INTEGRATED ENERGETIC APPROACH FOR A CONTROLABLE ELECTROCHROMIC DEVICE

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ABSTRACT

The potential of controlling techniques for an electrochromic device is investigated in a systematic way, using both experimental and theoretical tools. Concerning the theoretical part a model was developed in the TRNSYS environment and validated against experimental data. These data were collected from experiments, which were carried out in a PASSYS test cell with a movable wall. Having established a good model performance several cases of window types (such as a 4mm clear window and a low-e double glazing) and controlling strategies for the electrochromic device are simulated. Obtained results from the series of simulations were compared in terms of the heating and cooling loads of the test cell for each case. It was found that the development of a scheduled control strategy for the electrochromic glazing is bettering terms of cooling loads.

KEYWORDS

Electrochromic glazing, control strategies

INTRODUCTION

Windows have always been a critical link in the energy system of buildings. Recently control strategies oriented towards energy saving have been developed for windows. The purpose of the current work is the development of a model able to describe a test cell with a movable wall, in order to simulate its thermal behaviour using different window types. The model is validated against experimental data obtained from the test cell using an electrochromic window. Having established a good model performance, five windows with variable transmitting properties as well as a static window are simulated and compared, using the TRNSYS 15 environment, in order to identify the optimum performance. The results obtained imply that the solar control strategy appears to be the most feasible approach in order to construct switchable windows, which behave well with respect to energy efficiency and comfort.

EXPERIMENTAL SETUP

A series of experiments have been carried out in a PASSYS test cell (Wouters and Wandaele 1995). In particular, the experiments aimed at investigating the possibility of energy conservation using an electrochromic façade. The PASSYS test cell is a fully equipped, two-zone, outdoor facility for thermal monitoring. The south façade of the cell is removable and allows installation and testing of specific building components. Experiments were carried out in the 'test room' while the door connecting it to the 'service room' was kept closed and sealed. The test room has a height of 2.72 and a volume of 35 m^3.

The major parameters defining the thermal performance of the test room were constantly measured. Measurements of room air temperature were realised by seven double-shielded PT100 sensors. Furthermore, the surface temperature was measured by an array of eight PT100 sensors. The arrangement of the air temperature and surface temperature sensors (marked X and grey circle respectively) is illustrated in Fig. 1. Ambient air temperature data were provided from a standard meteorological station next to the test cell by both a shielded and a ventilated air sensor. All indoor and outdoor temperature sensors were accurately calibrated in order to achieve the highest possible accuracy regarding the temperature difference between indoor and outdoor environment. Wind speed and wind direction measurements were obtained by a 3-cup anemometer (accuracy 2%) and a vane (accuracy 5%) mounted on a 10 m height mast. Additionally, the meteorological station provided with data of global irradiances on horizontal and south vertical plane, diffuse irradiation, long wave radiation and relative humidity.

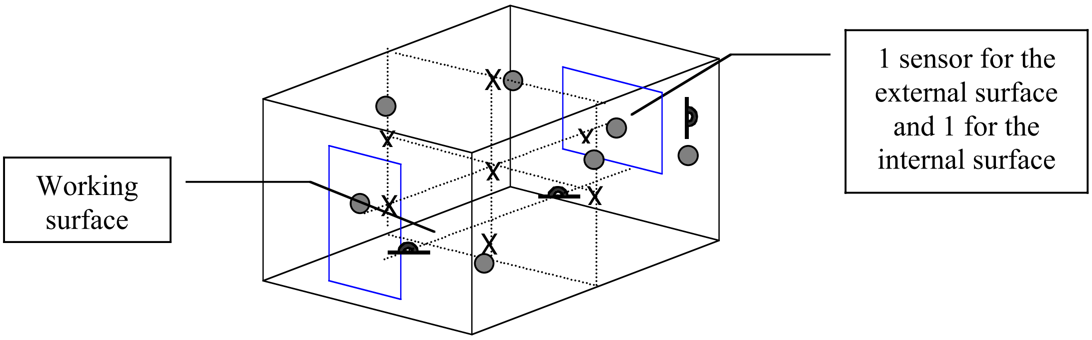

Figure 1: The test cell with the position of the sensors

Internal illuminance sensors were installed on the working surface of the test cell. One sensor was placed close to the tested façade (1.3 m from the window) and another was placed 4.3 m from the window. While at the same time external global and diffuse illuminance were measured. Infiltration experiments were performed using the tracer gas decay method (sampling at 4 locations). Finally, on the electrochromic façade, which is installed on the south wall, two sensors were placed in order to monitor the temperature variations of the surface of the glazing.

SIMULATIONS

Following the experimental campaign a theoretical model was implemented in the TRNSYS environment, which was then validated against the experimental data. It was found that the general tendency as well as the temperature deviation followed the same pattern. Having established its good performance a series of theoretical cases were adapted in order to compare the electrochromic device to several types of conventional and high performance windows.

The developed model was then applied to simulate the thermal behaviour of several types of windows with different properties. The glazing units simulated were: one single clear 4 mm, one double clear low-e, one double reflective low-e and one electrochromic in its two extreme states (bleached and coloured). Finally the case of a simple control of the electrochromic glazing unit was simulated. The single clear 4 mm unit was defined as the base case. The properties of the cases examined are shown below in table 1:

TABLE 1

Properties of the glazings simulated as obtained by the WINDOW 4.1 software.

	U	g	T_{vis}	T_{sol}
Base case: single clear 4mm	5.8	0.87	0.9	0.85
Case 1: double clear low-e	1.4	0.59	0.7	0.42
Case 2: double reflective low-e	1.1	0.36	0.5	0.27
Case 3: EDGU (bleached state)	1.42	0.36	0.5	0.3
Case 4: EDGU (coloured state)	1.42	0.22	0.32	0.17
Case 5: EDGU (scheduled control)	-	-	-	-

Validation

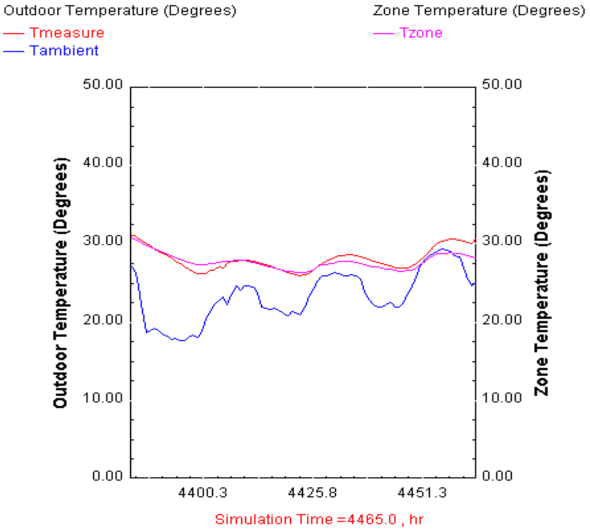

Figure 2: Comparison of the theoretical model to actual measurements.

In Fig.2 the external temperature, which varied between 18 °C -29 °C, and the corresponding simulated (magenta) and measured (red) zone temperatures are depicted. It must be noted that the internal measured and simulated temperatures were limited to a smaller range between 25 °C -32 °C. Coming out to the comparison between the simulated and measured temperatures it is obvious that the agreement is quite good throughout the experimental testing period. In particular, the two lines coincide for the greatest part of the simulation time. A more careful examination shows that the model simulations smooth out the largest temperature deviations of the measured values. This was expected since the measured temperature values are point measurements while the model produces rather integrated values.

A series of simulations were performed using the developed model and typical climatic data in order to calculate the heating and cooling loads in each of the 5 different cases. The results are illustrated in Fig. 3.

Base case: The red line corresponds to the typical temperature of the region of Athens covering a range of nearly 40 °C. The seasonal temperature variation is also large reaching about 20 °C. The simulated temperature (Tzone), illustrated by the blue line, indicates similar trends to those of the ambient temperature. During the cold period of the year the mean temperature is about 22 °C while during the warm period of the year the temperature stabilises at 26 °C. It is obvious that the heating load during the winter is much smaller than the cooling load, which reach the values of 14.8×10^5kJ and 23.6×10^5kJ respectively.

Double clear low-e: The results obtained in figure 11 are quite similar to the previous case for the cooling period (18.4×10^5kJ). Of course as it was expected that the differences for the heating period is great since the base case allows 90% of the incident solar radiation to penetrate the glass and heat the test cell. At the same time the low-e coating does not permit to the long wave radiation to leave the room (6.02×10^5kJ).

Double reflective low-e: The impact of the reflective membrane is obvious especially during the summer, where the duration of the cooling is shorter than that of the previous cases. However, because of the reflective film the heating load is slightly higher than that of the double clear low-e glazing.

EDGU (bleached): The electrochromic glazing unit in its bleached state behaves nearly identical to the previous case (double reflective low-e glazing). The only difference is for the heating period where an increase of approximately 12% of the heating load can be observed (heating load: 9.07×10^5kJ, cooling load: 10.2×10^5kJ).

EDGU (coloured): the very bad performance of the electrochromic glazing unit in its coloured state during the heating period where the heating load value approaches the value obtained for the base case (11.9×10^5kJ and 14.8×10^5kJ respectively). When the glazing is operating in the coloured state only a small part of the incident solar radiation is entering the test cell and therefore more energy is required to heat the room.

On the contrary for the warm period the cooling load is the best value obtained for all six cases considered (7.5×10^5kJ). This however is of great importance especially for cooling-dominated climates, such as Athens.

EDGU (scheduled control): The previous examples indicated that it would be of interest to consider another case, which is a combination of the two states of the EDGU. In this respect it was decided to formulate a simple control strategy where the EDGU would be in the coloured state during the warm period and in the bleached state for the remaining of the year. Thus, an optimisation of the two previous cases would be achieved. The figure above shows the corresponding simulations where significant improvement during the heating period was obtained (9.06×10^5kJ) without damaging the good performance during the cooling period (8.2×10^5kJ).

REMARKS

According to the results obtained, it is obvious that the most appropriate strategy would be to develop a schedule of operating hours of the EDGU following the needs of the test cell. The simplest form of control proposed was to maintain the EDGU in the coloured state during the summer. Between the different types of glazing units simulated, the EDGU operated in the coloured state throughout the year presented very low cooling loads, while the cooling loads calculated in the case where the simple control scheme was applied where slightly elevated. However, during the winter the heating loads are slightly high because of the low value of the visible transmittance, with respect to the other glazing units). The relative differences (percentage) of the heating loads (A) and the cooling loads (B) with respect to the base case unit are given in eqn. 1 and eqn. 2:

$$A = \frac{C.E_{vitrage} - C.E_{4mm}}{C.E_{4mm}} * 100 \qquad \text{Eqn. 1}$$

$$B = \frac{C.R_{vitrage} - C.R_{4mm}}{C.R_{4mm}} * 100 \qquad \text{Eqn. 2}$$

where $H.L_{glazing}$ is the heating load for each glazing unit, $H.L_{basecase}$ is the heating load for the base case glazing unit, $C.L_{glazing}$ is the cooling load for each glazing unit and $C.L_{basecase}$ is the cooling load for the base case glazing unit. The heating and cooling loads calculated for each unit as well as the relative differences between the base case and the other glazing units simulated are summarised in the table 2.

TABLE 2
Heating and cooling loads and the relative differences of the glazing units simulated with respect to the base case.

	C.E. (kJ)	C.R. (kJ)	A (%)	B(%)
Base case: single clear 4mm	$14.8*10^5$	$23.6*10^5$	-	-
Case 1: double clear low-e	$6.02*10^5$	$18.4*10^5$	59.3	22
Case 2: double reflective low-e	$8.2*10^5$	$10.4*10^5$	44.6	55.9
Case 3: EDGU (bleached)	$9.07*10^5$	$10.2*10^5$	38.7	56.8
Case 4: EDGU (coloured)	11.9*10	$7.5*10^5$	19.6	68.2
Case 5: EDGU (scheduled control)	$9.06*10^5$	$8.2*10^5$	38.8	65.2

ACKNOWLEDGEMENTS

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REFERENCES

Karlsson, J. (2000) Control System and Energy Saving Potential for Switchable Windows. *Departement of Materials Science, The Ångström laboratory, Uppsala University*

Karlsson, J., Karlsson, B., Roos,A. (2000). Control Strategies and Energy Saving Potential for Variable Transmittance Windows Versus Static Windows. *Department of Materials Science, The Ångström laboratory, Uppsala University*

Sullivan, R., Lee, E., Papamichael, K., Rubin, M., Selkowitz, S. (1994). Effect of Switching Control Strategies on the Energy Performance of Electrochromic Windows. *Building Technologies Program, Energy and Environment Division, Lawrence Berkeley Laboratory, Berkeley CA*

Sullivan, R., Lee, E., Papamichael K., Rubin, M., Selkowitz, S. (1996). The Energy Performance of Electrochromic Windows in Heating-Dominated Geographic Locations. *Building Technologies Program, Energy and Environment Division, Lawrence Berkeley Laboratory, Berkeley CA*

Sullivan, R., Lee, E., Papamichael K., Rubin, M., Selkowitz, S. (1996b). Energy Performance Analysis of Prototype Electrochromic Windows. *Building Technologies Program, Energy and Environment Division, Lawrence Berkeley Laboratory, Berkeley CA*

Wouters, P., Wandaele, L., (1995). The PASSYS services. *Final report of the PASSYS research project. European Commision, DG XII.*

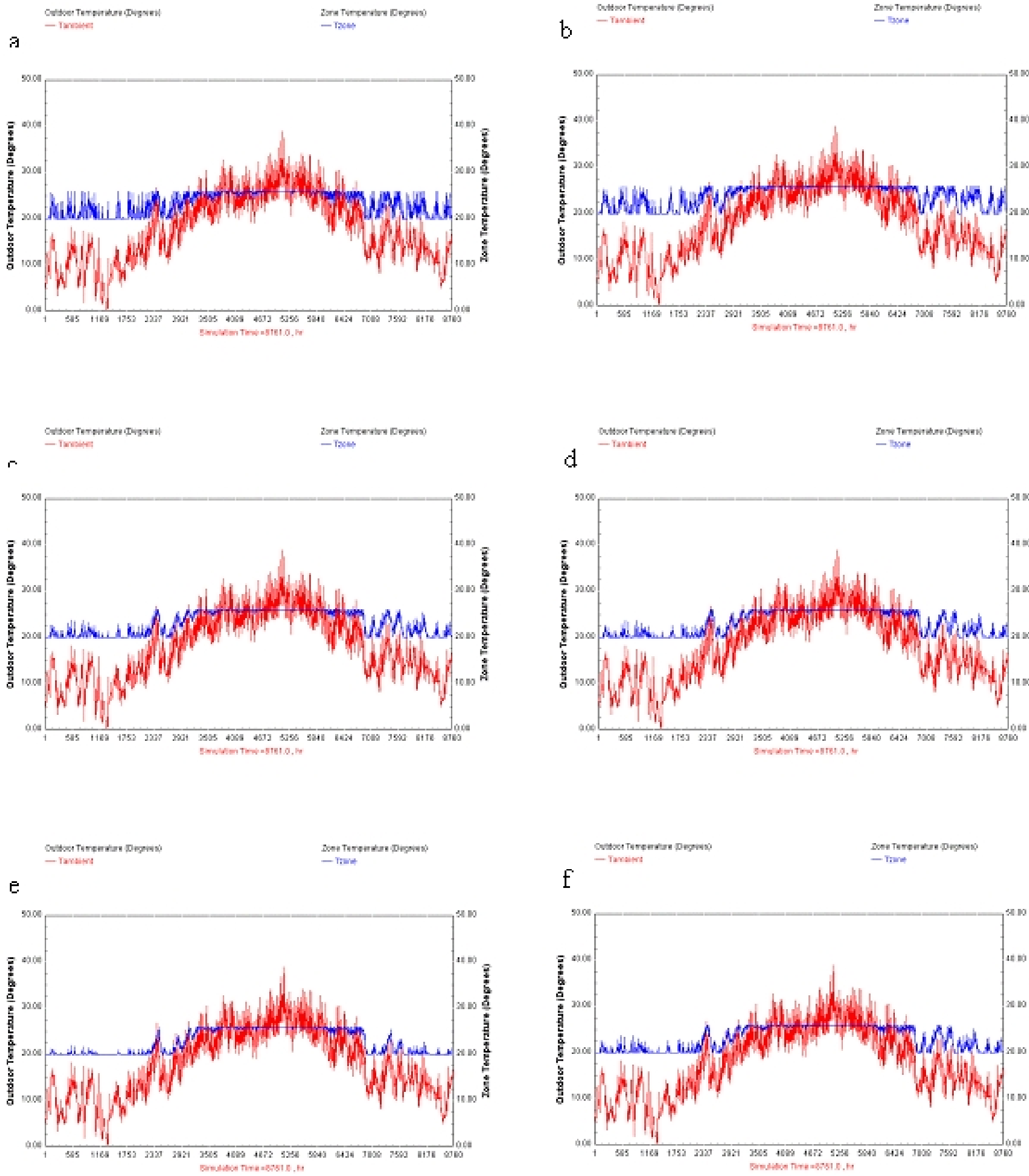

Figure 3: Profiles of the internal (red line) and the external (blue line) temperatures for: a. 4mm clear, b. double clear low-e, c. double reflective low-e, d. EDGU (bleached), e. EDGU (coloured), f. EDGU (scheduled control).