Energy & Buildings 170 (2018) 61–73

Contents lists available at ScienceDirect

Energy & Buildings

journal homepage: www.elsevier.com/locate/enbuild

In situ measurement of façades with a low U-value: Avoiding deviations

Katia Gaspar*, Miquel Casals, Marta Gangolells

Universitat Politècnica de Catalunya·BarcelonaTech (UPC), Group of Construction Research and Innovation (GRIC), C/ Colom, 11, Ed. TR5, Terrassa, Barcelona 08222, Spain

ARTICLE INFO

Article history:
Received 26 October 2017
Revised 5 April 2018
Accepted 8 April 2018
Available online 17 April 2018

Keywords:
Low thermal transmittance
In situ measurements
HFM method
Temperature difference
Test duration
Equipment accuracy

ABSTRACT

In situ measurements of low thermal transmittance façades are required to ensure compliance with energy performance strategies for new nearly zero-energy buildings (nZEB) and with energy policies for the transition of existing building stock to nZEB. The aim of this paper was to enhance the accuracy of the in situ measurement of low U-value façades, employing the widely used ISO 9869-1:2014 HFM method and exploring the limits of its conditions. To refine the testing conditions, three variables were analysed and compared with indications of ISO 9869-1:2014 and the existing literature: the temperature difference, the test duration and the accuracy of equipment. A continuous experimental campaign was conducted in a building mock-up. The findings showed that to accurately measure in situ low U-value façades, the temperature differences must be greater than those indicated in the existing literature. Temperature differences above 19 °C required a test duration of 72 h, while for lower temperature differences the test duration must be prolonged. The accuracy of temperature sensors had a greater impact on the accuracy of measurement in the initial cycles of the test. Likewise, the accuracy of ambient temperature sensors was found to have a considerable influence on the uncertainty of measurements.

1. Introduction

To meet the 2020 energy targets, the Directive on the energy performance of buildings establishes that all new buildings must be nearly zero-energy by 31 December 2020. New buildings that are publicly occupied or owned must be nearly zero-energy by 31 December 2018 [1]. The definition of nearly zero-energy buildings has been widely studied [2–6]. Most EU member states use a primary energy use indicator in kWh/(m^2·y), but other parameters are also employed, such as net and final energy for heating and cooling, CO_2 emissions and the U-values of building envelope components [7].

Existing approaches in literature reviews on nearly zero-energy building technologies can be summarized in three categories: passive energy-saving technologies, energy-efficient building service systems, and renewable energy production technologies [8]. Focusing on passive energy saving technologies, Friess and Rakhshan [9], Omrany et al. [10] and Sadineni et al. [11] reviewed various advanced wall technologies to improve the energy efficiency and comfort levels in buildings. According to Sadineni et al. [11], the improvement of building envelopes primarily relies on reducing thermal transmittances, combined with passive heating or cooling [8].

Currently, there is great concern about the role of building envelopes in defining strategies for new nearly zero-energy buildings. There are numerous strategies available to design and construct building façades for low-energy or nearly zero-energy buildings. Several authors [12–19] have studied the optimization of building envelope design for nearly zero-energy buildings through models and simulations in different climate zones. Ascione et al. [12] focused on the optimization of the building envelope design for nearly zero-energy buildings in the Mediterranean climate through energy simulations. Berry and Davidson [13] explored the economic feasibility of the net zero-energy building policy in warm temperate climates based on energy monitoring evidence and construction economics. In order to achieve the NZEB goal, Buonomano et al. [14] developed a computer model for predicting the energy demand of buildings integrating new technologies such as phase change materials, photovoltaic-thermal collectors, adjacent sunspaces and innovative daylighting control. Charisi [15] conducted a study focusing on the potential reduction of energy demands in typical Greek residential building. The researcher modelled the effect of insulation, openings and shading devices of building envelopes on the energy demand. The model was ex-

* Corresponding author.
E-mail addresses: katia.gaspar@upc.edu (K. Gaspar), miquel.casals@upc.edu (M. Casals), marta.gangolells@upc.edu (M. Gangolells).

https://doi.org/10.1016/j.enbuild.2018.04.012
0378-7788/

amined in four climate zones using dynamic simulation software tools. In order to achieve nearly-zero energy buildings in the climate conditions of Cyprus, Loukaidou et al. [16] conducted a cost-optimal analysis of thermal features of the building envelope, including thermal insulation on wall, roof and ground floor and optimal window properties. Micono and Zanzottera [17] checked the results of the simulation of an office building in Northern Italy taking into consideration variations occurred during the construction phase to guarantee the energy performances forecasted. Moran et al. [18] conducted a study to determine the optimal strategy to design a nearly zero-energy building in a temperate oceanic climate, such as Ireland. Eight different versions of a modelled semi-detached house were investigated with two different building fabrics, airtightness and ventilation strategies employed. The analysis was focused on the life cycle cost and environmental analysis of nearly zero-energy buildings using various heat sources. To optimality design of eleven nearly zero-energy new buildings types in cold climate conditions, Zakis et al. [19] coupled evolutionary algorithms with a building dynamic simulation engine. The multi-objective computer model took into account life cycle cost and performance modulation.

Energy renovation measures for existing building stock to bring it up to the nearly zero-energy building level were also analysed by several authors [20–26] through energy simulation tools. Albadry at al. [20] proposed a validated guideline to achieve net zero-energy buildings through retrofitting existing residential buildings using photovoltaic panels in Egypt. Brandão De Vasconcelos et al. [21] identified cost-optimal packages of energy efficient solutions from among a set of possible refurbishment measures taking into consideration different discount rates and building orientations. The research was applied to a Portuguese reference building. Corrado et al. [22] showed the approach and the methodology adopted in the European Project, RePublic_ZEB, for the assessment of retrofit measures suitable to reach nearly zero-energy buildings. In order to reach the nearly zero-energy target for buildings that represent the national residential building stock in Italy, Corrado et al. [23] identified packages of energy efficiency measures to apply. Ferreira et al. [24] compared cost-optimal renovation packages with nearly zero-energy building levels of energy performance in building renovation of modelled representative buildings of Portuguese residential building stock. Based on site surveys and expert interviews, Hou et al. [25] conducted a comparative analysis on incentive policies to implement commercial building energy efficiency retrofit programs in China. Kuusk et al. [26] discussed energy renovation scenarios from major renovation to nearly zero-energy building level for apartment buildings in a cold climate (Estonia).

Due to deviations between predicted and actual energy consumption in nearly zero-energy buildings, energy performance strategies for both new and existing buildings need to be checked. Some authors [27–32] have modelled differences between forecasted and actual energy consumption. Ascione et al. [27] created a numerical model to investigate deviations between the expected and the measured electric usage in the areas of heating and domestic hot water, ventilation, lighting, equipment and auxiliaries, yield of the photovoltaic system. The modelled building was a two-storey NZEB situated in Berlin. Kampelis et al. [28] investigated the operational performance of industrial, residential and research/educational buildings with the use of simulation tools. Researchers evaluated the significance for smart near-zero energy buildings energy efficient technologies, renewable energy technologies, storage and smart monitoring and controls. In order to determine if building designs reach target energy efficiency improvements, Kneifel and Webb [29] developed a statistically derived regression model to predict energy performance of a net-zero energy building. Ulpiani et al. [30] conducted an experimental study focused on the energy benefits achieved by coupling an energy efficient building with a sunspace in winter season and Mediterranean climate. The monitoring phase was used to calibrate the simulation model and provide on-site validated data for subsequent assessments and comparisons. Zavrl and Stegnar [31] investigated the calculated and metered energy use of monitored apartments in a highly energy efficient apartment building Eco Silver House committed to meet the national nearly zero energy buildings requirements. Zhou et al. [32] investigated the operational performance of an occupied net zero energy office building in Tianjin, China, during a year. Results showed that energy consumption of the case building was much higher than the energy generated from the solar photovoltaic system selected according to the simulated energy consumption of the building at design phase. The researchers highlighted that during the design process of net zero energy buildings, it was imperative to ensure that the energy simulation accurately reflects how the building will actually operate once occupied.

Deviations between a building's overall energy efficiency target and its actual operating performance are associated with factors in the design and construction of the building envelope and systems or in the management procedures affecting the operational phase of the building [28]. Therefore, in situ measurements are needed to assess the actual performance of building envelopes and ensure that they reach the nearly zero-energy building level. In 1994, the International Organization for Standardization published the first edition of the standard for in situ measurement of the thermal resistance and thermal transmittance, ISO 9869:1994, by the Technical Committee ISO/TC 163/SC 1 *Test and measurement methods*. This standard was revised and replaced by a new version in 2014 [33].

The literature review revealed that only a few researchers [34–39] have measured in situ the actual thermal transmittance of façades with low U-values. As shown in Table 1, these researchers encountered difficulties in the measurements, as they frequently obtained high deviations from theoretical U-values. Albatici et al. [34] validated quantitative infrared thermography for the evaluation of building thermal transmittance by assessing two walls with low U-values (0.17 $W/m^2{\cdot}K$ and 0.18 $W/m^2{\cdot}K$), using the standardized average calculation method [33] to obtain the HFM measured U-value. Asdrubali et al. [35] presented the results of in situ thermal transmittance measurements performed on six energy efficient buildings funded by the Umbria Region in Italy. The buildings were constructed between 2007 and 2008, and their calculated thermal transmittance using the standardized average calculation method [33] ranged from 0.23 $W/m^2{\cdot}K$ to 0.33 $W/m^2{\cdot}K$. For the energy performance analysis of two houses, Bros-Williamson et al. [36] monitored over two periods the corresponding façades, which had theoretical U-values of 0.10 $W/m^2{\cdot}K$ and 0.23 $W/m^2{\cdot}K$. In a study about the thermal behaviour of a building envelope with varying insulation conducted by Mandilaras et al. [37], the authors analysed performance with a vacuum insulation panel and compared it with a theoretical estimation of R-value of 4.98 $m^2{\cdot}K/W$, which is equal to thermal transmittance of 0.20 $W/m^2{\cdot}K$. The experimental determination of R-value was calculated using the dynamic method of ISO 9869:1994 [33]. In a comparison of experimental measurements of thermal transmittance using infrared technology, the heat flow meter method and the calculated U-value [40], Nardi el al. [38] analysed a wall with a theoretical U-value of 0.23 $W/m^2{\cdot}K$. Authors used the standardized average calculation method [33] to obtain the measured U-value. Finally, Samardzioska and Apostolska [39] conducted a study on façades with a new construction system. The thermal transmittance of the wall with the new construction system was 0.22 $W/m^2{\cdot}K$, according to calculations using analytical software. Authors performed measurements on the walls of three buildings whose façades had been constructed using the new system. To obtain the calculated thermal transmittances, they used the standardized average calculation method [33], but