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THE ROAD TO NEARLY ZERO-ENERGY BUILDINGS

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ABSTRACT

The building sector, accounting for about 40% of the energy consumption of the EU, provides a great potential for cost-effective energy savings. The recent recast of the Directive in 2010 calls for more concrete actions and further harmonisation of the approaches in the Member States to realise the full potential for energy savings in buildings. It contains a new article about the need to increase the number of buildings which go beyond current national requirements, and to draw up national plans for increasing the number of nearly zero-energy buildings (NZEB) with the final target that by 2020 all new buildings shall be nearly-zero energy. Nearly zero-energy buildings are buildings with a very high energy performance, where the remaining low energy demand can be supplied to a significant extent by renewable energy. However, no agreed definition of nearly zero-energy buildings is available yet.

In this paper, the proposed requirement system for nearly zero-energy buildings in Hungary is presented. The effect of the new requirements on the building envelope and the building service system is analysed. A fundamentally new approach in building design will be necessary treating functional, constructional, aesthetical and energetic aspects on the same level.

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Measures for reducing the energy demand are analysed and the reduction in energy use is calculated. Instead of choosing a few typical buildings, the energy demand analysis is done on a large building sample of detached houses. The building sample is described by a combination of geometric parameters, the realistic ranges of which were determined based on statistics, functional and architectural considerations. The 'global costs' or life cycle costs of the design options are evaluated taking into account the investment costs, the costs of maintenance/replacement and the energy costs as well.

Key words: nearly zero-energy building, design, energy efficiency, life cycle cost

Introduction

According to the recast of the Energy Performance of Building Directive (EPBD) [1] 'Member States shall ensure that: (a) By 31 December 2020, all new buildings are nearly zero-energy buildings; and (b) After 31 December 2018, new buildings occupied and owned by public authorities are nearly zero-energy buildings.

Member States shall draw up national plans for increasing the number of nearly zero-energy buildings.'

'Member States shall furthermore ... develop policies and take measures such as the setting of targets in order to stimulate the transformation of buildings that are refurbished into nearly zero-energy buildings.'

Nearly zero-energy buildings (NZEB) are buildings with a very high energy performance, where the remaining very low energy demand can be supplied to a very significant extent by renewable energy. Member States are responsible for 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/m^2 per year.' [1]

A zero-energy building or autonomous building is a technically feasible option. For experimentation and demonstration purposes it has already been realized, however this standard is not suitable for mass production in the forthcoming decades. Therefore the actual task is to define the measure of the 'near'.

A requirement system for Hungary has been elaborated in a research report [2]. This was revised in 2013 to integrate the results of the cost efficiency calculations [3]. Please note that the requirement system is still under discussion, and changes are possible.

In this paper, first the proposed NZEB requirements for Hungary are presented. The effect of certain measures, for example the architectural layout and the orientation on the heating energy demand is analyzed on the example of an NZEB detached house. Finally, the life cycle costs of different building service systems are compared.

Proposed NZEB Requirements in Hungary

Hungary has a continental European climate with warm, dry summers and fairly cold winters. The average heating degree hours are 72 000 kWh/yr for a base temperature of 12°C and an internal temperature of 20°C. The current requirement system in the Hungarian Building Regulation has three levels [4]. The building meets the requirements if all three levels are fulfilled.

- Level of the building elements: maximum average thermal transmittance, U (W/m^2k).
- Level of the building: specific heat loss coefficient of the building, q (W/m^3k).
- Level of the building and the building services: specific primary energy demand, Ep (kWh/m^2yr) incl. Gross energy demand for space heating, hot water supply, ventilation, cooling, (lighting), etc.

Table 1 is an extract of the requirements for building elements, showing the current and the proposed NZEB requirements. Note that although the decree was revised and partly modified in 2012, the requirement system remained unchanged since 2006.

Table 1 : Maximum thermal transmittance values of building elements since 2006 and proposed requirements of the NZEB (under discussion).

Building Element	Current Requirement (since 2006)	Foreseen Requirements NZEB
	U (W/m^2K)	U (W/m^2K)
External wall	0.45	0.20
Flat roof	0.25	0.15
Attic floor slab	0.30	0.15
Floor slab above basement	0.50	0.25
Window, non-metal frame	1.60	1.00
Window, metal frame	2.00	1.30
Entrance door	1.80	1.30

Figure 1 shows the current and the proposed NZEB requirements for the specific heat loss coefficient, expressed in terms of W/m^3K, as a function of the building envelope surface to heated volume ratio. The specific heat loss coefficient includes the building-related parameters, i.e. the transmission losses and the solar gains, but does not include the infiltration losses and internal gains.

The current requirements for the primary energy demand are expressed in kWh/m^{2}yr, as a function of the surface-to-volume ratio, and depending on the function of the building (requirements exist for residential, office and educational buildings). For NZEB, it is foreseen that instead of the surface-to-volume ratio, the requirements will depend on the number of storey(s) in the building. The NZEB requirements have been set based on technical considerations, but these have been later revised to reflect the results of the cost-optimal calculations (see Table 2). The technical considerations were the following [3]:

- The reference building has a high energy performance as defined for NZEB in Table 1, a condensing boiler for space and water heating and mechanical ventilation with heat recovery.
- The proposed requirements are lower than the primary energy demand calculated for the reference building, which makes the use of renewable energy sources necessary.
- Only one renewable energy source is expected to be available locally, which can be solar energy, biomass, heat pump, etc.
- The energy demand was calculated for every option, and depicted as a function of the number of storeys. The requirement was set as the envelope of the curves, corresponding to the least favourable renewable energy source in each category.

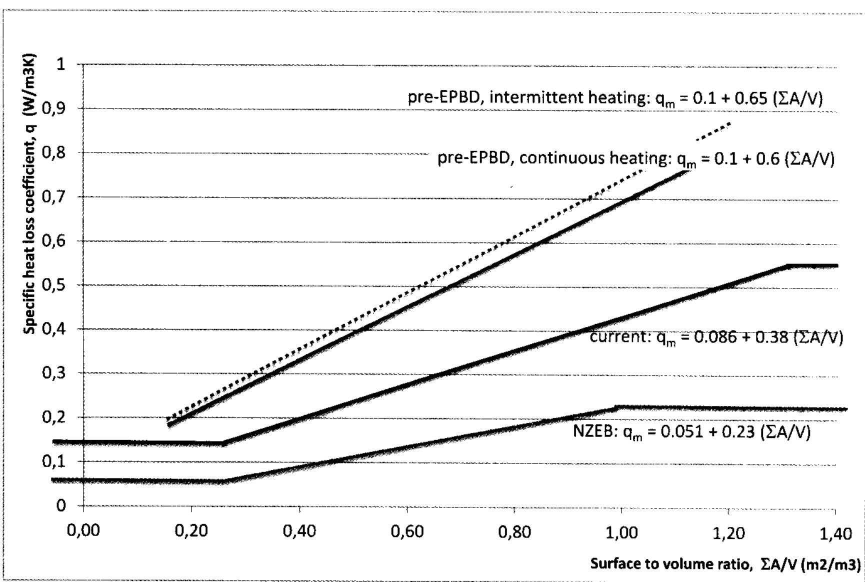

Figure 1 : The specific heat loss coefficient, q (W/m^{3}K) before (pre-EPBD) and after 2006 (current) and the proposed NZEB requirement (under discussion).

The cost optimal calculations have been carried out according to the common EU methodology framework issued by the 244/2012 order on the basis of the EPBD

Recast [5]. The results show that the current requirements are not strict enough, and for new buildings the cost optimal level is close to the nearly zero energy building level. For existing buildings, the cost optimum is between the current requirements and the nearly zero energy building. In the future it is accepted that the optimum range will move to the more energy efficient direction.

Table 2 : Proposed requirements for the primary energy demand of NZEB, new residential buildings (under discussion).

	Max. Primary Energy Demand (kWh/m^{2}yr)	
	Based on Technical Considerations	Cost-Optimal Levels
1 storey	72	80
2 storeys	60	80
3-4 storeys	53	70
5 or more storeys	50	70

Methodology

The goal was to optimize the design of a detached house that would meet the proposed Hungarian requirements for 2020. First, the effect of changes in the architectural layout and the orientation was analyzed, then several options for the building service systems were considered, and their life cycle costs were compared.

Geometrical Model

The heated floor area of the building was fixed at 130 m^2. This area can belong to one floor or can be distributed on two floors, which are the typical arrangements for detached houses. The ceiling height was assumed to be 2.7 m.

The heating energy demand is influenced by the 'compactness' of the architectural layout, whether it is a simple rectangular shape, or a complex shape with many protruding parts. To describe the compactness, the concept of the 'equivalent rectangle' was introduced. The equivalent rectangle is a rectangle having the same perimeter and area as the actual floor shape. The width of the equivalent rectangle mirrors the average building depth on the one hand and the complexity of the plan on the other hand. If we consider square the most compact shape, the maximum width of the equivalent rectangle is $\sqrt{A_F}$. The minimum width was assumed to be 6 m.

Another important parameter influencing the space heating energy demand is the window ratio and the orientation of the windows. The minimum window to floor area ratio is around 13 % due to lighting requirements. In residential buildings, window ratios above 40 % are atypical. Here, a window to floor area ratio between 15% and 30% was assumed. The ratio of the glazed surface to the total window area depends on the size and partition of the window and on the frame type. In the calculations, a frame ratio of 20-30 % was assumed, typical for wooden or vinyl frames and average size tilt-turn windows.

Based on these geometric parameters, the area of the building envelope components could be calculated, and consequently also the heat losses through the building envelope. The parameters were randomly varied in the pre-defined ranges, and this way a large population of buildings was generated. The advantage of this method is that the effect of certain measures, for example the compactness of the plan is analysed for not just a few, but a large number of variations. The method was presented in more detail in [6].

Calculation of the Total Energy Demand

The energy demand was calculated according to the Hungarian Government Decree on the energy performance of buildings [4]. The thermal transmittance of the elements was set according to the requirements for NZEB (Table 1). The total primary energy demand, including the energy demand for space heating, domestic hot water and ventilation was calculated for every option in terms of $kWh/m^2 \cdot yr$. The efficiency and losses of the building systems were also taken into account. In the base scenario, a condensing gas boiler for both space and hot water heating was assumed and no mechanical ventilation. No mechanical cooling was considered.

Calculation of Global Costs

The global costs were calculated according to the European Directive and Guidelines [5], [7]. Global costs correspond to 'life cycle costs', i.e. the initial investment costs, the sum of annual costs for every year (energy costs, maintenance, replacements, etc.), and the disposal costs if appropriate, all expressed as a Net Present Value referring to the starting year. For macroeconomic calculations, the cost of greenhouse gas emissions should also be taken into account, but here this was not considered.
The calculation period was 30 years, as defined for residential buildings in the Directive [5]. The expected life time of many components of the energy system, for example that of the condensing gas boiler, heat pump, solar collector is shorter than 30 years [8]. In these cases, the cost of one replacement was calculated, and the residual value of the new equipment at the end of the calculation period was also taken into account.

Table 3 summarises the investment costs for different energy systems, including the price of materials, the labour, the professional fees and permits if necessary. The costs are for the Hungarian market and an average of several quotes (1 EUR ≈ 300 HUF).
As first the building envelope was optimised, the investment cost of the building itself was assumed to be the same in every option, and hence not considered.

For the long-term energy price development, two scenarios were considered (Table 4), based on the information provided in [7]. Please note that the Hungarian Government has been recently committed to reduce the energy prices. An average 10% cut in the energy prices was introduced in 2013, which may be followed by further cuts later this year. These measures are controversial and not supported by professionals. It is also questionable if such political actions can be maintained in long term, because it is against the market trends. Therefore this is expected to be a short-term energy strategy, and was not considered here. The discount rate, excluding inflation, was 3% [5].

Table 3 : Investment cost of energy systems.

Energy system	Price (1000 HUF), incl. VAT
Condensing boiler	1 932
Mech. ventilation with heat recovery (MVHR)	1 670
Wood gasifying stove	2 129
Solar collector for DHW, 4.6 m^2, storage 300 l	1 168
Heat pump, borehole	7 379
Heat pump, horizontal loop	5 474

Table 4 : Energy prices in Hungary, and the assumed rate of energy price escalation (2012 prices).

Prices	Energy Prices (HUF/kWh), incl. VAT	Energy Price Escalation, Scenario 1 (%)	Energy Price Escalation, Scenario 2 (%)
Gas	16	4.3	2.8
Electricity	50	5	2
Electricity tariff for heat pumps	32	5	2
Firewood	9	5	2.8

Results

Compactness and Orientation

Figure 2 shows the effect of the compactness of the architectural layout and the windows on the space heating energy demand, and consequently on the primary energy demand. One-storey buildings have a surface-to-volume ratio of 1.1-1.16 m^2/m^3. (The total floor area is 130 m^2 in every case). The effect of compactness, illustrated by the slope of the 'clouds', is significant; the difference in heating energy demand is about 8 kWh/m^2yr between the most and least compact floor shapes, if the orientation and window ratio is the same. For two-storey buildings, the area of one floor is about the half of the previous case, but the total floor area is 130 m^2. The surface-to-volume ratio is about 0.85 m^2/m^3. The energy demand has a much smaller spread, since due to the small floor area there is less room for shape variations.

Two-storey buildings in general have a lower heat loss than one-storey buildings. Only the most compact one-storey detached houses, i.e. buildings with a square floor plan have about the same heat losses than two-storey detached houses. Regarding the window-to-floor area ratio and the orientation of the windows, if the orientation is not favourable (facing North or shaded in the winter), decreasing the window area will result in energy savings. However, if the orientation is favourable (80% of the windows face South), the energy balance of the windows is positive for the winter due the high solar gains and low U-value. As a consequence, increasing the window ratio up to a certain limit will decrease the heating energy demand (but this is recommended only if shading is provided in the summer). The difference between the most and least favourable options is about 20 kWh/m^{2}yr, or about 16% of the total energy demand.

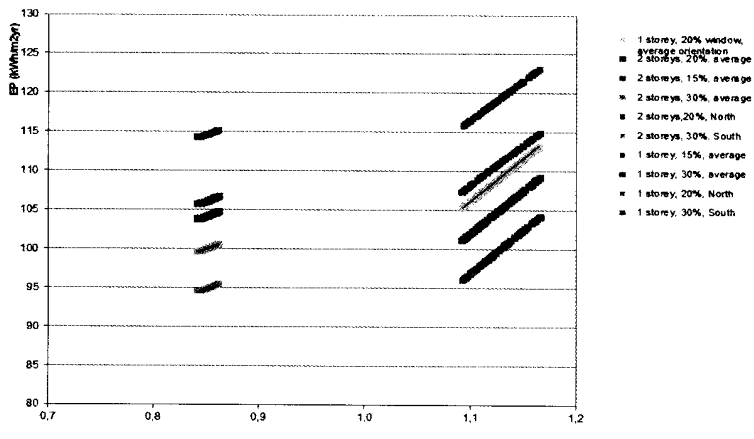

Figure 2 : Primary energy demand of one- and two-storey detached houses (window-to-floor area ratio 15-30%; average orientation: 60% S, 20% E-W, 20% N / North: all windows to North or shaded / South: 80% S, 15% E-W, 5% N).

Building Service Systems

The primary energy demand and the global costs were calculated for different building service systems. A two-storey building with large window-to-floor area (30%) and favourable orientation (80% South) was considered. The following options were analysed: 1) condensing boiler, 2) condensing boiler + MVHR, 3) condensing boiler + solar collectors for hot water, 4) condensing boiler + MVHR + solar collectors, 5) wood gasifying stove + MVHR, 6) wood gasifying stove + solar collector, 7) wood gasifying stove + MVHR + solar collector, 8) heat pump, borehole, 9) heat pump, borehole + MVHR, 10) heat pump, ground collector.

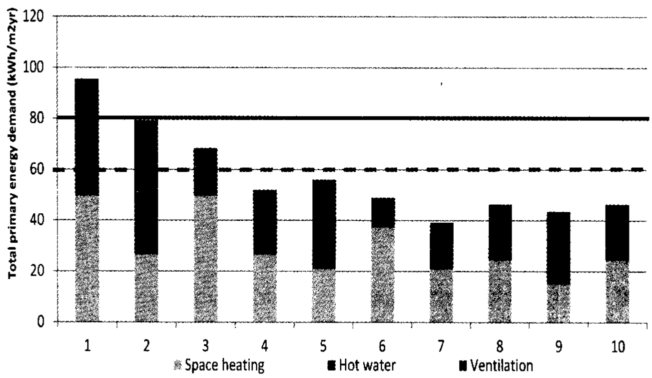

Figure 3 : Total primary energy demand with different building service systems (kWh/m^{2}yr).

The primary energy demand of the base scenario is 95 kWh/m^{2}yr, which can be reduced to 40 kWh/m^{2}yr if, for example, a wood gasifying stove with solar collectors for domestic hot water and mechanical ventilation with heat recovery is installed. The options below 80 kWh/m^{2}yr meet the NZEB cost-optimal levels, and the options below 60 kWh/m^{2}yr would even meet the NZEB requirements based only on technical considerations.

The global costs are the lowest for option 6 (gasifying wood stove + solar collectors), and the highest for the borehole ground heat pump with MVHR (figure 4). Even though the energy costs are greatly reduced with heat pumps, these systems are not yet economical due to their high investment costs.

It is interesting to see that the reference system (option 1) with condensing boiler is in the middle-range from the point of view of costs, but it does not meet the requirements. Mechanical ventilation significantly reduces the energy demand (option 2), but the global costs are higher than for Option 1. This means that with the assumed system prices this option is also not economical yet. The global costs for Option 3 with solar collectors are slightly lower than for Option 1.

Figure 5 shows the global costs vs. the total primary energy demand for both energy price development scenarios. There is a difference in the absolute values of the two scenarios, but their relative position of the options is the same for both cases, so it does not affect their order.

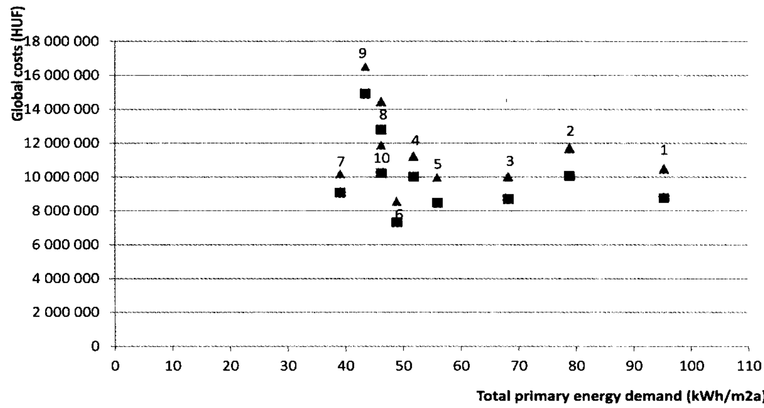

Figure 4 : Global costs for 30 years, energy price scenario 2.

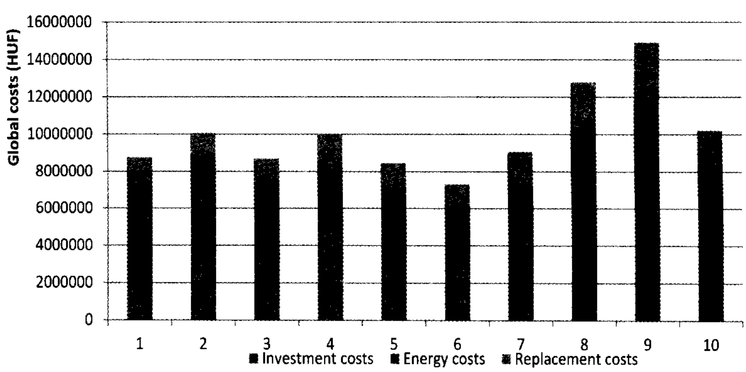

Figure 5 : Global costs vs. total primary energy demand, energy price scenario 1 and 2 (blue triangles: energy price scenario 1, red rectangles: energy price scenario 2).

Conclusion

The development of the requirements on the nearly zero energy buildings is an ongoing issue in all member states. The results of the cost optimum analysis carried out for a 30 years life cycle is one of the factors that should be taken into account. On the other hand the requirements are also influenced by the technical possibilities: they have to be achievable even in unfavourable circumstances and sometimes (particularly for the major renovation of densely built urban areas) this results in less efficient options than the cost optimal level. It is probably reasonable to require less strict requirements for major renovation than for new buildings.

It is also to be mentioned that the cost optimum calculations have been carried out with current cost levels, but the final NZEB requirements will have to be compared to the costs in 2020 that is not predictable at the moment. Thus, a revision of the calculations will be required at the end of the decade.

The final NZEB requirements will be strongly influenced by the political will. Introducing a strict level will result in the inevitable application of renewable energy sources for all buildings. A softer level would allow more space for alternative solutions: in buildings with smart design or favourable circumstances higher insulation level or passive solar methods could be sufficient.

In the presented case study the optimal geometry and orientation for a family house have been investigated. The impact of the surface-to-volume ratio and the orientation has been demonstrated with hundreds of automatically generated building models. In the analysed range the difference between the best and worst option was about 25% in primary energy demand.

A number of the heat supply system variations have also been compared from two aspects: the total primary energy demand and the total life cycle cost. In this concrete example for the Hungarian market conditions the optimum solution was turned out to be the wood gasifying boiler with solar collector, but the difference between the different solutions was not very high. A simple condensing boiler was also among the cheaper options. However the latter did not fulfil the predicted NZEB requirements and it does not meet the desire of the recast that a significant part of the demand should be covered by renewables. Although the wood gasifying boiler seems to be optimal, the disadvantages of this system should not be forgotten (demand for manual feeding, limited applicability in urban areas, etc.).

Owing to the EPBD recast a widespread use of the cost optimum design is predictable, although the method is rather unknown among building energy experts at the moment. In the case study this methodology has been applied and presented. It is also obvious that a boom in renewable applications in buildings is foreseen after the introduction of the NZEB.

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