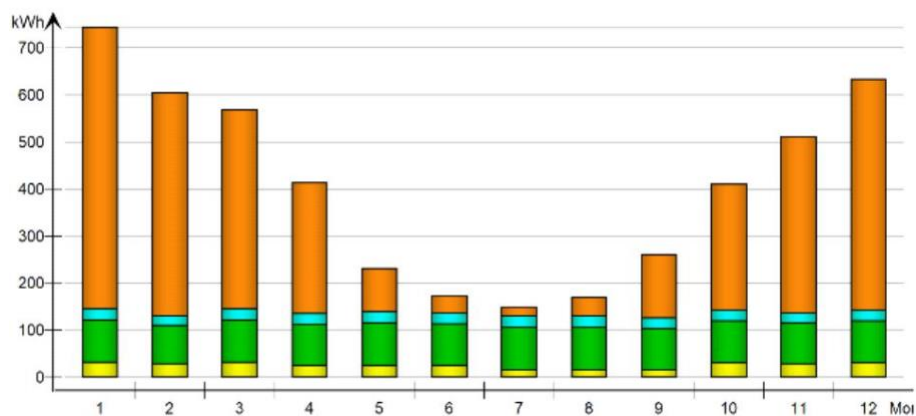


Figure 4. Energy use: Norwegian TEK-17 standard

Figure 3-7.

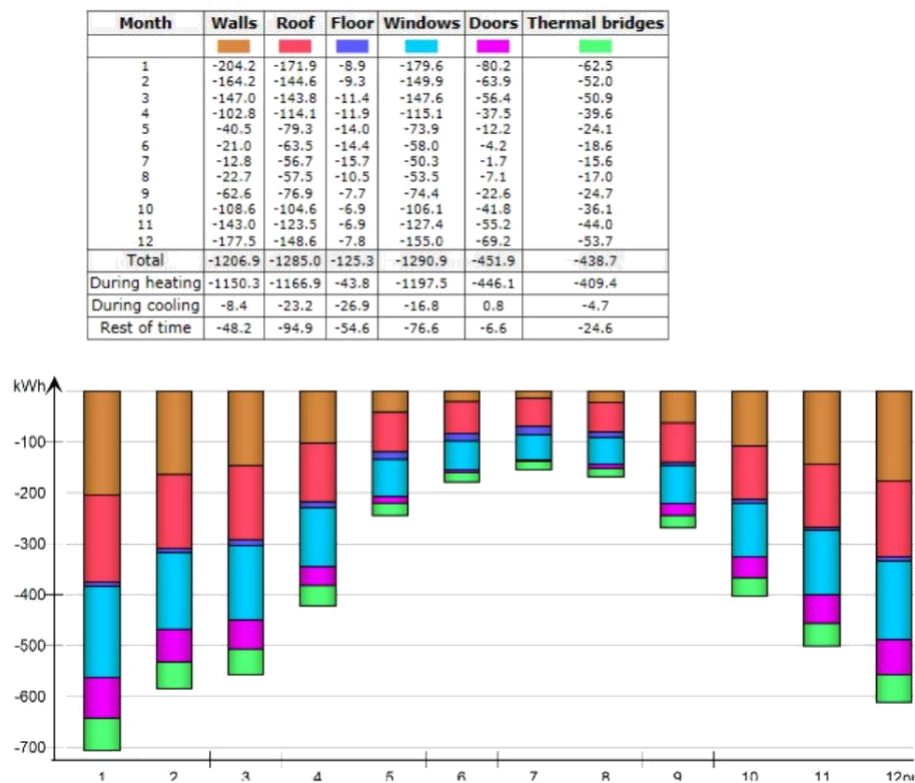


Figure 5. Envelope transmission: ZEB recommendations

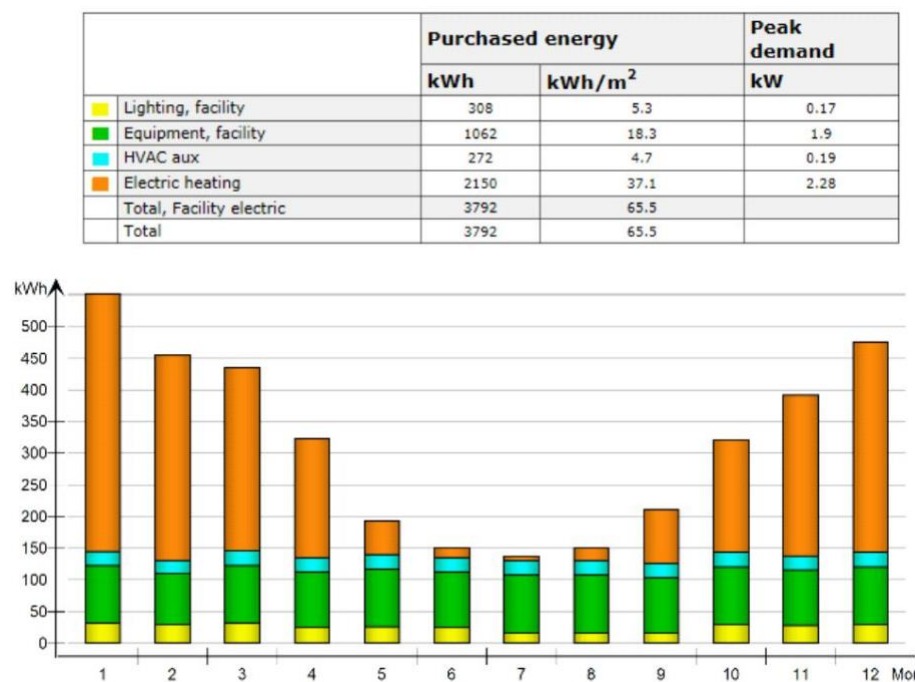


Figure 6. Energy use: ZEB recommendations

The mean and operative temperatures was mapped annually in the main area of the apart-

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 %

ment (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 under floor electrical heating, with an emitted power of 70 W/m² in the living room, 60 W/m² in the bathroom and 40 W/m² in the bed-rooms. 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 were 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 years observed rises. Due to recent research, there has been a 5% an. real increase in electricity

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

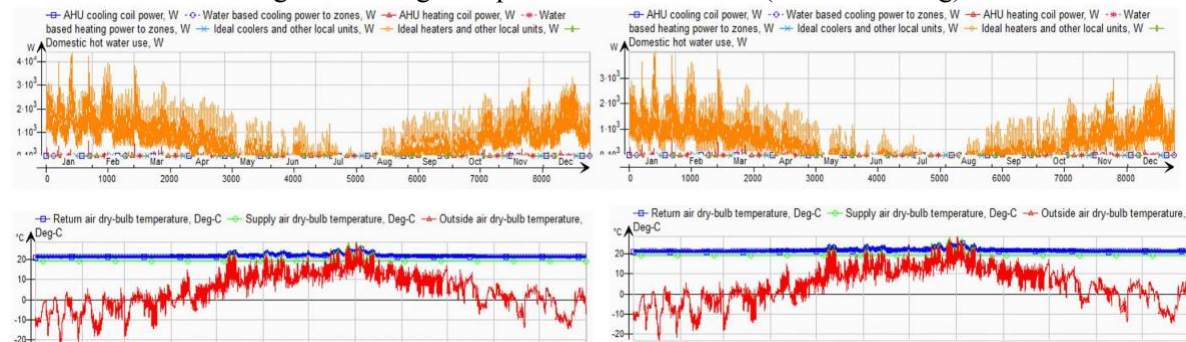


Table 5. Break even (PVGIS)

Efficiency	PVGIS											
	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

price from 2000-2010. Hence, this optimistic prediction was also presented in the study.

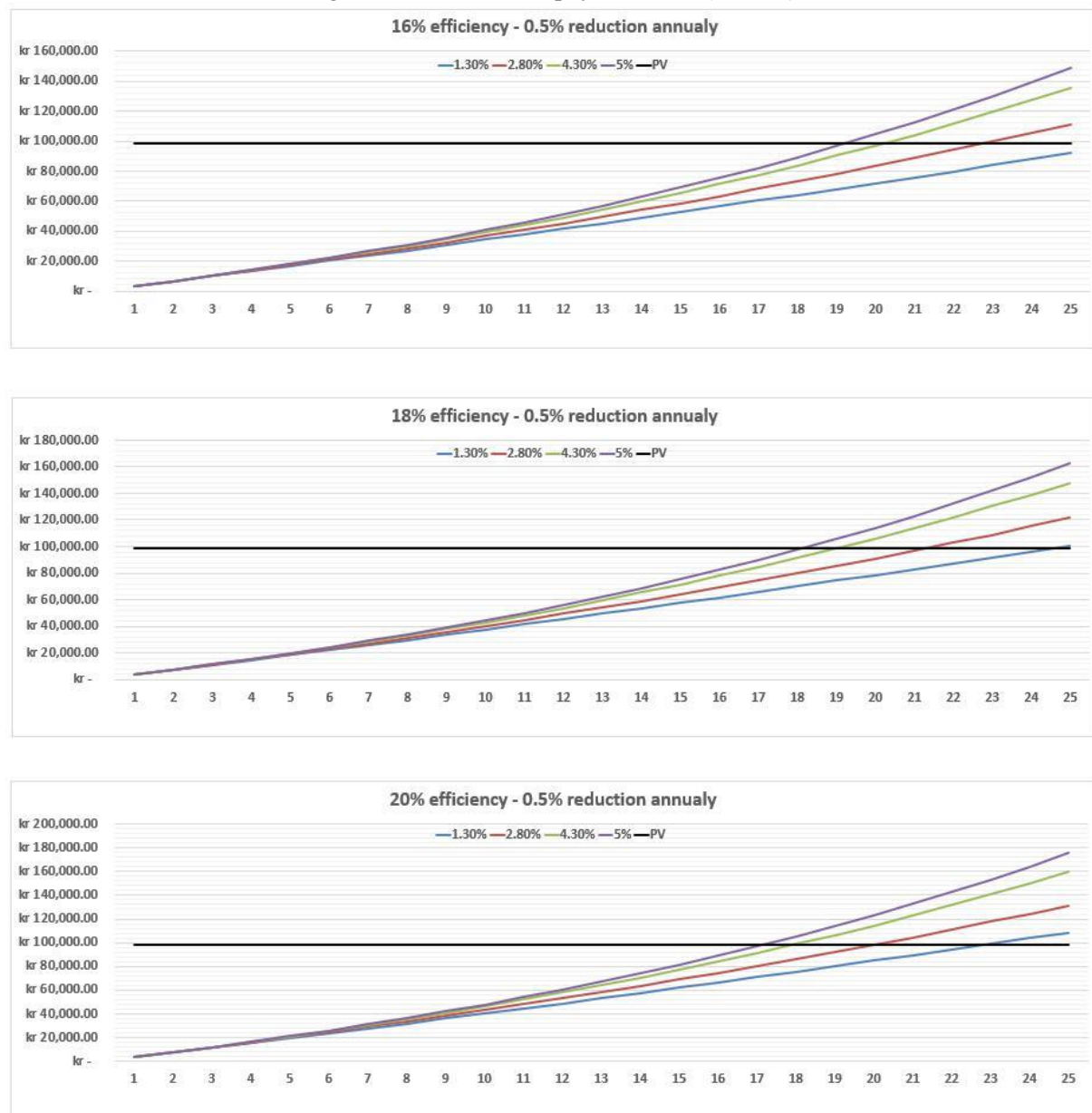
Energy efficiency technologies such as daylight control, thermal insulation, low-emissivity windows and on-site production of energy can be used to decrease energy use in new commercial buildings. Although the increased energy efficiency usually increases the upfront construction costs of a building, the energy savings over the service life of the building often offset these initial higher costs. The results gave a significant reduction in energy demand, from 84.1 to 65.5 kWh/m². 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 show that by investing photovoltaic 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 an 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 neglectable, compared to the cost of energy efficient measures, like the photovoltaic 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 paper 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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