Comfort and Energy Efficiency Recommendations for Net Zero Energy Buildings

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Abstract

A major advantage of the Net Zero Energy Building (Net ZEB) approach is claimed to be the absence of energy performance indicators, hence avoiding the need to set internationally agreed limits. Nevertheless, if the rationale is to endorse the design of environmentally friendly buildings that promote sustainable development, then reasonably strict requirements on energy efficiency should be satisfied while providing high levels of indoor environmental quality and consequent users comfort. Otherwise, the risk is that poorly designed buildings could achieve the definition of Net ZEB simply by means of oversized generation systems. The purpose of this paper is to provide an overview of existing international standards and/or design best practices based on comfort and energy efficiency requirements that can be taken as general recommendations for the design of Net ZEBs.

1. Introduction

The energy performance of a building depends, *inter alia*, on the level of comfort provided, and the two should always be evaluated together. Recommendations on comfort and energy efficiency would then differ with building categories, e.g. residential and non-residential buildings, and with climates, e.g. cold, temperate, hot and humid, etc. This paper addresses issues of climate classification, comfort criteria and energy efficiency and provides recommendations for the design of Net ZEBs.

2. Climate classification

Focusing on a Net ZEB as a high-performance building requires close attention on the optimization of the envelope and passive solutions as a function of climatic conditions. Evaluating a Net ZEB on a common international basis is essential to link a solution-set to the climate. There are existing climate classifications, based on a set of climatic parameters and eventually codified in national standards. A method commonly used to enable comparison of energy consumption from different periods, but also from places with different weather conditions, is the degree-days method. There are two main types of degree-days: heating degree-days and cooling degree-days. Although the heating degree-days are more often discussed, much of the information is also applicable for cooling degree-days.

A possible classification of climates based on degree-days has a major advantage: it is very simple. However, there is no existing international harmonized classification using degree days. There are a number of existing different methods for calculation and different definitions of reference temperatures. ASHRAE assumes base temperatures of 18.3°C and 10°C for heating and cooling, respectively [1], but other organization or standards use different values. According to [2]: "The degree-days method is used (and misused) in most Europe countries. This method is not harmonized in Europe, since each country has its own standard computation." Furthermore, there are countries using 5-years average degree-days as the multiplier, some use 10-20-year average degree-days and some use, additionally, standard degree-days to compare different regions [3].

Another index developed to allow the characterization of climate in relation to a building of known envelope characteristics is the 'Climate Severity Index' (CSI) [4]. The Passive-on project [5] reports Winter- and Summer Severity Index depending respectively on HDD and CDD and daylight hours. In particular for non-residential building in summer, taking into consideration also solar radiation, as in the CSI method, provides a better classification of the climate.

There will be no 'perfect' solution. However, a comparison of Net ZEBs in different climates seems possible by following a few suggestions. It can be said that the advantage of a simple degree-days method contributes to get an overview of climate adequate to Net ZEB approaches, but detailed calculation or simulation requires further climate data (e.g. solar radiation) as well as considerations of climate-adapted indoor comfort criteria.

3. Comfort criteria

Recent revisions of international standards have updated the definitions of comfort and ways to use them in designing and evaluating buildings. ASHRAE Standard 55:2004 [6] and EN 15251:2007 [7] have introduced the Adaptive model to be used in naturally ventilated buildings and ISO 7730:2005 [8] and EN 15251 have introduced the concept of comfort categories based on different ranges of Predicted Mean Vote (PMV) or operative temperature around the neutral conditions. There are differences in the approach taken by those standards that have relevant implications on the design of low energy buildings and Net ZEBs.

ASHRAE Standard 55 and EN 15251 both propose that acceptable temperature ranges actually depend on the type of system used to provide summer comfort. EN 15251 distinguishes two types of buildings, those with mechanical cooling and those without it, and for the analysis of the latter in summer both Fanger and adaptive models are allowed. In the definition section, "buildings without mechanical cooling" are defined in the standard as "buildings that do not have any mechanical cooling and rely on other techniques to reduce high indoor temperature during the warm season like moderately-sized windows, adequate sun shielding, use of building mass, natural ventilation, night time ventilation etc. for preventing overheating". Mechanical cooling is defined as "cooling of the indoor environment by mechanical means used to provide cooling of supply air, fan coil units, cooled surfaces, etc." The description of situations where it is appropriate to use the adaptive model is further detailed in the section A.2 of the same standard: "In order for this optional method to apply, the spaces in question shall be equipped with operable windows which open to the outdoors and which can be readily opened and adjusted by the occupants of the spaces. There shall be no mechanical cooling in operation in the space. Mechanical ventilation with unconditioned air (in summer) may be utilized, but opening and closing of windows shall be of primary importance as a means of regulating thermal conditions in the space. There may in addition be other low-energy methods of personally controlling the indoor environment such as fans, shutters, night ventilation etc." ASHRAE Standard 55 makes a similar distinction but not exactly with the same wording, allowing the application of an adaptive model (based on outdoor monthly average temperatures), in "occupant-controlled naturally conditioned spaces" defined as "those spaces where the thermal conditions of the space are regulated primarily by the occupants through opening and closing of windows".

A number of researchers have observed that some buildings will not fall exactly into the two ensembles and some of the interesting technologies for low energy and passive cooling are among those of uncertain classification both on the ground of the available data in the databases and of the wording of the standards, see for example [9]. This has direct implications on design procedures particularly for low energy and Net ZEBs. The standard EN 15251 states that: "The temperature limits presented in A.2 [author note: adaptive comfort range] should be used for the dimensioning of passive means to prevent overheating in summer conditions e.g. dimensions and the orientation of windows, dimensions of solar shading and the thermal capacity of the building's construction. Where the adaptive temperature limits presented in A.2 (upper limits) cannot be guaranteed by passive means mechanical cooling is unavoidable. In such cases the design criteria for buildings WITH mechanical cooling should be used."

Therefore, a procedure could be devised to vary building envelope parameters in order to minimise an "adaptive discomfort index". If the adaptive temperature limits cannot be guaranteed, a "Fanger discomfort index" can be used instead as the target to be minimised. These indexes can be selected among the ones proposed in EN 15251 [*Annex F (Informative): Long term evaluation of the general comfort conditions*]. Reducing the discomfort indexes by choice of passive means also implies a reduction of the energy needed for heating and/or cooling of the building and hence of the energy consumed by active means used to reduce the discomfort (if still needed). In [10] it is shown that using some of the indexes proposed by EN 15251 (i.e. method A: percentage outside the range) and their intended use (start with its adaptive variant and, if comfort conditions for the chosen category cannot be met, switch to Fanger variant) implies the presence of discontinuities in the procedure. This is due to the fact that with common assumptions on 'met' and 'clo' certain conditions will be above the comfort range for Fanger and below the range for adaptive.

Even with these limitations, these indexes can be useful as objective functions in an optimization procedure to guide design, particularly for the building envelope and passive features. In passive buildings the use of these indexes (in their adaptive variant) would be useful, for example, to control the operation of motorised openings for night ventilation in summer. In fact, since the comfort operative temperature to be reached depends on the recent history of external temperatures, the temperature set point (for operative or mean radiant temperature) at which night ventilation should be reduced/stopped cannot be set at the same level for the entire season. Instead, it should be calculated each day based on the previous history and on the building characteristics which determine its dynamic response. It would also be useful to adapt simulation tools in such a way that they can handle directly such control algorithms and calculate their effect.

Part of the discontinuities between the two variants (Fanger and adaptive) arising in the optimisation procedure with use of the long term indexes may be reduced when considering the large influence that certain variables like clothing (and total) insulation and air velocities have on the calculated values of PMV. Ensuring that clothing insulation is under 0,7 clo (e.g. by appropriate relaxation of explicit or implicit dressing codes) enables the use of the ASHRAE correction (in augmentation of the value calculated via PMV formula) to operative comfort temperature when velocities higher than 0.2 m/s are experienced by the occupants. These two changes have the effect of reducing the ambiguous zone between the two comfort ranges. The correction as it is proposed is applicable directly only to temperature, hence only within method A (hours outside range), but not in method B and C which rely on PMV and PPD values that are given in graphic form, hence not directly applicable in simulation or optimization tools. In [10] a modified version is proposed, where increased air velocities effects are described in terms of PMV in graphic form. Further work is ongoing in order to incorporate it into analytical and numeric procedures for optimization.

Alternatively, the Givoni psychrometric-bioclimatic chart [11] can be considered as an easy to use and pedagogical tool. The method is based on the comfort zones defined in ASHRAE Standard 55, but it also graphically represents the effect of passive measures, e.g. cross natural ventilation, hence helping designers to reduce or avoid the need for air-conditioning. See [12] for an example of the Givoni's chart applied in the design of a Net ZEB in tropical climate.

4. Energy efficiency

There are mainly two ways of expressing recommendations on energy efficiency. One is the *prescriptive method* and consists in giving specific technical requirements for a set of envelope and technical system elements or characteristics. The other is the *performance method* and consists in giving limits on energy needs, i.e. for heating and cooling, and/or for total primary energy. There are advantages and disadvantages in both approaches. However, it is also possible to adopt a tandem approach, meaning that it is enough to comply with either the prescriptive method – mostly suitable for conventional building solutions and for the very first choice in the early design stage – or with the performance method – mostly suitable for particular building solutions, e.g with double skin façades where the concept of U-values looses its meaning, and for the whole building assessment.

When standardized input are chosen as the basis for design and evaluation of performances, there are certain loads that are normally regarded as building load while others are regarded as user load. The border line between the two is somehow arbitrary. However, energy efficiency recommendations may be specified on both user and building loads.

4.1. User loads

In keeping with the intention of prioritizing energy efficiency and conservation, limits on user loads (plug loads, water usage, etc.) could be a requirement for Net ZEBs. User loads represent a significant portion of the total energy consumption in low-energy buildings. Unlike building loads such as heating and cooling, user loads are fairly independent of climate type; however, they are a strong function of factors such as building type, number of occupants and human behaviour. While it is necessary to encourage a rational use of energy resources, the aforementioned factors make it difficult to define specific limits. In this paper, different approaches are proposed for user load requirements for two different building categories: (a) low-rise residential buildings; (b) other buildings (for example, high-rise residential, commercial buildings, etc.).

4.1.1 User Loads in Low-Rise Residential Buildings

Lighting and appliances – prescriptive method

Labels are used to help consumers in the selection of energy-efficient appliances in many jurisdictions, such as the Energy Star label in the US [13], the EnerGuide labelling in Canada [14] and the Energy

Labels in the EU [15]. Taking into account that labelling programs attempt to keep track of the state-of-the-art technology for appliances, the prescriptive path proposed for low-rise residential Net ZEBs is the following:

- Net zero energy houses should be required to have, whenever possible, the highest one or two categories in the EU Energy Labels, Energy Star labels or equivalent labels according to the jurisdiction on all its major appliances and artificial lighting. Major appliances include: refrigeration equipment (freezer and refrigerator), washing machine, clothes dryers, water heaters and cooking appliances[1].

Lighting and appliances – performance method

Energy consumption for lighting and appliances can be compared to that of existing Net ZEBs, used as benchmarks. To illustrate typical figures of energy consumption of appliances two Canadian examples are considered, [16] and [17]. The number of occupants is a better index for appliance energy consumption in a residence than its floor area; the given cases are assumed to have 4 occupants on a total floor area of 180 m^2. For appliance energy consumption it is proposed the following performance compliance path:

- Net zero energy houses should limit their electric energy consumption in appliances and other plug-loads to less than 800 kWh/y per occupant.

Lighting electric energy consumption is estimated in 1100 kWh/year in a typical Canadian home: this number has been used as a reference value in the R-2000 program [18]. However, both [16] and [17] indicate 400 kWh/year or less. It is therefore proposed as a lighting criterion for the performance compliance path:

- Net zero energy houses are expected to make optimal use of daylight, leading to electric energy use for lighting close to 3 kWh/m^2/year for latitudes similar to those of the mentioned cases (approx. 45º).

Domestic hot water – performance method

A study presented at the IEA-SHC Task 26 [19] indicates that a typical DHW usage is 200 l/day of water at 60°C. This coincides with the number presented in the standard EN 15316 [20], a European house with 3 occupants (tapping program no. 3) uses the equivalent of 200 l/day at 60°C. The Canadian EQuilibrium Initiative established 225 l/day as the reference case for 4 occupants (56.25 l/day/person); however, it was possible to present significant reductions in DHW use, provided that the assumptions were justified (e.g., use of low-flow showerheads). In the case of the Alstonvale House [17], an equivalent hot water consumption of 130 l/day four 4 occupants (32.5 l/day/person) is suggested.

It can be considered as a reasonable assumption that net zero energy houses will use about 50 l/day/person; assuming a typical ΔT between the desired temperature and the water in the mains of about 45 K, then the corresponding thermal energy delivered to the water is 2.62 kWh/day/person. The following requirement is then proposed:

- Net zero energy houses should not exceed a hot water energy consumption corresponding to a daily average of 2.75 kWh thermal energy per day per occupant.

4.1.2 User Loads in Other Buildings

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[1] EnergyStar labels do not currently exist for cooking appliances.

The large variety of building types, i.e. offices, shops, hotels, schools, hospitals, etc., complicates setting up energy consumption limits for their user appliances and lighting and national standards may already exist stating reference energy consumption figures.

The energy consumed in lighting per unit of floor area (lighting power density), can be used as a benchmark for recommending efficiency measures in lighting. The standard ASHRAE 90.1 [21] specifies lighting power densities for a large number of applications. As the standard ASHRAE 90.1 was not created specifically for green, low energy and net zero energy buildings, applying it directly may not the best strategy for energy efficient buildings. The North American building rating program LEED [22] requires that a building consumes significantly less energy in lighting and appliances than ASHRAE 90.1, the minimum energy reduction to qualify for LEED certification being 15% better than ASHRAE 90.1. This includes all the energy consumed in the building (heating, cooling, lighting, appliances).

The diversity of plug-loads that might be present in buildings makes it difficult to establish a general rule. For office buildings, one of the most common cases, equipment with the Energy Star label (computers, printers, monitors, photocopiers, fax machines, etc.) can already be found [23]. The following requirement is proposed for plug-loads and other appliances in office buildings.

The recently released standard ASHRAE 189.1 [24] indicates numerous water usage limits and strategies: controls, special plumbing fixtures, water metering requirements. No maximum volume of hot water use per occupant is established, nor is there any defined limit for DHW energy consumption. The following recommendations are proposed:

- Net zero energy buildings (excepting low-rise residential buildings) are expected to have a specific electric energy use for lighting lower than 8 W/m^2 by optimizing daylight utilization and using efficient lighting systems
- Automatic lighting control system should be implemented according to the building schedule.
- Net zero energy office buildings should use equipment having the highest one or two categories in the EU Energy Labels, Energy Star labels or equivalent labels according to the jurisdiction.
- The energy management system (EMS) should measure the energy consumed by plug-loads separately from lighting and HVAC energy consumption.

4.2. Building loads

Considering Net ZEBs as being first of all very energy efficient buildings, a principle could easily be stated:

- Net zero energy buildings should be low energy buildings.

Such a principle may be easy to state but less easy to define. Indeed, there is no common agreement on what a low energy building is, nor is there a formal definition of it. Low energy buildings could be theoretically defined, in the European context, by the labels B, A or better (i.e. A+ etc.) in the EPBD labelling system (Energy Performance of Buildings Directive); but for the time being the labelling system is not yet well established in all European regions, nor is the necessary information readily available [25]. Other voluntary standards or labelling, as for example Passive House [26], Minergie [27] and Casaclima [28], are well defined, but mainly in the context of the temperate central European climate. For colder climates as in Scandinavia, the Norwegian definition of low energy and passive house may be considered [29]. For warmer climates a useful reference is the work done within the European project ‘Passive-On’ [5], aimed at adapting the definition of the German passive house standard to the Mediterranean climate. These standards and labelling were first developed for residential buildings but are being applied (or are in the process of being adapted) also to non-residential buildings, often without major variations in the values showed in the following tables.

Table 1 and Table 2 show a summary of the values found in the mentioned literature and sources for both low energy and passive house buildings, both prescriptive and performance methods.

The distinction between low energy and passive house buildings poses an issue on the heating system. Passive houses can provide high comfort without a conventional heating system, hence the term ‘passive’; see [26] for further information. This results in the fact that a higher investment in the building envelope is compensated by a lower investment in a simplified heating system.

Table 1: Technical requirements – prescriptive method (indicative values)

Parameter	Heating DD ≥	Cooling DD ≥	Low Energy building			Passive House building		
Peak heating load [W/m^2] ≤	-	-	-			10		
Air tightness	2000	-	1.0			0.6		
n_{50} [ach] ≤	1500	-	1.0			1.0		
			Wall, Roof	Floor	Window[a]	Wall, Roof	Floor	Window[a]
U-values	3000	-	0.15 – 0.18	0.13	1.2	0.10 – 0.15	0.13	0.8
[W/m^{2}K] ≤	1500	-	-	-	-	0.15 – 0.30	0.35	1.2 – 1.5
	500	-	-	-	-	0.25 – 0.40	0.5 – 1.7	1.5 – 2.0
Thermal bridges ψ [W/mK] ≤	500	-	≤ 0.03			≤ 0.01		
Windows shading effectiv. (S, E, W) ≥	-	500	70 %			70 %		
Opaque env. displacement (S,E,W, Hor.) [h] ≥	-	500	10			10		
Thermal admittance Y [W/m²K] ≤	-	500	0.1			0.1		
Heat recovery efficiency ≥	-	-	70 %			80 %		
Specific Fan Power SFP [kW/(m^3/s)] ≤	-	-	2.0			1.5		

[a] overall, including frame

Table 2: Energy requirements – performance method (indicative values)

Energy	Heating DD ≥	Cooling DD ≤	Low Energy building [kWh/m^{2}a]	Passive House building [kWh/m^{2}a]
Energy need for heating ≤	4000	-	30 – 50 or EU labels A/B	20 – 30
	500	-	EU labels A/B	15
Energy need for cooling ≤	-	1000	15 or EU labels A/B	
Primary energy ≤	-	-	-	120

It should be noted that when giving energy requirements (performance method) the actual input for climate, user loads and the adopted calculation method itself will influence the results. To this respect, the calculation method should be compliant with the norm ISO 13790 [30]. Additionally, figures on primary energy depend on the conversion factors adopted and may vary for each country. The values shown in Table 1 and Table 2 are simply indicative values.

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