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Phase Change Materials in glazing: implications on light distribution and visual comfort. Preliminary results

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Abstract

The visual comfort concerned with a technology with PCM embedded into a double glazing unit was analyzed, using the Daylight Probability Glare and the 'Useful Illuminance' (percent of workplane with an illuminance in the range 100-3000 lx). A sample office room was modeled using Radiance, under a clear sky and with the façade facing south.
The visible transmittance of PCM was measured in laboratory and used as input in Radiance. The simulations were carried out for the two solstices and the Autumn equinox (four hours per day), for three sites (Östersund, 63.2°N; Turin, 45.2°N; Abu Dhabi, 24.4°N), considering the solid state of the PCM only.

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Keywords: phase change material (PCM); visual comfort; glare; Radiance simulation; Daylight Glare Probability; Useful Illuminance.

1. Introduction

During the last decade, the research activity in the field of building envelope components and building services has led to the identification and implementation of numerous solutions able to considerably reduce the energy need in buildings. Relevant improvements can be achieved by conceiving envelope components as "living" membranes [1]. With such an approach, the building envelope is actively used to filter, store and/or modify the mass and heat flux between the indoor and the outdoor, with the aim of assuring an optimal Indoor Environmental Quality with minimum energy demand [2]. A key feature is thus the capability of the building envelope to react and change its properties and features over time. Adaptiveness of transparent façades can be achieved through different solutions

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and materials (e.g. an air flow in a cavity [3-4], integration of Phase Change Materials (PCM) [5], switchable layers [6]), and can perform at different timescales and take place at different component/system levels. Therefore, these façades are particularly complex to be characterized, due to the high level of dynamicity and to the interdependency among different performance aspects. The lack of synthetic metrics and standardized characterization procedures are also major barriers that prevent the diffusion of this kind of concept/technologies.

When the focus is limited to the influence of an adaptive transparent façade on the visual comfort in the indoor space, the selection of performance criteria is often not so straightforward [7,8]. The standardized visual comfort condition [9] depends on the relationship between the user needs and the luminous environment. This is usually assessed by evaluating the amount, quality and spatial distribution uniformity of light, together with the estimation of the risk of glare (both disability glare and discomfort glare) for the user. For this analysis, the use of daylight metrics that incorporate temporal and spatial considerations is necessary to fully address the human perception of a space. The integration of space and time variable in one metric is clearly a challenge in case of conventional glazing systems, and becomes even more problematical for glazing components that exhibit dynamic optical properties. To analyse the glare risk, complexity is further increased by spatial (user position and luminance distribution) and physiological (subjective adaptation to luminous environment) variables. For office buildings, the Daylight Glare Probability (DGP) [10] is the most-widely accepted metric to assess the discomfort glare risk for side-daylighting conditions. This index is based on empirical correlations between the luminance distribution in the visual field (taken into account through the vertical illuminance measured at the eye level) and the glare perceived by the users.

Visual comfort implications and glare risk were investigated for dynamic fenestrations equipped with shading systems [11], or switchable glass panes [12], as well as for (static) translucent façades [13]. This latter investigation also points out that glare risk may be noticeable when a translucent façade (with a total light transmittance of 29%) is adopted and that it was not possible to prove the hypothesis that the glare sensation may be reduced if a part of a façade enables a view to the outside, due to psychological aspects [14,15].

Results from investigations on visual comfort condition and glare perception for translucent windows are a relevant benchmark when assessing the implication on the visual environment of a given dynamic glazing technology, based on the incorporation of PCM. While extensive experimental and numerical analyses of the performance of PCM glazing systems have been conducted and results are available in literature [5], no information can be currently found on the performance of this/these concept/technologies on the visual environment of a room equipped with this glazing system. Several PCMs that are adopted in these glazing solutions are in fact partially transparent to electromagnetic radiation (translucent to visible light when in solid and in transition phase state, and transparent when in full liquid state). While the liquid state is characterized by an optical behavior very similar to that of a conventional glazing system, the solid state is characterized by dominant scattering phenomena, that make the evaluation of the performance of this system much less trivial than for conventional windows.

The idea of integrating PCM into glazing components arose with the aim of improving both the thermal inertia and the overall performance of the glazed components, by allowing a better exploitation of solar energy. Most of the visible radiation is transmitted by PCM glazing system and this allowed daylight to be exploited, while most of the infrared radiation was absorbed and converted into heat. Different configurations of this main concept have been tested or simulated along the time, ranging from simple systems (e.g. a double glazed-unit where the cavity is filled with a PCM [16-20], to more advanced solutions that make use of triple-glazed units [21,22] equipped with dynamic glass panes [23], prismatic glass panes [24-26], or additional insulation materials [27].

Within this frame, this paper presents the preliminary results from a research activity on the impact of a PCM transparent façade on the visual comfort for the occupants, in a typical office room. As a first stage of the study, some extreme conditions, such as a totally transparent façade and a direction of view perpendicular to the window, were assumed, so as to define a worst-case scenario to characterize the performance of the component. Furthermore, the PCM was investigated in its solid/transition state only, because of two reasons. Firstly, the liquid state presents a conventional, specular behavior, with a visible transmittance in the same range of that of a conventional double glazed unit; therefore, the impact on the visual comfort can be then easily derived from well-established knowledge about conventional glazing systems. Secondly, the optical and thermal performance of a PCM layer in liquid state is, globally, worse than for the solid/transition state; a well-designed PCM glazing system should remain in solid (or better, transition) phase for most of the time, and never reach the (full) liquid state. Furthermore, the analysis was preliminarily limited to one orientation only for the transparent façade, to the presence of clear skies only and to a

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