Estonian Journal of Engineering, 2013, **19**, 4, 309–328 doi: 10.3176/eng.2013.4.06

Nearly zero energy office building without conventional heating

Martin Thalfeldt, Jarek Kurnitski and Alo Mikola

Tallinn University of Technology, Faculty of Civil Engineering, Ehitajate tee 5, 19086 Tallinn, Estonia; martin.thalfeldt@ttu.ee

Received 25 November 2013, in revised form 6 December 2013

Abstract. A case study of the first nearly zero energy office building (nZEB) in Rakvere, Estonia was conducted to determine whether an office building can be built without a conventional space heating system while ensuring adequate thermal comfort in the offices. Energy and indoor climate simulations of alternative solutions were carried out and the feasibility of the solutions, ensuring heated rooms throughout the year, was assessed based on investment cost and payback calculations. The results showed that despite of the low heat losses, a nZEB still needs a space heating system with room based temperature control. Heating needs primarily occurred during weekends and at night; however, without space heating the air temperatures in the rooms dropped down to 16.7 °C during occupancy and were below 21 °C during about 700 occupied hours. Supply air heating with variable air volume system, controlled according to the coldest room and on demand night operation, was able to keep +21 °C temperature in all rooms, but resulted in significant energy penalty caused by overheating of offices with lower heat losses and increased fan electricity use. The economic analysis showed that a building with simple constant air volume ventilation system and radiator heating was most feasible. The investment cost increase of the variable air flow ventilation system was too high compared to the savings in energy cost that was already low.

Key words: nearly zero energy buildings, nZEB, energy performance, indoor climate, thermal comfort, radiator heating.

1. INTRODUCTION

In well insulated low energy and passive houses the energy need for space heating is very low and the idea of leaving out a conventional heating system and thereby reducing building construction costs has been a topic over decades. One of the main characteristics of a passive house is that the whole building is heated with warm supply air [1]. The whole concept is introduced more throughly in [2]. Although it is suspected that air heating with upper distribution can cause thermal discomfort due to stratification or cold draught from windows, Krajcik et al. [3] came to the conclusion that supplying warm air for heating in low-energy buildings does not cause problems due to vertical air differences in a single room with controlled environment in case of calculated heat losses up to 13 W/m^2.

The role of internal and solar gains in the heat balance of growingly better insulated buildings is increasing and therefore the heat, stored in building structures, increases the role of passive solar heating in keeping comfortable thermal conditions. Five different passive solar heating strategies were analysed in [4] with methods for reducing diurnal variations, which ranged between 0.1 and 10.3 °C. In addition, thermal monitoring of passive solar building was conducted in [5], where formulae to predict indoor air temperature for such buildings were developed.

Although the combination of highly insulated building envelope and air heating seems to work in theory, the analysis in [6] refers to some limitations of the air heating concept in Nordic countries related to uneven temperature distribution in a building and stresses the need for multi-zone analysis. In the investigation of 20 low-energy houses located in Sweden, Isaksson and Karlsson [7] concluded that the indoor cliamte in the buildings is generally good; however, problems have occurred with thermal comfort in case of houses with larger external wall area and less active use. After the investigation, extra radiators were installed in some of the studied houses, which improved occupants' satisfaction with indoor climate. Similarly, in [8] it is reported that the occupants of recently built 39 Swedish passive houses experienced cold floors to a higher degree than in the conventional buildings, and that there were a higher number of complaints related to high temperatures during summer in the passive houses. Overheating might also be a problem in low-energy buildings. In [9] it was stated that optimization of design parameters plays a significant role in mitigating future overheating risks. Therefore, the solutions replacing conventional heating systems need careful verification in order to be safely used.

Most of the previous studies on low-energy buildings have been done regarding residential buildings and it is clear that careful consideration is needed to assure premium indoor climate in these high-end buildings. Dwellings usually have lower daily and weekly fluctuations of internal gains, which make ensuring comfortable temperatures easier. In non-residential buildings, e.g. offices, the fluctuations in internal gains are much larger and in addition, due to larger number of floors and rooms, the objective of keeping acceptably stable thermal conditions without a conventional heating system in all rooms is much harder to fulfill.

This paper describes a case study of the first nearly zero energy office building in Rakvere, Estonia the office building of the Smart Building Competence Centre, currently under technical design and value engineering process. The need to improve construction cost effectiveness arised during the design development and one of the questions addressed was whether a space heating system with water radiators is needed. The purpose of the study was to analyse is it possible to avoid installation of the space heating system in a highly insulated office building and what is the impact of alternative solutions on the thermal comfort and energy use. The focus was mainly set on highly insulated building envelope and heating with warm supply air with variable air volume (VAV) ventilation system. The insulation thicknesses of external walls and the roof ranged between 200–600 mm and 250–750 mm, respectively, windows with up to 4 panes were used. In addition, to avoid room temperatures dropping below +21 °C, the problem of overheating was also studied. Finally, the energy costs and rough estimates of construction costs of studied alternatives were calculated to assess the feasibility of design alternatives.

2. METHODS

The heating and overheating problem with consequent energy use effects was studied in a nearly zero office case building with simulations, which included the following analyses:

(1) determination of the heating period in offices and assessment of the decrease in thermal comfort when heating system was neglected;
(2) identification of measures to assure +21 °C in all offices without radiator heating;
(3) determination of measures to reduce overheating;
(4) assessment of investment and energy costs.

2.1. Building simulation model of Rakvere nZEB

Energy and indoor climate simulations were conducted on the basis of the technical design documents of the building, which was currently under some redesign and value engineering process. The building has 3 office floors, a heated atrium, an unheated atrium and a basement with a garage and technical rooms underground. The total heated net floor area is 2257 m^2. The heated e.g. warm atrium divides the office floors into north and south parts of which the latter also has a double-skin facade with openable hatches to ventilate it (Fig. 1).

Detailed room by room simulation model of the whole building was considered to be too complicated and time consuming to run in the beginning and therefore focus was set on the office rooms, located in the south part of the second office floor, shown in Fig. 2. The studied group of office rooms has smaller heat losses than other parts of the building and thus it would be easiest to keep temperatures above +21 °C in these rooms. It was assumed that if leaving out the heating system would be successful in this part of the building, then the whole building could be simulated to test the performance of solutions applied. Larger simplified zones were used in rest of the model and in addition the offices, located in the Northern part and the basement floor were left out from the model. The heating system was used only in the warm atrium in all cases. Total heated area of the simplified office building model is 1521.6 m^2.

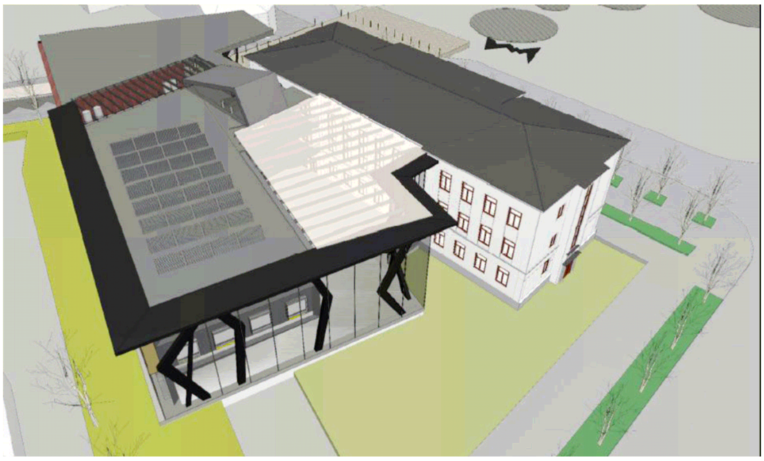


Fig. 1. View on the Rakvere nZEB from south; the cold atrium is fully glazed and the roof window of the warm atrium, dividing the offices to south and north parts, is also seen. The nZEB is connected to an existing building.

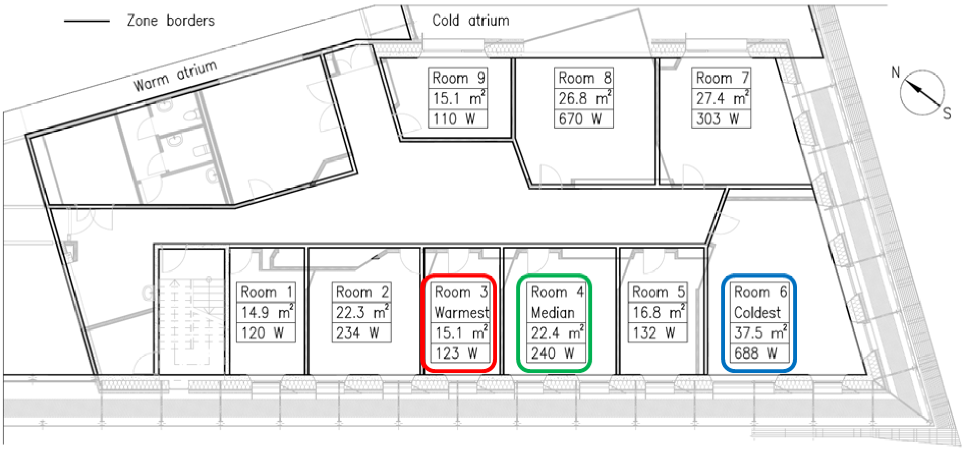


Fig. 2. Office rooms's plan, where the zone borders were slightly simplified compared to architectural solution (depicted in grey).

The simulations were conducted with input data of the Estonian regulations on the energy performance of buildings [10]. The rooms were heated with radiators (ideal heaters in the model) and a ground source heat pump, connected to energy wells, was used. The air conditioning was done with room conditioning units (ideal coolers in the model) and mechanical supply and extract ventilation with heat recovery was used. The working hours were from 7:00 to 18:00 on weekdays and the usage factor of heat gains during working hours was 55%. The default value of the energy performance regulation was used for lighting and includes some margin. The time schedule of air handling units (AHU) was from

Table 1. Input data of office rooms and HVAC systems for energy calculations

Building parameter	Value
Occupants, W/m^2	5
Equipment, W/m^2	12
Lighting, W/m^2	12
Temperature set point for heating and cooling	+21 and +25 °C
Outdoor air flow rate	2 l/s·m^2
Total irradiance on façade, above which solar shading is down, W/m^2	200
Set point for lighting control, lux	500
Frame ratio of windows, %	15
Heating system (radiators) efficiency	0.97
Heat source (ground source heat pump) seasonal coefficient of performance (SCOP)	4.0
Cooling system losses, % of cooling energy need	10
Mechanical cooling SEER*	3.5
Free cooling SEER	10.0
VAV ventilation SFP at full capacity, kW/m^3/s	2.3
Annual domestic hot water use, l/m^2 per heated area	100

---

* SEER – seasonal energy efficiency ratio.

6:00 to 19:00 on weekdays. The initial data of simulation model is shown in Table 1. External blinds, located behind the double skin façade, were automatically drawn when total irradiance on the façade exceeded 200 W/m^2 to avoid glare. The lighting system was controlled according to demand so that during occupancy the setpoint at a workplace was 500 lux. Lighting and shading control principles were adopted from REHVA Guidebook No. 12 "Solar Shading" [11]. Energy simulations were conducted with the well-validated simulation tool IDA ICE 4.5 [12] and the climate data of the test reference year of Estonia was used [13]. The energy needs for heating and cooling were simulated with ideal heaters and coolers and system losses and efficiencies were taken into account when calculating delivered energy. For the primary energy calculation in this all-electric building, the Estonian primary energy factor for electricity 2.0 was used.

2.2. Criteria for satisfactory thermal comfort

The requirements of indoor environment classes, given in [14], were used to assess the general thermal comfort. EN 15251:2007 defines the lower and upper limit for all indoor environment classes, e.g., during winter the indoor temperature in offices should remain between +21 and +23 °C in class I, that was used as natural target for high performance nZEB building. Thermal comfort was assessed considering both limits for all classes according to EN 15251:2007. Local thermal discomfort, which may be easily caused by supply air heating, was not studied, because the simulations showed heating need outside occupied hours, as reported in Table 2. Therefore, supply air heating cannot deteriorate thermal comfort, because the rooms are not occupied during heating period.

Table 2. Duration of occupancy, heating period, their overlapping and unsatisfying indoor temperature during occupancy

Period	Duration, hours/a	Duration, % of a year
Occupancy	2860	32.6
Heating need	1964	22.4
Heating need during occupancy (heated)	126	1.4
Room temperature <+21 °C during occupancy (unheated)	683	7.8

2.3. Studied cases

Initially the hours when there is a heating need in any of the heated offices and hours when the temperatures drop below +21 °C in any of the unheated offices were determined with the base case simulation model to verify the heating period to be used in subsequent analysis. Also the indoor temperatures of the heated and unheated base case were simulated. Initially there was room based variable air volume ventilation in the rooms and in addition the effect of constant air volume (CAV) ventilation was studied with a heated case. The ventilation air flows were designed to assure adequate indoor air quality (CO_2 level below 1000 ppm) and no recirculation was used.

The following simulation cases were developed with the focus initially set on the improvement of building envelope and the following attention was paid on the control solutions and supply air heating of the ventilation system. Firstly it was analyzed whether increasing the insulation thicknesses of external walls and roof, the number of window panes and air tightness of building envelope helps reaching acceptable thermal comfort throughout the year. The description of simulation cases with different building envelope properties has been shown in Table 3.

Table 3. Description of cases with different thermal properties of the building envelope

Case code	*U*-value*, W(m^2 K)			*g*-value** of glazing		Building envelope air tightness at pressure difference 50 Pa n_{50}, m^3/h ext. surface m^2	Specific heat loss coefficient per heated floor area *H/A****, W/m^2 K
	External wall	Roof	Windows	Windows	Double skin		
H/A 0.63	0.19	0.15	0.80	0.56	0.86	3	0.63
H/A 0.53	0.10	0.08	0.80	0.56	0.86	3	0.56
H/A 0.38	0.10	0.08	0.40	0.34	0.86	1	0.38
H/A 0.32	0.07	0.05	0.40	0.34	0.86	1	0.32

---

* *U*-value – thermal transmittance, W/m^2 K

** *g*-value – solar heat gain coefficient

****H/A* – specific heat loss coefficient per heated floor area, W/m^2 K

The external wall insulation thicknesses were increased as follows: 200, 400 and 600 mm; roof insulation thicknesses are 250, 500 and 750 mm, number of window panes was increased from 3 to 4.

In the cases with air heating the concept of night ventilation (NV) was introduced to the models. The base case ventilation was switched on and off one hour before and after the office hours, respectively. Besides regular working hours, the air handling units also worked in case of heating need, i.e., when the extract air temperature or the air temperature in the coldest office zone was below +21 °C, depending on the control solution. Generally the supply air temperature was controlled according to extract air and in case of air heating the supply air temperature setpoint was raised to the design value when heating was needed. The description of cases with air heating is shown in Table 4. Design temperatures were calculated as

$$\Delta t = \frac{q_v \rho c_p}{\Phi}, \tag{1}$$

where, Δt is temperature difference between supply air and room temperature (+21 °C), °C, q_v is the supply air flow rate, L/s, ρ is air density, 1.2 kg/m^3, c_p is specific heat of air, 1.005 kJ/kg °C and Φ is heat loss, W.

As supply air heating unnecessarily increases the temperatures in the warmer rooms two methods for reducing the effect of overheating were studied (Table 4). Firstly the design air flow rate of VAV ventilation was increased, which allowed lower supply air temperatures. Secondly the supply air temperature control for two of the coldest rooms was controlled separately from the air supplied to warmer rooms, which reduced the supply of warm air into the warmer offices.

The simulations were mainly done so that the occupancy profile was the same for all zones. However, an unoccupied office may have a significant impact on

Table 4. Description of cases with different ventilation solutions and supply air heating

Case code	System type	Design air flow rate, L/s m^2	Control solutions	
			Working hours	Supply air temperature, °C
Base case	VAV	2	Schedule	+16...20
NV, CAV (2), Ex.	CAV	2	Schedule + exhaust air temp.	+16...20, 28.6
NV, VAV (2), Ex.	VAV	2	Schedule + exhaust air temp.	+16...20, 28.6
NV, VAV (2), Zones	VAV	2	Schedule + min. zone temp.	+16...20, 28.6
NV, VAV (3), Zones	VAV	3	Schedule + min. zone temp.	+16...20, 26.1
NV, VAV, 2xAHU	VAV	2	Schedule + min. zone temp.*	+16...20, 28.6

* The supply air temperatures of two of the coldest rooms and the other rooms are controlled separately by using either two separate AHU’s or heating coils.

heating need. To study the worst possible situation, simulations were conducted also with an unoccupied coldest room of the following cases:

(1) base case,
(2) CAV night ventilation controlled according to exhaust air temperature,
(3) VAV night ventilation controlled according to the coldest zone.

The design air flow rates of all cases were 2 l/s m^2.

2.4. Assessment of investment and energy costs

Investment costs were calculated for all cases ensuring temperatures above +21 °C and their feasibility was assessed by calculating the simple payback times compared to the case with the lowest investment cost – base case building with radiator heating and CAV ventilation. In addition, as an improvement of the original design, a case with CAV ventilation was created where the AHU's and ventilation ducts were increased by one size to determine which is more reasonable – investing in the VAV system or more reliable and simple CAV system with larger ducts and AHUs.

3. RESULTS

3.1. Neglecting the heating system of the base case

The results shown in Table 2 indicate that only a minor proportion of heating need occurred during office hours, which means that generally heat loss is compensated by internal and solar heat gains during occupied hours. However in an unheated case the duration of air temperatures being below +21 °C during occupancy was 683 hours and that is a significantly longer period compared to heating need duration. Therefore this period of 683 hours was used in subsequent thermal comfort analysis as the heating period. The results shown in Fig. 3 show that room heating need occurred only during the weekend and first nights of a cold week, which suggests that heating would not have been needed if the room would have been in use throughout the whole week. Increasing supply air heating needs during the workdays can be explained by increased air flow rates of the VAV system, needed to keep the room temperature below 24 °C during occupancy.

The minimum temperatures of unheated office rooms ranged between +16.7 °C (room 6) and +20.0 °C (room 3) with median being +19.2 °C (room 4) during occupied hours. Lowest temperatures occurred in larger rooms with higher external wall area (Fig. 4). Based on this information, the results for the rooms 3, 4 and 6 (Fig. 2) are presented further in the paper and are referred to as "Warmest", "Median" and "Coldest" rooms, respectively.

The indoor climate simulations indicate that temperatures drop below +21 °C in all unheated office rooms (Fig. 5), whereas indoor climate class II requirements were not fulfilled almost for 50% of the heating period time in the coldest

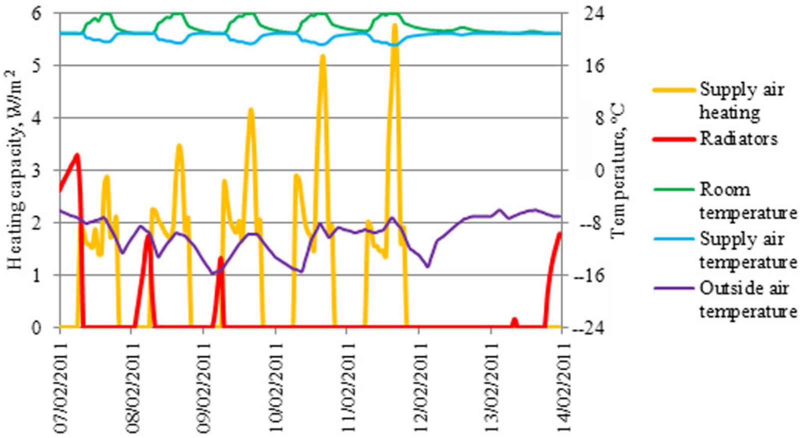


Fig. 3. The radiator and supply air heating capacities, room, supply and outside air temperatures of median office during one of the coldest weeks in test reference year

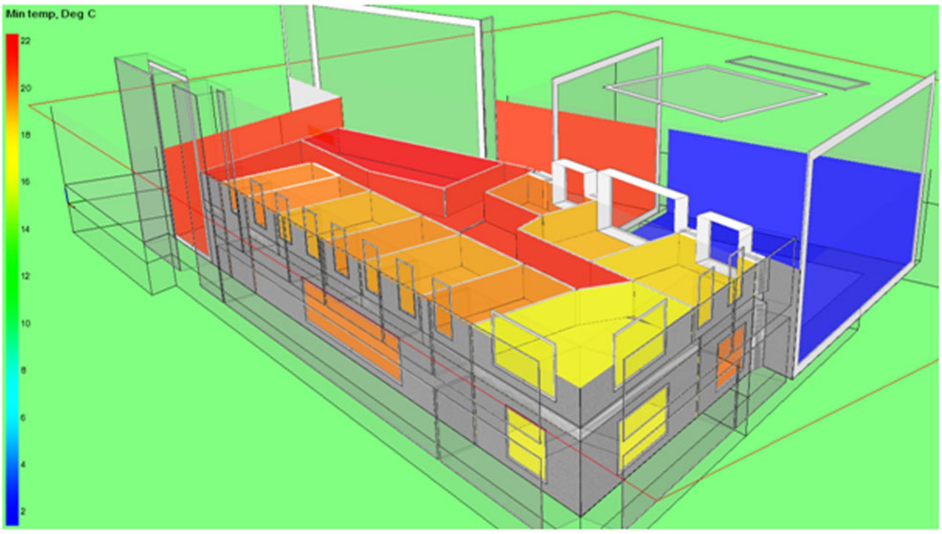


Fig. 4. 3D simulation model and minimum temperatures of an unheated base case, the first and third floor zones have been simplified and the zones in north of the warm atrium have been left out from the model.

room (Fig. 6). The indoor temperatures of heated warmest and median rooms did not differ significantly, but without a heating system the median room may be up to 0.5 °C colder. It also turned out that the case with CAV ventilation was the only one assuring comfortable indoor temperatures below +23 °C during the heating period (Fig. 7).

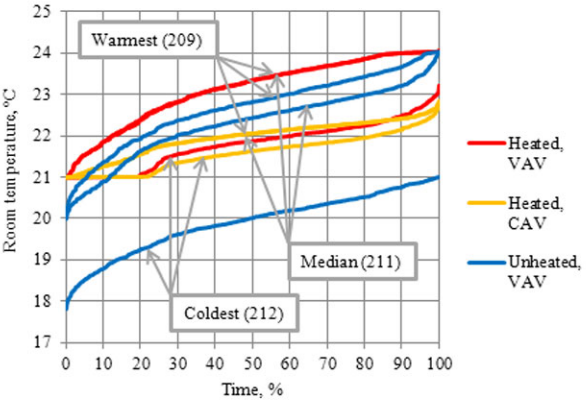


Fig. 5. Heating period room temperatures of heated and unheated base case office rooms during occupancy (683 hours).

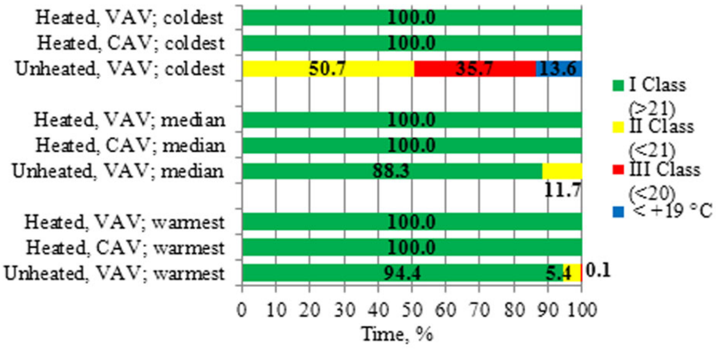


Fig. 6. Distribution of heated and unheated base case office rooms' temperatures regarding underheating according to indoor enviroment classes of EN 15251:2007 during occupancy in the heating period (683 hours).

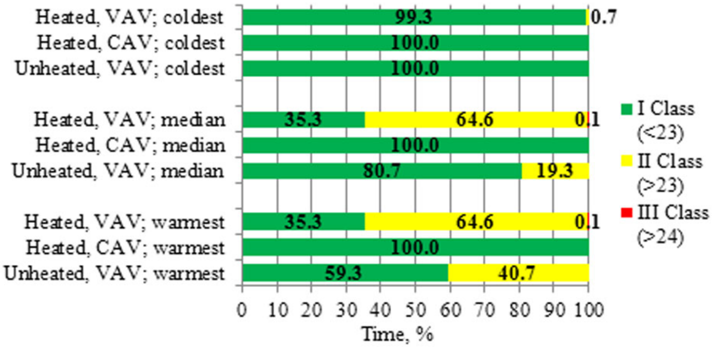


Fig. 7. Distribution of heated and unheated base case office rooms' temperatures regarding overheating according to indoor environment classes during occupancy in the heating period (683 hours).

3.2. Building envelope thermal insulation

Increasing the thermal insulation of the building envelope reduced the underheated period of office rooms (Fig. 8) with room temperatures of warmer rooms over +21 °C prevailing; however, the same conditions were rarely reached in the coldest room. On the other hand, the indoor temperatures of the warmer rooms increased significantly and the overheating occurred up to 60% of the heating period in the warmer rooms. Increasing insulation thicknesses, number of window panes and airtightness did not assure satisfactory thermal comfort and further methods had to be studied, e.g., using night ventilation and warm ventilation supply air for space heating.

3.3. Room heating with ventilation supply air

The calculations showed that specific heat loss of office rooms at outside air temperature –22 °C varies between 7.3 and 18.4 W/m^2 and design supply air temperatures of air heating in case of airflow rates 2 and 3 l/s m^2 were 28.6 and 26.1 °C, respectively (Table 5). The specific heat loss of the coldest room significantly dominated and therefore supplying air with the same temperature and constant air flow rate caused unnecessary overheating in most of rooms. The indoor temperatures at these conditions may rise up to +24 °C as can be seen in Table 5.

The energy simulations with air heating showed that assuring +21 °C at all times in all office rooms was only possible if the air handling unit operation was controlled according to the zone with minimum air temperature. On the other hand, AHU control according to the coldest room caused significant overheating

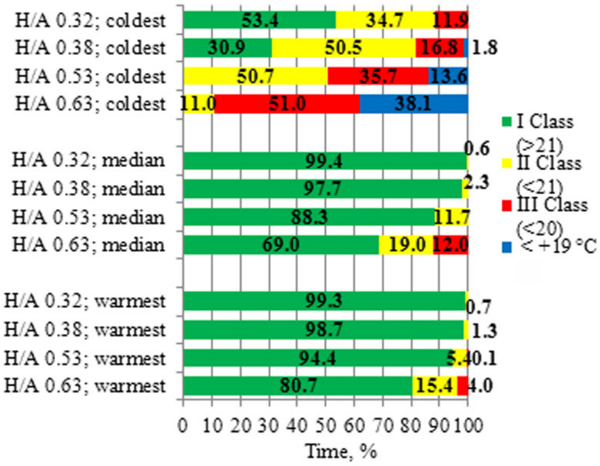


Fig. 8. The effect of thermal insulation on temperature distribution of office rooms' temperatures regarding underheating according to indoor environment classes during occupancy in the heating period (683 hours), H/A in the case codes indicates specific heat loss coefficients.

Table 5. Heat loss, design supply air temperatures for air heating and room temperatures in case of a heating design day

Heat loss and temperatures	1	2	3	4	5	6	7	8	9
Heat loss, W/m^2									
	8.0	10.5	8.2	10.7	7.8	18.4	11.1	13.8	7.3
Supply temperature, l/s m^2									
2	24.3	25.4	24.4	25.4	24.3	**28.6**	25.6	26.7	24.0
3	23.2	23.9	23.3	24.0	23.2	**26.1**	24.1	24.8	23.0
Room temperature, l/s m^2									
2	23.3	23.1	23.6	22.9	23.5	21.0	23.2	22.4	24.0
3	22.9	22.7	23.1	22.6	23.0	21.0	22.7	22.1	23.4

in the warmer offices (Fig. 9). The room temperature curves shown in Fig. 8 indicate that temperatures above +21 °C are ensured in the warmer rooms for most of the time if ventilation was controlled according to the extract air temperature; however, thermal comfort in the coldest rooms was not assured (Fig. 10). The case with constant air flow rate controlled according to extract air temperature was also studied, but minimum air temperatures of rooms did not improve. The only effect was decreased maximum air temperatures in the warmer rooms.

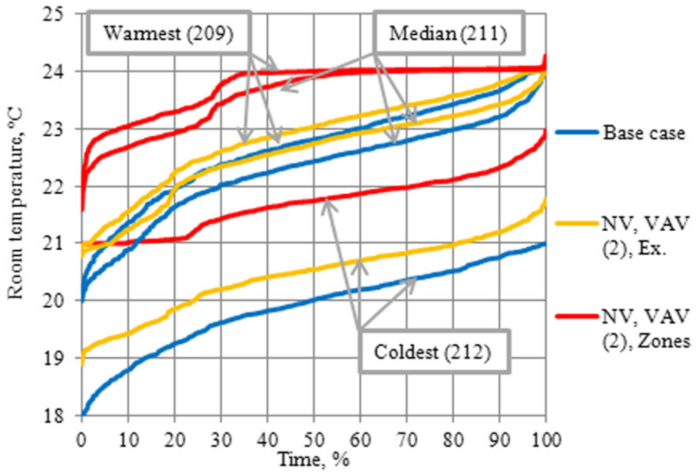


Fig. 9. Heating period room temperatures of office rooms with ventilation supply air heating during occupancy (683 hours).

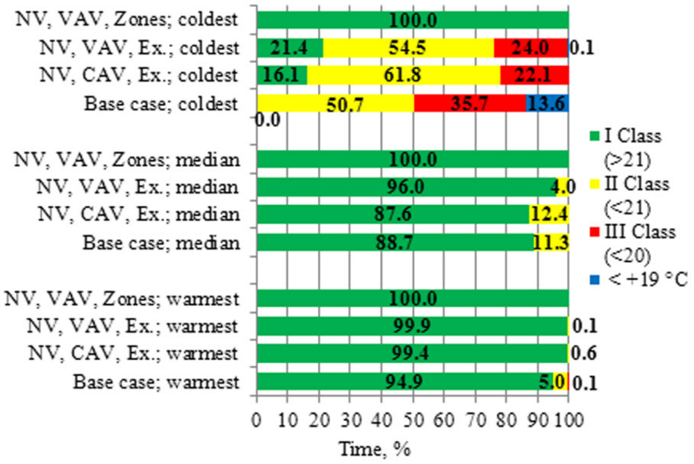


Fig. 10. The effect of ventilation heating control solutions on temperature distribution of office rooms' temperatures regarding underheating according to indoor environment classes in the heating period during occupancy (683 hours).

3.4. Optimizing thermal comfort

The simulation results show that increasing air flow rates and thus lowering supply air temperatures reduce overheating of warmer rooms (Fig. 11). The effect of controlling the supply air temperatures of colder and warmer rooms separately had even larger effect on thermal comfort compared to reducing the supply air temperature. The effects on thermal comfort of the warmest and median rooms were similar and the results of the median room are not presented for the clarity of Fig. 11.

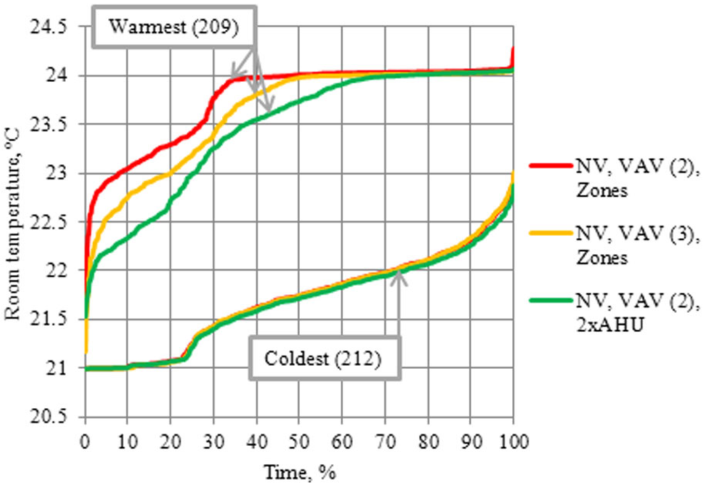


Fig. 11. Heating period room temperatures of office rooms duringwhen means of reducing overheating have been implemented occupancy (683 hours).

3.5. The effect of an unoccupied room

Thermal comfort analysis in case of an unoccupied coldest room without internal gains shows that a single unoccupied office can cause significant overheating in other rooms. The results shown in Figs 12 and 13 indicate that cooling needs may occur for a large part of the heating period resulting in increased energy use and that air temperatures rarely drop below +23 °C in the warmer rooms. This shows that although theoretically satisfactory indoor climate may be assured with night ventilation, the real use of the rooms may cause unacceptable thermal comfort in at least some of the offices.

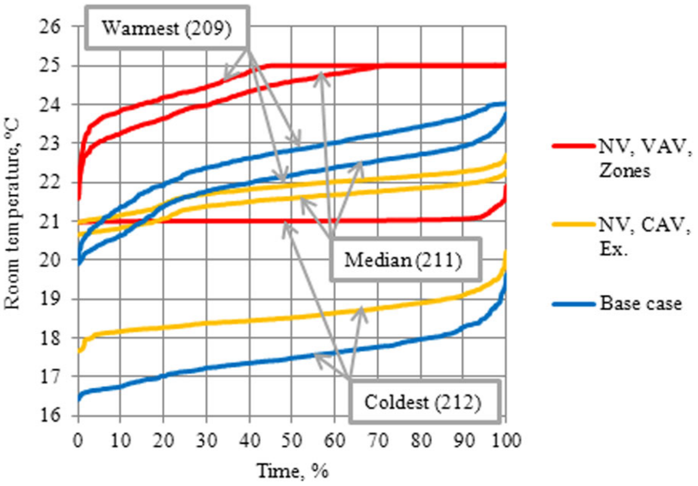


Fig. 12. Heating period room temperatures of office rooms during occupancy (683 hours) when the coldest room is unoccupied.

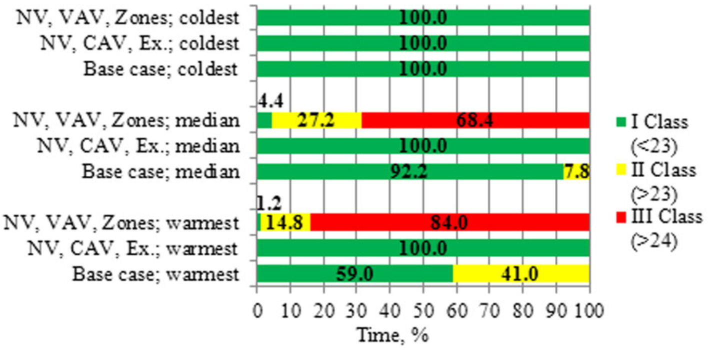
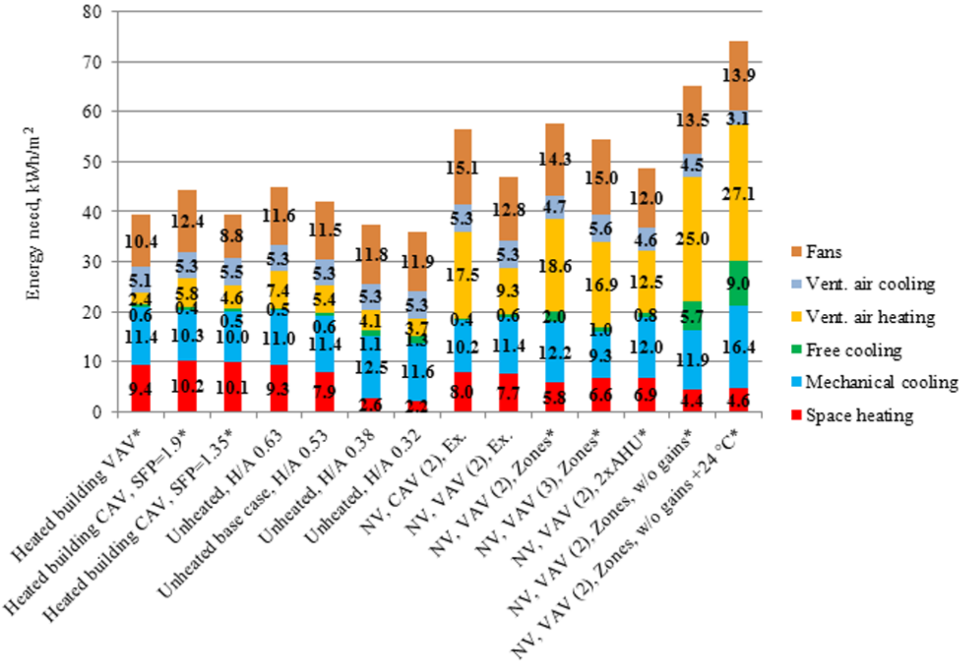


Fig. 13. The effect of the unoccupied coldest room on temperature distribution of office rooms' temperatures in the heating period during occupancy (683 hours) regarding overheating according to indoor environment classes.

3.6. Energy performance analysis

The energy performance analysis showed that assuring +21 °C with warm supply air, increases annual electricity use by 6.2–14.1 kWh/m^2 and thus primary energy by 8.3–19.1 kWh/m^2. The energy need and primary energy of most studied cases are shown in Figs 14 and 15, respectively (note that the delivered energy is half of the primary energy, because of all-electric building and primary energy factor 2.0). It can be seen that the control solutions of ventilation may have much larger impact on energy efficiency of a nearly zero energy office building than altering the thermal insulation level of the building envelope. Although increasing insulation thicknesses may reduce heating need by more than twice, the overall effect is not as large since heating does not dominate in energy use in nZEB offices.

Also using VAV dampers and altering the size of ducts had a large impact on the specific fan power (SFP) and it reflected in the results. The SFP of base case with CAV ventilation was 1.9 kW/m^3/s and adding VAV dampers to the system increased the pressure drop of ducts from 300 to 400 Pa and therefore the SFP was increased to 2.3 kW/m^3/s. Using larger ducts and air handling units in a CAV system improved the temperature efficiency of heat recovery from 75% to 82% and SFP dropped to 1.35 kW/m^3/s.



* The cases that ensures temperatures above +21 °C in all offices.

Fig. 14. The energy needs of studied cases.

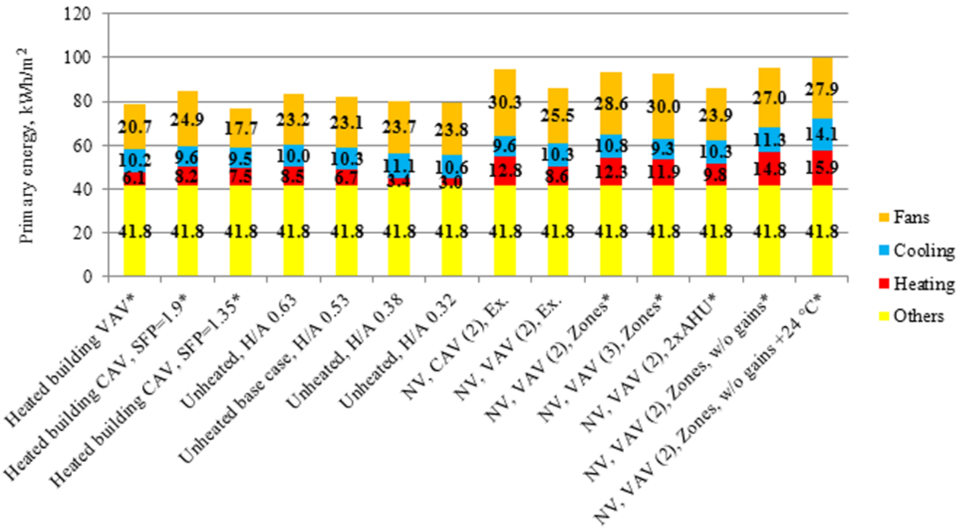


Fig. 15. The primary energy of studied cases. “Others” is formed by lighting (24.2 kWh/m^2), equipment (37.8), domestic hot water (3.4) and circulation pumps (2.0), from which PV electricity production (25.6) has been subtracted.

Using night ventilation for heating increased fans electricity consumption by more than 25% and supply air heating need more than 10 times which together substantially damaged energy efficiency. This increased the need for on-site or nearby renewable energy production to fulfill nZEB requirements.

The calculated annual primary energy limit for nearly zero office buildings in Estonia is 100 kWh/m^2 and the primary energy of the base case was 78.8 kWh/m^2, which safely meets the requirements and basically allows to reduce the size of the photovoltaic (PV) system. If only ventilation system with VAV dampers is used for room heating (NV, VAV (2), Zones), then simulated primary energy increased to 93.5 kWh/m^2, which still meets the requirements; however, it makes optimizing the construction cost more difficult.

3.7. Economic calculations

The economic calculations show that most reasonable solution is a radiator heated building with CAV ventilation that has been sized according to the base case. Increasing air handling units and air ducts proved to be too expensive compared to savings in energy. All cases, which used VAV ventilation, surpassed the cost of radiator heating, and the energy cost of the cases with no radiators was also higher. If only cases with VAV ventilation are compared then the payback time of investing in radiator heating is 7.5 years if all rooms are occupied and it decreases to 5.3 years if the coldest room is unoccupied making a radiator heating system a reasonable choice.

Table 6. Investment and energy costs and payback time of studied cases

Case	Changed components of building HVAC system	Investment cost change, €/m^2	Annual energy cost increase, €/m^2	Payback time, years
Heated, CAV (2), SFP = 1.9	–	**0.0**	**0.0**	–
Heated, CAV (2), SFP = 1.35		**+22.4**	**−0.55**	**67.0**
	Larger AHU's	+7.1		
	Material	+10.8		
	Labour	+4.5		
Heated, VAV (2)		**+14.6**	**−0.39**	**37.0**
	VAV dampers	+8.0		
	AHU control systems	+1.0		
	CO$_2$ sensors and wiring	+5.2		
	Noise attenuators	+1.2		
	Removed balancing dampers	−0.8		
NV, VAV (2), Zones		**+6.9**	**0.59**	*
	Same as Heated VAV (2)	+14.6		
	Removal of heating system	−7.6		
NV, VAV (3), Zones		**30.6**	**0.55**	*
	Same as NV, VAV (2), Zones	+6.9		
	Larger AHU's	+7.0		
	Material and labour	+15.6		
	Larger heating and cooling coil loops	+1.1		
NV, VAV (2), 2 × AHU		**41.7**	**0.05**	*
	Same as NV, VAV (2), Zones	+6.9		
	AHU's	+12.2		
	Additional AHU control systems	+13.7		
	Additional heating and cooling coils	+8.8		
NV, VAV (2), Zones, w/o gains	Same as NV, VAV (2), Zones	**6.9**	**0.69**	*
NV, VAV (2), Zones, w/o gains +24 °C	Same as NV, VAV (2), Zones	**6.9**	**1.02**	*

* Payback time cannot be calculated because both investment and energy cost increased.

4. DISCUSSION

The analysis shows that heating needs in a nearly zero office building mostly occur outside working period and therefore the heating system necessarily does not have to assure premium thermal comfort; however, room based temperature control is necessary to keep energy cost under control and to meet the nZEB requirements. It would be possible to use other solutions besides radiator heating, e.g. active beams for heating and cooling or air heating with coils on the supply air branches of each room. These measures would not give savings in construction cost; however, they could serve architectural purposes. On the other hand, they would require to use the ventilation system during night time increasing energy use similarly to simulated NV cases.

Comparing different ventilation solutions indicated that variable air flow ventilation did not give very large savings in a nearly zero energy building and installing a more simple constant air volume ventilation system that requires less maintenance could be seen as a more reasonable choice. Relatively high SFP value of 1.9 kW/m^3/s in base case with CAV ventilation shows the role of ventilation ductwork layout and AHU locations, which optimization could lead to shorter ductworks and lower SFP value with fan energy saving. Thorough analysis while choosing air handling units and designing ductwork is essential in the design of a nZEB.

It has to be underlined that when making decisions, based on energy and indoor climate solutions, other situations besides standardized use of building have to be considered. In some cases of this study one unoccupied office room severely worsened the indoor climate of other rooms and damaged the energy performance. The actual use mostly differs from the conditions used in energy simulations and ignoring this during design process might lead to inefficient solutions and actual energy use significantly higher than the calculated one.

5. CONCLUSIONS

A case study of the first nearly zero energy office building in Rakvere, Estonia was conducted to determine whether an office building can be built without a conventional radiator heating system while ensuring adequate thermal comfort in the offices. Energy and indoor climate simulations of different building envelope and ventilation solutions were carried out and the feasibility of solutions ensuring +21 °C throughout the year was assessed, based on investment cost and payback calculations.

The results showed that despite of low heat losses, a nZEB still needs a space heating system with room based temperature control. Without space heating the air temperatures in the rooms dropped down to 16.7 °C during occupancy and were below 21 °C during about 700 occupied hours. However, heating need mostly occurred out of occupied hours showing that the quality of space heating solution is not crucial in a nZEB.

Supply air heating with VAV system controlled according to the coldest room and on demand night operation was able to keep +21 °C temperature in all rooms, but resulted in significant energy penalty as primary energy of the base case of

78.8 kWh/m^2 increased to 93.5 kWh/m^2. The differences in the heat losses of office rooms were the main reason why heating with warm supply air overheated the middle offices. Simulating the coldest room without occupancy further increased overheating of other rooms and resulted in primary energy of about 100 kWh/m^2.

The economic analysis showed that a building with simple constant air volume ventilation system and radiator heating was most feasible. The investment cost increase of a variable air flow ventilation system was too high compared to the savings in energy cost that was already low. The simple payback time of the VAV system was 37 years. Also the CAV system with larger ductwork and air handling units was not feasible in this case because of a payback time of 67 years. This long payback time was partly a result of quite long ductwork and AHU location in the basement, which indicates the potential to decrease the specific fan power through careful ductwork design and optimal location of air handling units.

ACKNOWLEDGEMENTS

This research was supported by the Rakvere Smart House Competence Centre, the Estonian Research Council (Institutional research funding grant IUT1-15) and by a grant of the European Union, the European Social Fund (Mobilitas grant No. MTT74).

REFERENCES

1. About passive house – what is a passive house? http://www.passiv.de/en/02_informations/01_whatisapassivehouse/01_whatisapassivehouse.htm
2. Feist, W., Schnieders, J., Dorer, V. and Haas, A. Re-inventing air heating: Convenient and comfortable within the frame of Passive House concept. *Energy Build.*, 2005, **37**, 1186–1203.
3. Krajcik, M., Simone, A. and Olesen, B. W. Air distribution and ventilation effectiveness in an occupied room heated by warm air. *Energy Build.*, 2012, **55**, 94–101.
4. Fernandez-Gonzales, A. Analysis of the thermal performance and comfort conditions produced by five different passive solar heating strategies in the United States midwest. *Solar Energy*, 2007, **81**, 581–593.
5. Krüger, E. and Givoni, B. Thermal monitoring and indoor temperature predictions in a passive solar building in an arid environment. *Build. Environ.*, 2008, **43**, 1792–1804.
6. Georges, L., Berner, M., Berge, M. and Mathiesin, H. M. Analysis of the air heating in Norwegian passive houses using detailed simulations. In *Proceedings 13th International Conference of IBPSA*. Chambery, France, 2013.
7. Isaksson, C. and Karlsson, F. Indoor climate in low-energy houses – an interdisciplinary investigation. *Build. Environ.*, 2006, **41**, 1678–1690.
8. Rohdin, P., Molin, A. and Moshfegh, B. Experiences from nine passive houses in Sweden – indoor thermal environment and energy use. *Build. Environ.*, 2013, doi: 10.1016/j.buildenv.2013.09.017

9. McLeod, R. S., Hopfe, C. and Kwan, A. An investigation into future performance and overheating risks in Passivhaus dwellings. *Build. Environ.*, 2013, **70**, 189–209.
10. Estonian Government Ordinance No. 68. Energiatõhususe miinimumnõuded (Minimum requirements for energy performance of buildings) 30.08.2012. *Riigi Teataja*, I, 05.09.2012, 4.
11. Beck, W., Dolmans, D., Dutoo, G., Hall, A. and Seppänen, O. *Solar Shading. REHVA Guidebook 12*. Forssa, Finland, 2010.
12. IDA-ICE, IDA Indoor Climate and Energy 4.5. http://www.equa-solutions.co.uk/
13. Kalamees, T. and Kurnitski, J. Estonian test reference year for energy calculations. *Proc. Estonian Acad. Sci., Eng.*, 2006, **12**, 40–58.
14. BS EN 15251:2007. Indoor environmental input parameters for design and assessment of energy performance of buildings- addressing indoor air quality, thermal environment, lighting and acoustics.

Küttesüsteemita liginullenergia büroohoone

Martin Thalfeldt, Jarek Kurnitski ja Alo Mikola

Välja selgitamaks, kas on võimalik ehitada tavapärase radiaator- või põrandküttesüsteemita büroohoonet ja samal ajal tagada kontoriruumides sobiv soojus, tehti uurimus Eesti esimese Rakverre kavandatava liginullenergia büroohoone põhjal. Teostati erinevate võimalike lahenduste energia- ja sisekliima simulatsioonid. Variantide puhul, mis tagasid hea sisekliima, tehti ehituskulude ja tasuvusaegade hindamise abil jätkusuutlikkuse analüüs. Selgus, et liginullenergiahoone madalatest soojuskadudest hoolimata on vaja välja ehitada küttesüsteem, mis võimaldab ruumipõhist temperatuuri reguleerimist. Küttesüsteemi olemasolu korral on vaja soojust reguleerida peamiselt enne tööpäeva algust. Küttesüsteemi puudumisel jahtusid suuremate soojuskadudega ruumid kuni temperatuurini +16,7 °C ja õhutemperatuur alla lubatud +21 °C oli ligi 700 tundi aastas. Minimaalset vajalikku õhutemperatuuri +21 °C oli võimalik tagada ka soojendatud ventilatsiooni sissepuhkeõhuga, kasutades muutuva õhuvooluhulgaga süsteemi, mis töötas vajadusel ka öösel. Samas suurenesid selle tulemusena märgatavalt ülekütmine ja ventilaatorite elektritarve, sest ventilatsioonisüsteemi tööd tuli juhtida suurima soojuskadudega ruumi küttevajaduse järgi. Õhkkütte korral suurenes esialgne arvutuslik energiatõhususarv 78,8 kWh/m^2 aastas väärtuseni 93,5 kWh/m^2. Lisaks võib üksik kasutamata tuba oluliselt mõjutada kogu hoone energiatarvet, ja sellisel juhul ületas tegelik kulu märgatavalt arvutuslikku. Majanduslik analüüs näitas, et kõige mõistlikum lahendus on radiaatorküte koos lihtsa ja töökindla muutumatu vooluhulgaga ventilatsioonisüsteemiga. Muutuva õhuvooluhulgaga ventilatsiooni mõju hoone niigi madalale energiatarbele ei olnud piisavalt suur, et see end ära tasuks.