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Criteria For Low Energy Buildings

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Short Summary

The Recast of the Directive on the Energy Performance of Buildings (the EPB Directive) came into force on 9 June 2010. EU member states should until 9 June 2012, publish the relevant laws and administrative regulations necessary to implement its provisions. European regulatory efforts towards increasing energy efficiency of buildings are focusing on a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements. Such requirements should be the first step into low or zero energy buildings.

In this paper the consideration on different indicators for requirements of low energy and nearly zero energy buildings are presented. The scope of the paper is to show that none of the buildings system (like hybrid or natural ventilation) can be excluded from using in such buildings. This conclusion is crucial for integrated energy design process as designer should not be limited to specific number of systems solutions.

In the paper the calculation of three systems are presented (natural ventilation, DCV ventilation and mechanical ventilation with heat recovery). It was shown that, the choice of indicator for requirements should include not only the useful energy (heat), but also electricity (heater) and other non-energy operating costs (filters). The correct ratio is multi-dimensional, and its range depends on the used assumptions.

The given consideration shows that the estimation of energy requirement cannot be done using only one indicator eg.: useful, final or primary energy. Such approach may leads to excluding some systems that can be other than recommended.

Keywords:Low energy buildings; energy criteria; LCC

1. Introduction

Directive 31/2010/EU [1] requires the introduction of nearly zero-energy buildings but does not specify a minimum or maximum harmonized requirements and detailed guidance framework procedure for calculating the energy performance of building. Member states have to define what that means exactly for them. Taking into account the local conditions in the definition does not preclude the adoption of a uniform methodology in all Member States.

The Directive defines a nearly zero-energy building as a high energy performance building and requires the determination of the ratio of primary energy. Very low or almost zero energy demand of the building should be covered from renewable energy sources or renewable sources produced on-site.

Based on the definition given in the directive, the nearly zero-energy building is technically *net zero energy* building that is consuming 0 kWh/(m^{2}a) energy (however it is not clarified what kind of energy should be taken into account: final, primary, supplied). According to the rule of optimal costs laid down in Directive almost net zero net energy building is defined as a building determined using the rules of the national methodology of optimal costs, consuming more than 0 kWh/(m^{2}a) energy. In order to clarify the general definition it was necessary to specify which energy flows should be included in the evaluation of energy performance and how the primary energy factors should be used to calculate the ratio of primary energy of building. To standardize the methodology the overall definition of the balance border with the inclusion of active solar systems and wind power, as well as technical clarification of the term "near" contained in the Directive becomes an essential element.

Methodology of the cost optimal and requirements defined of its use indicates use as an indicator a final or delivered energy, as they are associated with costs. Primary energy can be defined as an additional indicator, as used for its determination the primary energy factors include biased (not related to the quality of the building) political aspect. However, many Member States selected as requirement a primary energy supplemented by other requirements. The requirements have technical and economical quality which means that they must refer to existing technologies and be set as economically viable. This cost-effective level by the European Commission may be determined by the cost optimal methodology described in Regulation EC 244/2012 [2].

In this paper the consideration on different indicators for requirements of low energy and nearly zero energy buildings are presented. The scope of the paper is to show that none of the buildings system can be excluded from using in such buildings. This conclusion is crucial for integrated energy design process as designer should not be limited to specific number of systems solutions.

2. Energy in requirements

Genesis of formulating energy requirements is derived from the early twentieth century. With the development of technology and the decreasing availability of raw materials it began to formulate the energy requirements for buildings. At the beginning heat loss was the main issue, so a maximum heat transfer coefficient for a single partition or the entire building were given. Since 1995, Poland has introduced requirements for the maximum permissible value of useful energy for residential buildings in kWh/m^{2}a, which coincided with the publication of the method for calculating this value. From the point of view of energy performance of buildings it was the only requirement, although by then some first calculations of final energy and thus costs were given. For other types of buildings maintained the requirements for building components such as heat transfer coefficients and the surface area of the glass partitions. In accordance with the adoption of the climate package, published directives on buildings, measures to reduce energy consumption have become systematically harmonized. In connection with the implementation of Directive 91/2002 on the Energy Performance of Buildings Member States were obliged to publish the so-called. minimum requirements. A summary of these activities is provided in online accessible publication titled Implementation of the Energy Performance of Buildings Directive (EPBD), Country Reports 2008, Brussels, 2008, ISBN 2-930471-29-8, EAN 9782930471297) [3]. During the implementation of the EPBD some research aimed at comparing the requirements from the various Member States were carried out. Examples of such works are Intelligent Energy for Europe projects called TABULA and ASIEPI. In comparison the rules adopted in Poland in 2008 are the least demanding of all member countries.

The requirements for nearly zero energy building consist of several specific requirements. These include primary energy and useful energy, as well as the tightness of the building and in the case of non-residential buildings useful energy for cooling.

An expressing requirements in units of primary energy is burdened with charges of adjusting object location (same building with electric power for heating has to be three times better than a building supplied with district heating networks). If we assume, that the requirements should be independent of the location then the variables that affect the energy consumption of the building are the quality of envelopes and windows of the building, the efficiency of installations, climate and standard usage. Determination of whether the building have good or bad energy performance will be easy to define, regardless of its location. In this case, the requirements can be formulated in units of final and useful energy. Otherwise, if the distinction is primary energy it will not be able to conclude what is the energy performance of the building itself.

In conclusion, each indicator adopted for the requirements has its advantages and disadvantages, which should be know when deciding to choice it. Poland in the proposal of the new requirements for buildings plans to introduce partial requirements and primary energy requirements.

3. Traps of useful and final energy

In guidelines of Passivhaus Institut in Germany, the Austrian standards, definitions used in countries such as Sweden, Denmark, Norway and Finland requirements are always formulated with regard to the rate of useful energy demand for heating and ventilation rather than rate of final energy demand. So it is defined by the passive house standard according to Passivhaus Institut in Germany. Building achieved the passive standard if:

- usable energy demand for heating and ventilation does not exceed 15 kWh/m^{2}a,
- primary energy demand for heating, ventilation, hot water, auxiliary equipment, lighting, all the building equipment, household appliances and electronics, cooking, etc. does not exceed 120 kWh/m^{2}a.

Requirements for low energy standards should also be related to the rate of useful energy demand for heating. The indicators should not be taken into account additional energy consumption by auxiliaries.

Statement of requirements as indicators of final energy demand is a big mistake and can lead to increased energy consumption in buildings. For example, in buildings where the ground heat pump is the heat source the total efficiency of heating system will be about 3.0. With this performance achievement of final energy demand equivalent to 15 kWh/m^{2}a occurs with a usable energy demand for heating and ventilation equal to 45 kWh/m^{2}a. The achievement of final energy demand equal to 75 kWh/m^{2}a occurs with a usable energy demand for heating and ventilation equal to 225 kWh/m^{2}a. This means that when heat pump system with heating efficiency of an average 3.0 is used the buildings which should have passive standard are only low energy buildings, and low energy buildings are much worse than currently build.

The problem of final energy can be solved using the method cost optimal methodology. The calculation of the global cost is performed according to the methodology given in the comparative Commission Delegated Regulation 244/2012 (EU), using the method of financial calculations, from the formula:

$$C_g(\tau) = C_I + \sum_j \left[\sum_{i=1}^{\tau} \left(C_{a,i}(j) \times R_d(i) \right) - V_{f,\tau}(j) \right] \tag{1}$$

where:

τ	means the calculation period (30 years for residential and public buildings and 20 years for non-residential buildings),
$C_g(\tau)$	means global cost (referred to starting year τ_0) over the calculation period,
C_I	means initial investment costs for measure or set of measures j,
$C_{a,i}(j)$	means annual cost during year i for measure or set of measures j,
$V_{f,\tau}(j)$	means residual value of measure or set of measures j at the end of the calculation period (discounted to the starting year τ_0),

$R_d(i)$ means discount factor for year i based on discount rate r to be calculated according to (2)

$$R_d(p) = \left(\frac{1}{1+r/100}\right)^p \tag{2}$$

where p means the number of years from the starting period and r means the real discount rate.

Calcutalion of global cost is performed on the basis of knowledge (estimation) of the final energy. Therefore, the determination of the requirements should be done using LCC methodology. It follows that the requirements laid down by the LCC will be different for different power systems.

4. The paradox of useful energy ratio - case study

In order to show the paradox of using in the requirements the useful energy the calculation of the energy demand for ventilation in the single family house were provided. It was assumed that the heat loses through external envelopes are constant and only ventilation system was taken into account.

According to Polish standard the hygienic air flow rates for single family house with two bathrooms and kitchen with gas cooker are: 2x50 + 70 = 170 m^3/s. It was assumed that ventilated volume of the building is 300 m^3, and ratio of n_{50}=3 air change per hour (for natural ventilation system). The total outside air flow is then:

$$V_{ve} = V_0 + V_{\inf} = \frac{170}{3600} + \frac{0.05 \cdot 3 \cdot 300}{3600} = 0.047 + 0.013 = 0.06 \quad m^3/s \tag{3}$$

The heat transfer coefficient for heat loses for natural ventilation is equal:

$$H_{ve} = \rho_a \cdot c_a \cdot \sum_k \left(b_{ve,k} \cdot V_{ve,k,mn}\right) = 1200 \cdot \left[1 \cdot V_0 + 1 \cdot V_{\inf}\right] = 1200 \cdot \left[1 \cdot 0.047 + 1 \cdot 0.013\right] = 72 \quad W/K \tag{4}$$

The heat transfer coefficient for heat loses for mechanical ventilation with heat recovery of 85% is equal:

$$\begin{aligned} H_{ve} &= \rho_a \cdot c_a \cdot \sum_k \left(b_{ve,k} \cdot V_{ve,k,mn}\right) = 1200 \cdot \left[(1-\eta_{HR}) \cdot V_f + 1 \cdot V_x\right] = \\ &= 1200 \cdot \left[0.15 \cdot 0.047 + 1 \cdot 0.00875\right] = 18.96 \quad W/K \end{aligned} \tag{5}$$

Where V_x:

$$V_x = \frac{V \frac{n_{50}}{3600} e}{1 + \frac{e}{f}\left(\frac{V_{su} - V_{ex}}{V \frac{n_{50}}{3600}}\right)^2} = \frac{300 \frac{1.5}{3600} 0.07}{1 + \frac{0.07}{15}\left(\frac{170-170}{300 \frac{1.5}{3600}}\right)^2} = 0.00875 \quad m^3/s \tag{6}$$

For the mechanical ventilation n_{50}=1.5 1/h and the *e* and *f* coefficient were taken from standard EN 13790.

In Table 1 the summary of heat transfer coefficient for natural and mechanical ventilation is given.

Table 1: Heat transfer coefficient for ventilation

Ventilation	Heat transfer coefficient [W/K]
Natural	72.00
Mechanical	18.96

On the basis of the calculated values of heat transfer coefficient for ventilation the heat demand for whole year can be estimated. The calculation was done using Warsaw climate data and using monthly calculation method. In Table 2 the results of the calculation are presented.

Table 2: Heat demand for ventilation

Ventilation	Heat demand [kWh/a]
Natural	7031
Mechanical	1852

It can be noticed that heat demand in case of the mechanical ventilation is about 3.8 times less than for the natural ventilation. However in the mechanical ventilation additional energy for fans is required. Using the national regulation [4] it was assumed that in the mechanical ventilation two fans (each of 80 W) are installed and the ventilation is working whole year. For such data the energy demand for electricity was calculated.

$$E_{el} = 160 \cdot 8760 = 1387 \quad kWh/a \tag{7}$$

Taking into account the energy consumption of fans the mechanical ventilation system needs 1852 kWh of thermal energy and 1387.2 kWh of electrical energy. For the determination of the useful energy for heating only thermal energy needed to heat the ventilation air taken into account, while omitted larger and more expensive part associated with the electricity. A more complete assessment of the two systems is when referring them to the primary energy or costs. In the case of natural ventilation system thermal energy of 7031 kWh/a, is about 3.8 times higher than for the mechanical ventilation with heat recovery 1153 kWh/a. If we take into account the primary energy or costs, the mechanical ventilation system with heat recovery needs 1852 kWh/a + 3*1387 kWh/a = 6015 kWh/a primary energy to 7031 kWh for natural ventilation system, so that the difference is significantly reduced.

The first conclusion that must be drawn here is that the eligibility criterion in units of useful energy (heat) eliminate from the analysis a components necessary for the operation of technical systems including ventilation.

The second conclusion from the analysis is 3.8 times higher thermal energy consumption by natural ventilation system. Assessing qualifications or eliminations from the list of recommended technology, based on just the heat demand can lead to false results. After taking electricity consumption, it appears that natural ventilation is not much worse than mechanical. This means that at least should be allowed to be used along with mandatory recommendation.

The third conclusion is that eligibility criteria of useful energy should be supplemented by other forms of energy necessary for the operation of technical systems.

Natural ventilation is unpredictable and in many situations is not working. Demand controlled ventilation (DCV) eliminates the disadvantages of natural ventilation, making it works regardless of weather conditions, and also by the ability to control ventilation can adjust the air flow in each room to the needs of users. In practice, the possibility of reducing the air flow is used in the absence of people or at night. Most of the central mechanical ventilation units has three levels of performance. Selection of these units is made in such a way as to meet the hygienic performance requirements for middle level of ventilation unit performance. Installed in the units programmers allow individual time programming of the air flows. Inhabitants reduce airflow during their absence, and increase it in the summer in order to disperse of the heat gains. Sometimes they turn down mechanical ventilation and open windows (which from the point of view of the Polish regulations is not allowed).

In the case of demand-controlled ventilation it is possible to individually adjust the air flow to the ventilation needs in each room. The degree of this adjustment depends on the technical sophistication of the system. Below, the estimation of the ventilation air flow reduction in accordance with the technical capabilities of both ventilation systems and the impact of the reduction on the heat and electricity consumption are presented.

4.1 Mechanical ventilation with heat recovery

Mechanical ventilation should work whole year, for 8760 hours. In presented case study the calculated hygienic air flow is equal 170 m^3/h. The second step (II) in the mechanical ventilation unit provide 200 m^3/h (first step (I) gives 100 and third (III) 400 m^3/h). It was assumed that in the winter ventilation unit on II step only during the presence of all inhabitants for example during 12 hours a day, at other times is running at I step. In the summer, during the day (approximately 10 hours) in order to disperse heat from the solar gains a ventilation unit is operating at III step and at the rest of the day at II step. This assumption is justified if we assume that the priority of people is the most out of the ventilation system. In practice, in the summer ventilation system is used to set hygienic air flow requirements and the heat gains are being removed by opening of the windows. In accordance with Polish ventilation regulation a ventilation air flow for the calculation can be reduced by 40%.

Average hourly flow of ventilation air supplied during the heating season by the air handling unit is (5840 * 170 + 0.6 * 170 * 2920) / 8760 = 147 m^3/h, and in the summer is 170 m^3/h, therefore to calculate the electricity consumption of the fans we can assume that the ventilation unit operates all year round on the second step providing 200 m^3 of air per hour. From this assumption the heat transfer coefficient for mechanical ventilation with 85% of the heat recovery is equal:

$$\begin{aligned} H_{ve} &= \rho_a \cdot c_a \cdot \sum_k \left(b_{ve,k} \cdot V_{ve,k,mn}\right) = 1200 \cdot \left[\left(1-\eta_{HR}\right) \cdot 0.6 \cdot V_f + 1 \cdot V_x\right] = \\ &= 1200 \cdot \left[0.15 \cdot 0.6 \cdot 0.047 + 1 \cdot 0.00875\right] = 16.55 \quad W/K \end{aligned} \tag{8}$$

The heat demand for this case is equal to 1616 kWh/a.

Calculation of electrical energy consumption should be made on the basis of the technical specifications of the selected ventilation unit. After analyzing of several air handlings units it can be assumed that on the second step the fan power is equal to 150 W (see Table 3).

Table 3: Fan power at given air flow rate of selected air handling unit

Step of working	Air flow [m^3/h]	Fan power [W]
I	100	38
II	200	150
III	400	600

For such data the energy demand for electricity was calculated.

$$E_{el} = 150 \cdot 8760 = 1314 \quad kWh/a \tag{9}$$

Taking into account the energy consumption of fans the mechanical ventilation system with 85% heat recovery needs 1616 kWh/a of thermal energy and 1314 kWh/a of electrical energy.

Assuming primary energy factors (gas primary energy factor = 1.1 and electricity 3.0) and energy cost (0.54 PLN/kWh for electricity and 0.20 PLN/kWh for gas, 1 euro = 4 PLN) the total primary energy demand and total operating costs can be calculated. The results are presented in Table 4.

Table 4: The primary energy and total operation cost of mechanical ventilation with heat recovery

Parameter	Heat	Electricity	Total
Primary energy [kWh/a]	1.1*1616	3*1314	5720
Cost [PLN/a]	1616*0.20	1314*0.54	1032.76

4.2 Demand Control Ventilation (DCV)

Ventilation DCV is a type of mechanical exhaust ventilation in which the area of the inlet openings are regulated and the buoyancy force is supported when needed (at times when the temperature difference is too small to produce adequate buoyancy). The buoyancy force is supported by low-speed exhaust fan mounted on the outlet duct. The power of such fun for the single family building is about 6-10 W. In the heating period the number of hours in which a temperature is above 12℃ is about 1000. In the summer, the building is ventilated by opening the windows.

The heat transfer coefficient for DCV ventilation can be calculated from following formula:

$$
\begin{aligned}
H_{ve} &= \rho_a \cdot c_a \cdot \sum_k \left(b_{ve,k} \cdot V_{ve,k,mn}\right) = 1200 \cdot \left[1 \cdot V_0 + 1 \cdot V_x\right] = \\
&= 1200 \cdot \left[0.7 \cdot 170 / 3600 + 1 \cdot 0.00875\right] = 50.2 \quad W/K
\end{aligned}
\tag{10}
$$

According to the Regulation on the scope and form of the energy audit using automatically regulated diffusers the ventilation air flow can be reduce by a factor of 0.7.

The heat demand for this case is equal to 4902 kWh/a.

For such data the energy demand for electricity was calculated.

$$
E_{el} = 10 \cdot 8760 = 88 \quad kWh/a \tag{11}
$$

Taking into account the energy consumption of fans the DVC ventilation system needs 4902 kWh/a of thermal energy and 88 kWh/a of electrical energy.

Assuming primary energy factors (gas primary energy factor = 1.1 and electricity 3.0) and energy cost (0.54 PLN/kWh for electricity and 0.20 PLN/kWh for gas) the total primary energy demand and total operating costs can be calculated. The results are presented in Table 5.

Table 5: The primary energy and total operation cost of DCV ventilation

Parameter	Heat	Electricity	Total
Primary energy [kWh/a]	1.1*4902	3*88	5655
Cost [PLN/a]	4902*0.20	88*0.54	1027.92

The presented analysis of energy demand of three systems: natural ventilation, mechanical ventilation with heat recovery and DCV ventilation, done on the basis of existing legislation and the given assumptions indicates a significant disadvantage for determining energy standard of buildings in units of useful energy. Forcing investors to use mechanical ventilation leads to some savings during heating period, but that decision has consequences related to the consumption of electricity during whole year. As shown in Table 5 it can lead to higher operating costs of the mechanical ventilation system than DCV. The estimation of the operation cost of mechanical ventilation does not include: the cost of filters replacement and electricity consumption of the heater to defrost the heat exchanger or to heat the inlet air. This is important in the case of high-performance heat exchangers (eg 85% such as that above). Detailed calculation of energy demand for these ventilation systems can be performed using the simulation method. These considerations were carried out using standard balance methods just to address the problem.

5. Conclusions

On the basis of the considerations, the choice of indicator for requirements should include not only the useful energy (heat), but also electricity (heater) and other non-energy operating costs (filters). The correct ratio is multi-dimensional, and its range depends on the used assumptions.

As it was presented in the analysis the total primary energy demand can be higher for systems with lower energy demand for heating (DCV ventilation vs. mechanical ventilation with heat recovery). In some cases the additional energy demand for electricity for fan can provide higher primary energy demand for whole building. Also the operational cost are higher in the case of mechanical ventilation with heat recovery. It must be stated that in the cost calculation only energy cost were taken into account.

The given consideration shows that the estimation of energy requirement can not be done using only one indicator eg.: useful, final or primary energy. Such approch may leads to excluding some systems that can be other than recomended.

The paper was focused on requirements for heating period. It should be noticed that requirements only for heat demand decreasing can lead to very good standards in the heating and overheating in the summer. For example, nearly zero-energy buildings in Denmark and Belgium are checked for possibility of overheating. Using Polish methodology of energy demand calculation such indicators are not calculated.

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7. References

[1] Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (OJ L 153, 18.06.2010).

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