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Discussion of the performance improvement of thermochromic smart glazing applied in passive buildings

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Abstract

The passive application performance of a thermochromic (VO_2) smart glazing was evaluated via energy saving equivalent (ESE) and energy saving index (ESI). ESE represents the hypothetical energy needed to maintain a passive room at the same thermal state as that when a particular material or component is adopted. ESI is the ratio of a particular material or component's energy saving equivalent to the corresponding value of an ideal material or component that can maintain the room at an ideal thermal state in passive mode. The discussions of the effects of the glazing's properties on the ESI revealed that due to the marked increase of solar absorptivity when transformed into the metallic state, the assumed smart regulation capacity of some VO_2 glazing could not be demonstrated. To realize the material's smart regulation capacity, the solar absorptivity in its metallic state should not be too much higher than that in its semiconductor state to decrease the heat transfer from the glazing to the room. When in its metallic state, the VO_2 glazing should also have low solar transmittance and absorptivity and a high infrared emissivity, and when in the semiconductor state, it should have high solar transmittance and low infrared emissivity.

Keywords: Thermochromic; Smart glazing; Vanadium dioxide; Passive building; Energy saving index

1. Introduction

As one of the main sources of carbon dioxide emissions, buildings sector shares about 25% of primary energy consumption in 2010 in China (International-Energy-Agency). With appropriate energy efficient design, a passive building has the potential to minimize its operating energy consumption, as they can make full use of renewable energy (solar energy in most cases). The thermal comfort in a passive building is achieved by passive techniques instead of active heating, ventilation and air conditioning (HVAC) systems. Passive techniques have been widely studied (Pacheco et al., 2012; Sadineni et al., 2011), and can be classified into two types mainly: the use of passive building components or materials (e.g., cool colored coatings (Karlessi et al., 2011; Synnefa et al., 2007), phase change materials (Barreneche et al., 2013; Kuznik and Virgone, 2009; Zhou et al., 2012), etc.) and the adoption of certain energy efficient methods (e.g., reasonable ventilation strategies (Lomas, 2007; Zhou et al., 2009), suitable orientation (Morrissey et al., 2011), etc.).

Vanadium dioxide (VO_2) glazing, a representative thermochromic smart glazing, has the capacity of dynamic solar gain adjustment (Granqvist, 2007). VO_2 is able to undergo a reversible transition at a phase transition temperature (T_τ) (Morin, 1959): when the temperature is lower than T_τ, it is monoclinic, semiconducting and rather

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infrared transparent; and when the temperature is higher than T_τ, it is tetragonal, metallic and infrared reflecting. T_τ of the bulk VO_2 is 68 °C, which is obviously too high for the building application. And doping with transition metal ions, e.g., tungsten (Tan et al., 2012), can lower T_τ significantly. VO_2 film with a T_τ of 30 °C was reported (Huang et al., 2011). Many researches have been conducted to improve the application performance and discuss the application prospect of the VO_2 glazing (Du et al., 2013; Gao et al., 2012; Granqvist, 2012; Li et al., 2012; Yao et al., 2013). We have demonstrated the application performance of VO_2 single glazing with a T_τ of 41.3 °C in a full-scale room and simulated that to a residential building (Ye et al., 2013). The results showed that the discussed VO_2 glazing could save $15 \pm 5\%$ and $\sim 9.4\%$ cooling energy consumption in a low mass room and a residential room, respectively. It can be inferred from the results that the adoption of the VO_2 glazing may be effective to improve the thermal comfort degree in a passive building as well as decrease the energy consumption in an active building. The passive application of the VO_2 glazing, which is rarely studied before, will be discussed in this study.

An appropriate index is essential to evaluating the application performance of not only the VO_2 glazing but also all kinds of passive building components or materials. Both subjective indices (e.g., predicted mean vote (Fanger, 1970), predicted percentage of dissatisfied (ANSI/ASHRAE Standard 55-2010), etc.) and objective indices (e.g., integrated discomfort degree (Zeng et al., 2011), thermal deviation index (Pisello et al., 2012), time lag and decrement factor (Kontoleon and Eumorfopoulou, 2008), total equivalent temperature difference (Kaşka et al., 2009), etc.) have been used for evaluation. For these evaluation indices, the performance of a building material or component is usually evaluated indirectly through some thermal state parameters of the passive building (indoor air temperature in most cases). Actually, the energy consumption that "saved" by the adoption of a building material or component should be a direct and natural index to evaluate the energy saving performance of the material or component. However, the application of energy saving techniques to a passive building does not involve the active input of energy. To evaluate performance based directly on the energy consumption, we presented the concepts of the energy saving equivalent (ESE), which can connect the thermal state parameter with a hypothetical energy consumption, and the energy saving index (ESI), which can be used to evaluate the performance of building components or materials on a common basis (Ye et al., 2014). The definitions of ESE and ESI and the methodology of calculation are restated in the next section for the convenience of readers. In this study, the passive application performance of three kinds of VO_2 glazing was simulated for a residential room. And the effects of the VO_2 glazing's radiation properties on the passive performance were discussed with ESI as the evaluation index.

2. The concepts of ESE and ESI

2.1. Definition

The original thermal state of a passive room over a particular time period can be described as S_1. After the use of a passive building component or material (e.g., insulation material, PCM, etc.), the thermal state during the same period becomes S_2. The parameter used to characterize the thermal state is set as the indoor air temperature in this paper. In the scenario illustrated in Fig. 1, the black solid line represents the original indoor temperature state, S_1, and the red dotted line represents the indoor temperature state after the use of a building component or material, S_2. If the indoor temperature state S_1 is forced to transfer into S_2 without the addition of the component or material, a cooling quantity (described as Q_c, the light-colored area in Fig. 1) and a heating quantity (described as Q_c, the dark-colored area in Fig. 1) will be delivered into the room. Consequently, the use of the building component or material and the delivery of Q_c and Q_h have the same effect on the indoor temperature: they change the indoor temperature state from S_1 into S_2. From the perspective of changing the indoor temperature state, the use of the building component or material is equivalent to the effect of the Q_c and Q_h input, and means that Q_c and Q_h can be used to represent the effect of the building component or material applied to the passive room.

According to Fig. 1, the effect of the component or material on reducing the indoor temperature is equivalent to Q_c and that on increasing the temperature is equivalent to Q_h. In the summer, the former is a positive effect and the latter is a negative effect. To comprehensively evaluate the

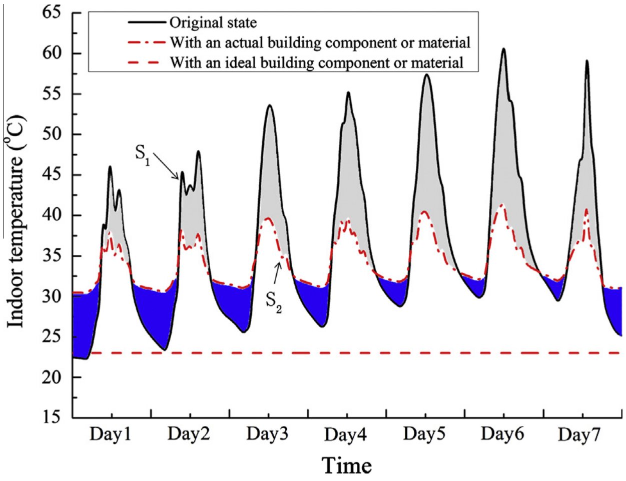

Fig. 1. Schematic representation of the energy saving equivalent. S_1 represents the original indoor temperature state of a passive room. S_2 represents the indoor temperature state with the adoption of a passive building component or material. To change S_1 into S_2 without the passive building component or material, a hypothetical cooling quantity (the gray area) and a heating quantity (the blue area) should be delivered into the room. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)