IOP Conference Series: Earth and Environmental Science

Future energy pathways for a university campus considering possibilities for energy efficiency improvements

IOP Conf. Series: Earth and Environmental Science **352** (2019) 012037 doi:10.1088/1755-1315/352/1/012037

Future energy pathways for a university campus considering possibilities for energy efficiency improvements

Natasa Nord, Nina Holck Sandberg, Huy Ngo, Eirik Nesgård, Aleksandra Woszczek, Tymofii Tereshchenko, Jan Sandstad Næss, Helge Brattebø

Norwegian University of Science and Technology, Kolbjørn Hejes v 1B, Trondheim, NO-7491, Norway

Abstract. The study aimed to show in a systematic way possible energy efficiency measures that would decrease the total energy use at the university campus in Trondheim, Norway. The entire study was developed in close collaboration with the NTNU Property and Technical Management divisions, meaning that suggested energy efficiency scenarios and other assumptions were highly relevant. Currently, the campus floor area is about 300 000 m^2 and consists of buildings combining offices, lecturing halls, study halls, and laboratories. The campus building stock has been built from 1910 to 2002. To perform this study, building performance simulation and the dynamic segmented modeling were combined. A dynamic neighborhood building stock model was utilized to aggregate the outputs from the building simulation and evaluate global effects of energy efficiency measures. Reference building models for each university cohort were developed based on the methodology for defining the reference buildings. The results of the single reference building analyses showed that a decrease of up to 50% in heating energy use might be achieved by increasing efficiency of the ventilation system and by decreasing the temperature of the heating system. The results showed that in spite of building stock growth, the estimated energy use would decrease from 2017 to 2050 by 10% for the standard renovation, and by 26% for the combination of ambitious renovation and technical improvements.

1. Introduction

Energy planning of the building stock is a highly important topic and highly relevant for energy policy, requirements, and standards development. Regardless of its importance, this research topic is still in its infancy. Different tools have been developed, but they have only partially succeeded due to sectional and particular interests when developing the tools [1, 2]. There are several reasons for this, such as a fragmented building industry, complex building ownership, divergent interests regarding energy use and supply.

Different methods are suggested to model energy use and emissions of the building stocks. The extrapolation method considering the occupant behavior is done by many researchers in Japan. Energy Solar Planning (ESP) tool is a simple tool for municipalities' district planning based on a steady-state monthly energy balance method [1]. Monte Carlo simulation has been used to predict space heating energy use of housing stocks in a bottom-up approach [3], but the model shows to have uncertainties in prediction. A software to deal with this topic is the Sustainable Urban Neighborhood modeling tool (SUNtool) and its successor CitySim. Even though these tools are dealing with occupant behavior, they are not treating energy storage associated with buildings or district energy systems. In no of the over mentioned tools, the dynamic segmented modeling of the building stocks over many years has not been treated. The dynamic segmented modeling of the building stocks is highly necessary tool to estimate development of the building stocks in the future and thereby development of global emission in the future [4].

The aim of the study was to develop energy pathways for a university campus in Trondheim, Norway. This campus will undergo various developments and for this purpose detailed building simulation and the dynamic segmented modeling were combined. Building models covering different building codes were developed in IDA ICE.

The paper is organized as follows. Methodology is introduced in brief by presenting the main calculation steps and data collection process. In the result section, energy use of the university campus buildings at different standard are firstly introduced. Based on the dynamic segmented modeling of the building stock, total energy demand until 2050 was presented. Due to effectiveness of the paper, only the main results are introduced.

2. Methodology

In this study, the methodology was including the following steps: 1) data collection about building properties and energy use at the university campus, 2) definition of a typical university building with typical energy efficiency measures, 3) detail building simulation of a typical university building, and 4) energy use aggregation and projection by using the dynamic segmented modeling. The collected data about the university were analyzed and organized to develop a typical university building for further analysis in the dynamic segmented modeling for the building stocks. The mathematical background for the dynamic segmented modeling of the building stock was implemented in a tool called Dynamic Zero Emission Neighbourhood (ZEN) model [5]. Therefore, in the text below, the details about that tool are explained.

2.1. Dynamic Zero Emission Neighbourhood model

The ZEN model developed by Næss et al. [5] investigates the development of a neighbourhood building stock over time in the context of its size, composition, energy use and greenhouse gas emissions associated with energy use at neighbourhood level. The model is generic and can be used for any type of neighbourhood (residential, service or mixed).

The ZEN model is dynamic and allows studying the long-term development of a neighbourhood building stock. At the start of the modelling period, the model uses a detailed description of the initial stock as well as given or assumed plans for future construction. In addition, demolition and renovation activity can be based on concrete plans or modeled by use of probability functions. Various floor area types in the buildings are grouped together in floor area classes. The building stock is segmented in archetypes defined by floor area class, cohort, and renovation stated. The model calculates the heated floor area for each archetype for all years of simulations. Buildings can move between archetypes after renovation. Furthermore, the ZEN model allows for detailed long-term energy analyses of a neighbourhood building stock. The model is described in detail in the report written by Næss et al. [5].

In this study, archetype-specific hourly energy load profiles for heating and electricity were used as the input. These hourly profiles were developed based on the detail simulation of the typical university building. In this study, the archetypes of the university building development were developed based on the building year. Detail description about the archetypes and the university development is given in the subsection below.

2.2. Data collection

The energy use data of Gløshugen campus were collected from the energy monitoring system. The heat energy use, electricity use, and other relevant indicators were obtained and organized. In order to develop sophisticated model of the campus buildings, several data sources have been employed. For building envelope and geometry, data from energy certification documents issued by Norwegian Water Resources and Energy Directorate (NVE) [6] were used. The classification of campus area use was received from the NTNU Technical Management Division. In order to define technical systems and their functions, energy certifications were used together with the standard, NS3031 [7], and the national building code, TEK17 [8]. In addition, maintenance personnel contributed with experiences and data understanding.

2.3. Reference model

The analyzed NTNU campus consists of 46 buildings, excluding 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 DH utility company in Trondheim. In addition, waste heat recycled from an IT data center was also utilized. The reference model of the campus building should be based on the most common building types in the analyzed area. It was important to choose buildings from the same construction period, location, and building category.

First, a statistical analysis was made to identify number of buildings and their related properties. A previous detail statistical analysis of the energy use at the NTNU campus gives relevant inputs [9]. The statistical analysis of the university campus showed that the largest number of the buildings was built in the period of 1951-1970. This corresponds to 26 of all the buildings in the campus area. Further, it was necessary to define building geometry and building envelope. After evaluation of all the criteria, 18 buildings were selected as reference buildings. The analysis of these 18 buildings showed that the highest electricity use was 197 kWh/m^2, while highest heating use was 510 kWh/m^2. At the same time the most energy effective buildings showed that the total specific energy use was 121 kWh/m^2. This shows that variation in energy use is rather big at the campus level. Finally, the energy use was defined as the average and constituted 133 kWh/m^2 for electricity use and 140 kWh/m^2 for the heating use.

After evaluation of the building content and construction year for all the available buildings, the cohorts were introduced as shown in Table 1.

Table 1. Overview of cohorts

Cohort	Model
Before 1950 – C1	B1
1951-1970 – C2	B2
1971-1999 – C3	B3
2000-2010 – C4	B4
2017 – after – C5	B5

Based on the information from Technical Management Division about the area classification, it was found that the total area was divided into 140 rooms and 18 zones. Finally, all the zones were combined to form the nine most representative. The statistical analysis of the rooms and zones at the campus is given in Figure 1.

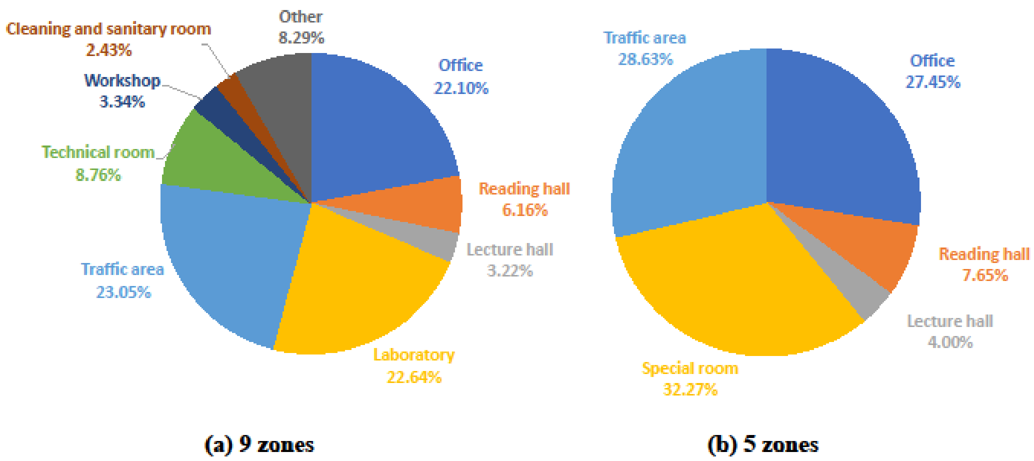


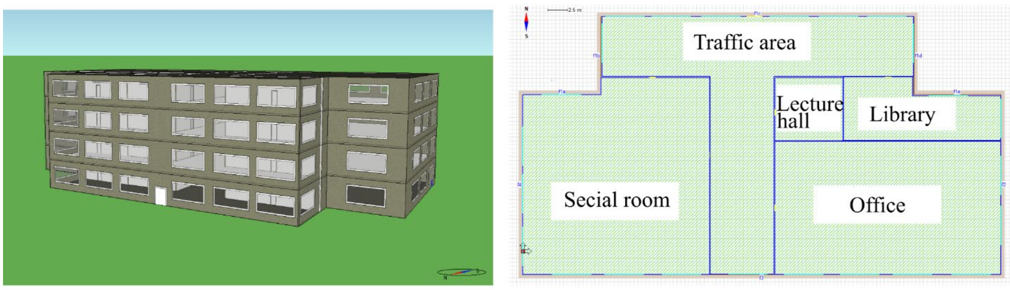
Figure 1. Zone distribution of reference building

As given in Figure 1, the content of the university reference building was defined. Figure 1 shows that office, traffic area, and laboratory accounted for the largest share of 67.79 % in total. Due to similar functionality of some zones, it was decided to combine them. Laboratories, workshop rooms, and various rooms requiring a lot of electricity (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, because they occupied a small area and had small contribution to energy use. The final zone distribution implemented in the study is shown in Figure 1b. Finally, the geometry and size were selected for the reference building. The most relevant information for the model development are summarized in Table 2.

Table 2. Reference model building areas

Building's geometry	Parameter	Reference model
General	Total area [m^2]	7220.00
	Heated are gross [m^2]	7159.20
	Floor area [m^2]	1805.00
	Number of floors	4
Total zone area/ per floor area	Office [m^2]	1967.60 / 491.90
	Library [m^2]	545.20 / 136.30
	Educational facilities [m^2]	282.00 / 70.50
	Special room [m^2]	2321.20 / 580.30
	Traffic area [m^2]	2043.20 / 510.80

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

2.4. *Establishment of energy efficiency measures*

To find solutions for reduction of energy use at the university campus, the energy efficiency measures were introduced. This step aimed to show potential of energy efficiency measures for educational buildings based on currently technical possible solutions. To efficiently post-process building simulation outputs in the dynamic segmented model for the building stock, the suggested energy efficiency measures were combined into four packages of the 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

2.5. *Development of future energy use*

The reduction of energy use is one of the objectives that our university, NTNU, put forward within their energy strategy. In order to investigate possible future energy development pathways, a neighbourhood building stock energy model was developed. It was founded on dynamic material flow analysis principles. The detailed model description and background can be found in the report [5]. Two scenarios were introduced to analyze possible energy efficiency developments: baseline scenario and advanced renovation scenario.

Baseline scenario considered that the future development of the existing and new buildings would follow current trends. This means that the renovation activities and new buildings would happen in compliance with present policy and regulations. The existing building stock was assumed to undergo standard renovation in a 40-year renovation cycle. The new buildings were expected to be built according to passive house requirements.

Advanced renovation prioritized increased energy efficiency of the building stock. This meant that the existing buildings were expected to undergo advanced renovation, whereas the new buildings are presumed to be built according to passive house requirements. Energy supply systems are assumed to be the same as in *Baseline scenario*.

3. Results

The most relevant results for the campus development and future energy use are presented below. Duration curves for heating use after the energy efficiency implementation are presented too.

3.1. *Building stock development*

Figure 3 shows the building stock development at the university campus in the period 2017-2050. Figure 3 shows also the change in the total floor area for various cohorts. Please note that the cohorts are marked with “C”, while the meaning and the content of each cohort is given in Table 1.

The building stock model considered plans about new construction at the campus towards 2025. Therefore, an increase in stock size occurred in this period, see Figure 3 at about 2025. Later on, it was assumed that some buildings would be demolished, as they reach their estimated end of life. The building stock model did no add new construction to replace the demolished buildings, and therefore the simulated stock seemed to be decreasing after 2025. This decrease was a result of the demolition of buildings from the cohort group 1951-1970.

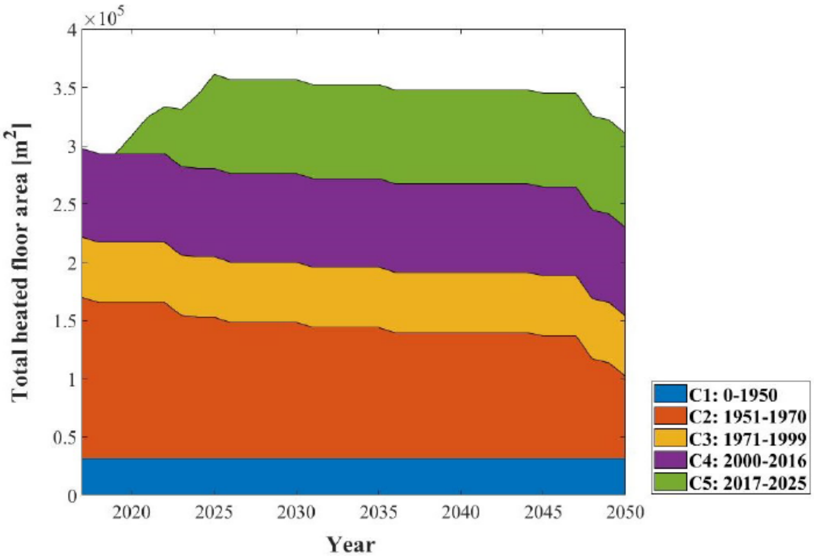


Figure 3. Neighbourhood building stock development at Gløshaugen campus 2017-2050. Total stock size and distribution to cohorts

3.2. Heating demand after implementation of energy efficiency measures

Taking in account that the building type 2, B2, see Table 1, included the most buildings at the university campus, the results are given for this cohort. Specifically, the focus was on the heating use, because the biggest potential for savings were identified there by implementing technically available measures. In addition, the building category 4, B4, with the newest building requirements and implemented measures is presented. Figure 5 and Figure 6 show the heat duration curves with the introduced renovation packages, while Table 4 and Table 5 show specific DH energy use and savings.

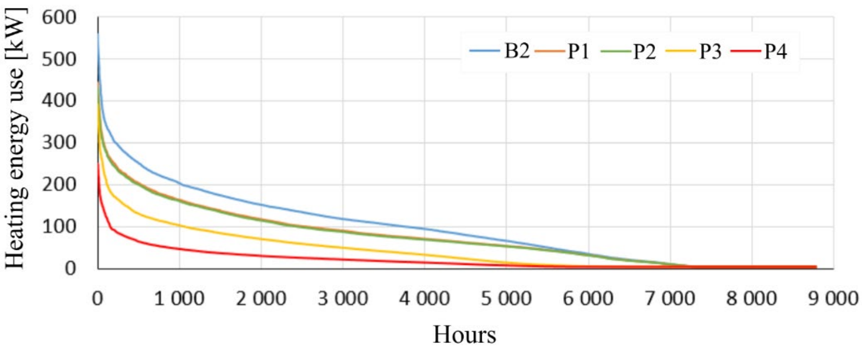


Figure 4. Heat duration curve for B2 model and corresponding renovation packages

Table 4. Specific heating energy use for B2 model with introduced energy efficiency measures

	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

As it can be seen from Figure 5 and Table 4, big savings could be achieved with the façade renovation packages. The results showed values in the range of 20-22%, while the technical package, P3, yielded a saving of 55%.

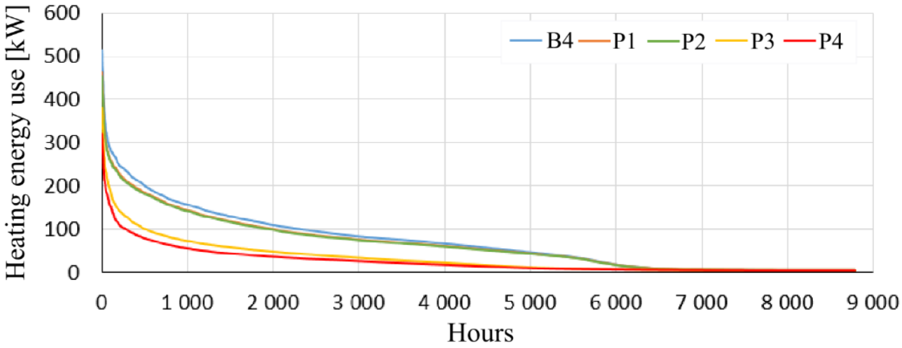


Figure 5. Heat duration curve for B4 model and corresponding renovation packages

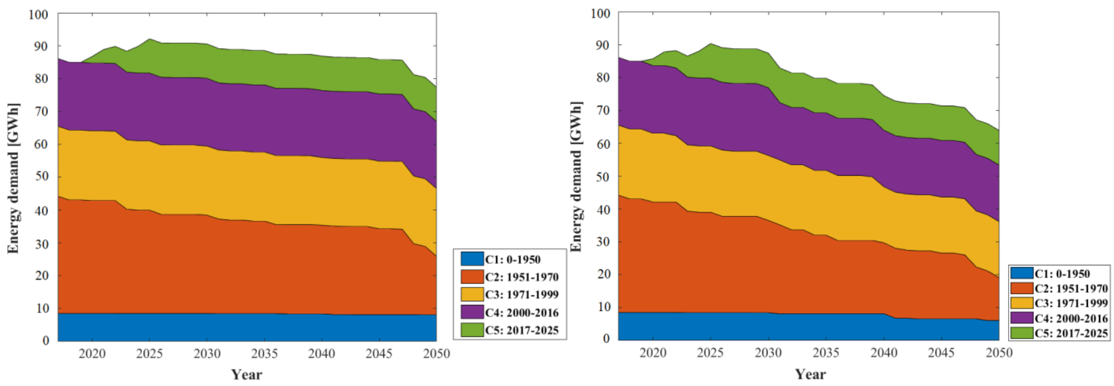
Table 5. Specific heating energy use for B4 model with introduced energy efficiency measures

	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

Figure 6 and Table 5 show that not as much savings for the building type B4 was achieved in comparison to B2 model. However, the technical packages, P3, P4, still provide high savings. Further, for both B2 and B4 models, it can be noticed that the heat duration curves had different shapes. The reason for this was that they belong to different construction year with different technical requirements. Regarding the specific energy use, there was no increase due to implementation of ambitious renovation in combination with technical improvements, the technical package P4, because, the indoor temperature was always satisfied during the working hours regardless of the cohorts and the technical packages.

3.3. *Results on campus energy use development towards 2017-2050*

Figure 7 shows the total energy demand with respect to cohorts and for two development scenarios.



(a) Standard renovation (b) Ambitious renovation

Figure 6. Energy demand with respect to cohort group

Figure 7a shows the results with respect to *Baseline scenario*. The results shows that energy demand of Cohort 1, 3, and 4 (C1, C3, and C4) decreased slightly as a result of renovation activity. For the newest cohort, C5, after the completion of the construction, the total energy demand would remain the same. It can be noted that Cohort 2, C2, marked red, diminishes substantially over the modelling period. The reason for this is demolition and renovation activities that would occur in this cohort group.

Figure 7b shows development with respect to *Advanced renovation*. At the beginning of the simulation, the total energy demand increased due to the emergence of new construction reaching a maximum of 90 GWh in the year 2025. The total energy demand decreased constantly due to renovation and demolition. Compared to the 2017 level, this means that the total energy demand of the campus in 2050 would be expected to be 26 % lower. The drastic decline in the total energy demand (by almost 60% compared to the 2017 level) occurred in Cohort 2 as a result of demolition and renovation activities. The energy demand of Cohort 1, 3, and 4 diminished over the simulation period and the total energy demand of the newest cohort remained unchanged after 2025 until the end of the modelling period.

Table 6 shows the results on development of the energy use in the university campus introduced in Section 2.5. The results show a percentage change in the value of energy demand at year 2050 with regard to the 2017 level.

Table 6. Energy demand and GHG emissions in all scenarios in 2050 compared to 2017 level

	Baseline	Advanced renovation
Electricity demand	+1.4%	-0.5%
Heat demand	-28.7%	-66.7%

The analysis on the energy use revealed that despite the stock growth, the total energy demand would decrease. The main reason for this was due to a substantial decrease in heat demand due to introduction of energy efficiency measures and construction of new low energy and passive standard buildings.

4. Conclusions

The aim of the study was to develop energy pathways for the university campus in Trondheim, towards 2050, because reduction of energy use is one of the our university objectives. The study showed that most of the buildings at the campus were built between 1951-1970. Four energy efficiency packages were introduced for reduction of energy use. Energy efficiency packages were mainly focused on heating saving potentials. It was found that saving potentials were highly dependent on the construction period of the buildings. Further, the technical package P4, ambitious renovation in combination with technical improvements, showed the greatest improvement in terms of energy efficiency. However, a substantial heating energy could be saved by implementation of simple technical measures. Specifically, improvement in the ventilation system gave the best results.

Detail analysis of the electricity use is required to introduce measures that would decrease electricity use. All energy efficiency measures should be analyzed with consideration of cost estimates. Real savings could be higher than the simulated results depending on energy price models. In addition, since the expensive peak load was reduced due to implementation of some energy efficiency measures, the economic benefits could also be higher than simulated.

Due to the planned relocation of the campuses, the campus building stock is expected to grow substantially until the year 2025 as a consequence of the construction activity. After 2025 the stock is estimated to gradually decrease as a result of the demolition of buildings from the cohort group 1951-1970.

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 the part of the investigation study for the campus development.

References

[1] Robinson D. Integrated resource flow modelling of the urban built environment. Building Performance Simulating for Design and Operation2012. p. 441-68.
[2] Chen Y, Hong T, Piette MA. Automatic generation and simulation of urban building energy models based on city datasets for city-scale building retrofit analysis. Applied Energy. 2017;205:323-35.

[3] Kavgic M, Summerfield A, Mumovic D, Stevanovic Z. Application of a Monte Carlo model to predict space heating energy use of Belgrade's housing stock. Journal of Building Performance Simulation. 2014.
[4] Sandberg NH, Sartori I, Brattebø H. Using a dynamic segmented model to examine future renovation activities in the Norwegian dwelling stock. Energy and Buildings. 2014;82:287-95.
[5] Næss JS, Sandberg NH, 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. 2018.
[6] Directorate NWRaE. Energy use. 2011.
[7] NS 3031, Calculation of energy performances of buildings, Method and data. In: Norway S, editor.2007.
[8] Regulations on technical requirements for construction works. Norwegian Building Authority. 2017.
[9] Guan J, Nord N, Chen S. Energy planning of university campus building complex: Energy usage and coincidental analysis of individual buildings with a case study. Energy and Buildings. 2016;124(Supplement C):99-111.