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Design of the first net-zero-energy buildings in Estonia

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In Estonia, comprehensive regulation establishes the methods for calculating the indoor climate and energy performance of buildings to prove their compliance with minimum requirements. The definition of a nearly zero-energy building and a net-zero-energy building, and the methodology for the calculation of the energy performance of the buildings in Estonia are explained. The problems and results of the design process of the first zero-energy building in Estonia are described through a case study. The current study showed that it is possible to reach zero-energy building levels in Estonia by careful and detailed designs of the energy performance of a building. More thorough analyses are needed in the very first stage of the design to find suitable solutions and possible compromises between architecture and energy efficiency. In any case, well-insulated buildings, effective building service systems, and local electricity production on-site is needed for zero-energy building. Finally this article discusses the problems and limitations of the regulations influencing the motivation and actions needed to achieve zero-energy buildings. The study shows the influence of the different parts of the building on the balance of the energy consumption and utilization, and on the energy performance of the building to achieve zero-energy building status.

Introduction

Europe has adopted an ambitious vision for the energy performance of its buildings: By the end of 2018, all new public buildings and by the end of 2020 all new buildings must be nearly zero energy buildings (nZEB). In the energy performance of buildings directive recast (EPBD 2010) nZEB buildings are defined as buildings with a very high energy performance and where nearly zero or very low amount of energy need is covered by energy from renewable sources, including energy from renewable sources produced on-site or nearby. The directive requires nZEB, but it does not give minimum or maximum harmonized requirements. The limits and energy performance calculation framework for the nZEB buildings are set by the Member States.

With the net-ZEBs, the definition is simpler. In current practice, the most common approach to a ZEB is a building that has the primary or delivered energy (DE) balance (used and exported) on an annual basis as zero. A ZEB is typically a grid-connected building with a very high energy performance. A ZEB balances its energy use so that the energy feed-in to the grid equals to the energy delivered to ZEB from energy networks or/fuels. ZEBs can have also on-site energy storage systems. In the Vale and Vale (2002) study about an “autonomous” off-grid building versus “grid connected” ZEB, they concluded that connecting a domestic renewable system to the electricity grid and achieving a ZEB can have better life cycle performance than an autonomous building, as using electric storage systems is avoided and some flexibility in the use of appliances is gained.

ZEB uses on-site produced heat and electricity when conditions are suitable, and uses DE during rest of the time. It is important to find the balance between the capacity and control strategy of the energy source (Dar et al. 2014; Schibuola et al. 2015). In cold climates there is a large difference between energy need and possible on-site energy production during winter and summer. Therefore, ZEBs in cold climates typically lead to the situation where a significant amount of the on-site energy production should be exchanged with the grid. The study of the scope and emphasis of European and North American discussions on ZEBs is presented by Cole and Fedoruk (2015).

It is important to specify which energy flows are included in the energy performance calculations and which ones are not. Either all energy used in the buildings may be taken into account, or certain energy flows, such as household electricity use, may be excluded. Kurnitski et. al. (2011) proposed the energy boundary is modified from EN 15603 (2008) and, as stated in EPBD recast (EPBD 2010), renewable energy produced on-site is not considered part of DE, for example, the net positive influence of it is taken into account, Figure 1. This is taken for granted also in Estonian regulation of Estonian Methodology for calculating the energy performance of buildings Minister of Economic Affairs and Communications Regulation (MEACR No. 63 2012).

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Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/uhvc.
building, the owner has responsibilities in the design and construction process. The state or local municipalities have to be the first ones to transition to nZEB and ZEB buildings as the construction industry is relatively conservative and changes happen slowly. Today, only a few ZEBs exist, and they show in their design, construction, and operation a dramatic challenge for many reasons (Butera 2013). Mistakes made in different stages of the design phase can lead to unwanted results. There have been only a few projects with an acceptable description of the design and construction process and with a subsequent monitoring of the building in operation that have aimed to achieve ZEB. Achieving the ZEB goal on a given building project depends on four characteristics: number of stories; plug and process loads; principal building activity; and location (Griffith et al. 2007). Even though cases exist for which the design principle has been to achieve ZEB (Berggren et al. 2012; U.S. DOE 2015; EnOB; Garde and Donn 2014; Lenoir et al. 2011; Musall et al. 2010), there is much less experience in the realization of ZEBs in cold climates, where possibilities of on-site energy production are smaller and energy use during winter is greater. One such example is presented in this article. This article describes the outcome of the building design process and the energy performance of the first ZEB in Estonia (cold climate). In this case study, following the expert supervision of the design stages, questions arose about the implementation of the project.

The research questions were:

- Is it theoretically possible to achieve a nZEB without on-site electricity production using photovoltaic (PV) panels?
- Is it possible to achieve the ZEB level if PV panels with a nominal power of 100 kW are installed?

The case study discusses the problems and limitations of the regulations influencing the motivation and actions needed to achieve ZEB.

**Methodology**

First, the authors present the methodology to calculate the energy use of a ZEB using the standard use of the building according to the calculations presented in Estonian regulations.

To find answers to the research questions, investigations into the design documentation and energy simulations were conducted. The authors of the article were involved in the process as independent external experts employed by the owner of the building (a local municipality). The description of the design process and the design documentation were obtained from the local municipality. For further studies energy simulations were carried out by the authors to study the energy efficiency of the designed building.

In order to verify the compliance of a building with the requirements of energy performance, an energy calculation is performed with respect to the standard use of the building, using the input parameters which are set out in the regulation and which characterize the indoor and outdoor climate, the periods of use and operation of the building and the utility systems, heat gains and the building’s air leakage rate (MEACR
Calculation of indoor climate and energy performance of buildings

In Estonia, to prove the building’s compliance for energy performance, calculation software must be used. The calculation software must have dynamic calculation of the building’s thermal exchange and climate processing module while calculating the hourly values of solar radiation on surfaces, including shadows. Additionally, the possibility to model heat recovery of a ventilation system, and preferably also the possibility to model HVAC systems at the level of their main components and functions. The software must have the feature to use actual room temperatures in calculations and the possibility to model control graphs. Additionally, the calculation software must be validated pursuant to the relevant standard.

The energy performance of buildings in Estonia is expressed as an annual primary energy (PE) usage and presented as the energy performance value (EPV; kWh / [m²·a]). The EPV includes the heat and fuel consumption for space heating, heating of ventilation and infiltration air, domestic hot water and cooling, electricity for lighting, electrical appliances, and technical systems. The system boundary is similar, presented in Figure 1. The EPV is the total weighted specific use of DE consumed in the course of the standard use of the building.

Energy calculation determines the building’s aggregate energy use in relation to indoor climate control, the heating of hot water and the operation of electrical equipment. The use of DE, exported energy, and the EPV of the buildings are calculated on the basis of the result of the energy simulation. The energy simulations ought to be carried out with validated dynamic simulation software that must have the following features: dynamic building’s thermal exchange; allows using hourly weather data including solar radiation and shadow features; modeling of the heat recovery of the ventilation system.

In case of the nZEB, the limit value of the building’s total weighted specific energy use and other requirements established in the regulation, which are in accordance with the purpose of use of the building and which take into account its technical parameters for different buildings to be constructed, may not exceed the following value:

- detached houses: EPV < 50 kWh / (m²·a);
- multi-apartment buildings: EPV < 100 kWh / (m²·a);
- office buildings: EPV ≤ 100 kWh / (m²·a);
- public buildings: EPV ≤ 120 kWh / (m²·a);
- schools and other educational buildings: EPV ≤ 90 kWh / (m²·a);
- kindergarten and day care centers: EPV ≤ 100 kWh / (m²·a).

The conversion factors for different energy carriers to calculate the EPV are:

- fuels based on renewable energy sources (wood and wood-based fuels) 0.75;
- district heating 0.9;
- solid fossil fuels (gas, oil, coal) 1.0;
- peat and peat briquette 1.0;
- electricity 2.0.

Requirements for indoor climate

The energy calculations are done taking into account the minimum indoor climate requirements presented in the regulation. Minimum required airflow rate of the ventilation systems are presented in Table 1. The set-point of indoor temperature during heating is 21°C and during the cooling period is 27°C.

The corresponding energy calculation must include the energy need related to space cooling and the calculation of the energy use of the cooling system if the operation of a cooling system is required in a building in order to comply with the summertime indoor temperature requirement. The indoor temperature may not exceed the cooling set-point temperature by more than 150 degree hours (°Ch) in residential buildings and by more than 100°Ch in nonresidential buildings during the period from June 1st to August 31st.

In the case of variable air volume ventilation (VAV) system with indoor air quality control (CO₂, temperature, humidity), the airflow rates presented in Table 1 are used as the maximum airflow rates of the rooms. If ventilation is used for cooling then the maximum airflow rate is determined according to the cooling need. The minimum airflow rate must be ensured to avoid exceeding the maximum level of 1000 ppm of CO₂ in case of outdoor air CO₂ level of 400 ppm. During unoccupied hours, the ventilation airflow rate of nonresidential buildings is deemed to be 0.15 L / (s·m²).

In the energy simulations, regardless of the building’s location, the Estonian test reference year (TRY) is used for outdoor climate in Estonia. The Estonian TRY (HDD 4160°C/d at t₁ +17°C; Kalamees and Kurnitski 2006) represents the typical outdoor climate of the 30-year period from 1970 to 2000.

Input parameters of the energy simulations

Energy simulations are carried out in the course of standard use of the building. The standard use of buildings show the building’s occupied hours and the maximum heat gains from appliances, lighting and occupants during the building’s occupied hours (Table 2). There is an exception for the lighting. Lower wattage can be used, if a separate calculation of illuminance is provided as part of the energy calculation to prove the needed level of illuminance in the rooms of the building. To calculate the

Table 1. Supply airflow rates for the ventilation system used in the energy calculation.

<table>
<thead>
<tr>
<th>Building type</th>
<th>Airflow rate, L/(s·m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detached house</td>
<td>0.42</td>
</tr>
<tr>
<td>Multi-apartment building</td>
<td>0.5</td>
</tr>
<tr>
<td>Office building</td>
<td>2</td>
</tr>
<tr>
<td>Public building</td>
<td>2</td>
</tr>
<tr>
<td>Educational building</td>
<td>3</td>
</tr>
<tr>
<td>Pre-school institutions</td>
<td>3</td>
</tr>
</tbody>
</table>

The corresponding energy calculation must include the energy need related to space cooling and the calculation of the energy use of the cooling system. The indoor temperature during heating is 21°C and during the cooling period is 27°C. The minimum airflow rate must be ensured to avoid exceeding the maximum level of 1000 ppm of CO₂ in case of outdoor air CO₂ level of 400 ppm. During unoccupied hours, the ventilation airflow rate of nonresidential buildings is deemed to be 0.15 L / (s·m²).

In the energy simulations, regardless of the building’s location, the Estonian test reference year (TRY) is used for outdoor climate in Estonia. The Estonian TRY (HDD 4160°C/d at t₁ +17°C; Kalamees and Kurnitski 2006) represents the typical outdoor climate of the 30-year period from 1970 to 2000.
Table 2. Standard use of buildings and the corresponding max values of heat gain.

<table>
<thead>
<tr>
<th>Building type</th>
<th>Occupied hours</th>
<th>Usage rate</th>
<th>Lighting W/m²</th>
<th>Appliances W/m²</th>
<th>Occupants* W/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detached house</td>
<td>0000–0000</td>
<td>0.6</td>
<td>3</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Multi-apartment building</td>
<td>24</td>
<td></td>
<td>8**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Office building</td>
<td>0700–1800</td>
<td>0.55</td>
<td>12</td>
<td>12</td>
<td>5</td>
</tr>
<tr>
<td>Public building</td>
<td>0800–2200</td>
<td>0.5</td>
<td>14</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>Educational building</td>
<td>0800–1600</td>
<td>0.6</td>
<td>15</td>
<td>8</td>
<td>14</td>
</tr>
<tr>
<td>Pre-school institutions</td>
<td>0700–1900</td>
<td>0.4</td>
<td>15</td>
<td>4</td>
<td>20</td>
</tr>
</tbody>
</table>

*The internal heat gain from occupants only includes the sensible heat.
**The usage rate of the lighting in residential buildings is 0.1.

energy, the heat released by the lighting and appliances is equal to the use of electricity.

To calculate the energy of the ventilation systems, the working hours of the ventilation system on full power equals additional 1 hour before and after the occupied hours.

For the specific use of domestic hot water the liters per square meter of heated area per annum are used. The values used are presented in Table 3.

The heat loss of the building envelope

The information about the building is obtained from the building’s design documentation. The building’s design documentation contains the architectural plans, and information on the thermal transmittance of the building envelope, windows and doors. In the calculation of heat losses, the calculation is done for every room. The heat loss through the building envelope is calculated based on the thermal transmittance areas of the exterior walls, floors, roofs, windows, and doors. The area of the building envelope is calculated on the basis of the internal dimensions of the building. The junctions between the different envelope parts are taken into account separately using the linear thermal transmittance values of the thermal bridges.

If the air leakage rate is verified by the designer or supplier of the house, then the verified value is used in the energy calculation, otherwise the base value of air leakage of buildings has to be used in calculations. The base value for the new nonresidential buildings is $q_{50} = 3 \text{ m}^3/(\text{h} \cdot \text{m}^2)$; (MEACR No. 63 2012). The infiltration airflow rate is calculated using the $q_{50}$ value, building envelope area, and the factor describing the number of stories of the building, based on Jokisalo et al. (2009).

Building service systems

The energy calculations concerning the heating systems take into account the energy use for space heating, the heating of ventilation air, and the heating of household hot water. The use of heat and electricity are treated separately in order to take into account the source of DE. The energy use of the heating system is calculated taking into account the efficiency of the heat source and the losses related to the distribution and output of the heat. The efficiency factors of the heat source, distribution, and output of the heat are:

- **Energy source:**
  - District heating 1.0
  - Oil or gas boiler 0.85
  - Oil, condensing boiler 0.90
  - Gas, condensing boiler 0.95
  - Pellet boiler 0.85
  - Solid fuel boiler 0.75
  - Electric boiler 1.0

- **Heating system:**
  - Radiators 0.97
  - Floor heating (floor on ground or above vented crawl space) 0.85
  - Floor heating (inserted ceiling) 1.0
  - Electricity use of pump of hydronic system: kWh/(m²·a):
    - Radiators 0.5
    - Floor heating 1

In case of the heat pump systems, the coefficient of performance is used instead of the efficiency factor. To calculate
Fig. 2. Architectural layout of the ZEB kindergarten (Kauss Architects 2014).

the use of electricity by the heat pump system, the heating energy produced by the heat pump is divided by the average coefficient of performance of the heat pump system during the heating period. The electricity use of the circulation pump and any other auxiliary devices connected to the heating system are taken into account calculating the average coefficient of performance. The efficiency factor of the distribution and output of the heat are calculated according to Table 3. Average values of the coefficient of performance of heat pumps for the heating period and for the domestic hot water are:

- Ground source heat pump (temperature 40°C/33°C) 3.6
- Ground source heat pump (temperature 5°C/35°C) 3.2
- Ground source heat pump (temperature 50°C/35°C) 3.0
- Ground source heat pump heating of domestic hot water 2.7
- Air-to-water heat pump (temperature 40°C/33°C) at outdoor temperature –7°C 3.0
- Air-to-water heat pump heating of domestic hot water 2.0

The airflow rate of the ventilation system is calculated according to Table 1. The energy use of the ventilation system is calculated taking into account the electricity use of the ventilation units and heat recovery based on the design documentation. Heat recovery is calculated simultaneously with the energy need for the heating of the ventilation air and space heating. The calculation of the heat recovery is based on the temperature ratio value of the heat exchanger. For the heat recovery value the manufacturer’s data is used or the following values: 0.7 for rotary heat exchangers; 0.7 for counter-flow plate heat exchangers; 0.6 for cross-flow heat exchangers.

To take into account the energy that is needed to avoid frost formation on the heat exchanger, the minimum temperature of exhaust air is controlled and in nonresidential buildings the minimum temperature is 0°C in case of a plate heat exchanger and –5°C in case of a rotary heat exchanger.

Additionally, the electricity use of ventilation systems is calculated. The electricity use is assessed based on the specific fan power (SFP) of the ventilation system at a calculated airflow.

For the calculation of the energy use of cooling systems the energy use for the production of cooling energy is taken into account. Additionally, the electricity use needed for the distribution and emission of cooling energy with heat losses are calculated.

The case study building

The case study building (Figure 2) is unique: the first ZEB day care center in Estonia, located in Palamuse. The Palamuse municipality had already taken first steps toward energy efficient buildings (Raide et al. 2015) when they planned and built a community center according to the passive house principle. Therefore, the customer has previous experience available designing and constructing an energy efficient building.

The information about the building is obtained from the building design documentation. The building design documentation consists of the architectural plans, the thermal transmittance of the building envelope, windows and doors, the design of the building HVAC, and electricity systems. As part of the design process the energy calculation was done by the HVAC designer and the result of the energy calculation based on the information of the design was included in the design documentation.

In the case study, simulations are used to calculate the indoor climate and energy use of the building. The multi-zone indoor climate and energy simulation program IDA Indoor Climate and Energy (IDA ICE) 4.5.1 (Björsell et al. 1999; Sahlén 1996) was used for the indoor climate and energy

Results

**The realization of the first ZEB day care center in Estonia**

**The initial works**

To get the best architectural and energy efficient opinions, the project started in 2014 with an architectural competition to find the architect and the draft design of the building to work on in the next steps.

Based on the initial task, the net area of the building was planned to be approximately 1900 m². The building was planned for five groups, in total 104 children. Day care facilities are planned on the first floor, technical rooms may be located on the second floor or basement.

All together there were 17 architectural proposals submitted to the architectural competition. A committee consisting of local authorities and architects was selected to evaluate the submitted works and to choose the best architectural solution for the further stages. The winning design (Figure 2) was chosen and there were no conflicts with the initial task. The initial task was deemed to be implementable.

The call for the architectural competition also included an energy efficiency component. It was stated that the building had to fulfill the requirements for a nZEB without using PV panels presented in energy efficiency regulations (MEACR No. 68 2012). Moreover, if PV panels with a nominal power of 100 kW are installed, then the building must fulfill the ZEB building requirements and the EPV of the new building must be 0 kWh/(m²·a). And finally, it was recommended to involve an energy efficiency consultant in the design process. Additionally, it was stated that the designed solutions had to be cost effective and the solutions had to ensure the passive house standards (maximum allowed energy demand for heating is 15 kWh / [m²·a], the architecture must support the passive solar energy usage, envelope must be without thermal bridges, ventilation system must be with high heat recovery, and air leakage rate n₅₀ must be <0.6 h⁻¹).

**Design process**

After receiving the contract, the design work proceeded to the next design stages. In Estonia there are three main design stages: preliminary (resulting in a building permit), principle design (resulting in bidding), and operational documentation.

After the preliminary design the customer ordered a survey of the design from a professional consulting company. Even though there were minor comments there were no comments or problems about the accessibility of ZEB.

The architect changed the energy efficiency consultant after the preliminary design. In the principle design stage the energy performance calculation was performed again. The result indicated that the calculations in the first stage had been too optimistic and a mistake in the energy performance calculations was highlighted. Consequently the ZEB level was unachievable. In the principle design stage the calculations were conducted by the company that also designed the HVAC systems of the building. The resulting design was a building with a ground source heat pump and floor heating, ventilation with heat recovery, an air-tight building (q₅₀ = 0.8 m³ / [h·m²]) and a building envelope with the specific heat loss coefficient of 0.34 W / [K·m²].

After the principle design stage, the architect proposed to lower the energy efficiency target level from nZEB to low energy building level or change the initial task so that the PV panels would be installed without the target level of a ZEB. The results of the energy efficiency component showed that the EPV of the designed building would be 22 kWh / [m²·a] if the PV panels and solar collectors were taken into account. The distribution of the energy use and EPV is shown in Figure 3.

**Indoor climate and energy simulations of the case study building**

To find answers to the questions that had arisen, simulations were used to calculate the indoor climate and energy use of the building. The simulation model was done according to

![Fig. 3. Distribution of energy use (kWh/m²·a; left) and EPV (kWh/m²·a; right) of the designed building in the principle design stage.](image-url)
Table 4. Key characteristics of the building in energy simulation.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Building in BASE CASE</th>
<th>Building in version 9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of floors*</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>Area under building, m²</td>
<td>2390</td>
<td></td>
</tr>
<tr>
<td>Closed net area, m²</td>
<td>1950</td>
<td></td>
</tr>
<tr>
<td>Heated area, m²</td>
<td>1950</td>
<td></td>
</tr>
<tr>
<td>External wall area, m²</td>
<td>514</td>
<td>589</td>
</tr>
<tr>
<td>Area of windows and doors, m²</td>
<td>319</td>
<td>244</td>
</tr>
<tr>
<td>Ratio of external wall area and heated volume, m⁻¹</td>
<td>0.125</td>
<td></td>
</tr>
<tr>
<td>Thermal transmittance of building envelope U, W/(m²·K)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>External wall</td>
<td>0.08</td>
<td>0.094</td>
</tr>
<tr>
<td>Floor</td>
<td>0.09</td>
<td>0.096</td>
</tr>
<tr>
<td>Windows</td>
<td>0.64</td>
<td>0.64</td>
</tr>
<tr>
<td>Roof</td>
<td>0.08</td>
<td>0.07</td>
</tr>
<tr>
<td>Air leakage of building envelope q50, m³/(h·m²)**</td>
<td>3</td>
<td>0.8</td>
</tr>
</tbody>
</table>

*Technical room for ventilation and cooling units on roof.
**Design value.

the architectural plan and design documentation. Key characteristics describing the size and shape of the building are presented in Table 4. A floor plan and the picture of the model of the simulation model of the building are presented in Figure 4.

Internal heat gains were as follows: lighting (15 W/m²) with a usage rate 0.4; appliances and equipment (4 W/m²) with a usage rate 0.4; heat gains from the inhabitants (20 W/m²) with the building usage rate 0.4. For the energy calculation the use of electricity by lighting and appliances equals the heat gains from the lighting and appliances.

The simulation model with input data according to the methodology was set as the base case. After that a simulation was carried out to see the influence of different factors. It was taken into account that the floor plan cannot be changed. Possible energy saving measures had to be found without changing the architectural appearance. Changes to simulation models were done one at a time and finally combinations of the different factors were taken into account. The different simulations cases and descriptions of the cases are presented in Table 5.

In all the cases the architectural design was kept as it is, except in the simulation case no. 8, since the changes in architectural design can have considerable effect on the appearance of the building. Only the change of the height of the window was considered because it could be excused by the interior decoration design since furniture was planned in front of the windows. Also the suggestion to change the size of the windows and raising the windows up from the floor was made in terms of safety.

Results of the simulation cases of the case study

To demonstrate the influence of different factors, DE simulations and EPV calculations were made. The results of the energy simulations are shown in Table 5. The distribution of energy losses and energy gains in the room of the simulation case no. 9 is presented in Figure 5.

The results of the energy simulation showed that if simulation case no. 9 is considered, the building's total energy use is 99 MWh (46.5 kWh / [m²·a], in case of radiator heating) and 100 MWh (47 kWh / [m²·a], in case of floor heating).
Table 5. The description of the energy simulation cases.

<table>
<thead>
<tr>
<th>Simulation case</th>
<th>Description of the case</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Base case</td>
<td>Energy simulation completed according to the energy calculation methodology—input data about the building's indoor climate according to Table 1; standard use and heat gains according to the Table 2; air leakage rate according to base value of new buildings $q_{50} = 3 , m^3 / (h \cdot m^2)$; SFP of the ventilation system $SFP = 1.7 , kW / (m^3 \cdot s)$; heat recovery of the ventilation $0.8$; min. temperature of exhaust air $-5^\circ C$; efficiency of the heating system $0.85$ (floor heating) and $0.97$ (radiator heating); thermal transmittance of the building body and values of the thermal bridges according to the architectural design.</td>
</tr>
<tr>
<td>2. $q_{50} , 0.8$</td>
<td>All data according to the base case, except the air leakage rate. The air leakage rate is changed from $3 , m^3 / (h \cdot m^2)$ to $0.8 , m^3 / (h \cdot m^2)$ which was the value presented in the architectural design.</td>
</tr>
<tr>
<td>3. SFP $1.5$</td>
<td>All data according to the base case, except the SFP of the ventilation system. The SFP of the ventilation system is changed from $1.7 , kW / (m^3 \cdot s)$ to $1.5 , kW / (m^3 \cdot s)$.</td>
</tr>
<tr>
<td>4. Lighting $10 , W/m^2$</td>
<td>All data according to the base case, except heat gain and the energy use of electricity of the lighting presented in Table 2. The value of the lighting is changed from $15$ to $10 , W/m^2$.</td>
</tr>
<tr>
<td>5. Version 2</td>
<td>All data according to the base case, except the lighting and the thermal transmittance of the building body and values of the thermal bridges. The value of the lighting is according to the simulation case no. 4. The thermal transmittance and the thermal bridge values are changed to correct values based on the calculation results using the drawings of the construction types and construction's junctions from the architectural design.</td>
</tr>
<tr>
<td>6. Version 2 + $q_{50} , 0.8$</td>
<td>Simulation model according to the simulation case no. 5 and the air leakage rate according to the simulation case no. 2.</td>
</tr>
<tr>
<td>7. Version 2 + lighting $10 , W/m^2 + \text{VAV}$</td>
<td>Simulation model according to simulation case no. 5 and the value of the lighting according to the simulation case no. 4. The ventilation system is changed from constant airflow (CAV) to variable airflow (VAV). The ventilation system is regulated according to the CO$_2$ level and room temperature.</td>
</tr>
<tr>
<td>8. Version 2 + lighting $10 , W/m^2 + \text{VAV} + \text{window size}$</td>
<td>Simulation model according to simulation case no. 7. Additional changes made in architectural design. The window size is changed so that the height of the windows is lowered $0.5$ meters. The original windows that were from floor to ceiling are raised up $0.5$ meters from the floor and the upper level is left as in the architectural design. The original window height of $2.4 , m$ is changed to a height of $1.9 , m$.</td>
</tr>
<tr>
<td>9. Version 2 + lighting $10 , W/m^2 + \text{VAV} + \text{window size} + q_{50} , 0.8$</td>
<td>Simulation model according to simulation case no. 8 and simulation case no. 2. Additionally to simulation case no. 9, the air leakage rate is changed from $3 , m^3 / (h \cdot m^2)$ to $0.8 , m^3 / (h \cdot m^2)$.</td>
</tr>
</tbody>
</table>

FIG. 5. The distribution of energy losses and gains in the room.

per year. The question was if the nZEB can be changed to a ZEB in the case where PV panels with nominal power of $100 \, kW$ were installed. An interactive map of photovoltaic geographical information system (European Commission Joint Research Center, 2012; Huld et al. 2012; Šuri et al. 2007) was used to estimate the performance of the grid-connected PV system. The building integrated PV panels, installation on the roof of the building, oriented to south with an installation an-
Discussion

In Estonia, the regulations establish minimum requirements for the energy performance of buildings (EGO No 68), including low-energy buildings, nZEBs, and ZEBs. The regulation for minimum requirements of energy performance extends to new buildings and to existing buildings that undergo major renovation. Minimum requirements are based on cost optimal analysis (Kurnitski et al. 2013).

In the Estonian regulation, a ZEB is a building that has the best possible construction practice, that employs solutions based on energy efficiency and renewable energy technologies, and its energy performance indicator is 0 kWh (m²-a).

The energy performance is evaluated for the building as a whole. For the purposes of calculating the energy performance of the building, in addition to the envelope of the building and its utility systems, the local energy generation systems (such as solar collectors and panels, wind turbines, combined heat and power producers) which are located within the building or on the building site and which feed into the building are regarded as constituent elements of the building. Utility systems (such as district heating) which are connected to an energy network, up to the connection point to the energy network, are regarded as constituent elements of building 9.

Architecture has a significant impact on the energy efficiency of the building (Thalfeldt et al. 2013). Architects have a complicated task, in some cases the architectural design has to be replaced with a rational solution in cases of nZEB and ZEB. An early stage energy performance assessment could help to find the compromise between art and energy performance (Kurnitski et al. 2012).

The mindset of designers, constructors, and supervisors has to change because compared to a traditional construction project, nZEB, and ZEB projects are more challenging because of their different aspects. To design a ZEB, it needs more analyses in the early stages (Kantola 2015). Even regulations allow for exceptions for adjustment if more detailed calculations are performed and presented with energy performance calculations. For example, the use of lower wattage lighting in the illuminance calculations must be presented. The HVAC systems can have an effect on the energy use and architectural design. For example, to ensure the lower electricity use of the ventilation systems (lower SFP of the fans) in some cases the space for the installation of the air-handling units and ventilation air ducts needs a larger space compared to a traditional HVAC system. The problem can be the space needed for the installation of the HVAC systems. To use the VAV system, the HVAC systems of the building and the everyday usage of the building should be more thought-out before the energy calculations.

In nZEBs and ZEBs, the building envelope must be highly insulated and air-tight, the building service systems have to be state of the art, and renewable energy systems can be considered a standard feature. The know-how concerning the nZEB features among project managers and designers is one main concern.

In Estonia, the most commonly used procurement in case of state owned buildings when constructing a new building or retrofitting existing building, the contractor is chosen based on the lowest offered price. This may lead to a situation when the owner has no opportunity to choose the best designer who would make a complete design. In the case study, this was avoided by arranging the public architectural competition. It enabled the choice of the designer to be based on the preferred design. The committee consisted of representatives of the local municipality and architects. Unfortunately, the committee of judges did not include any energy efficiency experts.

In case of Estonia the limited size of the market can be seen as a deficiency. In cases of public procurement the common practice is that the final project documentation will go through the commissioning of a third-party expert. During the initial design process and in the end of the design process of the case study, the commissioning was done on the construction documentation and there were no comments concerning energy efficiency or HVAC systems of the designed building. There is lack of experts in the field and it makes it difficult to get independent opinions in case of supervision. It would be best if the consultant who conducts the supervision is involved from the very beginning of the project before any other parties of the project. It helps to avoid the problems caused by lack of experience or incompetence of the owner. The expectations and needs of the owner have to be put clearly to the contractor.

The European Union (EU) definition states that part of the energy needs of the nZEB and ZEB have to be produced with on-site or nearby renewable energy sources. The highest need for energy in buildings is during the heating period in Estonia; it is during this period when there is not so much sun light. In Estonia the possibility to use the solar energy is during the summer period when there is not such a large need for energy in the buildings. The possibility to gain benefits from solar energy requires the possibility to sell produced electricity to the grid in the case of nZEBs and ZEBs. The current electricity legislation limits the design and building of ZEB because the current electricity legislation limits the nominal power of PV panels to 100 kW in the case of local small scale electricity production by renewable sources without the need to become registered as an energy producer together with the accompanying statutory tax obligations.

The energy use is calculated based on annual net delivered PE without taking embodied energy for on-site generation units into account (Hernandez and Kenny 2010). Berggren et al. (2013) showed that even the embodied energy increases slightly when taking the step from a low-energy building toward ZEB balance, the energy savings achieved related to building operation energy exceeds, with great margin, the increased embodied energy.

Conclusion

The problems and results of the design process of the first net-ZEB in Estonia are described through a case study on
a kindergarten building. The current study showed that it is possible to reach ZEB levels in Estonia by a careful and detailed design of the building’s energy performance. Achieving zero energy for larger building could be restricted because of special requirements on house owner if electricity production is over 100 kW. To motivate the house owners to build more ZEBs in different scales, the current electricity legislation has to be adjusted to the energy performance requirements of the building.

ZEBs are ambitious targets, taking into account current practice and knowledge of architects and customers. The most essential step is to organize training and education for architects and responsible staff in the municipalities. Guidelines for the design and for the construction process are needed to help to follow the different stages of design and construction works from the beginning to the end. The guidelines would make it possible for contract authorities to prevent mistakes and help to achieve the designed and calculated energy efficiency levels of the buildings also in real life.

As the majority of energy efficiency will be fixed by architectural sketch, a more thorough analysis is needed in the very first stage of the design to find a suitable solution and possible compromises between the architecture and energy efficiency. In any case, well-insulated buildings, effective building service systems, and local electricity production on-site are needed for ZEBs.

Further ZEB pilot projects as examples are needed. Additionally, it is important to collect all the examples and to make it public to motivate and instruct about suitable solutions and how to avoid mistakes in all the involved disciplines in the ZEB topic.

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