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Quantitative analysis of the divergence in energy losses allowed through building envelopes

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ABSTRACT

There is currently a lack of international harmonization on the insulation requirements for the buildings. Given that this parameter defines the maximum energy losses allowed through a thermal envelope, building energy consumptions can vary considerably between countries. Both the United States of America (US) and the European Union (EU) should address this problem by unifying the energy design criteria of their buildings. The EU requires that all new buildings constructed starting in 2020 must be nearly zero-energy buildings (nZEB), as defined in the Directive on Energy Efficiency in Buildings of 2010.

To evaluate the extent of this lack of harmonization, in this paper are calculated the maximum energy losses through the thermal envelope of a typical dwelling when applying various international regulations (such as the US regulations and those established by Germany, France, England and Wales, and Spain). The results are compared with those obtained when applying the requirements of the Passivhaus standard (taken as a reference for nZEB in the EU). It will be verified that there are major differences in the energy losses allowed through building envelopes among these countries and among the different climate zones defined in each country.

Moreover, the challenges set by these countries related to energy consumption and CO_2 emissions are also reviewed. The disparity between the objectives proposed by these countries suggested a distinct tendency towards increasing current differences in their standards.

Contents

1. Introduction

With the approval of the Kyoto protocol in 1997, common objectives were established at an international level to reduce CO_2

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emissions and energy consumption to avoid their adverse effects on the environment [1–6]. Given that the limits established in the Kyoto protocol have been insufficient to halt climate change, these limits were revised in 2007 and new plans for action were proposed.

As a result, the EU approved a packet of measures known as "20-20-20". Among others, these measures have the goal of reducing energy consumption and CO_2 emissions by 20% before the year 2020 [10,11]. The construction sector is among the principal sectors responsible for energy consumption and CO_2 emissions, accounting for approximately 40% of each [7,9]. One of the European directives approved to reach the "20-20-20" objectives is the 2010 Directive on Energy Efficiency in Buildings (DEEB), which requires the construction of nearly zero-energy buildings (nZEB) starting in 2020 [12]. In the US, the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) and the International Code Council (ICC) have also published several recommendations that aim to drastically reduce building energy consumption.

The DEEB directive and its subsequent Development regulations indicate a lack of harmonization among the different countries in the EU concerning energy efficiency requirements in buildings [8,13–16]. Insufficient information provided by the European Directive about how nZEBs should be built has resulted in each country establishing different energy parameters to define these types of buildings. To mitigate this problem, the European Commission has proposed the city of Darmstadt's passive houses, built according to the Passivhaus standards, as an example of an nZEB [17]. This article shows that there is also a lack of harmonization in the United States regarding the parameters that define building energy losses in different climate zones. However, to the authors' knowledge, there are no documents that address this problem.

The majority of international rules on energy efficiency establish several maximum thermal envelope transmittances for each climate zone to limit energy losses through the building of thermal envelope. In contrast, the Passivhaus standard establishes a different criterion limiting maximum energy consumption for both heating and cooling to 15 kWh/m^2 a year instead of fixing the transmittances [18]. The standard proposes a set of transmittance values as a guide to achieve this objective. Limiting energy consumption due to energy losses through the building envelope is a key task needed to achieve this objective given that these losses are responsible for the majority of the total energy consumption of dwellings [19–27].

This lack of harmonization among maximum energy losses allowable through the envelope has already been analyzed from a regulatory standpoint in a previous work, which compared the parameters that regulate those losses in different countries. The research shows that the root of the problem lies in limiting the thermal envelope transmittance in each country for different climate zones defined on the basis of different ranges of degree-day variation, rather than limiting maximum energy losses. A new procedure has recently been developed that allows to harmonize these energy losses in different climate zones (the International Procedure for the Optimal Design of Thermal Envelopes, or IPODTE) [28].

This article broadens that analysis and quantifies the existing differences between the maximum thermal envelope energy losses allowed by different countries. Given that two-thirds of the emissions produced and energy consumed by the building sector come from the residential sector [29–32], will be calculated and compared the energy losses through the envelope of a residential dwelling type. The calculation uses the transmittance values imposed in the climate zones defined by various countries in the EU and by the US. The EU countries included in the analysis are Germany, France, England and Wales, and Spain, which are representative of different climates. The obtained values were compared with the requirements of the Passivhaus standard, which served as a reference for nZEB.

Finally, the long-term measures and objectives proposed by different countries to reduce CO_2 emissions and energy consumption will be also analyzed, especially in the construction sector. The existing disparity in these countries' future challenges suggested that the differences in their established requirements could widen in the future.

2. Background

The energy losses that occur through each enclosure of a thermal envelope can be calculated using Eq. 1:

$$\text{Energy losses through the enclosure in a year} = \sum U \cdot A \times (\text{degree} - \text{days per year}) \text{ in W} \quad (1)$$

where U is the thermal transmittance of the enclosure (W/(m^2 k)) and A is the enclosure area (m^2).

The term annual degree-days indicates the differences throughout the year between the average outside temperature $\overline{T}_i$ and a reference base temperature, T_{base}, at which it is considered necessary to air condition a room. The sums account only for positive values, as indicated by the + superscript in Eqs. 2 and 3:

$$\text{Heating Degree Days} = HDD = \sum_{1}^{N} (T_{base} - \overline{T}_i)^+ \text{ in K} \quad (2)$$

$$\text{Cooling Degree Days} = CDD = \sum_{1}^{N} (\overline{T}_i - T_{base})^+ \text{ in K} \quad (3)$$

where N is the number of days in the winter (Eq. 2) or in the summer (Eq. 3) [33].

The thermal envelope is considered to include the basement walls, exterior walls, floor, roof, and any other building element that encloses a conditioned space. This boundary also includes the boundary between the conditioned space and any exempt or unconditioned space. The thermal transmittance is the time rate of heat flow through a body from one of its bounding surfaces to the other surface for a unit temperature difference between the two surfaces, under steady state conditions, per unit area Btu/(h ft^2 °F) or W/(m^2 K). Both definitions were taken from the International Energy Conservation Code (IECC) [34].

The thermal transmittance is calculated using Eq. 4:

$$U = 1/R_i + \sum \lambda_i / e_i + 1/R_e \quad (4)$$

where λ_i is the thermal conductivity of each material in W/(mK), e_i is the thickness of each layer of material in meters, and R_i and R_e are the surface thermal resistances of the interior and exterior air, respectively, in m^2 K/W.

3. Analysis of annual envelope energy losses in a typical dwelling in the countries under study

This section analyses the extent of the dysfunction created by setting transmittances according to the different degree-day-variation climate zones defined by the different countries. The energy loss caused for the envelope will be calculated for a typical dwelling in each of the climate zones in all of the countries under study to quantitatively demonstrate that the energy losses are not harmonized.