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BUILDING ENGINEERING

Lessons learnt from the first public buildings in Estonia intended to be passive houses

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Abstract. The energy efficiency of buildings and the use of energy from renewable sources in the building sector constitute important measures needed to reduce the European Union's energy dependence and greenhouse gas emissions. Since changes in the building sector are slow, good examples and analysis of real performance are needed to motivate investors, constructors, and designers to evoke changes and warn against possible failures. In this paper data on the monitored and simulated performance of energy use, indoor climate, and building service systems of two non-residential buildings (a refurbishment case and a new building) are presented. In both cases very high energy efficiency goals were set initially (passive house standard), but neither building meets the desired levels. Both buildings do have a high-quality envelope, but their performance is unsatisfactory because of too simplified control of building service systems, too optimistic and inadequate assumptions in energy calculations and initial data, overheating of rooms during winter and summer seasons, and failure to achieve a low air leakage rate of the building envelope. The main reasons for these shortcomings are lack of conscious project leadership and inadequate final component selection. The lessons learnt from these cases should be taken into account when moving forward with nearly zero-energy buildings in the future.

Key words: energy efficiency, non-residential building, passive house, low-energy building, building service system.

1. INTRODUCTION

In the European Union buildings account for 40% of energy consumption [1,2]. Increasing the use of energy from renewable sources in the building sector is an important measure needed to reduce the EU's energy dependence and greenhouse gas emissions. Europe has adopted an ambitious vision for the energy performance of its buildings: by the end of 2018, all new public buildings must be 'nearly zero-energy buildings'.

As in Estonia the annually constructed new residential buildings make up 0.5% and non-residential buildings 1.8% of the building stock [3], the high requirements for new buildings will improve the energy performance of the whole building stock very slowly. Therefore, the energy renovation of existing buildings is very important. Many currently suggested energy-performance measures are usable in renovation as well.

The Passive House (PH) standard [4] is a widely known energy performance standard. With good insulation, minimized thermal bridges, airtightness, optimized glazing, and heat recovery ventilation the annual specific net energy demand according to the PH standard for net space heating and ventilation is 15 kWh/(m^2·a), while the total primary energy for space heating, domestic hot water, and household appliances may not exceed 120 kWh/(m^2·a).

Although the PH standard is mostly implemented in new buildings, the concept is also used for refurbishments [5–9]. Due to limitations of existing buildings, the possibility of meeting the PH standard during renovation is more difficult; therefore, knowledge about success and reasons for failures is valuable. There is a lack of thoroughly documented solutions for energy-

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efficient refurbished buildings starting from the design stage and leading up to the use of the building. Therefore, the reasons for a difference in the planned and actual energy costs are often hard to analyse. The situation concerning non-residential renovation is particularly problematic because the wide variety of building types makes generalization of the solutions and their use in other objects difficult [10].

In many energy-renovation cases, there is a difference between the predicted and actually measured energy savings. Hens [11] compared, measured, and predicted the energy consumption for space heating and found that the classical energy efficiency measures resulted in 28% smaller energy loss than predicted. Ridley et al. [12] monitored the performance of the first new London dwelling certified to the PH standard and showed annual primary energy demand above the target. The expected savings could be smaller due to better indoor climate after renovation as the original building had been under-heated and under-ventilated. Milne and Boardman [13] showed that 30% of the potential energy savings will be taken as an increase in the comfort temperature. Mørck et al. [14] compared the measured and calculated energy consumption in a social housing settlement and in a detached single-family house. The measured results showed around 35% higher energy consumption than the calculated consumption. On a month-on-month basis, deviation ranged between 12% in January and 75% in May. Thus, there are relatively large discrepancies between the measured and calculated results, and information about the reasons is needed.

Sharpened attention to energy performance of buildings in Estonia started with new regulations for the minimum requirements of the energy performance of buildings that came into effect in 2007 [15]. Before that standard, recommendations existed for thermal transmittance for the building envelope [16,17]. The year 2009 saw the commencement of development projects in which meeting the PH standard was the objective for the first time in Estonia. The first certified PH was built in Estonia in 2012 [18].

In this paper data on the monitored and simulated energy performance, indoor climate, and building service systems are presented for two non-residential buildings (one renovated and one newly constructed building), where the PH standard was the objective in the designing phase. Both buildings failed to achieve the energy efficiency according to the PH criteria, but still, having a well-insulated envelope, perform better than most buildings. Currently these buildings are in everyday use, which gives us a good opportunity to analyse their real performance and the reasons for failure to meet the initially set PH goals. Lessons learnt here can be taken into account when moving towards nearly zero-energy buildings in the future.

2. METHODS, THEORY, CALCULATIONS

2.1. Studied buildings

The first public buildings in Estonia that were planned and built according to the PH principle are located in southern Estonia. The initial desire of both building owners was to reach the PH level. These buildings are a nursery school (renovation in Valga, see Fig. 1) and a community centre (new building, see Fig. 1). The renovation of the 'Soviet-time' energy-wasting nursery school was completed in July 2009 and the construction of the new community centre in December 2009. Shortly after the completion, the buildings were taken into use. The main properties of the buildings are presented in Table 1.

The heat sources for space heating and hot water in the nursery school are district heating and solar collectors (70 m^2). The heating system is a central air-heating system, combined with the ventilation system. The heat source for space heating and hot water in the community centre is a ground-source heat pump (GSHP). A hydronic floor-heating system combined with the ventilation system is used. According to the design solution, both buildings are operating with a constant air volume (CAV) ventilation system and without mechanical cooling systems. Demand-controlled ventilation was not installed because the ventilation system is used also for space heating.

2.2. Measurements

2.2.1. Indoor climate

In order to evaluate the indoor climate, the following parameters were measured in the winter of 2011 (average exterior temperature t_e –15.6 °C) and in the community centre (average t_e –7.4 °C) with data loggers at 10-min intervals:

- air temperature (Ebro EBI 20 TH; – 30 °C… +60 °C, ±0.5 °C),
- relative humidity (Ebro EBI 20 TH; 0%…95%, ±3%),
- carbon dioxide (CO_2) concentration (Comark N2015; 4 to 20 mA, ±0.3%).

2.2.2. Service systems and energy performance of the buildings

In addition to the indoor climate measurements, the important parameters of the heating and ventilation systems were measured to evaluate the performance and principles of the selected systems and equipment and to assess their suitability for the respective building. In the nursery school, where a multi-stage air-heating system is used, the temperatures and relative humidity of the ventilation air inside the ducts were measured with data

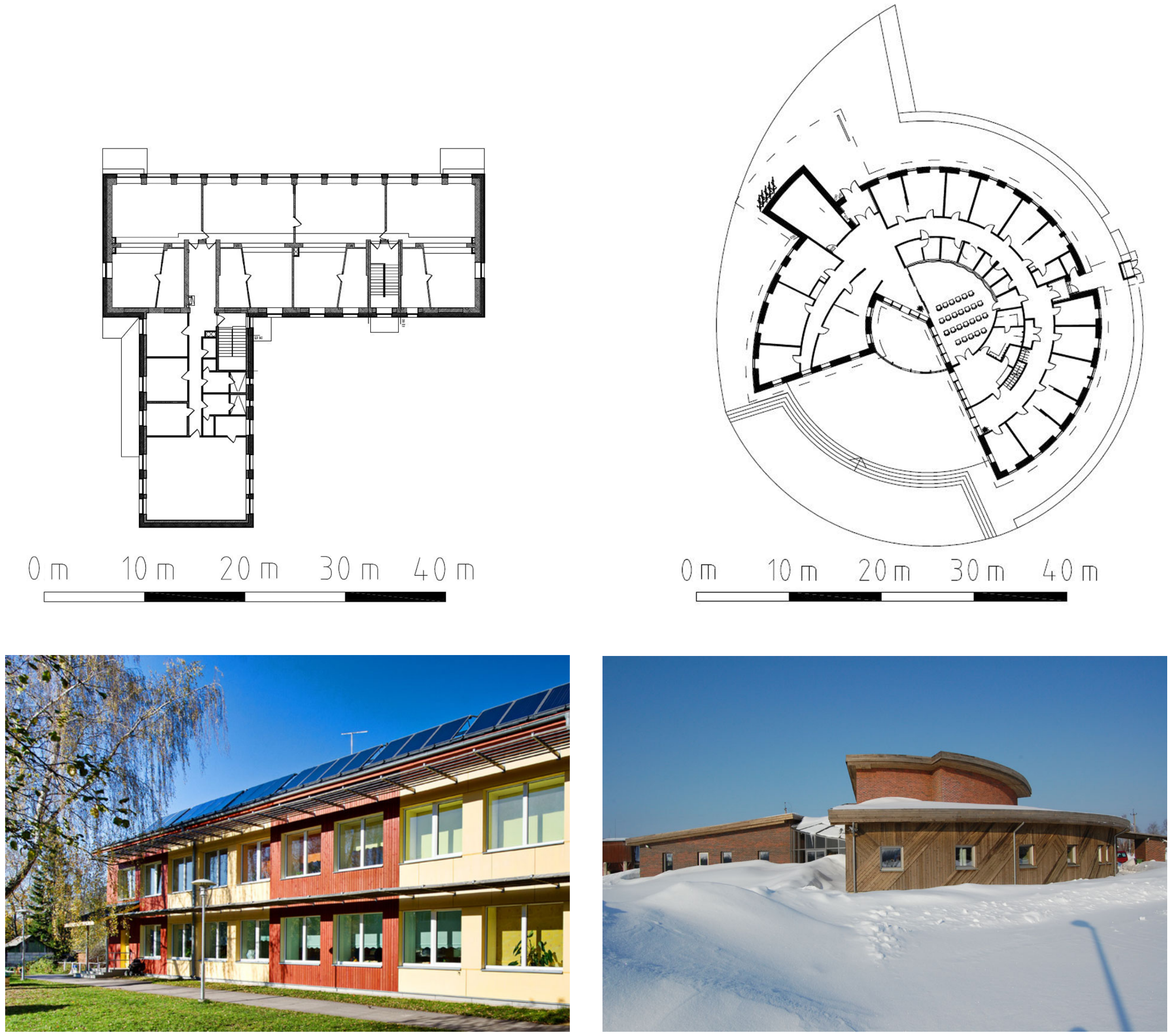


Fig. 1. The first public buildings in Estonia designed and built according to the passive house principle: refurbished nursery school (left) and a newly built community centre (right).

Table 1. Properties of the buildings (as designed)

	Nursery school	Community centre
Net area and heated area, m^2	1280	727
Volume, m^3	4208	2674
Energy performance value EPV, kWh/(m^2·a); [15]	41	91
Energy performance certificate EPC; [19]	A (the best)	A (the best)
Thermal transmittance of building envelope U, W/(m^2·K)		
Walls	0.10	0.08
Roof	0.08	0.06
Floor	0.13	0.08
Window glazing/frame	0.51/0.76	0.55/0.70
Doors	0.70	0.70
Air leakage rate q_{50}, m^3/(m^2·h)	0.41	0.71
Specific heat loss H, W/K	330	202
Specific heat loss per heated area H/A, W/(m^2·K)	0.26	0.28
Specific heat load, W/m^2	11.1	12.5

loggers (at 10-min intervals) after every heating coil to evaluate the balance of the system and the performance of the control system. In the community centre, which has a hydronic heating system, the average temperatures of the heating system were measured at various points on the surface of the heat substation.

In order to evaluate the efficiency of the heat exchangers of the ventilation units, the air temperatures in the ventilation units were measured with data loggers before and after the heat exchangers. The results of the measurements were used to calculate the current energy efficiency of heat recovery. To assess the energy performance of the fans of the air-handling units, the current static and dynamic pressures and air flows of the units were measured with a Pitot tube.

In the community centre heat meters were installed in all parts of the heating system. This made it possible to compare the actual and the calculated energy consumption quite precisely over a longer period. In the nursery school, where there was only a heat meter that measured the total heat consumption, the energy amount was divided between the different parts of the heating system according to the calculated results and dynamical simulations.

2.3. Assessment of indoor climate and energy performance

In determining the design parameters of indoor climate, all aspects of PH, such as high thermal storage capacity, high thermal resistance, and great temperature rise from heat gains, were taken into account. Therefore, the design temperatures for heat load calculations are in some rooms up to 3 °C lower than normally, for example 18 °C instead of 21 °C.

Ventilation air flows are calculated according to the number of persons in the respective room and air flow per person. Air flow per person is 10 L/s (36 m^3/h) per an adult and 5 L/s (18 m^3/h) per a child in the nursery school. With the assumptions used, the air flow should be sufficient to make sure that the carbon dioxide level does not exceed the 900 ppm limit in rooms if the ventilation systems are working properly and the air distribution solution is correct.

Relative humidity levels in rooms are not limited by the Estonian regulations. According to indications and suggestions, the level should remain between 20% and 40% in the heating period and below 60% during the cooling period.

The energy performance objectives of the buildings were set very high. The construction permit was given according to the official requirements in Estonia [15]. In addition, the goals were to refurbish (nursery school) and to build (community centre) the first non-residential buildings in Estonia that meet the criteria of PH for Central Europe [4]. One of the criteria is that net heating energy for space heating and ventilation air heating must not exceed the prescribed norm. The initial desire of both building owners was to reach the PH level.

In order to compare the actual energy consumption (heat and electrical) with the theoretical one, indoor climate and energy models of the buildings were constructed. The main purpose of the models was to evaluate the energy balance of the buildings and to have theoretical energy balance results by systems.

Energy performance was modelled using the IDA Indoor Climate and Energy (IDA ICE) 4.2 building simulation software. This software allows the modelling of a multi-zone building [20], its heating, ventilation, and air conditioning (HVAC) systems, internal and external loads, outdoor climate, etc. and provides simultaneous dynamic simulation of heat transfer and air flows. In simulations, the Estonian Test Reference Year (TRY) climate data file was used to get more adequate results (compared to the calculation software, which does not consider the building dynamics, for example PHPP 2007). The calculation method and software used correspond to the highest level of the European Union standard ISO 13790:2008 [21]. The performance of IDA ICE was studied and validated; for example, the targeted indoor temperature for heating seasons was +21 °C. For periods when energy was needed for space cooling, the window airing function was used if indoor temperatures exceeded 25 °C (no mechanical cooling systems). The use of domestic hot water (DHW) was taken into account based on the actual demand in 2010. The occupants were counted according to the actual use: the number of staff and other occupants. The difference in the temperatures of domestic hot and cold water is 50 °C, etc.

The following internal heat gains were used:

- Occupants: 0.1 in/m^2; total ~ 6.9 kWh/(m^2·a). Heat from occupants is calculated using 80 W/person according to the ISO 7730 standard (1.2 met, 0.7 clo) and with usage rate 0.4 (on business days from 7 a.m. to 7 p.m.);
- Appliances, equipment: total ~ 7.2 kWh/(m^2·a). Heat from appliances and equipment is calculated using 6.0 W/m^2 and with usage rate 0.4 (on business days from 7 a.m. to 7 p.m.);
- Lighting: total ~ 10.8 kWh/(m^2·a). Heat from lighting is calculated using 9 W/m^2 and the usage rate 0.4 (on business days from 7 a.m. to 7 p.m.).

The ventilation system is used for hygiene ventilation and for space heating. The actual value of the ventilation airflow, 1.0 L/(s·m^2), was applied in the simulations. Infiltration rate in the simulations was used according to the actual measurement result (q_{50}) 0.41 m^3/(m^2·h).

Annual efficiency of the energy source and heat distribution systems followed the Estonian requirements and standards, according to which the efficiency of an electrical heating system is 1.0. Therefore, the net heating and the delivered electric energy for heating were regarded as equal.

3. RESULTS AND DISCUSSION

3.1. Indoor climate

In Estonia, situated in the northern part of the temperate climate zone, energy is needed for heating to provide a healthy indoor climate. In this study, indoor thermal environment (temperature and relative humidity used as assessment parameters) and indoor air quality (carbon dioxide concentration used as an assessment parameter) were used in analysing the quality of indoor climate. The normal level of expectation ([22], Category II: for new buildings and renovations) was used in the assessment of indoor climate.

3.1.1. Temperature and relative humidity

The average indoor temperature in the nursery school was 23.7 °C during the winter period, while the average in different rooms was 22.1–25.4 °C (Fig. 2a). Room temperature exceeded the recommended ([22], Category II) level most of the time in the measurement period. The too high indoor temperature in the cold period was directly caused by overheating by the heating system and its control system and by too optimistic estimations of heat storage in the building structure. The sharp drop of the indoor temperature when the outdoor temperature was −10 °C was caused by the control system, which turns off the preheating unit of the air intake.

The average indoor temperature in the community centre was 21.6 °C during the winter period, with the average in different rooms from 20.8 to 22.6 °C (Fig. 2b). Although the given results are the average temperatures throughout the measurement period (including the non-occupied period), these are still approximately 1 to 1.5 degrees too low. The graph shows the great differences between rooms and the smaller heat storage capability than estimated in the calculations.

A combination of overheating and low outdoor water vapour content during winter may cause the relative indoor humidity to decrease to an unacceptably low level. In both buildings, the indoor relative humidity remained between 10% and 20% in the measurement periods. In colder weather conditions, the indoor relative humidity dropped occasionally below 10% in some rooms, which is not compatible with comfortable indoor climate of Category II [23–25].

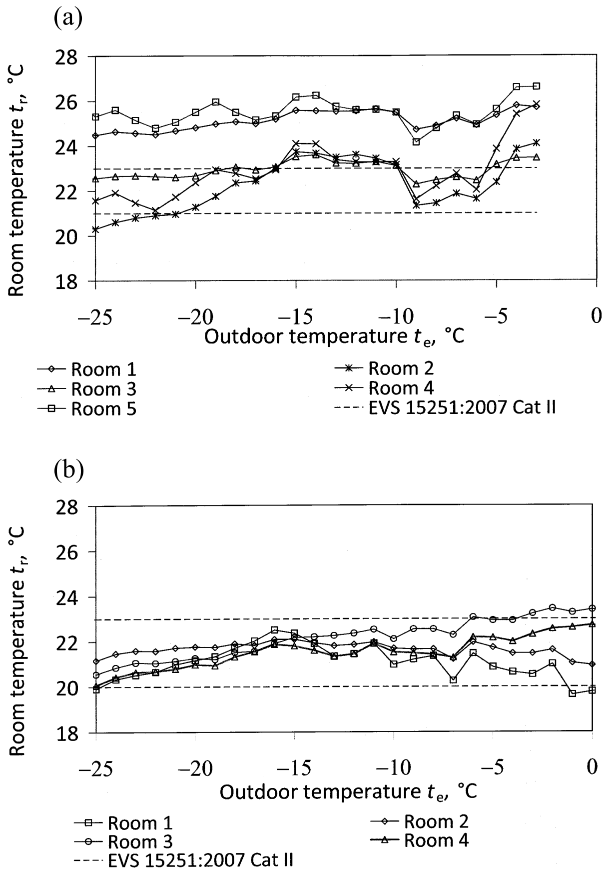


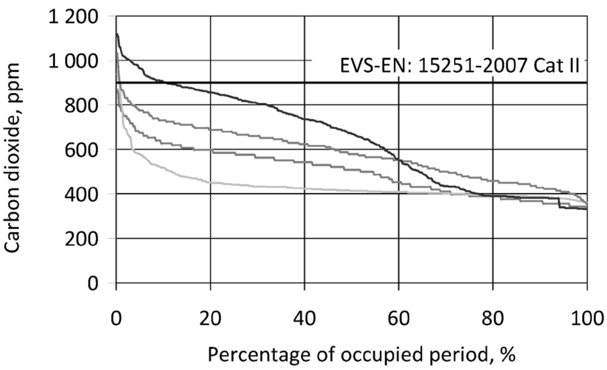
Fig. 2. Room temperatures in the nursery school (a) and the community centre (b). The results are given as averages of every degree of ambient temperature.

In the nursery school, the relatively low indoor humidity was caused partly also by the selection and operation of the building service systems. The counterflow plate-type heat exchanger, which does not return humidity, was used in the air heating unit. The air-heating system does not use recirculated air, but takes all the required air from outside, which leads to the situation where the rooms are ventilated more than needed in cold weather to provide fresh air. Therefore, the relative humidity decreases even more than it should.

3.1.2. Indoor air quality

In both of the studied buildings, carbon dioxide (CO_2) content in the air was used as the indicator of indoor air quality because the main sources of pollutants were human-based pollutants. In the winter, during the occupation period, the average of the maximum values of CO_2 level in different rooms was 689 ppm in the nursery school (Fig. 3) and 586 ppm in the community centre (Fig. 3b).

(a)



(b)

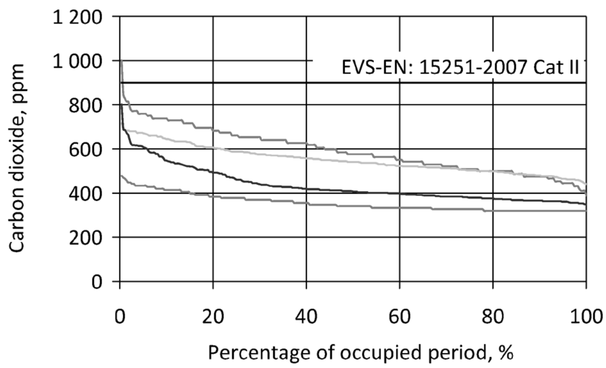


Fig. 3. Carbon dioxide (CO_2) concentration in the nursery school (a) and the community centre (b) in winter.

Based on CO_2 measurements, the indoor air quality met the Category II criteria [22] during almost the entire measurement period in both buildings. From the point of energy performance, it gives a potential to save heating energy and electricity by controlling the air flows according to demand.

3.2. Heat consumption

The heat was used in the buildings for space heating, heating the ventilation air, and hot water supply. A summary of the heat distribution and the difference between targeted and actually consumed values is presented in Table 2.

3.2.1. Nursery school

In the nursery school, the real consumed energy for space heating was more than three times higher than targeted. The main reasons for this are as follows:

- too optimistic and inadequate assumptions of usable free energy, and
- too simplified control system of the heating system.

The target value for space heating in the nursery school had been calculated on the basis of a large amount of free energy (internal heat gains) and a perfectly functioning heating system that allows for using all energy as useful heating energy. If a system makes use of all the benefits from the building's thermal storage and so the extra heat stored in the daytime can be used for heating at the time when the building is not in use, an ideal situation will be achieved and theoretically the maximum amount of energy is saved to ensure the required indoor climate. The designed heating system and its control system, however, do not enable very punctual control, which is not consistent with the assumptions made in the design of the building and the actual situation. Designing a system where the room temperature is not controlled by rooms but by groups of rooms leads to continuous overheating of rooms and to significantly higher energy consumption of the building.

In addition, it was assumed in the design phase that approximately 25% of the energy needed for space heating would come from the solar collectors. The assumption that in a building that has as short a heating period as estimated in the calculations and 45 °C temperature of the heat supply for space heating, solar collectors can guarantee 25% of space heating was very optimistic. According to the parameters of the solar heating system and the solution selected and executed for space heating, where in the heating period the medium temperatures of the heat system are set at 45 °C/35 °C, the heat from solar panels cannot supply more than 0.1 MWh/a or <1% of the total space heating energy needed.

Table 2. Heat consumption, kWh/(m^2·a)

Service system	Nursery school			Community centre		
	Net energy		Real delivered energy	Net energy		Real delivered energy
	Targeted value	Real consumption		Targeted value	Real consumption	
Space heating	3.9	13	13	6.4	39	17.3*
Ventilation	4.0	71	71	7.5	19	7.5
Hot water	12	6.4	6.4	5.8	12	4.8
Total	20	90	90	20	69	30

* An auxiliary electrical heater was used.

The heat consumption for preheating the ventilation supply air is so great because the circulation air was not used for space heating and all the air flow needed to heat the rooms in non-occupied periods was taken from outside and preheated. Therefore, the fans worked constantly 24 hours a day and 7 days a week and always took the air from outside, which needed preheating. The preheating coil of the ventilation supply air is a large energy consumer. This is due to the fact that the designed and installed electrical preheating coil is regulated on the ON/OFF mode and at maximum power (raises the temperature by 15 °C compared to the outdoor temperature (designed from –25 °C to –10 °C)). The annual energy use for preheating the air with the coil was 9540 kWh. If the preheater coil had been controlled smoothly, the estimated energy use would have been 2932 kWh. The presented calculation results are given for the system working 24 hours a day and 7 days a week. If the right schedules had been applied, the energy demand for preheating the supply air would have been 1117 kWh, which is over 8 times smaller than the actual consumption.

3.2.2. Community centre

The real energy consumption for space heating was approximately six times higher than the target value. The main reasons for this are as follows:

- too optimistic and simplified calculations;
- overrating the internal heat gain from occupancy: 35 persons were considered in the calculations, but the real number of the users of the building did not exceed 15, which reduces the useful free energy by approximately 3500 kWh/a (4.8 kWh/(m^2·a);
- the building has not achieved the air leakage value required in the passive house criteria (air change rate $n_{50} \leq 0.6$ ach);
- according to the infrared thermography analysis, the building has some critical thermal bridges in the envelope;
- higher indoor temperature than used in calculations. In the calculations, the indoor temperature of 20 °C was used, but the users of the building keep the temperature higher (Fig. 2a).

In a cold climate, a 1 °C higher indoor temperature increases the space heating energy consumption on average by 5% in typical buildings [26], but in low-energy or PH buildings, where the heating period is notably shorter, the relative influence is much higher.

There are two main reasons why in the community centre the heating of ventilation air consumed more energy than estimated:

- In the design calculation, the estimated heat recovery with thermal efficiency is 90% without frost protection. This means that the extra energy needed to heat the ambient air that passes the heat exchanger when the outdoor temperature is low was not taken into account in the calculations.
- The actually mounted rotary-type heat exchanger has a thermal efficiency of 76% and has frost protection, which is regulated by the rotation speed of the rotary (decreases the efficiency). Since the risk of freezing the rotary is controlled by the pressure lost in the rotary and taking into account that the moisture excess of extract air is low during the cold period, it is difficult to assess the actual heat loss due to frost protection. The data of actually consumed energies are based on 2010, when the winter months were, according to the degree-days method, more than 50% colder than in the test reference year used in the calculations. This significantly increased the heat demand for heating the ventilation air.

In the community centre, the heat was produced by a GSHP, which itself consumes over a third of the total energy. The annual energy use for the GSHP was more than three times larger than estimated. The main reason for this is the 6-fold higher energy demand for space heating, but also the lower efficiency of the GSHP than expected. The seasonal performance factors (SPF) of the GSHP are as follows:

- SPF_{HP} 3.03;
- $SPF_{HP+brine\ circ.}$ 2.48;
- $SPF_{Heat\ supply}$ 2.23 (including brine circulation pumps and auxiliary electrical heating).

According to the measured consumption, the SPF of the heat pump system was 2.48, which is 29% smaller than the expected 3.5 in the design calculations. In the technical data sheet of the used heat pump, the given coefficient of performance COP_1 is 3.70 and COP_2 is 3.03 according to EN 14511 [27] (incl. circulation pumps). More than 18% of the total electricity consumption of the heat pump is consumed by the brine circulation pumps, which can be regarded too high. Reasons for such a high electricity consumption may be too great pressure loss over the evaporator side of the heat pump, over-dimensioned heat pump, wrongly regulated circulation pump's working schedules, etc.

3.3. Electricity consumption

Electricity was used in the buildings for electrical appliances, lighting, and building service systems (fans, circulation pumps). Electricity was used also to produce heat (GSHP in the community centre) and for preheating the ventilation air (summarized in Table 2). Table 3 shows the total electricity consumption, the distribution of electricity use, and the difference between the targeted and real values.

Table 3. Electricity consumption, kWh/(m^2·a)

Service system	Nursery school		Community centre	
	Targeted value [4]	Real consumption	Targeted value [4]	Real consumption
Electrical appliances and lighting	6.6	15.0	6.0	28.7
Ventilation fan	5.3	25.7	4.9	4.3
Total	11.9	40.7	10.9	33.0

The electricity consumption in the nursery school for ventilation fans is as large because of the problems in controlling the ventilation airflows. The set schedules for fans did not work as intended, and during the later inspection the fans were working constantly 24 hours a day and 7 days a week. Compared to the scheduled time set initially, the number of working hours was 65% greater. The specific fan power (SFP) of the air-handling unit (AHU) in the nursery school was 1.71 kW/(m^3/s) and in the community centre, 1.60 kW/(m^3/s).

3.4. Energy performance of the buildings

In Estonia, the energy performance of buildings is treated as primary energy use (presented as the energy performance value EPV, kWh/(m^2·a)). According to the minimum requirements from 2008, to calculate the EPV the delivered energy is multiplied by the weighting factor of the energy carrier; for example, in case of wood-based fuels by 0.75, district heating 0.9, fossil fuels 1.0, electricity 2.0.

3.4.1. Delivered energy

The improved performance of the building service systems was determined by IDA ICE simulations. Figure 4 shows the current energy use in the buildings and the approximate energy use if the energy efficiency of all systems had been improved to a maximum; for example, if the heating systems had been regulated so that there would not occur any overheating and the ventilation systems would work only when the building was occupied. All the improvements were calculated on the basis of the current systems and their capabilities to work more efficiently. For example, if there is a constant air volume (CAV) ventilation system in the building, the energy saving was calculated from working schedules as demand-controlled ventilation DCV (or variable air volume, VAV).

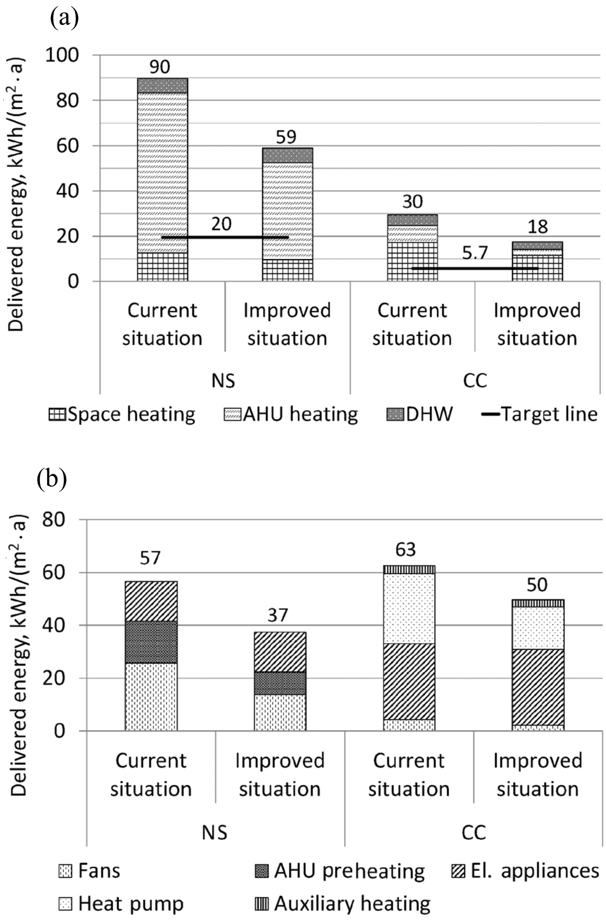


Fig. 4. Delivered heat (a) and electricity (b) consumption in the nursery school (NS) and the community centre (CC). AHU – air handling unit, DHW – domestic hot water.

3.4.2. Primary energy according to the Estonian regulation from 2008 [19]

There are eight energy classes for non-residential buildings, ranging from A to H. The scale for the energy rating is different for different types of buildings with schools and other public buildings rated differently. According to the actual energy performance, the nursery school's energy class is D and that of the community centre B (Table 4). The higher than expected EPV is directly caused by greater heat energy and electricity consumption in both buildings. The main reasons for this are described in the previous chapters.

3.5. The main lessons learnt

In accordance with the relevant regulations and standards, a building's energy needs for the building permit with the necessary accuracy are determined

Table 4. Actual energy performance value of the studied buildings

	Energy certificate and energy performance value (kWh/(m^2·a)) according to weighted delivered energy in the nursery school							
	A ≤ 100	B ≤ 140	C ≤ 190	**D ≤ 240**	E ≤ 300	F ≤ 380	G ≤ 480	H ≥ 481
Measured result, kWh/(m^2·a)				**194**				
	Energy certificate and energy performance value (kWh/(m^2·a)) according to weighted delivered energy in the community centre							
	A ≤ 120	**B ≤ 150**	C ≤ 200	D ≤ 250	E ≤ 310	F ≤ 390	G ≤ 490	H ≥ 491
Measured result, kWh/(m^2·a)		**126**						

during the preliminary design stage. Usually this is the only design stage when indoor climate and energy calculations are made. Our study showed that it is not sufficient to declare the goals and make energy calculations only once during the preliminary design phase. Indoor climate and energy calculations should be repeated in the developed design and construction documentation, because a lot of input data will have been specified by then. For the building permit the indoor climate and energy simulations are made considering the standard use of the building. To get information about the real energy use, it may be necessary to make parallel simulations with input data that are closer to the real use of the building. For achieving energy efficiency the following activities are necessary: leading the project professionally from the energy efficiency point of view through the design and construction phase, performing regularly the necessary quality assurance activities, and communicating with the building's owner to get a realistic overview of the future use of the building.

For the low-energy or PH buildings all the HVAC solutions must be considered very carefully. Solutions that cause the primary energy consumption to vary several times from year to year and depend critically on the ambient parameters should be avoided or their effects should be minimized. Furthermore, it is not only the solutions of the systems that are very important but also the technical parameters of the HVAC devices. As the working periods of heat supply devices and heat distribution devices are short, the relative influence of energy need for the circulation pumps and other additional devices is great. Therefore, the systems must be analysed and solutions must be simulated in the situation where they are meant to operate.

From the standpoint of indoor climate, the large proportion of free energy in the total heat demand has to be taken into account already in the design phase. Because of the low heating load of the building (rooms), the influence of free energy is large and frequent, and failure to construct building's service systems without considering this will result in overheated rooms and greater energy demand than assumed. The problem with overheating is more critical in buildings that are refurbished to meet the low-energy or PH standards because an already fixed architectural solution (proportion of windows, their orientation, height, shadings, etc.) and solutions for passive cooling are limited. Therefore, the heating and ventilation systems must be analysed from the point of avoiding overheating as well, or even a cooling system should be considered. For instance, according to the results of the dynamical simulations, the annual free energy from internal heat gains is 24.9 kWh/(m^2·a); however, from this the useful energy to decrease the heating demand is only 6.6 kWh/(m^2·a) or approximately 25%. This proves that the building's energy demand for heating is low because of the short heating period. However, considering the heating load of 10 W/m^2 [4], the proportion of the internal heat gain is 90% or 9 W/m^2. This means that more or less throughout the year, the building does not need energy for space heating while it is occupied and the building's service systems must deal with avoiding overheating.

4. CONCLUSIONS

In this study, the indoor climate and energy performance of two non-residential buildings (a refurbishment case and a new building) are analysed. In both cases the passive house standard was set as a goal initially. Neither building achieved the goal because of the lack of conscious project leadership and unsatisfactory final component selection. Both buildings still perform as well-insulated structures. The main reasons for failures were as follows:

- too optimistic assumptions in initial data and too simplified energy calculations [20];
- too simplified control of the buildings' service systems;
- overheating of rooms during winter and summer seasons;
- desired air leakage rate and thermal transmittance of the building's envelope were not achieved in the case of the community centre;

- lack of thorough analyses in the preliminary designing phase in terms of HVAC systems in the case of the nursery school;
- too high expectations in utilizing the internal heat gains as useful energy in both buildings.

A very low thermal transmittance of the buildings' envelopes has become increasingly easier to reach due to the availability of specialists and improved calculation software. However, different people often deal with the design of the building physics and with HVAC systems. Lack of cooperation could lead to a result where a good job of one party does not lead to the desired final results because of the imperfections from other parties. Most importantly, it is vital to have responsible project leadership that would understand the objective of energy efficiency and the necessary quality assurance issues.

The study revealed many new aspects that should be taken into account in the future projects, and numerous new issues that are not considered as important in the regular building design became apparent. In order to learn from the demo and pilot projects and to get as many useful data for the future as possible, all the projects must be documented very punctually and the buildings performance must be measured when they are taken into use. Unfortunately, the monitoring, analysis, and publication of the results are still an area where there is room for improvement for the experts in Estonia.

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Õppetunnid esimestest passiivmajadeks kavandatud avalikest hoonetest Eestis

Indrek Raide, Targo Kalamees ja Tõnu Mauring

On mõõdetud ja arvutuslikult analüüsitud Eesti esimeste passiivmajadeks kavandatud avalike hoonete sisekliimat, energiatõhusust ning tehnosüsteemide toimivust. Mõlema hoone piirdetarindid olid piisavalt soojustatud. Oodatud energiatõhususe ja sisekliima eesmärgid jäid saavutamata, kuna puudus eesmärgipärane projektijuhtimine, lõplike hooneosade ning tehnosüsteemide valik polnud piisavalt hoolikas, kasutati liiga lihtsustatud tehnosüsteemide juhtimist ja liiga optimistlikke ning ebaadekvaatseid eeldusi ja lähteandmeid energiaarvutustes. Suvel ja talvel esines ruumide ülekuumenemist. Eelnimetatud õppetunnid tuleb arvesse võtta juba nelja aasta pärast kehtima hakkavate liginullenergiahoonenõuete rakendamisel.