The nearly zero-energy requirements and the reference buildings

András Zöld[a] and Zsuzsa Szalay[b,*]

[a] Debrecen University, Department of Building Service Systems, Ótemető utca 2-4, Debrecen, 4028, Hungary, profzold@yahoo.fr

[b] Department of Building Energetics, Budapest University of Technology and Economics, Műegyetem rkp. 3-9., Budapest, 1111, Hungary, zsuzsa.szalay@yahoo.com

* Corresponding author

Abstract

According to the recast of the European Directive on the Energy Performance of Buildings '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'. It is the responsibility of the Member States to define the measure of 'nearly'.

This paper analyses the challenges of setting the requirements. In order to ensure that the requirements are realistic, they should be checked on reference buildings. The statistical evaluation of a large building sample as reference is recommended instead of using a few 'typical' case studies.

The potential and problems of different renewable energy sources are analysed for favourably located buildings and for buildings in urban areas, where solar access and space may be limited. Urban buildings will be able to comply with the requirements only if energy production from renewables on a district or urban scale (off-site) is realised and acknowledged in the energy balance. A case study of apartment buildings shows the future importance of the ratio of the energy collecting surface and the floor area.

Keywords

Nearly zero-energy; buildings; regulation; EPBD; reference building; renewable energy; on-site; off-site; urban

1. Introduction

According to the recast of the Energy Performance of Building Directive (EPBD) '*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 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.'

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/m² per year.'* [1]

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

The EPBD and its recast encompass exclusively the operational energy consumption. Although this philosophy is disputable, the following analysis is restricted to the operational energy consumption in order to present the possibilities and constrains of the "nearly zero" energy consumption in *that interpretation*.

The measure of “nearly” depends on the use of the building and should depend on its size and geometric features. It must not be forgotten that when “nearly” is defined it will result in an obligatory requirement, to be fulfilled by all new buildings. In order to ensure that the definition is realistic and practically all new buildings can fulfil the nearly zero-energy requirement, feasibility studies should be carried out. The applicability of the definition is to be checked on *reference buildings* or – which seems more plausible – the definition should be based on the analysis of *reference buildings*.

2. The role of the reference buildings

With regard to the measure of “nearly” a very judicious compromise must be found. In order to radically decrease the fossil energy consumption, the new requirements should be demanding. However, exaggerated requirements may make the fulfilment of the regulation irrational in many new buildings, which should be avoided.

Both sides of the coin should be considered: the energy need as well as the potential of energy production from renewables. Zero can be approached only if the considerable amount of energy need is covered or compensated by renewables.

The risks of the selection of reference buildings are obvious: the overestimation of the renewable potential may result in a requirement which cannot be reasonably fulfilled, if at all, by many of the new buildings, whilst the underestimation may lead to a less demanding requirement and it may be supposed that many new buildings would not perform as well as rationally possible.

No doubt a “nearly zero” definition based on one or a few “typical” sample building(s) may lead to an unwanted situation: either the requirement is too moderate and the energy saving will be far from the desired or the requirement system will collapse if many of the new buildings do not fulfil it. This risk can be avoided or at least minimized if the requirement is based on the statistical analysis of a huge number of sample buildings – hundreds or thousand in each category. None of the sample buildings alone is the reference one; the reference building is an abstraction, based on the statistical population characterised by the net energy demand, the potential of in situ energy production from renewables and their balance, the final primary energy consumption. Having these data the way of thinking is simple. If the average of the final energy consumption would be taken as the requirement, then half of the sample buildings would fulfil it, the other half would not. Defining the confidence interval of the data at given percentiles the requirement can be defined so that a given percent of buildings – e.g. 90% – will fulfil it. The remaining 10% of buildings are either unfavourably located or they are not typical designs, which need extreme energy saving measures or systems.

The border of the confidence interval is subject of consideration, the percentiles can be 20% as well as 5%, the consequences are obvious.

Certainly to collect the data for the statistical evaluation would be very time consuming and therefore hopeless, rather than to do so, the sample is to be generated.

3. Interpretation of nearly zero operational energy buildings

3.1. Buildings with on-site renewable sources

It is to be clarified in advance that different reference buildings are to be analysed for different uses (detached houses, apartment buildings, public buildings and so on). According to the recast [1], nearly zero-energy buildings should have

- *a very high energy performance,*
- *the amount of energy required should be nearly zero or very low,*

- *the 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.*

The very high energy performance is an obvious requirement.

As far as the required amount of energy is concerned this expectation (as it is in the quotation) is absurd: even if the heating and cooling energy demand may approach zero using the techniques of the classic solar architecture and at the cost of extra insulation and heat recovery, the (net) energy need of the domestic hot water must not be forgotten and it could *not* be nearly zero. The net energy need of the domestic hot water supply depends on the number of habitants and on the use of the building only (it can be given as a function of the floor area introducing "national" statistical data, e.g. floor area/capita). It is possible to calculate with input net demand data, as in the dreams of the partisans of sustainability or politicians, however it is more realistic to rely on statistical data. The net demand certainly may be influenced by the cost of hot water consumption, but that is a longer process unless the decision makers take the risk of drastic market intervention. Thus rather than making tricks or 'cheating' with the *net* demand input, the water saving fittings, efficient systems and the use of renewables are to be encompassed in order to decrease the *gross primary* energy consumption.

Among the possible renewable sources, solar energy, biomass and – under certain conditions – geothermal energy are to be considered, if on-site utilisation is aimed at. As far as passive solar measures, solar thermal and photovoltaic systems are investigated, the renewable potential depends – among others – on the geometry, orientation and solar access of the building. Thus not only the energy need but the exposed energy collecting surfaces, their area, orientation and tilt is to be taken into account. Certainly, the number of possible combinations is unlimited; it is hopeless to expect that the wide range of combinations will be covered by selecting a few existing buildings. The primary energy content of solar energy is taken as 0 in the Member States, only the energy input for the pumps, fans and control system should be considered in the case of solar thermal systems.

The use of biomass depends on the building and the building site (fuel storage), on the use of the building and on its location (with regard to the emissions). It is to be mentioned that the primary energy content of biomass exhibits quite extreme values in the recent national regulations from 0.1 to 0.6.

Geothermal energy systems need energy input, thus their value depends not only on the source of the geothermal energy (soil, thermal water, water, air) and the COP of the system but on the source of the external input, which is typically electric power (however a compressor may be driven by gas or diesel engine too and this leads to the applicability of biofuels). This means that the COP and the primary energy content of the input energy are decisive.

Theoretically there are two possible types of nearly zero-energy buildings depending on whether they are connected to the energy infrastructure. In this regard, these two types are often called grid-connected and stand-alone buildings.

The extreme version of the stand alone building is the autonomous house which is completely independent of any kind of energy supply, including not only electric power, gas and district heating but even the transport of any kind of fuel: among them biomass. Although such a building is technically feasible -- moreover, already exists -- for a long time this will not be a realistic option for mass production due to the high investment costs, the space requirement of energy storage and the difficult control system.

Practically all nearly zero-energy buildings are grid-connected since the already applied method of the on-site energy production is the use of photovoltaics (PV) where the electric grid plays the role of the storage system. (Only this simple fact alone makes the restriction to the on-site production of energy from renewables questionable, since the power, bought from the grid may be based on renewables, too.)

The excess of the energy production is sold to the grid whilst power can be taken from the grid if the actual need exceeds the actual production. In this version the energy taken from, and sold to the grid can be balanced (net zero power consumption) or the surplus of the power, sold to the grid may compensate some other fossil energy consumption (e.g. gas for back-up domestic hot water supply), moreover may exceed it ("energy plus" buildings). Obviously each version refers to the annual balance.

Solar thermal systems are typically stand alone ones, the energy is stored in the building or on the building site. The long term or seasonal storage requires a voluminous tank buried on the building site – besides, the costs do not allow the widespread use of this solution.

3.2. Buildings in urban areas

The precondition of the utilisation of solar thermal and photovoltaic systems is good solar access. It is easy to apply them on single, well-oriented houses built on the south-facing slope of a hill. Conscientious urban planning may provide the unobstructed solar access in a new urban area too (at the cost of the lower density of buildings).

Nevertheless, in a dense urban area due to the obstruction caused by surrounding buildings (and sometimes the topography) the sky view factor is limited, the orientation of buildings is adjusted to the existing network of streets and the possibility of the use of solar energy is restricted. One could say that this is not true in the case of taller buildings, however, it must not be forgotten that in this case there are more floors under the same roof which may be too small to accommodate enough collector and PV arrays which would cover the multiplied needs.

The problem of the solar access can be illustrated with the solar pyramid (Fig. 1.)

The projected shadow of a building is bordered by the shadows of its edges. The size of the shadow depends on the Sun altitude, determined by the latitude of the location, the day of the year and the hour of the day (Fig. 1.).

The peak of the energy need occurs in the winter months, thus the solar access should be checked for December when the altitude is the lowest. Table 1. shows the average altitude between 10AM and 3PM in December for different latitudes.

D/H is the ratio of the horizontal distance (D) and the height difference (H) where the solar access becomes obstructed. Taking horizontal planes at different heights it can be seen that the solar access of the lower floors will be obstructed, thus neither passive solar gain can be taken into account nor energy collecting elements (collector or PV array) can be used there (better to say there is no reason to allocate them there, since they would only be exposed to diffuse radiation in winter). With regards to the roof, if the width of a street is 12 m, the height of the opposite building towards South must not exceed that of the given roof by 1.1, 2.8, and 5 m for the latitudes of 60, 50 and 40, respectively, otherwise the solar access of the *roofs* will be obstructed.

The above data illustrate what the price of the unobstructed facades is: the distance between the buildings should be 10.6, 4.2 or 2.4 times more than the height of them for the latitudes 60, 50 and 40, respectively. It is clear that such an urban design may be possible in a healthy residential district in the suburbs with green areas and gardens, but it is hardly imaginable in the downtown where the network of the streets and the access to the buildings result in compromised orientation.

As far as biomass is concerned, theoretically it can be used if we have a chimney and space for the fuel storage, however this option for individual buildings in dense urban areas is more than problematic. On one hand, the emission would cover the same dense area, contributing to the development of smog, on the other hand, the storage of the fuel would require valuable space.

The lack of space and the existing network of utilities is the barrier of the use of individual geothermal systems, e.g. soil heat exchangers.

The aforementioned problems will become more serious in the near future due to the fast increase of the urban population. Fig. 2. shows the scenario of the UN Department of Economic and Social Affairs [3].

In other words this means that by 2025 in most of the European countries the urban population will be higher than 60% of the total and in nine Member States this ratio will exceed 80%.

Regarding the existing urban areas, on one hand, and the cost of the building sites, on the other hand, it is hopeless to suppose that this huge number of urban citizens will live in well insolated "solar" houses. It can be seen that the potential of renewables in urban areas is restricted and this restriction affects more and more buildings.

The aforementioned constrains may be tackled in two ways. One option is to define the measure of "nearly zero" with respect to the limited solar access. In this case the fulfilment of the requirement would be possible even if the building is in a dense urban area, however this requirement would be less demanding and the potential of renewables may not be fully utilised in favourably situated buildings.

The other option is to give up the formal meaningless restriction that the energy production from renewables must be on-site or nearby. Making use of the flexible interpretation of the last term, the off-site energy production from renewables should be acknowledged on an urban scale. District energy supply may be based on, or supported by, renewables. In a well allocated boiler house with tall chimneys the incineration of biomass represents less risk of smog development, the storage and the transport of the fuel cause less problems. District heating and cooling may be based on, or supported by geothermal energy in an easier and more efficient way. It is possible to make use of solar energy either with collector arrays allocated in the free outskirt areas or on buildings with good solar access. In the last case the buildings are only the supports of the collector arrays, which are connected to a district network preferably with central long term or seasonal storage tank(s). These solar thermal systems may support the district energy supply, first of all the domestic hot water supply.

Provided the renewable energy taken from the grid is acknowledged similarly to the on-site production, the requirement can be more demanding, exhausting the potential of favourably situated buildings. In summary, the use of renewables should be interpreted on an urban scale when the on-site utilisation is not reasonable or not possible.

4. Selection or creation of reference buildings? – a case study

When aiming at the reliable estimation of the potential of renewables, a huge number of buildings must be analysed, partly with regard to the energy demand, partly to calculate the available supply from renewable sources. Selecting a huge number of samples from the existing building stock does not guarantee that the statistical evaluation will be reliable, not mentioning the time consuming data collection. If typical buildings are collected, first each must be redesigned (thermal insulation, windows), and the applicability of collector and PV arrays should be checked for the given building. Developing sketch designs of buildings which are deemed to be typical in the next decade suffers from the same problems, too. In both cases we would have only a few incidental samples and the buildings which will be erected in the future may considerably differ from the samples.

This problem can be bridged if a huge number of technically feasible buildings is randomly generated and this statistical population is evaluated [4].

4.1. Building geometry

The building sample covers the population of "technically feasible" buildings. The parameters describing the building geometry and the realistic ranges of these parameters are determined based on statistics, functional and architectural considerations. The selected parameters are the floor area, the number of storeys, the perimeter to floor area ratio, the fraction of the building envelope adjacent to neighbouring heated buildings (adiabatic surfaces without heat losses) and the window to floor area ratio. The perimeter to floor area is influenced by the absolute dimensions of the floor and the compactness of the plan. Excluding atypical circular buildings, a quadratic floor plan can be considered to be the most compact. To determine the highest possible perimeter to area ratio describing irregularly shaped or very narrow buildings, the concept of the "equivalent rectangle" is introduced. The equivalent rectangle is a rectangle having the same perimeter and area as the actual floor shape. The depth of the equivalent rectangle mirrors the average building depth on the one hand, and the complexity of the plan on the other hand. The question is the minimum depth of the equivalent rectangle. The minimum economical depth is assumed to be 8 m in apartment buildings. The building depth is limited to 14 m to allow for sufficient daylight penetration.

Based on the geometric parameters the area of the building elements and the volume of the building can be calculated.

Different building types can be distinguished, for example detached, semi-detached and terraced dwellings or low-rise and high-rise apartment buildings. In this case study, 1,000 low-rise apartment buildings were analysed as an example. The characteristic parameters are summarised in Table 2.

4.2. Energy performance

The buildings are assumed to have a very high energy performance. As far as the thermal properties of elements are concerned, the average U-value of the opaque elements is around 0.17 W/m^{2}K.Triple-glazed windows and mechanical ventilation system with heat recovery are considered. (*In general for new buildings the maximum of the allowable U values, given in the national regulations should be the starting values. It is to be mentioned that the procedure can be repeated with a set of U values, characterising the existing building stock. On this base the marginal cost of added thermal insulation and change of windows can be calculated*.)

The space heating energy demand is calculated based on EN ISO 13790 and for the typical continental climate of Hungary. Some assumptions are made according to the Hungarian regulation on the energy performance of buildings (e.g. heat losses due to thermal bridges, net energy demand for hot water and lighting, internal gains, system losses, primary energy factors, etc.). Although lighting is not considered in the labelling of residential buildings, it should not be missed when analysing the possibilities and constrains of nearly zero operational energy consumption.

Space and water heating is assumed to be provided by a condensing gas boiler and solar thermal collectors. Solar collectors can be mounted on a pitched roof or in rows on a flat roof. The total roof area is considered, but this is somewhat idealised since in practice the typically large number of chimneys, flues, elevator engine rooms etc. make the installation complicated and cause overshading.

If the available roof surface exceeds the optimum collector area for domestic hot water production, multi-silicon photovoltaic panels are assumed to be installed on the remaining surface.

Three alternatives were tested:

1. windows with good orientation (70% of glazing to South), solar collectors and photovoltaics mounted on a South facing pitched roof
2. windows with good orientation (70% of glazing to South), solar collectors and photovoltaics mounted on a flat roof in rows
3. windows with average orientation, no solar collectors and photovoltaics on the roof due to overshading

Option 1 and 2 represent a building with favourable orientation and little overshading, while option 3 is representative for buildings in a dense urban area.

4.3. Results

The specific total primary energy demand of option 1 is about 7 kWh/m^{2}y in 3-storey buildings and about 24 kWh/m^{2}y in 4-storey buildings, including the primary energy demand for space and hot water heating, ventilation and lighting minus the electricity produced by the photovoltaic panels, and all divided by the total heated floor area. The difference is due to the simple fact that the more stories we have under the same roof, the smaller fragment of the energy need can be covered by solar thermal and PV systems. For buildings with a flat roof, the available energy collecting surface is less, hence the amount of energy produced by solar collectors and photovoltaics is also less, and the total primary energy demand is higher. For option 3, the total primary energy demand is significantly higher, about 87 kWh/m^{2}y. (Fig. 3.)

In an urban situation, biomass and geothermal energy are not realistic solutions, but it is possible to apply off-site renewable energy sources if reduction is desirable.

It is remarkable that the primary energy demand of option 3 buildings is lower if the building size is larger (smaller surface to volume ratios), but it is higher for option 1 and 2 buildings. This can be explained with the roof surface available for energy production: in larger, but taller buildings the roof surface per heated floor area is less and hence also the produced energy.

4.4. The potential of renewables

As proven by the results, the net energy need is far from zero. When comparing option 3 and 1 it can be seen that a considerable part of the energy need can be covered with on-site renewable energy sources using solar thermal and PV systems *on well insolated buildings*.

If we intend to formulate a requirement which can be fulfilled by 90% of the well insolated 3 and 4-storey buildings with flat roof, the corresponding confidence interval around the mean of option 2 should be calculated. Due to the central limit theorem the distribution is normal, since the sample is based on a huge number of independent variables, the border of the interval is at 45.3.

Obviously the buildings with pitched roof will satisfy this requirement without problem if the energy collecting area is oriented towards South and may just fulfil the requirement with East-West facing roof.

To adjust a requirement to option 3 would mean a much less demanding value. The improvement of the thermal insulation would result in a very modest decrease of the primary energy need. Further decrease of the primary energy consumption is possible by using biomass. Nevertheless in dense urban areas the on-site incineration of biomass is not advisable. But just the density of buildings, accompanied with the “heat density” makes the use of district energy supply based on, or supported by renewables rational. If off-site energy production from renewables is acknowledged, the same requirements can be applied to an urban building as for the favourably allocated “solar” buildings.

5 Conclusions

The case study illustrates the very comprehensive results of the statistical evaluation of the randomly generated statistical population of sample buildings. The detailed data of the components of energy need show that if we have a high quality building envelope and mechanical ventilation with heat recovery, the domestic hot water supply becomes the key issue. This fact makes disputable the comparability of the requirements in the different Member States since here the input data, i.e. the net energy demands depend on the floor area per capita ratio and on the users' behaviour. Besides the net demand, the possibility of using an active solar thermal system for water heating is decisive as seen when comparing the different options.

As a result of having a high quality building envelope and mechanical ventilation with heat recovery, the primary energy consumption depends mainly on the ratio of floor area and the insolated energy collecting surfaces: windows, collectors, PV arrays: even the form of the building and the roof are of importance – compare options 1 and 2.

The energy collecting surface/floor area ratio depends on the number of stories: there is a significant difference between the 3 and 4-storey buildings both in terms of this ratio and the primary energy consumption. A compromise should be found: either to increase the number of building categories (e.g. within the category of residential buildings separate the single family, semi-detached houses, 2,3,4,5-…storey blocks) which would result in a more precise requirement with narrower confidence intervals (at the cost of a more complex requirement system) or to consider less and wider categories with wider confidence intervals. Interim solutions such as to give the requirement as a staged function of the number of stories are possible, too.

Regarding the building geometry, if all of the insolated exposed surfaces are used for energy collection, the energy collecting surface/floor area ratio is of especial importance and the surface to volume ratio loses its importance.

"Urban buildings" with no solar access and restricted possibility of using biomass can fulfil the requirements only if energy production from renewables on a district or urban scale (thus off-site) is realised and acknowledged in the energy balance. Special attention is to be paid to the application of these – already available – technologies from the point of view of environmental impact, too.

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