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The effect of variation in the transition hysteresis width and gradient in thermochromic glazing systems

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ABSTRACT

Glazing based on thermochromic thin films has been noted to potentially reduce the energy demand in buildings by modulating the solar heat gain depending on the coating temperature. Such “intelligent” glazing has been researched for a number of years with little attention paid to the thermochromic transition details such as the transition width and transition gradient. In this study we use idealised thermochromic spectra and the programme Energy Plus to simulate the effect of simultaneous variations in thermochromic transition width and gradient on building energy demand in order to elucidate which parameters are the most important for optimal energy saving behaviour. The investigation takes place across warm, varied and cold climates and the results are compared against current industry standards. The results suggest that under ideal conditions energy savings of greater than 50% compared to standard double-glazing are obtainable in a hot climate where the thermochromic transition occurs at a low temperature with a narrow hysteresis and sharp gradient.

1. Introduction

“Intelligent” glazing systems based on thermochromic vanadium dioxide have been postulated since the early 1990s [1]. This technology is based on a temperature modulated structural phase change, which occurs in the pure vanadium dioxide material at 68 °C where the low temperature monoclinic phase (VO_2 M) converts to the higher temperature rutile phase (VO_2 R) [2]. Significant changes in infrared optical properties and electrical conductivity occur in the material as a result of this structural change. The monoclinic phase is a semiconductor and transmissive across a wide range of solar radiation whereas the rutile material is metallic in nature and reflects across the same range of solar radiation [3]. Significant research has been conducted on the fabrication and modification of vanadium dioxide thin films structure and thermochromic properties [4]. With regard to “intelligent” glazing it has been assumed that the ideal properties are that the transition temperature for the material needs to be near that of room temperature (20–25 °C), and that the transition should occur quickly meaning that the hysteresis loop width should be as narrow as possible and the gradient of the hysteresis should be steep as possible. While these parameters seem to be reasonable assumptions there has been little work assessing the energy performance dependence on these parameters [5,6].

This variable optical behaviour is in contrast to the existing commercial approaches which rely on glazing with fixed optical behaviour such as absorbing glass, heat mirrors or Low-E coatings [7].

For vanadium dioxide to be effective in “intelligent” glazing it is essential to lower the transition temperature from 68 °C seen for the pure material to nearer room temperature [8]. It has been demonstrated that the transition temperature may be tuned to some level through doping of metal ions into the vanadium dioxide lattice [9,10]. It has been previously shown that tungsten is the most effective metal ion as it is found to lower the transition temperature of the material by 25 °C for every atomic percent of the element incorporated into the film [11]. Film strain has also been demonstrated to influence the transition temperature [12] and further that careful choice of deposition conditions can induce varying levels of strain [3]. Various methods have been utilised for the production of tungsten doped vanadium dioxide films including physical vapour deposition [13], sol–gel [14], and chemical vapour deposition (CVD) methodologies [15–17]. CVD routes to the production of VO_2 films may be considered more attractive because of the ability to integrate CVD processes with high volume float glass manufacture and the

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desirable physical properties of CVD produced films, which are generally adherent and durable [18].

A variety of studies have been performed on thermotropic systems by Lee et al. [19] who found that the use of thermochromic polymer blends that had a change in optical properties in the visible portion of the spectrum would lead to a reduction in shading requirements, but an increase in lighting needs whilst overall improving the energy characteristics of a building. Vanadium dioxide based systems have a potential advantage compared to these systems as there is no change in the visible portion of the spectrum, only in the infrared portion when undergoing the transition [7].

Ye et al. have discussed at lengths the requirements for a perfect window that could be considered to be thermochromic in nature [20–22]. They found through their modelling work [20] that variable absorption gave a larger contribution to the energy saving properties of the glazing than variable reflectance. They also found that modulation of emissivity was important. In other work by the same group they have demonstrated that current thermochromic systems based on solution processed vanadium dioxide films [23] do not live up to the performance of the ideal thermochromic window; although additional work has demonstrated that thermochromic films do have an energy saving effect, inspite of a high transition temperature [24].

The synthesis of thermochromic vanadium dioxide films is well known [4], an extensive range of transition hysteresis properties have been demonstrated [3,16,25]. However there is a major gap in understanding how these properties impact upon the energy demand reduction characteristics that these films may give to glazing systems. In this paper we seek to address this knowledge gap by performing energy-modelling studies in Energy Plus; using idealised thermochromic vanadium dioxide spectra (based on existing start of the art) to examine the effect of thermochromic transition hysteresis width and transition gradient on the energy demand reduction properties of thermochromic glazing systems based on VO_2 in several different climates. They are assessed with reference to some existing industrial standards. This study is crucial to evaluate and quantify the performance of thermochromic glazing and the various transition parameters.

2. Experimental section

Energy modelling and analysis was performed on the simulation software Energy Plus™ developed at Lawrence Berkley National Laboratory and US Department of Energy. Energy Plus™ software is an energy analysis and thermal load programme allowing the user to input a building based on its dimensions, physical construction, usage and mechanical systems present. The software has two modes of input/editing either through the software interface or by use of a text file. This work used Energy Plus™ version 5.0.

2.1. Building parameters

The building set up was of a simple single room assumed to be within a building such that only on wall was exposed to the external environment. The dimensions of the model were 6 m × 5 m × 3 m (length × width × height) and was orientated such that each wall was perpendicular to either North South or East West with the external wall being the South facing. The external wall of the building was modelled such that the wall was covered by a window for 99% a schematic of the model can be seen in Fig. 1. A 99% glazed façade was chosen as to be representative of modern office blocks. The model is a mid floor office in a multifloor complex and is therefore buffered from above and blow by conditioned spaces for this reason the ground temperature would have no effect on the models performance. The choice of the ground temperature was taken to be 18 °C throughout the year not to reflect the ground temperature but to be representative of a further buffering zone below the model. All walls other than external were assumed to be adiabatic with a constant temperature of 18 °C.

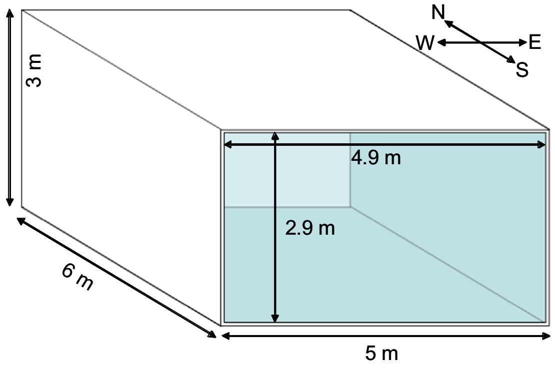

Fig. 1. Schematic of room modelled in Energy Plus™.

The materials shown in Table 1 are the standards used in Energy Plus and the data is taken straight from the programme defaults.

Table 2 shows how each of the building components were constructed and the properties of the materials are shown in Table 1. The window of the building was the only part of the structure that was modified through out the simulations and this was done by changing the glazed layer in the system. The air gap in the windows was 12 mm and the glazing was modelled so as to be on the inside face of the outer pane of glass in all cases.

2.2. Building conditions

The internal conditions of the building were chosen so as to represent the conditions found in an office bloc. The internal temperature, controlled by the inbuilt HVAC model, was chosen to be between 19 and 26 °C to allow for comfortable working conditions. The required luminance in the building was taken to be 500 lx, this corresponds to a lighting load of 400 W. The lights are allowed to be fully dimmable and will be reduced when adequate light can enter through the window. The lighting was fully dimmable between 0% and 100% and was automated and zoned. The casual heat gain (equipment and people) is set to 500 W in total. The ventilation rate was 0.025 $m^3 s^{-1}$. To simulate an office like building the occupancy was set to be from 8:00 to 18:00, for five days a week.

2.3. External conditions

External conditions were controlled by use of weather files. The weather files give a yearly reading of the conditions in various locations around the world with all required information i.e. solar gains, outside temperature etc.

2.4. Model limitations

The main limitation to this model is its simplicity and its directional confinements, assuming a South facing façade. The model could be expanded upon by introduction of further units with different orientations or window sizes. The model is also limited as the building will not be fully optimised for all climates. In the different climates, warmer, cooler, variable, the materials and insulating would vary for optimisation. The materials would