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Editorial

Special Issue "Building Thermal Envelope"

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1. Introduction

The increasing requirements in building thermal and energy performance standards and the need to design nearly zero-energy buildings, while still enhancing the indoor comfort conditions, have led to a demand for more efficient thermal building envelope solutions. In fact, the effective use of building thermal envelope, as a mediator between outdoors and indoors, plays a key role in sustainable and energy efficient building design. Therefore, there is a need for continuous search of innovative materials, construction solutions and technologies that manage the energy and mass transfer between the building and the external environment taking into account not only the climatic changes but also the user preferences. Knowledge concerning the performance of building thermal envelope solutions and the existing design support tools, such as building performance simulation, is crucial for stakeholders to make informed decisions with respect to the definition and implementation of energy efficient strategies for new and refurbished buildings.

This Special Issue intends to provide an overview of the existing knowledge related with various aspects of "Building Thermal Envelope" and contributions on, but not limited to, the following subjects were encouraged: building envelope materials and systems envisaging indoor comfort and energy efficiency; building thermal and energy modelling and simulation; lab test procedures and methods of field measurement to assess the performance of materials and building solutions; smart materials and renewable energy in building envelope; adaptive and intelligent building envelope; integrated building envelope technologies for high performance buildings and cities.

So far, 13 papers have been published in the Special Issue of a total of 21 submitted. The next sections provide a brief summary of each of the papers published.

2. Building Envelope Materials and Systems Envisaging Indoor Comfort and Energy Efficiency

Kim et al. [1] analyzed the thermal performance data of the windows provided by the Korea Energy Agency and confirmed the change in the thermal performance of the windows by year and by frame material. It was found that the average U-value of the window decreased significantly from 2012 to 2015, maintaining similar values until 2017, and decreased again in 2018. This study also confirmed that the frame U-value of the PVC windows is lower than the frame U-value of the aluminum windows. The results of U-value of the windows through actual physical experiments show that, in the case of aluminum windows, the U-value corresponding to Grade 3 (1.4–2.1 $W/m^2{\cdot}K$) was as high as about 60%, whereas in PVC windows, Grade 3 (U-value of 1.4–2.1 $W/m^2{\cdot}K$) accounted for about 35%, and Grade 2 (U-value of 1.0–1.4 $W/m^2{\cdot}K$) for about 29%. Moreover, a performance index of the glazing in PVC and aluminum window design was proposed.

Tywoniak et al. [2] focused on roof windows in pitched roofs. Building physics methods were used to support the design of new solutions for passive house level design, namely the avoidance of the risk of frame surface water condensation under reference conditions in the interior. The results of two-dimensional heat transfer calculations in the form of parametric studies are presented in order to express the most important factors influencing thermal transmittance and minimum surface temperatures. It was found that a combination of wood and hardened plastics in the window frame and sash is the preferred solution. The resulting thermal transmittance can be up to twice as low as usual (from 0.7 down to 0.5 W/(m^2·K) and surface temperature requirements to avoid the risk of condensation can be fulfilled. The effect of the slanting of the side lining was investigated by simulation and measurement in a daylight laboratory. It was found that the increase in thermal coupling due to slanting was negligible.

Another study was developed by Silvestre et al. [3] on the environmental, economic and energy (3E) assessment of external wall energy retrofitting with a cork-based (as recycled lightweight aggregate) thermal insulating rendering mortar (TIRM). The case study was a flat roof of an average building with the most current characteristics used in Portugal. The energy and economic costs and savings, as well as the environmental impacts, expressed with a declared unit of 1 m^2 of an external wall for a 50-year study period, were analytically modelled and compared for two main alternatives: the reference wall without any intervention and the energetically rehabilitated solution with the application of TIRM. They concluded that walls with improved energy performance (with TIRM) show lower economic and environmental impacts, with reductions from 6% to 32% in carbon emissions, non-renewable energy consumption and costs during the use stage. These results are dependent on the thickness and relative place where TIRM layers are applied.

3. Building Thermal and Energy Modelling and Simulation

In their research, Ayçam et al. [4] performed a study on the specification of traditional architectural parameters for houses in the hot-dry climatic region of Diyarbakır, Turkey. The courtyard types, settlement patterns, and street texture of traditional Diyarbakır houses were modeled through DesignBuilder energy simulation program for the case study of urban fabric of the traditional houses in Historical Diyarbakir Suriçi-Old Town settlement and the Şilbe Mass Housing Area. Annual heating, cooling, and total energy loads were calculated, and their thermal performances were compared. The aim was to create a less energy-consuming and sustainable environment with the adaptation of traditional building form-street texture to today's housing sector. The development of a settlement model, which is based on traditional houses' bioclimatic design for a hot-dry region, was intended to be applied in the modern housing sector of Turkey. The results showed that, adapting local and traditional houses forms, urban texture, and settlement patterns to modern housing sector in Turkey has significant potential for sustainable architecture and energy-efficient buildings.

A computational fluid dynamics (CFD) study was performed by Chung et al. [5] to assess the effect of a different number of awning windows and their installation locations on the airflow patterns and air contaminant distributions in restrooms in K-12 (for kindergarten to 12th grade) public schools in Taiwan, for various wind speeds and directions. A representative restroom configuration with dimensions of 10.65 m × 9.2 m × 3.2 m (height) was selected and based on the façade design feasibility, seven possible awning window configurations were considered. The numerical results were compared with the experimental results obtained in a reduced-scale model. The results indicate that an adequate number of windows and appropriate installation locations are required to ensure the natural ventilation effectiveness of awning windows. It was recommended, based on the modified odor removal efficiency (ORE) results, that K-12 school restrooms should use window configuration W2 in their north walls and that the opening angle should be set to 45° for all seasons.

4. Lab Test Procedures and Methods of Field Measurement to Assess the Performance of Materials and Building Solutions

Krause and Nowoświat [6] carried out in situ tests and laboratory studies to evaluate the impact of solar radiation on the behavior of expanded polystyrene with the addition of graphite. Temperature distributions were determined in field and laboratory conditions were determined on the surfaces of three types of panels: (A) two-layer polystyrene (gray bottom layer and white top layer); (B) polystyrene with the addition of graphite (gray polystyrene); and (C) expanded polystyrene (EPS) (white polystyrene). The distributions of temperature were recorded for different wind and solar radiation conditions. Moreover, geometric changes and deformation levels of the panels exposed to artificial sun radiation were determined in laboratory conditions. The panel entirely made of polystyrene with the addition of graphite (panel B) demonstrated high sensitivity to external factors, such as insolation and wind, whereas panels A and C are characterized by low sensitivity to solar radiation. The composite panel (A-panel) proved to avoid many adverse effects of environmental conditions compared to B-panels. The extent and nature of temperature changes on the external surface of the panels depends on the area of impact and exposure time, while the extent of deformations is also dependent on the method used to fix the panels to the ground.

An integrated measuring and control system for hot box experiments, based on a general-purpose microcontroller and on a wireless sensors network was presented by de Rubeis et al. [7]. The results of 72 h experiment on a double insulation X-lam wall revealed that the system was able to maintain stable temperature set points inside the chambers and to log the temperatures measured by the 135 probes, allowing to know both the U-value of the sample (equal to 0.216 ± 0.01 W/m^2·K) and the thermal models of all the hot box components. The U-value experimentally obtained with the hot box method was compared with the values gathered through theoretical calculation and heat flow meter measurements, showing differences lower than 20%. Furthermore, the developed data post-processing allowed creating 2D and 3D thermal models of specimen wall and chambers.

5. Smart Materials and Renewable Energy in Building Envelope

Yu et al. [8] experimentally investigated the effect of the aspect ratio (AR) of a rectangular thermosiphon loop on its natural convection performance using boundary conditions of a constant heat flux and a fixed wall temperature for the heating and cooling sections of the loop, respectively. The experimental model consisted of a loop body with an inner diameter of 11 mm, a heating section, a cooling section, located in the vertical portions of the rectangular loop, and adiabatic sections. The analyzed aspect ratios were 6, 4.5, and 3.5 (with potential differences of 41, 27, and 18, respectively, between the cold and hot ends), and the input thermal power ranged from 30 to 60 W (with a heat flux of 600 to 3800 W/m^2). The results showed that it was feasible to install a rectangular thermosiphon inside a metal curtain wall to obtain solar heated water and that increasing the height of the opaque part of the metal curtain wall could improve the heat transfer efficiency by increasing the aspect ratio of the rectangular thermosiphon installed inside the wall.

Huang et al. [9] also presented an experimental study on the natural convection heat transfer performance of a rectangular thermosiphon with an aspect ratio of 3.5 and an inner diameter of the loop of 11 mm. Different heating powers, height differences between the heating and cooling ends, and cold end temperatures were tested. The results show that the value of the dimensionless heat transfer coefficient (Nusselt number), is generally between 5 and 10 and that the heating power is the main factor affecting the natural convection intensity of the thermosiphon.

Another study carried out by Choi and Ko [10] analysed the convergence characteristics of the in situ thermal transmittance (U-value) and thermal resistance (R-value) calculation of building envelopes obtained from onsite measurements using the ISO 9869-1 average method. The criteria for determining the average method convergence, namely the test duration, are very strict, and to shorten the test duration, environmental variables should be kept constant throughout the test or an appropriate period should be selected. The results indicate that the convergence of the in situ U-value and R-value is more sensible to the length of the test duration than to the temperature difference. Moreover, no difference was found between the use of the U-value and R-value in determining the end of the test.

6. Adaptive and Intelligent Building Envelope

A hybrid heat collecting facade (HHCF) that increases the indoor air temperature and reduces the heating energy consumption was studied by Wang et al. [11]. A heat transfer model based on the heat balance method, experimentally validated, was used to analyze the thermal performance of the HHCF. Moreover, the energy saving potential of a room with the HHCF was evaluated. The results indicated that the HHCF can reduce the heating need by 40.2% and 21.5% compared with the conventional direct solar heat gain window and the Trombe wall, respectively. Furthermore, a parametric analysis was performed and it was concluded that the thermal performance of the HHCF is mostly dependent on the window operational schedule, the width and the absorptivity of heat collecting wall, and the thermal performance of the inner double-glass window.

7. Integrated Building Envelope Technologies for High Performance Buildings and Cities

Biswas et al. [12] investigated the application of thermally anisotropic composites (TACs), composed by alternate layers of rigid foam insulation and thin and high-conductivity aluminum foil, for improving the energy efficiency of building envelopes. The TAC was coupled with copper tubes with circulating water, which acted as a heat sink and source, and the system was applied to a conventional wood-framed wall assembly. The energy benefits of the system were investigated both experimentally and numerically. Large scale test wall specimens were built with and without the TAC system and tested in an environmental chamber. Moreover, component-level and whole building numerical simulations were performed under cooling-dominated and heating-dominated climate conditions to investigate the energy benefits of applying the TAC system to the external walls of a typical, single-family residential building. It was concluded that the TAC coupled with a heat sink/source was shown to be more effective in reducing both cooling and heating loads and peak cooling loads than foam insulation of the same thickness. TAC connected to copper tubes circulating water were able to reduce cooling and heating loads by 86% and 63% compared to a baseline wall with only cavity insulation. Simulation results showed that the TAC system is able to reduce the cooling energy use by 11% under cooling-dominated climate and heating energy use by 21% in the heating-dominated climate.

An investigation on the use of Building Information Modeling (BIM) to assess the sustainability index of green buildings was performed by Liu et al. [13]. A cloud-based BIM platform was developed to digitalize the Envelope Thermal Transfer Value (ETTV) calculation, which is one of the prerequisite criteria to achieve a Green Mark score. The authors have validated the Envelope Thermal Transfer Value (ETTV) calculation, by using the developed cloud-based BIM platform in three case studies in Singapore. It was concluded that the proposed platform enhanced the productivity and accuracy of ETTV calculation and facilitated parametric capabilities that promote change management. Moreover, it allowed the relevant information to be shared and validated and project stakeholders to keep track of the GM data generated throughout the design stage and project lifecycle.

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