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Different ventilation strategy implementation for achieving nZEB standard of school building

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Abstract

Implementation of nZEB (nearly zero energy building) standard for public buildings will be an essential requirements of EU in near future. It is going to be especially important in school buildings as promoting energy efficiency for wide range of people. In the other hands improving energy standard of schools may often be connected with decreasing of indoor environment conditions.

In these context it is crucial during the renovation of school building to improve both indoor climate and energy standards. Complex modernization of public buildings is a subject of a KODnZEB project co-financed by Norwegian founds. One of the work done within a project was preparing energy efficiency ventilation concepts for classroom with special attention paid for both indoor climate and nZEB requirements.

The paper presents results of renovation an typical school classroom with different ventilation strategy. One is mechanical balanced ventilation with heat recovery and the second is natural/hybrid concept of ventilation. For both cases of ventilation model of energy performance as well as calculation of indoor climate were analyzed.

It has been showed that providing thermal comfort condition is rather not problematic, but energy performance and indoor air quality can vary a lot between different ventilation strategies. As a results the primary energy (heating energy and electricity used for ventilation) were analyzed and commented. It has been showed that in middle Europe (Poland) it is possible to meet nZEB standards together with proper indoor air quality by balanced mechanical ventilation with heat recovery and rather problematic by natural/hybrid ventilation.

Keywords – school building, energy performance, ventilation, nZEB

1. Introduction

The definition of nearly zero-energy building (nZEB) was introduced by the EU EPBD Recast [2], which imposed a requirement that all new buildings are to meet nZEB standard from 31 December 2020. In the case of government buildings this requirement is to take effect from 31 December 2018. Definition of nZEB is provided under Article 2 of the EPBD [2]:

> "*nearly zero-energy building' means a building that has a very high energy performance, as determined in accordance with Annex I. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby*"

However, in Article 9 there were delegating specific definition to the Member States:

> "*the Member State's detailed application in practice of the definition of nearly zero-energy buildings, reflecting their national, regional or local conditions, and including a numerical indicator of primary energy use expressed in kWh/m² per year. Primary energy factors used for the determination of the primary energy use may be based on national or regional yearly average values and may take into account relevant European standards*;"

To summarize it can be said that the main requirement of the Directive nZEB definition is the criterion for primary energy demand expressed in kWh/m^2 per year of typical use of a building. This value should be calculated or measured in accordance with relevant European standards and regulations, taking into account local requirements introduced by national legislation.

One of the main aims of bilateral Polish-Norwegian project "Thermo-modernization of two chosen public buildings according to nZEB Standards", called KODnZEB, founded by EEA Financial Mechanism and the Norwegian Financial Mechanism is a development of methodology of refurbishments of two university / dormitory buildings to nZEB standard. The methodology should include technology and financing aspects. The first step of one of work packages is preparing the definition of the nZEB standard used during the project. It seems that the definition of nZEB implemented in the Polish legal order (14/10/2014 draft of resolution of the Council of Ministers on the adoption of the "National plan aimed at increasing the number of low energy buildings") does not meet the expectations of the project, therefore, it would be expedient to adopt the definition according to the project objectives and the Norwegian experience. Overview of nZEB definitions varies greatly both as to the type of energy entering the balance and energy balance boundaries [7], [9], [10].

Calculation of energy demand for building in nZEB standard should include at least:

- thermal characteristics of the building and partitions (capacity and thermal insulation, passive heating, cooling elements, thermal bridges)
- heating systems, domestic hot water, cooling and ventilation
- built-in lighting (for residential buildings)
- the location, orientation, and architectural characteristics of the building,
- the use and protection from solar gains,
- parameters of the indoor climate

- internal heat gains.

Including a positive effect:

- active solar systems to produce heat and electricity (also from other renewable sources)
- electricity from cogeneration systems,
- heating networks and cooling energy distribution networks,
- daylighting.

The most classic interpretation of the provisions contained in the EPBD Recast means that the subject balancing energy, which is supplied to the building on the need to ensure adequate indoor environmental parameters such as temperature, cleanliness, lighting and for hot water preparation. At the same time, you can skip the energy that enters the building in the form of e.g. wind pressure, unused solar gains, etc. focusing solely on the energy supplied to the plant responsible for the individual parameters. These installations respectively, for the following environmental parameters are: the system of heating, cooling, ventilation, lighting and for domestic hot water installation preparation and distribution of hot water for the production of energy from renewable sources on site (or in the immediate vicinity) energy as a whole is subject to deduction of demand, even if the time shift between production and demand.

This approach is the most popular among the member countries. The differences arise in in the form of requirements of primary energy, CO_2 emissions, a minimum share of energy from renewable sources. In relation to the primary energy requirements have been set in the range of 25 to 270 kWh/m^2/year for non-residential buildings and 20-217 kWh/m^2/year for residential buildings [6].

According to the draft of Polish national plan [8] of increasing of nZEB standard buildings in the Polish legal system nZEB is a building that meets the building code requirements that will apply from 1 January 2021 year. and in the case of buildings occupied by public authorities and owned from 1 January 2019 year. This means that the maximum value of primary energy demand for heating, cooling, ventilation, hot water and lighting of the built-in (in the case of collective residential buildings and utilities) will follow:

- apartment building (without cooling): 65 kWh/m^2/year
- apartment building (cooling): 65 +5*A_{fc}/A_f kWh/m^2/year
- collective residential building (without cooling): 75+25 kWh/m^2/year
- collective residential building (cooling): 75+25+25*A_{fc}/A_f kWh/m^2/year
- public building (without cooling): 45 +50 kWh/m^2/year
- public building (cooling): 45 + 50 + 25*A_{fc}/A_f kWh/m^2/year

where:

A_f – space heating floor area

A_{fc} – space cooling floor area.

Energy balance boundary is defined as external surface of building envelope including all energy installations mounted on this envelope. In case of all internal technical installations the boundary is defined as meter connections between internal and external buildings installations. Energy will be balanced for typical meteorological years. Primary energy will be balanced in building boundaries and in the time of building use. The coefficients of primary energy input will come from the Polish ministry ordinance of defining methodology for calculating the energy performance of the buildings. The energy balance will consist of the energy used for heating, ventilation and cooling with auxiliary energy, DHW along with auxiliary energy, lightning.

Criterion pointing to meet the definition of nearly zero-energy building (nZEB) will be appropriate EP coefficient for energy demand counted as outlined below.

It was assumed that the KODnZEB project nZEB standard building, is a building with EP coefficient in range between zero-energy building with 0 kWh/m^2/year and less than a building that meets actual minimum building code requirements.

Actual minimal energy requirements for new buildings in Poland are:

- apartment building (without cooling): 105 kWh/m^2/year
- apartment building (cooling): $105+10*A_{fc}/A_f$ kWh/m^2/year
- collective residential building (without cooling): 95+50 kWh/m^2/year
- collective residential building (cooling): $95+50+25*A_{fc}/A_f$ kWh/m^2/year
- public building (without refrigeration): 65+100 kWh/m^2/year
- public building (cooling): $65+100+25*A_{fc}/A_f$ kWh/m^2/year

where:

A_f – space heating floor area

A_{fc} – space cooling floor area.

Assuming a linear decrease of the EP coefficient from actual minimal energy requirements to zero, KODnZEB project accepts that building reaching 90% compliance with the EP range is the nZEB standard building. This means that building is a nZEB standard with EP coefficient:

- apartment building (without cooling): 10,5 kWh/m^2/year
- apartment building (cooling): $10,5+1*A_{fc}/A_f$ kWh/m^2/year
- collective residential building (without cooling): 9,5+5 kWh/m^2/year
- collective residential building (cooling): $9,5+5+2,5*A_{fc}/A_f$ kWh/m^2/year
- public building (without refrigeration): 6,5+10 kWh/m^2/year
- public building (cooling): $6,5+10+2,5*A_{fc}/A_f$ kWh/m^2/year

where:

A_f – space heating floor area

A_{fc} – space cooling floor area.

Accepted in KODnZEB project nZEB standard definition mean that it energy demand for primary energy should be reduced for two analyzed university / dormitory buildings about 95% and 88%.

On the other hand, according to a BIPE study [11], the proposed value of primary energy demand for the construction of nearly zero energy consumption in Poland equals for multifamily buildings 30-50 kWh/m^2/year, and office buildings 50-60 kWh/m^2/year. These values were described as "ambitious but still realistic in terms of costs". If both these values relate to supply heat to the district heating network (which is analyzed in the case of buildings) is the minimum primary energy demand is respectively 59.7 and 108.9 kWh/m^2/year, and having regard to the production of energy by the PV panels, respectively 35.6 and 48 kWh/m^2/year. The most important values that define the nZEB standard for Polish economy are illustrated in the graph shown in figure below.

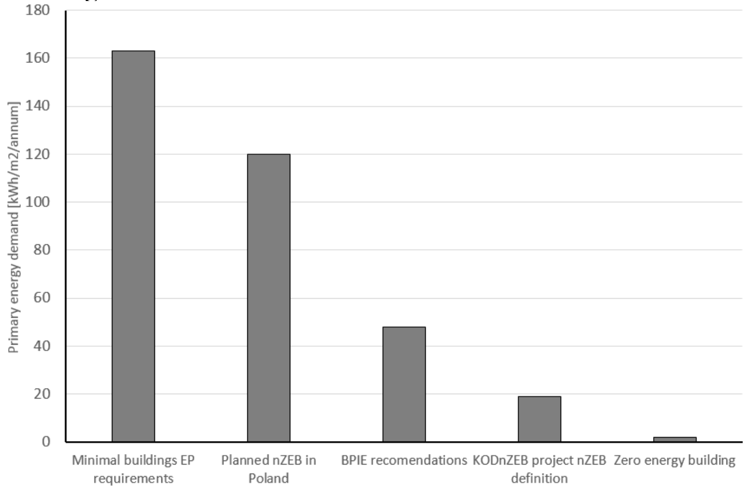

Fig. 1 Primary energy demand coefficients used for nZEB standard definition

Generally, for school buildings primary energy demand for heating and ventilation should not exceed 45 kWh/m^2 per year (planned nZEB in Poland, or about 18 45 kWh/m^2 (BPIE recommendation [11]) or 6,5 kWh/m^2 (KODnZEB definition). In this context, the question arises, which the ventilation strategy is able to meet these requirements.

2. Methods

To identify both energy performance and indoor climate during winter the model of energy performance as well as calculation of indoor climate were used. In this study, the 6R1C model with air handling unit (AHU) component developed at Warsaw University of Technology was used for simulation of energy performance [4]. The 6R1C tool integrates energy simulations of buildings (based on hourly method described in EN ISO 13790:2007 [3]) and behavior of ventilation and air-conditioning systems (based on EN 15241 [1]). Model of indoor climate is based on regression technics and results of measurements (indoor temperature, relative humidity, and CO_2 concentration) performed in real schools during heating season. These way of calculations can include both controlled air flows caused by ventilation and air change rate caused by stochastic in nature windows opening. These models were applied to one classroom in pre-school building located in Warsaw Poland. Scheme of analyzed classroom is presented on fig. 2.

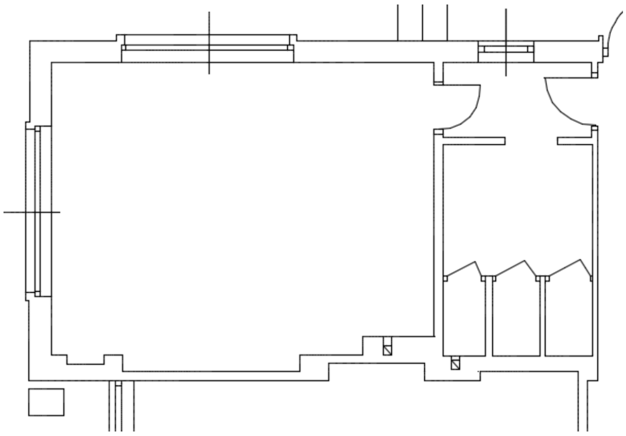

Fig. 2 An analysed clasroom

Calculations were performed for two ventilation systems: the first is mechanical balanced ventilation with HR and the second is natural/hybrid ventilation. Both systems were design to provide similar indoor air quality and thermal comfort. The main assumptions for classroom and ventilation systems are given in a table 1

Table 1. Description of simulation cases

	mechanical ventilation with HR	natural/ hybrid ventilation
Outdoor climate	Warsaw, Poland	
Hours of operating	7.00 – 17.00	
Area of classroom	40 m^2	
Volume of classroom	120 m^3	148 m^3
No of children in a classroom	18	
Limit of CO_2 concentration	1250 ppm	
Design indoor temperature for winter	21°C	22°C
Air inlets	¼ central AHU with HR	8 window's frame air inlets
Air outlets		two 14x20 cm ducts with hybrid exhaust
Max electricity power for ventilation	¼ x 770 W	14 + 18 W
Max HR efficiency	87%	-

Control of ventilation	time profile and CO_2 concentration	time profile and stack effect control
Heating energy source	district heating system	
Electricity source	national grid	

As a results the hourly energy consumptions of heating energy and electricity, as well as indoor temperature were calculated.

3. Results

The energy consumption for each variant of ventilation systems are presented on fig. 3 (heating energy) and fig. 4 (electricity).

a) b)

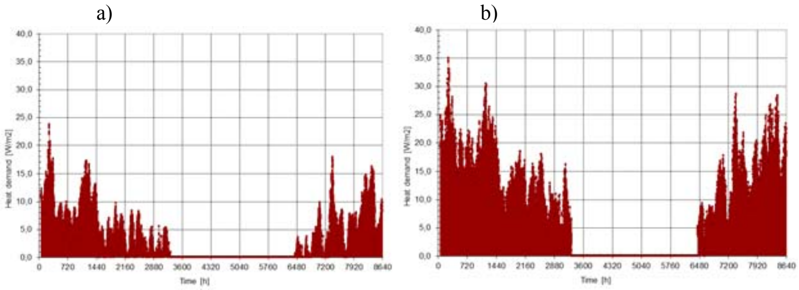

Fig. 3 Heating energy consumption for classroom with mechanical ventilation with HR (a) and with hybrid ventilation (b)

a) b)

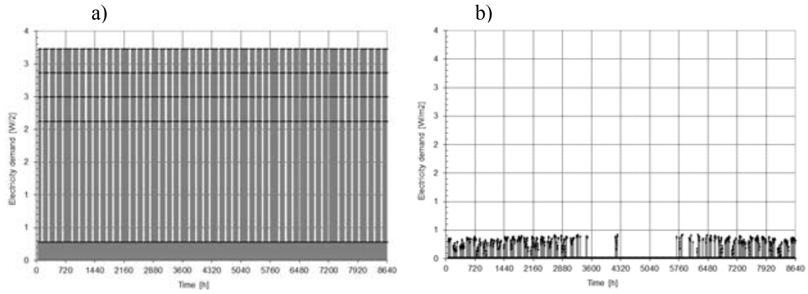

Fig. 4 Fans electricity consumption for classroom with mechanical ventilation with HR (a) and with hybrid ventilation (b)

These results were obtained for similar ventilation rate and indoor temperature provided by central heating system (fig. 5)

a) b)

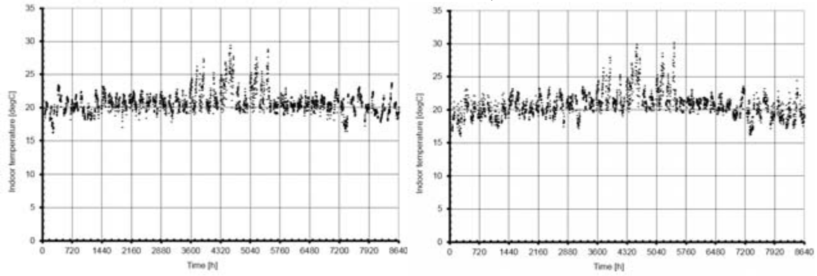

Fig. 5 Indoor temperature (only hours of oparating time for classroom with mechanical ventilation with HR (a) and with hybrid ventilation (b)

4. Discussion

It is obvious that ventilation with heat recovery consumes less energy than ventilation without HR. But at the same time mechanical ventilation needs more electricity for fans (and sometime for anti-frosting procedure) than hybrid ventilation. According to the results one may observe that more heating energy is consumed during colder period of year and maximum heating demand for a room with mechanical ventilation reach almost 25 W/m^2, and 35/m^2 kW for hybrid ventilation. Starting point of heating season begin at 6-14°C for HR ventilation and about 14°C for hybrid ventilation.

Maximum values of electricity consumption for fans reach nearly 3.5 W/m^2, and 1.0 W/m^2 for mechanical and hybrid ventilation. Yearly electricity consumption profile is more complex. For mechanical ventilation, as it is controlled by CO_2 concentration it mainly depends on occupancy profile. In the case of hybrid ventilation, it is reduced during winter time (as stack effect is enough for driving the air), and summer time when windows opening are the main ventilation strategy.

a) b)

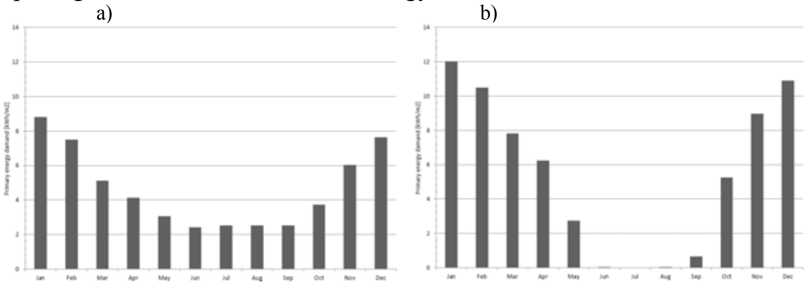

Fig. 6 Monthy primary energy demand for classroom with mechanical ventilation with HR (a) and with hybrid ventilation (b)

As the difference between mechanical balanced ventilation with HR and hybrid ventilation are opposite in heating energy and electricity, better comparison is possible for primary energy. In Poland according to a national law primary energy conversion factor is 0.8 for district heating system and 3.0 for electricity [5]. Monthly primary energy demand for a year is presented on fig. 6, and profile for two analyzed cases are presented on fig. 7.

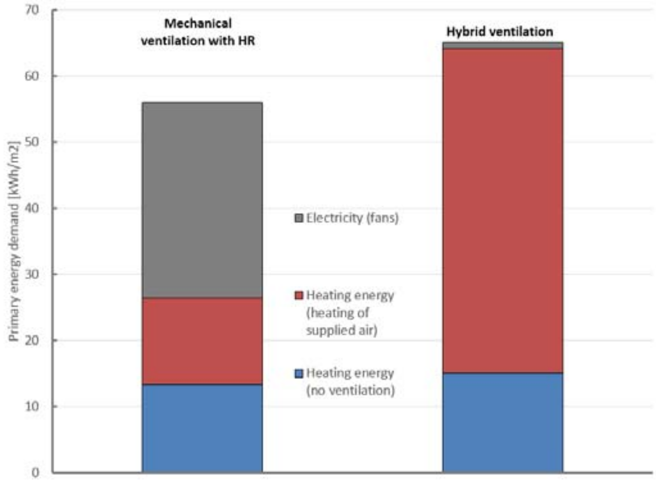

Fig. 7 Comparison of primary energy consumption for classroom with mechanical ventilation with HR and with hybrid ventilation

5. Conclusions

Ventilation with HR for that specific case consumes about 40% less primary energy (for heating and ventilation) than hybrid ventilation, when for both cases the indoor comfort is quite similar. Ventilation rate is controlled for both cases and for mechanical ventilation with HR it is controlled according to CO_2 concentration, and for hybrid ventilation it is controlled as time profiled constant ventilation with controlling of stack force. For providing similar thermal comfort it was necessary to increase design indoor temperature to 21°C for hybrid ventilation, as during cold period outdoor air is supplied to a room without any preheating.

In the case of ventilation with heat recovery, primary energy demand for building is above the nZEB definition. The difference is about 20%, which may be covered by other technical solutions, such as high efficiency fan motors, high efficiency heat recovery systems and renewable energy- photovoltaic panels. In the absence of heat recovery from exhaust air of a building having reaching nZEB standard is very difficult.

Acknowledgment

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