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Energy modelling studies of thermochromic glazing

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ABSTRACT

Theoretically thermochromic glazing has the potential to reduce energy consumption in buildings by allowing visible light for day lighting, reducing unwanted solar gain during the cooling season, whilst allowing useful solar gain in the heating season. In this study building simulation is used to predict the savings made by novel thermochromic glazing coatings compared to standard products, for locations with different climates. The results suggest that thermochromic glazing can have a significant energy saving effect compared to current approaches.

1. Introduction

Thin films of vanadium (IV) oxide have been the subject of intensive research efforts in recent years due to their potential application as an intelligent window coating [1,2]. These technologies are based on the thermochromic metal to semiconductor transition which occurs in the pure material at 68 °C, associated with the structural adjustment from the low temperature monoclinic phase (VO_2 M) to the higher temperature rutile phase (VO_2 R) [3]. This structural transformation causes significant changes in electrical conductivity and infra-red optical properties. The rutile material is metallic and reflects a wide range of solar radiation, whereas the monoclinic phase is a semiconductor and transmissive. This dynamic behaviour is in contrast to existing commercial approaches which rely on glazing with static behaviour such as heat mirrors, absorbing or Low-E coatings [4].

For vanadium dioxide to be effective as an intelligent window coating it is desirable to lower the transition temperature from 68 °C to nearer room temperature. Doping studies have shown that the transition temperature can be altered by the incorporation of metal ions into the vanadium dioxide lattice [5,6]. It was found that the most effective metal ion dopant was tungsten which lowers the transition temperature by 25 °C for every atomic percent incorporated of the dopant [7]. The transition temperature has also been shown to be affected by film strain [8] and it has been demonstrated that strain can be introduced by careful choice of deposition conditions [9].

Tungsten doped vanadium dioxide films have been prepared by a variety of methods including sol–gel [10], sputtering [11], and chemical vapour deposition (CVD) methodologies [12–14]. CVD routes to the production of doped VO_2 films are generally considered more attractive because of the compatibility of CVD processes with high volume glass manufacture and the physical properties of CVD produced films which are usually adherent and long lasting.

Recently a new hybrid CVD method has allowed for the easy incorporation of gold nanoparticles into growing films [15]. The incorporation of gold nanoparticles leads to significant changes in the optical and thermochromic properties of the film. The film colour can be altered dramatically from an undesirable yellow/brown colour to a range of more aesthetically pleasing greens and blues. The transition temperature is reduced and the film reflectance increased.

It has also been demonstrated that the use of surfactants in hybrid CVD reactions can influence the properties of the grown films. Surfactants are molecules that can change the surface tension of a liquid; within a hybrid CVD process, they can affect the deposition mechanisms and therefore the structure of the films. In the case of vanadium dioxide, they induce strain by templating film growth thus significantly lowering the thermochromic transition temperature [16,17].

All these data show that significant steps have been made in the production of thermochromic glazing; however the advantages in the use of these coating were not investigated conclusively – to our knowledge nothing has been published in the literature regarding the energy saving performance of thermochromic coatings. Several studies have been performed on thermotropic [18–20] and electrochromic [21–24] systems showing that these can significantly improve building energy performance. However, these are differ-

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Table 1
Summary of coatings, glass and optical data examined in this study.

Sample	T_c/°C	Cold visible transmittance/%	Hot visible transmittance/%	Room temperature emissivity	Hot state emissivity
Optifloat clear (plain float glass)	–	92	92	0.837	0.837
Sputtered Silver Coated Glass (thin metallic coating – SB)	–	82	82	0.030	0.030
Blue Body Tinted Glass (body tinted absorbing glass – AB)	–	76	76	0.837	0.837
Thermochromic 1 (VO_2)	59	78	74	0.825	0.795
Thermochromic 2 (VO_2 + gold)	43	56	48	0.800	0.752
Thermochromic 3 (VO_2 + TOAB)	38.5	61	51	0.827	0.789
Thermochromic 4 (VO_2 + gold + TOAB)	45.5	77	49	0.828	0.797

ent classes of material in that to work as smart windows they rely on a change in transmission in both the infra-red and the visible portion of the spectrum. Thermochromic vanadium dioxide has a constant visible spectrum but a change in the infra-red portion of the spectrum [25].

In this paper we use energy modelling studies to examine the behaviour of a variety of thermochromic vanadium dioxide films and the energy consumptions associated with them. They are assessed with reference to some existing commercial products; a comparison with thermochromic films with "ideal" optical properties based on what is obtainable in practice is also considered. This study, the first of this kind, is crucial to evaluate and quantify the performance of thermochromic glazing.

2. Glazing and simulation model data

The experimental routes and characterisation of the thermochromic thin films used in this study have been reported previously [9,15–17]. We have used four different types of thermochromic film in our modelling: pure vanadium dioxide, vanadium dioxide with gold nanoparticles, pure vanadium dioxide grown with a growth directing surfactant, and vanadium dioxide grown with both a growth directing surfactant and gold nanoparticles. These are compared with three standard commercial products, as summarised in Table 1.

The thermochromic coatings were deposited onto Optifloat clear (plain float glass) 4 mm thick glass. Spectral data was recorded using a PerkinElmer Lambda 950 spectrophotometer. Emissivity data was obtained using a PerkinElmer PE883 dual-beam IR spectrophotometer, using a NPL calibrated IR mirror as the reference standard. Emissivity was calculated according to standard EN763.

Energy Plus software developed by the Lawrence Berkeley National Laboratory [26] and US Department of Energy was used to perform energy simulations and analysis. Energy Plus^{TM} is an energy analysis and thermal load simulation program. Based on a user's description of a building from the perspective of the building's physical make-up, associated mechanical systems, etc.

A series of simulations with different configurations and settings were run in order to evaluate the performance of the thermochromic coatings in different climates. The simulation set period is one year, with data points gathered every hour.

A very simple model of a room in a building was constructed in Energy Plus^{TM}. The room has external dimensions 6 m × 5 m × 3 m (length × width × height) and it is placed so that the axis of every wall is perpendicular to one of the orientation north, south, west and east. We consider the room to represent the façade of a generic building so that just one wall is exposed to the external environment (weather, sun, wind, etc.); the remaining three walls are not affected by external conditions. The building is located in the northern hemisphere and the external wall is supposed to be exposed to the southern side. The modelled zone is a mid floor office, of a multi-storey block, buffered both above and below by conditioned spaces. The ground temperature would therefore have no effect on the performance of the studied zone. The choice of ground temperature was set not to reflect the real local ground temperature but rather the temperature of a further buffering zone, below the modelled spaces, and was taken to be 18 °C throughout the year.

Two different glazing possibilities were considered; one where the window was 1.5 m × 2.5 m located in the middle of the southern wall surface (covering 25% of this surface) considered to represent a residential scenario. The other comprised the whole of the southern face (100%) – a glazing wall, representing a modern commercial building. The model is summarised in Fig. 1.

Further details governing the materials used for walls, etc., have been previously reported [27]. In both cases the window is double glazed with a 12 mm air cavity, the coating was always modelled on the inside face of the outer pane. The only difference between each simulation was the glazing or coating used, the 7 examples investigated are summarised in Table 1.

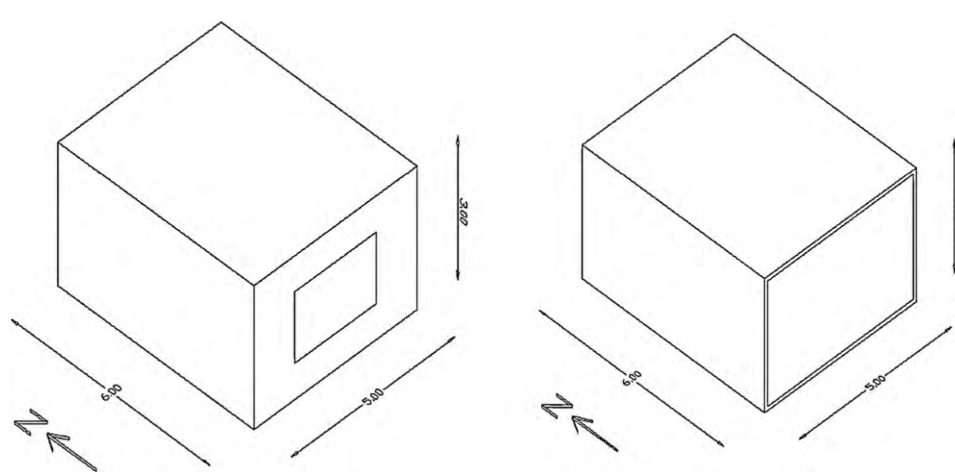

Fig. 1. The two room models: on the left – window 1.5 × 2.5 (25%); on the right – glazing wall (100%).