FUTURE ENERGY PATHWAYS FOR A UNIVERSITY CAMPUS CONSIDERING POSSIBILITIES FOR ENERGY EFFICIENCY IMPROVEMENTS

Natasa Nord*,[1], Tymofii Tereshchenko[1], Hamed Mohseni Pahlavan[1], Jan Sandstad Naess[1], Nina Holck Sandberg[1], and Helge Brattebø[1]

Department of Energy and Process Technology, Norwegian University of Science and Technology (NTNU), Kolbjørn Hejes vei 1 B, Trondheim 7491, Norway[1]

Abstract: The building sector has a significant influence on energy use and environmental impact. In educational buildings, specifically when observing university campus, analysis and reduction of energy use is a complex issue due to wide variety of building uses, variability in building construction age, and different implementation of improvement measures. To investigate how energy efficiency measures on a single building may influence the entire building group or campus, combination of building energy simulation tool and an aggregation method such as material flow analysis is necessary. In this study, a neighbourhood building stock model for energy analysis of neighbourhoods was developed based on material flow analysis. This study investigated possible energy efficiency measures at the Gløshaugen campus in Trondheim, Norway. Four energy efficiency packages were introduced to reduce energy use: 1) standard renovation of building envelope, 2) ambitious renovation of building envelope, 3) technical and operational improvements and 4) a combination of the last two packages. Building simulation results were aggregated for the entire campus by using the neighbourhood building stock model. Furthermore, a scenario analysis was used to identify the most critical factors for future development and to evaluate to what extent the campus may develop towards zero-emission neighbourhood in the period of 2017-2050. Four scenarios were introduced including two different aspects: the renovation of the existing building stock and changes in campus energy supply systems. The results on energy efficiency packages highlighted that saving potentials were highly dependent on the construction period of the buildings. The package combining envelope renovation and operation improvements showed the highest savings. However, substantial decrease in heating energy could be achieved by implementing simple technical measures. The findings indicated that advanced renovation, including extensive use of heat pumps, might be the most promising strategy for reducing energy demand by 26% and reducing emissions by 54%.

---

*Corresponding author e-mail: natasa.nord@ntnu.no

Keywords: Zero Emission Neighbourhood (ZEN), Low energy buildings, Energy use, District Heating (DH)

1. INTRODUCTION

In Norway, energy use in buildings accounts for 40% of total energy use, 22% of which constituted by the residential building stock and 18% by commercial buildings [1-3]. As a participant of the Paris agreement, Norway has an obligation to reduce environmental impact, and one of the ways to deal with this is through the introduction of energy efficiency measures in the building sector. According to the European Directive on Energy Performance of buildings [4], the interest in sustainable universities has increased even more.

Many studies could be found in the literature about improvements in the energy efficiency of university buildings. To assess the cost-benefit of implementing building energy efficiency upgrades, decision-makers frequently rely on a computer-simulation-based evaluation of potential retrofit strategies [5]. These days the greatest energy assessment on building level and neighborhood scale can be evaluated by application of the building energy model (BEM) [6]. BEM combines properties of building' envelop and detailed description of technical systems. In combination with energy audit techniques and the introduction of energy-saving scenarios, this approach brings quite accurate and reliable output. BEM technique implies on assumptions that building energy use depends not only on floor areas and variations in envelope configuration, but also on lighting, mechanical systems, and occupant behavior, which can result in considerably different energy use profiles for individual buildings. This means a dynamic energy model has to be individually fitted for each building on campus using the simulation input parameter [7].

BEM has been already applied for the analysis of energy use in numerous universities around the world. The authors in [8] established and calibrated two building-by-building energy models for 100 individual buildings on their university campus. The application of BEM and further urban building energy model (UBEM) for neighborhood level was considered. The result showed that the model was robust and useful for real-time predicted energy use and emissions impact. UBEM refers to applying physics-based, individual BEMs to a group of buildings, developed to serve as the analytical backbone for the various decision processes. In [9] authors provided an overview of different modeling, simulation, and calibration approaches for UBEM. They have organized these methods into four main application types and introduced the most appropriate techniques for each application scenario and user group(s). The case study in the University of Modena and Reggio Emilia employed methodology for the assessment of energy performance of building stocks based on the normalization of available energy use data and sample detailed energy audits [10]. A study at Osaka University attempted to achieve ZEB level in one of the buildings by the introduction of improvements in building's envelope, technical systems, and operation strategies. They implemented these energy-saving strategies for 2010-2015 and as a result, energy use per unit floor space declined by 22% over the period [11]. Celniker et al. [12] used the campus scale energy model to calculate potential energy savings from cool walls for 49 buildings at the University of California, Davis, USA. Their findings showed that about 35% of campus buildings could benefit most from cool walls, and this measure could save annually up to 861 MWh of source energy. Research work performed at the University of Korea surveyed the energy use pattern and introduced three energy saving scenarios: building performance improvement, efficiency improvement of energy facilities, and installation of renewable energy systems. In this study, results showed that when the energy saving rates of all three alternatives added up, the anticipated increase of electricity in a five-year period, reduced by 18%. [13].

Since educational buildings in Norway show high potential for improvement in energy efficiency, the Gløshaugen campus of Norwegian University of Science and Technology (NTNU) in Trondheim, Norway, aimed to be pioneering in this area. The energy development concept at NTNU aims to reduce the energy use by 20% in the period 2010-2020. In addition to this, 5% of existing building stock at the university campus should get energy certificate class "A". To achieve mentioned targets, there is a need for energy analysis and mapping of energy use in existing building stock with possibilities for rehabilitation. Therefore, the aim of this study was to identify energy efficiency pathways that may help to significantly decrease energy use and environmental impact of the campus over the years.

The paper is organized as follows. First, the description of data collection is given, then the selection of reference building and model composition are presented. Energy efficiency measures and development of future energy use towards 2050 are bound with available energy conversion technologies. Finally, the main findings of this study with conclusions are presented.

2. METHODOLOGY

The entire approach in the paper is combining different methods explained in the following text. Firstly, building data and energy use data for the entire campus were collected and used for analysis and BEM development. To simulate, the entire campus, a reference building model was developed by using energy use data. In this study, IDA-ICE was used as a simulation tool. Different energy efficiency measures for single building were developed and tested. Outputs from BEMs were aggregated by using the neighbourhood building stock model. The neighbourhood building stock model took in consideration that buildings belong to different periods and that different measures might be implemented. In this way, it was possible to estimate total energy demand of the campus on hourly basis for each year and the total energy demand over the years. Consequently, energy pathways for energy improvement considering energy use and emissions were defined. Details of each methodological step are explained below.

2.1. Data collection

The energy use data of the Gløshugen campus were collected from an energy monitoring system. The heat energy use, electricity use, and other relevant indicators have been exported. To develop a sophisticated model of the campus buildings, several data sources have been employed. For building's envelope and geometry, mainly data from energy certification, issued by the Norwegian Water Resources and Energy Directorate (NVE) [14], were used. In collaboration with the NTNU property management department, additional information about building operation and further development were obtained. When it was relevant, the operation of technical systems was defined by national standards like NS3031 [15] and national building code, TEK17 [16].

2.2. Reference model

Gløshugen campus consists of 46 buildings excluding the NINA building, Norwegian Institute for Nature Research, and ZEB laboratories. The total gross area is about 300 000 m^2. The campus has its own district heating (DH) ring supplied by the city DH utility company. In addition, waste energy recycled from the IT data center takes place. The reference model of the campus should be based on the most common building type in the analyzed area. Therefore, all building facilities on campus were investigated. Since all buildings are located in the same area, the building category was chosen as a main criterion for the reference model.

The analysis of all buildings on the campus showed that the largest number of buildings were erected in 1951-1970. This corresponds to 26 of all the buildings at the campus area. Hence, this construction period was chosen as a starting point. Further, it was necessary to define the building's geometry and envelope. The analysis of the buildings showed that the highest specific electricity energy use was 197 kWh/m^2, while the highest specific heating use was 510 kWh/m^2. Simultaneously, the most energy effective buildings revealed the total specific energy use of 121 kWh/m^2. This shows that variation in energy use is rather considerable. Finally, the energy use was defined as average and constituted 133 kWh/m^2 for specific electricity use and 140 kWh/m^2 for specific heating use. This provided the total specific energy use of 273 kWh/m^2. After evaluating all available buildings, the building cohorts were introduced, as shown in Table 1.

Table 1. Overview of building cohorts

Cohort		Number of buildings	Model
Before 1950	C1	8	B1
1951 - 1970	C2	26	B2
1971 – 2000	C3	10	B3
2001 - 2010	C4	1	B4
2017 - after	C5	0	B5

The NTNU property management department provided information about area and room distribution. It was found that the total area was divided by 140 rooms and 18 zones. Eventually, all zones have been combined to form the nine most representative, see Figure 1a. Figure 1 shows the zone distribution of the reference building.

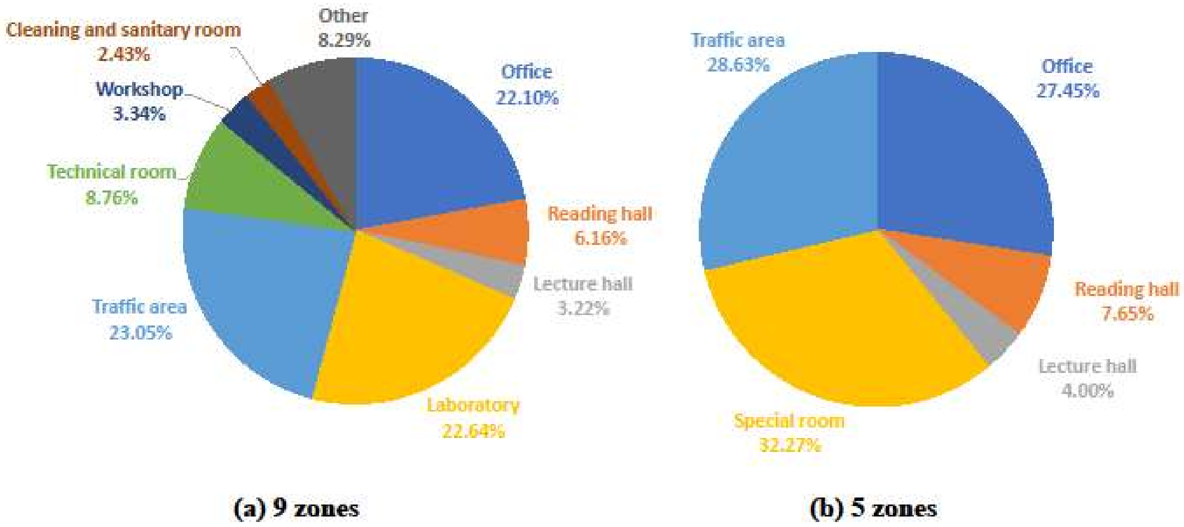


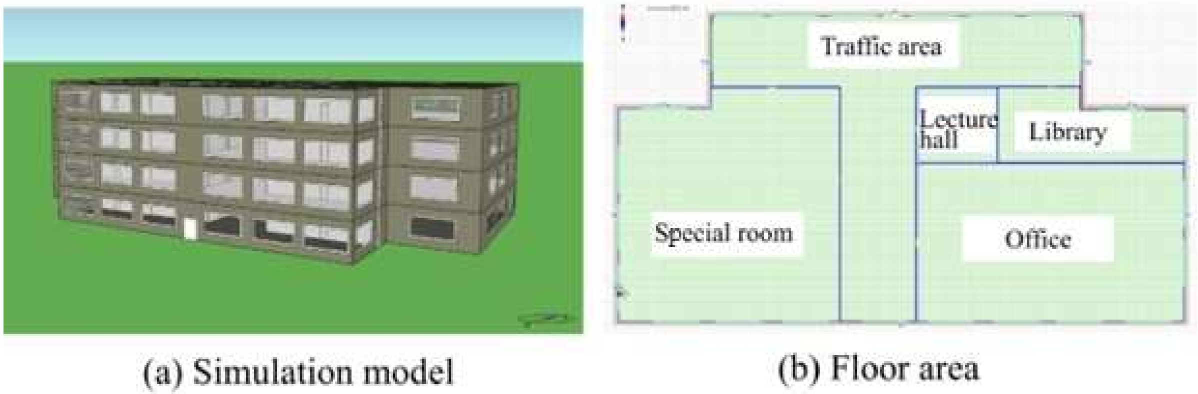
Figure 1. Zone distribution of reference building

Figure 1 shows that office, traffic area, and laboratory accounted for the largest share of 67.79 % in total, see Figure 1a. Due to the similar functionality of some zones, it was decided to combine them. Laboratories, workshops, and various rooms requiring high electricity use (server room, supercomputer room, refrigeration room, etc.) were merged into a single zone. This zone is referred to as Special room. Technical rooms, laundry, and sanitary facilities, and others were neglected. They make up a small part of the total area and are of little importance to the energy use. The final zone distribution model is shown in Figure 1b. Finally, the geometry and size have been selected for reference building. Table 2 summarizes key information analyzed from building certificates.

Table 2. Reference model building areas

Building's geometry	Parameter	Reference model
General	Total area [m^2]	7 220
	Heated are gross [m^2]	7 159.2
	Floor area [m^2]	1 805
	Number of floors	4
Total zone area/ per floor area	Office [m^2]	1967.6/491.9
	Library [m^2]	545.2/136.3
	Educational facilities [m^2]	282/70.5
	Special room [m^2]	2321.2/580.3
	Traffic area [m^2]	2043.2/510.8

Based on the geometry and building envelope parameters, the model was built in IDA-ICE simulation software. The simulation model and the floor area distribution are shown in Figure 2.



(a) Simulation model

(b) Floor area

Figure 2. Simulation model developed in IDA-ICE

2.3. Establishment of energy efficiency measures

To find solutions for the reduction of energy use at the university campus, energy efficiency measures were introduced. This step aimed to show energy-saving potential for educational buildings based on currently technical possible solutions. Feasibility of the suggested measures were also discussed with the property management department. To efficiently post-process building simulation outputs in the dynamic model of the neighbourhood building stock, the suggested energy efficiency measures were combined into four packages of measures: 1) standard renovation of building envelope, 2) ambitious renovation of building envelope, 3) technical and operational improvements, and 4) combination of the last two packages. The summary of established package measures is shown in Table 3.

Table 3. Establishment of Energy efficiency measures

Package		**Building envelope**	**Energy efficiency measures**
P1: Standard package		Outer walls 1	Insulation with 50mm mineral wool
		Roof	Insulation with 50mm mineral wool
		Windows 1	TEK17 level (U-value 0.8 $W/(m^2K)$)
		Air tightness	Improvement of leakage rate to 1.5 l/h
		Thermal bridge	Improvement of thermal bridge to 0.06 $W/(m^2K)$
P4= P2+P3	P2: Ambitious package	Outer walls 2	Insulation with 100mm mineral wool
		Roof	Insulation with 50mm mineral wool
		Windows 2	Ambitious level (U-value 0.6 $W/(m^2K)$)
		Air tightness	Improvement of leakage rate to 1.5 l/h
		Thermal bridge	Improvement of thermal bridge to 0.06 $W/(m^2K)$
	P3: Technical package	Heat recovery ventilation	Replacement of heat recovery with 80 %
		Low temperature heating system	Switch from 80/60°C to 60/40°C

From Table 3, it can be noticed that Standard and Ambitious packages focus on improvement in the building envelope. It is expected that the air leakage rate will decrease, and thermal bridge values will improve due to the refurbishment of walls, windows, and roof. The technical package, P3, aimed to uncover potentials for employment of various energy supply technologies for campus energy system, due decreased temperature levels in buildings. The property management department notified that some buildings have already made the transition to lower temperatures and some of the buildings were partially utilizing heat pumps for heating. Therefore, the technical package provided an opportunity to verify if the low temperature extension of the campus area might take place. P4 package aimed to implement ambitious and technical considerations simultaneously.

2.4. Neighborhood building stock model description

This study applied a neighbourhood building stock model for energy analysis of neighbourhoods, which was developed by Næss et al. [17]. The building stock is segmented depending on a building's age, renovation state, and floor area characteristics (zones) into a variety of archetypes to describe the initial state of the stock. Being built on dynamic material flow analysis principles, it is generic and applicable for any type of neighbourhood (residential, service, or mixed). Future building stock dynamics depend on the age distribution and renovation history of existing buildings [18, 19]. Collecting specific knowledge of near-term neighbourhood plans for new construction, renovation, and demolition increases modelling performance. With additional information about the local energy system, future long-term interactions between buildings and the local energy system are assessed dynamically.

An energy analysis is performed by combining the neighbourhood building stock model with specific hourly energy load profiles. Those profiles describe the energy use purpose, such as heating or electricity. These hourly energy load profiles are provided as energy intensities per building cohort on the building level. The estimated energy need of the individual buildings is dynamically aggregated for all energy carriers to the neighbourhood level. Local energy conversion was included in the analysis through building- or neighbourhood specific hourly profiles.

By performing multiple model runs using different input parameters and assumptions allowed for assessing different future energy pathways of stock development and energy efficiency measures in terms of long-term energy use. This provided a basis to compare the effects of different scenarios and measures in a long-term perspective. By applying this model to the campus case, the long-term potential of the campus to become a zero-emission neighbourhood (ZEN) was assessed.

2.5. Development of future energy use

Decreasing energy demand is one of the objectives NTNU Gløshaugen put forward within its energy strategy [17]. A scenario analysis was used to identify the most critical factors for the future development and to evaluate to what extent it is possible for the NTNU campus to develop towards ZEN in the period of 2017-2050. Four scenarios were introduced and included two different aspects, such as the renovation of the existing building stock and options for campus energy supply systems.

Baseline scenario consisted of assumptions about the future development of the existing building stock and new buildings. The assumptions followed the current trends and was in compliance with present policy and regulations. The existing building stock was assumed to undergo standard renovation in a 40-year cycle. The new buildings were expected to be built according to passive house requirements. Regarding energy supply systems, PV panels installed on the south façades of the new buildings were presumed to be a source of electricity in addition to the electrical grid. For heating purposes: waste heat from the data center would be utilized, and new heat pumps (HPs) were expected to be installed and used in line with the existing DH network.

Extensive local energy production scenario concentrated on generating energy from renewable sources within the Gløshaugen campus. The use of HPs, PVs, and a biogas-based CHP was expected to decrease the amount of imported energy and make the campus less dependent on the electricity grid. The assumptions about the renovation of the existing building stock and energy efficiency of the new buildings were considered to be identical to Baseline scenario.

Advanced renovation prioritized increased energy efficiency of the Gløshaugen building stock above local energy generation. The existing buildings were expected to undergo advanced renovation (a 40-year cycle), whereas the new buildings were presumed to be built according to passive house requirements. Energy supply systems were assumed to be the same as in Baseline scenario. Energy export to the electricity grid in a case when energy generation exceeds energy use was assumed to be feasible.

The hybrid scenario was a combination of Extensive local energy production and Advanced renovation scenarios. The hybrid scenario was the most ambitious of all the presented development paths and was characterized by the highest chance of meeting a Zero Emission balance at the neighbourhood level. Energy export to the electricity grid was assumed to be feasible, like in advanced renovation scenario.

The description of the analyzed scenarios is shown in Table 4. The assumptions made about renovation activity and energy supply systems are presented in the sections below.

Table 4 Scenario specification

		Base line	**Extensive local energy production**	**Advanced renovation**	**Hybrid**
Existing buildings	Renovation (a 40-year cycle)	Standard	Standard	Advanced	Advanced
New buildings	Construction	Passive house standard	Passive house standard	Passive house standard	Passive house standard
Energy supply systems	Electricity supply	Electrical grid PV on the new construction (*60% of full potential)*	Electrical grid PV on the new construction (*full potential*) PV on the existing buildings (*full potential*) Biogas based CHP	Electrical grid PV on the new construction (*60% of full potential)*	Electrical grid PV on the new construction (*full potential*) PV on the existing buildings (*full potential*) Biogas based CHP
	Electricity supply	DH HPs Waste energy from data center	DH HPs Waste energy from data center Biogas based CHP	DH HPs Waste energy from data center	DH HPs Waste energy from data center Biogas based CHP

3. RESULTS

3.1. Results on energy efficiency packages

Table 5 show results on energy use development and the effect of renovations packages. The results are given for building categories B1-B4, see Table 1. Specifically, the focus was on heating energy use, because the largest potential for savings was identified there by implementing technically available measures.

Table 5. Specific heating energy use for B1-B4 models with introduced energy efficiency measures

	B1	**P1**	**P2**	**P3**	**P4**
DH (kWh/m^2)	150.1	116.4	114	63.4	26.3
Savings (kWh/m^2)		33.7	36.1	87.6	123.8
Savings (%)		22	24	58	82
	B2	**P1**	**P2**	**P3**	**P4**
DH (kWh/m^2)	119.6	95.4	93.2	53.9	27
Savings (kWh/m^2)		24.2	26.4	65.7	92.6
Savings (%)		20	22	55	77
	B3	**P1**	**P2**	**P3**	**P4**
DH (kWh/m^2)	104.2	90.2	88.3	41.9	26
Savings (kWh/m^2)		14	15.9	62.3	78.2
Savings (%)		13	15	60	75
	B4	**P1**	**P2**	**P3**	**P4**
DH (kWh/m^2)	83.8	81.2	79.7	40.4	32.1
Savings (kWh/m^2)		7.1	8.6	47.9	56.2
Savings (%)		8	10	54	64

Table 5 shows the detailed description of findings related to energy use development and renovation packages for each cohort group. The results for B1 model show that P4 energy saving package provides the highest savings when it comes to DH use. This is reasonable, because P4 is based on combination of the most effective energy saving measures. P1 and P2, Standard and Ambitious packages showed approximately the same level of savings, 22%, and 24%. P3 and P4 showed high energy saving potential because of upgrading the heat recovery system. To recall, the biggest part of buildings on the campus area belongs to Cohort C2 and B2. Hence, it can be noticed that fairy big savings with façade renovation packages could be achieved for B2 model. The results showed values in the range of 20-22%, while the technical package, P3, yielded a saving of 55%.

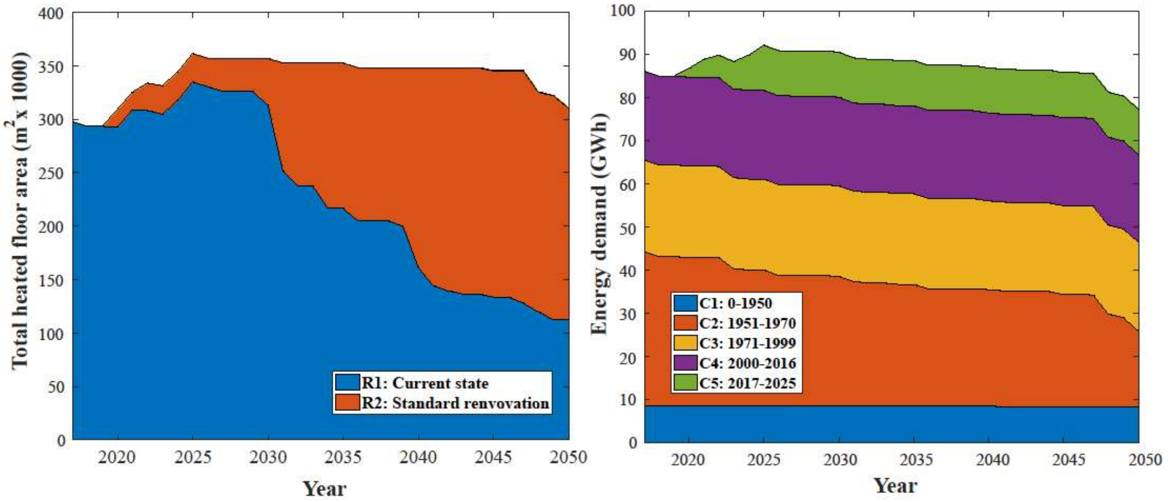
The results for B3 model showed energy savings of 13% and 15%. Those values were considerably lower than for B1 and B2 models. This is because less energy was saved with the façade renovation of new buildings. The technical package P3 provided the same level of energy savings as B2 model, 62.3 kWh/m^2. Further, the peak load decreased under P4 package from 496 kW to 243 kW, which is a reduction of 51%.

The results for B4 model revealed that not as much savings have been achieved in comparison to B2 model; however, technical packages, P3, P4, still provide high savings. Further, for both B2 and B4 models, it can be noticed that heat duration curves became smaller. This also shows that peak loads become smaller after implementing the energy packages.

3.2. Results on campus' energy development towards 2017-2050

The results below demonstrate the main findings on four scenarios of campus development presented in Section 2.4. The findings are presented for each scenario separately.

Standard renovation - Figure 3a shows the total heated area of the building stock in terms of renovation state with respect to the cohort group. From being seen that at the end of the modelling period, nearly two-thirds of the building stock would undergo standard renovation. None of the buildings would reach advanced renovation because a standard renovation cycle is 40 years. The total energy demand of the Gløshaugen building stock regarding cohort groups is illustrated in Figure 3b. The results show that at the beginning of the simulation, the energy demand increased due to the planned expansion of the campus reaching a maximum of 92 GWh in the year 2025 (in the same year when the building stock reaches maximum size). As the years go by, the total energy demand decreased due to renovation and demolition. Compared to the 2017 level, the energy demand of campus in 2050 was estimated to be 10% lower. The energy demand of cohort groups C1, C3, and C4 dropped slightly because of renovation activity, while the energy demand in buildings from the newest cohort, after the completion of the construction, remains at the same level. Interesting to note, the energy demand of cohort C2 (marked red) diminishes substantially over the modelling period. The reason for this was demolition and renovation activities occur in this cohort group.



(a) Total heated area with respect to renovation state

(b) Development of energy demand

Figure 3. Aggregated results for Standard renovation scenario

Extensive local energy production scenario - Since the building stock in Extensive local energy production scenario undergone standard renovation, the energy intensity of each cohort group during the modelling period, total heated floor area in terms of renovation state as well as energy demand with respect to cohort group are identical to Baseline scenario (see Figure 3). Figure 4 shows development of heat duration curves under Baseline scenario for different years. Figure 4 shows that heating energy use decreased gradually as a result of renovation activities. Further, it can be noticed that energy use was less than 6000 hours on an annual basis. This is due to the intensive use of waste heat utilization in the campus area.

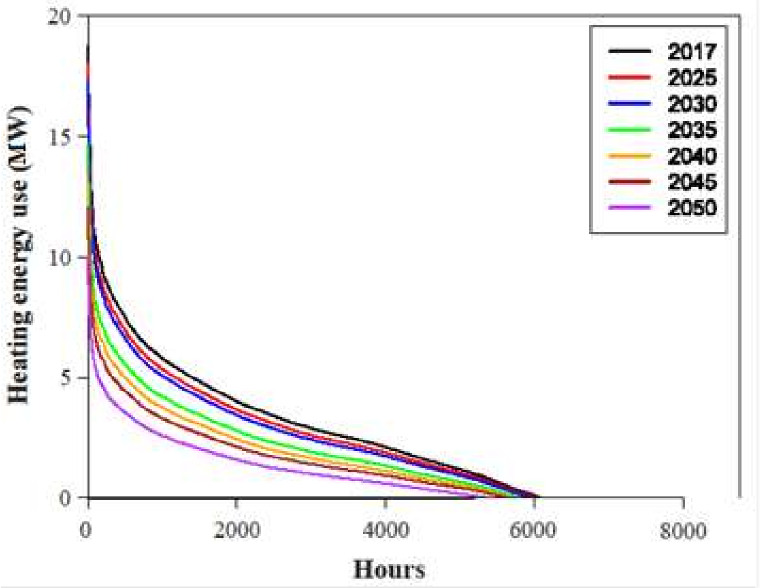
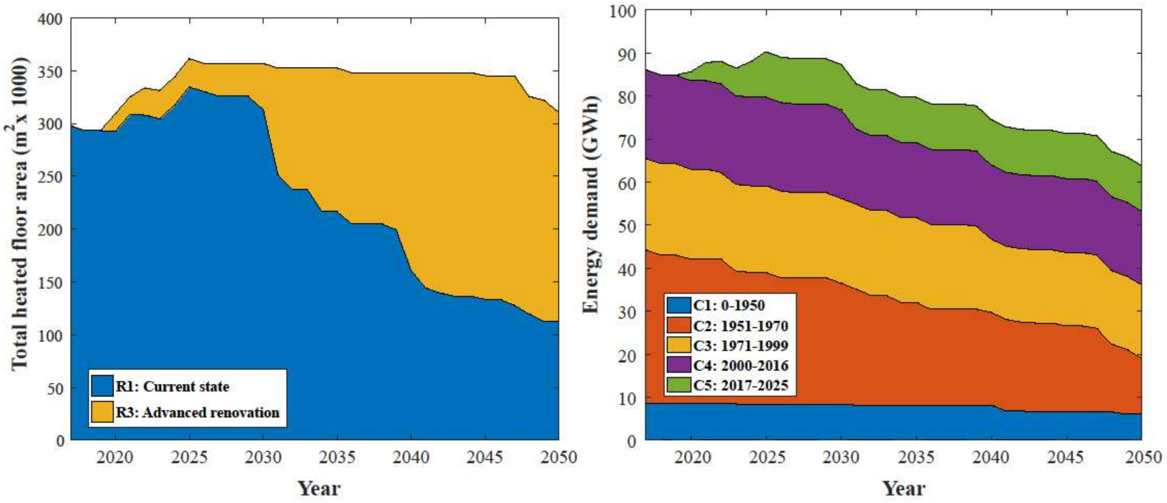


Figure 4. Development of heating energy use 2017-2050

Advanced renovation scenario - Figure 5a shows the total heated area of the building stock in terms of renovation state, while Figure 5b illustrates the development of energy demand with respect to the cohort group. From Figure 5a, it can be noticed that at the end of the modelling period nearly two-thirds of the building stock will have undergone advanced renovation.



(a) Total heated area with respect to renovation state

(b) Total heated area with respect

Figure 5. Aggregated results for Advanced renovation scenario

The total energy demand of the university building stock in terms of cohort groups is illustrated in Figure 5b. At the beginning of the modelling, the energy demand increased due to the expansion of new construction, reaching a maximum of 90 GWh in the year 2025. The total energy demand constantly decreased due to renovation and demolition. Compared to the 2017 level, the energy demand of the Gløshaugen building stock in 2050 was expected to be 26% lower. The drastic decline in energy demand (by almost 60% compared to the 2017 level) occurred in cohort group C2 as a result of demolition and renovation activities. The energy demand of the cohort groups C1, C3, and C4 diminished over the simulation period, and the energy demand of the newest cohort group remained unchanged after 2025 until the end of the modelling.

Hybrid scenario - Since the building stock in Hybrid scenario undergoes advanced renovation, the energy intensity of each cohort group during the modelling period, total heated floor area in terms of renovation state, as well as energy demand with respect to cohort group, are identical to Advanced renovation scenario (see Figure 5). Finally, the results obtained from the scenario analysis are summarized in Table 6. The results show a percentage change in the value of energy demand in the year 2050 with respect to the 2017 level.

Table 6. Percentage decrease of energy demand for heating and electricity for all scenarios in 2050 compared to 2017 level

	Baseline	**Extensive local energy production**	**Advanced renovation**	**Hybrid**
Energy demand	**-10.2%**	**-10.2%**	**-25.9%**	**-25.95**
Electricity demand	+1.4%	+1.4%	-0.5%	-0.5%
Heat demand	-28.7%	-28.7%	-66.7%	-66.7%

The analysis revealed that despite stock growth, the total energy demand declined by 10.2 % in Baseline and Extensive local energy production scenarios and 25.9% in Advanced renovation and Hybrid scenarios. The main reason for this was found due to a substantial decrease in heat demand due to the introduction of energy efficiency measures and construction of new low energy and passive buildings.

3. CONCLUSIONS

The purpose of this study was to establish several models to represent the NTNU Gløshaugen campus and further determine whether the building stock would become ZEN by 2050. In addition, the most promising energy efficiency packages and strategies to make campus energy independent were investigated. Four energy efficiency packages have been introduced for the reduction of energy use. Energy efficiency packages were mainly focused on improvements in heating energy use due to its high potential.

The results on energy efficiency packages highlighted that saving potentials were highly dependent on the construction period of the buildings. Further, P4, ambitious renovation in combination with technical improvements, showed the greatest improvement in terms of energy efficiency. However, substantial heating energy could also be saved by implementing simple technical measures like improvements in the ventilation system and better temperature control. The findings indicate that advanced renovation, including extensive use of HPs, was the most promising strategy for reduction in energy demand by 26%. It would decrease not only energy demand and make NTNU Gløshaugen self-sufficient in heat supply, but also considerably reduce environmental impact.

The results found that the Gløshaugen campus would need additional measures to reach Zero Emission Neighbourhood level in 2050. Despite a considerable decrease in heat demand and use of low carbon heat technologies, the university campus remains heavily dependent on imports of electricity from the electricity grid. Finally, the study demonstrated that the ZEN model for the building stock development was reliable for the future analyses of energy demand for a neighborhood like the NTNU campus. The conclusions from this study were used as part of the investigation study for the campus development.

ACKNOWLEDGEMENT

This paper is a product of two master thesis. “Fremtidens energiveier for bygninger - muligheter for energieffektivisering og konvertering til fornybar energikilde i bygningsmasse” by Eirik Nesgaard and Minh Huy Ngo and “Analysis of energy use and greenhouse gas emissions at the future building stock at the NTNU campus Gløshaugen” by Aleksandra Woszczek. The authors gratefully acknowledge those for their contribution. This article has been written within the research project “Methods for Transparent Energy Planning of Urban Building Stocks– ExPOSe”. The authors gratefully acknowledge the main support from the Research Council of Norway (ExPOSe programme, grant number: 268248). Further, the authors appreciate the support from the Research Council of Norway through the research project: the Research Centre on Zero Emission Neighbourhoods in Smart Cities (FME ZEN).

REFERENCES

[1] Ingrid H. Magnussen, D. Spilde, and M. Killingland, "Energibruk i Fastlands-Norge," 2011.

[2] B. Langseth, "Analyse av energibruk i yrkesbygg," 2016. [Online]. Available: from: http://publikasjoner.nve.no/rapport/2016/rapport2016_24.pdf

[3] I. Sartori, B. J. Wachenfeldt, and A. G. Hestnes, "Energy demand in the Norwegian building stock: Scenarios on potential reduction," *Energy Policy,* vol. 37, no. 5, pp. 1614-1627, 2009, doi: http://dx.doi.org/10.1016/j.enpol.2008.12.031.

[4] "The Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast)," European Commission, European Commission, 2010.

[5] *Standard 140-2011-standard method of test for the evaluation of building energy analysis computer programs.*, ASHRAE, 2011.

[6] C. F. Reinhart and C. Cerezo Davila, "Urban building energy modeling – A review of a nascent field," *Building and Environment,* vol. 97, pp. 196-202, 2016, doi: 10.1016/j.buildenv.2015.12.001.

[7] S. Nagpal and C. F. Reinhart, "A comparison of two modeling approaches for establishing and implementing energy use reduction targets for a university campus," *Energy and Buildings,* vol. 173, pp. 103-116, 2018, doi: 10.1016/j.enbuild.2018.05.035.

[8] S. Nagpal, J. Hanson, and C. Reinhart, "A framework for using calibrated campus-wide building energy models for continuous planning and greenhouse gas emissions reduction tracking," *Applied Energy,* vol. 241, pp. 82-97, 2019, doi: 10.1016/j.apenergy.2019.03.010.

[9] Z. M. B. Yu Qian Ang, Christoph F. Reinhart, "From concept to application: A review of use cases in urban building energy modeling," 2020, doi: 10.1016/j.apenergy.2020.115738.

[10] C. Lodi, V. Malaguti, F. Contini, L. Sala, A. Muscio, and P. Tartarini, "University energy planning for reducing energy consumption and GHG emissions: the case study of a university campus in Italy," *International Journal of Heat and Technology,* vol. 35, no. Special Issue1, pp. S27-S32, 2017, doi: 10.18280/ijht.35Sp0104.

[11] Y. Yoshida, Y. Shimoda, and T. Ohashi, "Strategies for a sustainable campus in Osaka University," *Energy and Buildings,* vol. 147, pp. 1-8, 2017, doi: 10.1016/j.enbuild.2017.04.020.

[12] C. Celniker, S. Chen, A. Meier, and R. Levinson, "Targeting buildings for energy-saving cool-wall retrofits: a case study at the University of California, Davis," *Energy and Buildings,* vol. 249, 2021, doi: 10.1016/j.enbuild.2021.111014.

[13] W.-H. Hong, J.-Y. Kim, C.-M. Lee, and G.-Y. Jeon, "Energy Consumption and the Power Saving Potential of a University in Korea: Using a Field Survey," *Journal of Asian Architecture and Building Engineering,* vol. 10, no. 2, pp. 445-452, 2018, doi: 10.3130/jaabe.10.445.

[14] N. W. R. a. E. Directorate. "Energy use." http://www.nve.no/Global/Publikasjoner/Publikasjoner%202011/Rapport%202011/rapport9-11.pdf (accessed 2013).

[15] *NS 3031, Calculation of energy performances of buildings, Method and data,* S. Norway, 2007.

[16] *Byggteknisk forskrift – TEK 10: Forskrift om tekniske krav til byggverk, Norway, 2010.*, 2010.

[17] S. N. Næss JS, Nord N, Vestrum MI, Lausselet C, Woszczek A, et al. , "Neighbourhood building stock model for long-term dynamic analyses of energy demand and GHG emissions. General model description and case studies.," 2018.

[18] N. H. Sandberg, I. Sartori, M. I. Vestrum, and H. Brattebø, "Using a segmented dynamic dwelling stock model for scenario analysis of future energy demand: The dwelling stock of Norway 2016–2050," *Energy and Buildings,* vol. 146, pp. 220-232, 2017.

[19] J. L. Reyna and M. V. Chester, "The Growth of Urban Building Stock: Unintended Lock-in and Embedded Environmental Effects," *Journal of Industrial Ecology,* vol. 19, no. 4, pp. 524-537, 2015, doi: 10.1111/jiec.12211.