Optimum geometry and orientation of a building opening with an electrochromic glazing

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ABSTRACT

Windows are considered an important factor for comfort in residential and commercial buildings. Research turned to window technology when it was realized that poor thermal characteristics resulted in serious energy and economical consumption and pollution. Following an experimental campaign, which was carried out in a PASSYS test cell which provided a complete data base, a fuzzy system was developed and tested theoretically in order to control an electrochromic glazing in the best possible way. Concerning the theoretical part a model was developed in the MATLAB –SIMULINK environment. In the present paper the optimum opening characteristics and the orientation of the test cell were calculated so that a minimisation of the heating and cooling loads is achieved. Preliminary results indicated that a large opening contributes to big energy loses for the winter period while for the summer period the energy consumption is similar for all types of windows tested.

1. INTRODUCTION

Windows have come a long way since the ‘passive behaviour control’ of buildings were carefully studied back in 1973. The conceptual work and the research carried out on the specific component and on building integration conditions have been a rich and challenging field for innovation both on the technologies and on architecture.

In the last decade great interest has been shown to electrochromic glazing units and their use in order to provide comfort to users and energy saving. In this respect it is worth mentioning the work on potential benefits of electrochromics in comparison to other currently available and the emerging glazing technologies (Warner et al. 1992), as well as the energy performance under a variety of state-switching control strategies (Sullivan et al. 1994, Sullivan et al. 1996).

Furthermore the visual quality of electrochromic glazing units has been compared to that of conventional glazing and other switchable glazing (Moeck et al., 1996; Lampert, 1998; Georg et al., 1997). More recently, several control strategies and energy saving potentials for windows with variable transmitting properties were tested (Karlsson et al., 2000). The energy, thermal and visual aspects of electrochromic glazing units in Mediterranean climates as a part of a light control system has also been tested, (Gugliermetti and Bisegna, 2003).

More recent work focuses on the comparison of the energy performance of ten different control strategies developed for an electrochromic glazing system, Assimakopoulos et al., (2004). The control strategies included schemes for the scheduled operation of the glazing, simple ON OFF controllers, PID controller as well as advanced fuzzy controllers.

In the present paper the main objective is to test the energetic performance of an electrochromic glazing unit equipped with a fuzzy control system integrated in a PASSYS test cell in a more generalised platform, (Fig. 1). In this respect it was thought to be of importance to investigate in depth the change of the environmental and the design conditions of the test cell. This will provide a better insight not only of the optimum design and placement of a building but

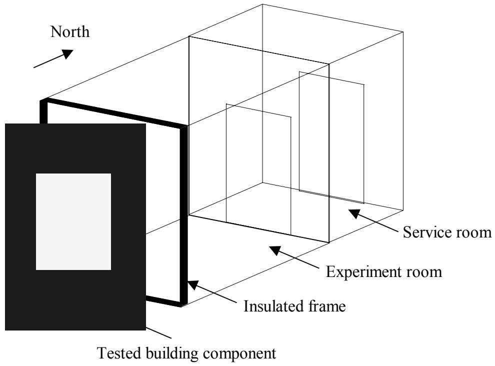


Figure 1: The PASSYS test cell.

also a thorough evaluation of the proposed control strategy.

2. THEORETICAL BACKGROUND

In Assimakopoulos et al., (2004) the energy performance of ten different control strategies developed for an electrochromic glazing system were compared. The control strategies included schemes for the scheduled operation of the glazing, simple ON OFF controllers, a PID controller as well as advanced fuzzy controllers. A series of simulations were carried out in order to test the relative performances of the developed control strategies and to investigate the influence of each control strategy to the thermal and visual behaviour of the building. The results indicated that because of the not so wide range of solar gain coefficient, (for the examined glazing is 0.36 and 0.18 for the bleached and coloured state respectively), the efficiency of the dynamic, (such as fuzzy), and control strategies decreases. These results will have a greater practical interest if they are applied in different buildings and climatic conditions. More precisely, it would be useful to discuss the change of orientation of the building and the geometry of the opening and to apply this generalization of the results to the advanced control system.

This paper focuses on the performance of the electrochromic glazing unit when controlled by a fuzzy system. The advanced fuzzy control systems were trained and checked using data collected from an experimental campaign during which the operation of the electrochromic glazing was performed manually. The experimental campaign had a period of three months during which two sets of experiments were performed. In the first one the expert would give priority to the indoor light level while in the second the priority was given to solar radiation. Therefore two control systems were developed, one for the summer period and one for the winter period. These controllers were used in a series of simulations, which were carried out with the aim of testing the relative performances of each case and of identifying the differences between the systems of control developed for various configurations. Initially seasonal simulations were made for each configuration and then their energy performances were compared. The simulations were carried out for a 90-day period for each season. In particular, the PASSYS test cell was simulated with the electrochromic glazing placed on the southern wall.

Several series of simulations were carried out with the aim of calculating the heating and cooling loads, (a 9000 BTU HVAC system was used). The results correspond to two three-month periods and they are divided to those of the cooling period and those of the heating period of the year. The HVAC system eliminates large fluctuations of the temperature, (set point temperatures are 21 °C for the winter and 26 °C for the summer).

The thermal and visual model of the PASSYS test cell was implemented in the 'SIBIL Building Toolbox' environment (Eftaxias et al., 1997). The `SIBIL Building Toolbox' is a computational tool used for the thermal simulation of the buildings. Its realization takes place in a `MATLAB-SIMULINK' environment (User's manual). The software 'SIBIL' was developed within the framework of the research project BUILTECH of the European Commission in order to provide a suitable environment for the development and testing of advanced intelligent control devices for buildings, while exploiting the existing functions of Toolbox of MATLAB available.

2.1 Change of orientation of the building

The model developed to simulate the PASSYS test cell was modified to fulfil the needs of the present investigation. In particular, the test cell was virtually rotated in all orientations.

The evaluation of the heating, cooling and lighting loads, according to the simulations carried out, is a very important parameter for the

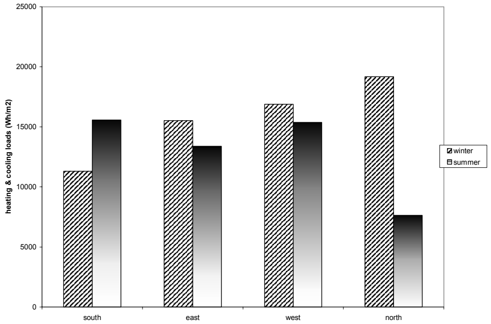


Figure 2: Heating and cooling loads calculated for the two periods (orientations).

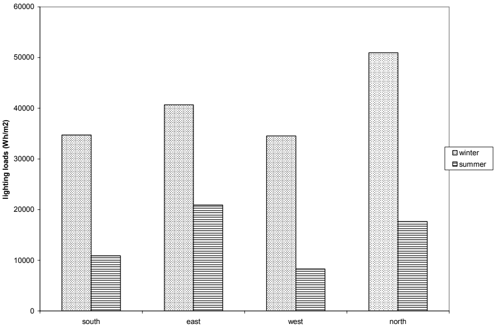


Figure 3: Lighting loads calculated for the two periods (orientations).

deduction of conclusions about the performance of the controllers in different orientations. Figure 2, illustrates the loads for the winter period. From this figure it can be seen that the orientation towards the north presents the greatest power consumption and the orientation towards the south the smallest. The other two orientations, (east and west), indicate similar values. This performance implies the importance of the building’s orientation even if the building is equipped with an electrochromic glazing and an advanced control system, as the selected cases of fuzzy logic among the most representative systems. The energy difference for the two extreme cases (northern, southern) exceeded 65%. This behaviour can be explained by the fact that the solar radiation does not enter the test cell when oriented towards the north, whereas for the other orientations the percentage of the incident radiation changes.

On the other hand during the summer (Fig. 3), it is the orientation towards east that presents the greatest power consumption. The three other cases are similar and the differences are limited to 1000 W/m2. The orientation towards the west presents the lowest energy consumption. This behaviour is directly associated the solar radiation entering the cell of test by the opening as well as to the angle of incidence of the solar radiation.

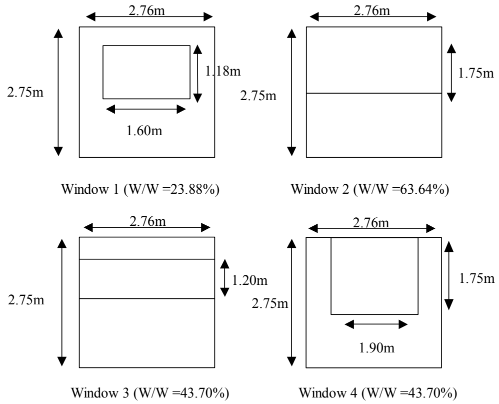
To check the remarks and the conclusions mentioned above, a table which indicates the period of operation of the electrochromic glazing, i.e. the whole of the hours during which the window is in each state is drown, (Table 1). This also illustrates the number of hours that each state of the electrochromic glazing is operated.

2.2 Change of size of the window

The window to wall ratio (window 1,2,3) and the openings geometry (window 3,4) were changed in order to study in depth their influence on the building performance. The four different types of windows, which were examined, are illustrated in Figure 4. The results indicate that, windows 2 and 3 give longer duration of high-level brightness since the shape of the windows allows for longer exposure to solar radiation. It should be noted that cases 2 and 3 maintain lower level of solar exposure than that of case 1, undoubtedly because they ‘see’ more dark regions of the sky. These results clearly indicate that the window opening is not the determining factor for a comfortable indoor envi-

Table 1: Indicator of the hours during which the window was in each state (all orientations).

	Summer (Hours of operation for each state)					Winter (Hours of operation for each state)			
State	South	East	West	North	South	East	West	North	South
P1	1130	1117	1116	1131	1562	1610	1667	1901	1562
P2	49	51	41	49	103	121	115	143	103
P3	69	52	88	83	105	143	175	79	105
P4	63	57	110	111	109	70	74	14	109
P5	850	884	806	787	282	217	130	24	282



Window 1 (W/W =23.88%) Window 2 (W/W =63.64%)

Window 3 (W/W =43.70%) Window 4 (W/W =43.70%)

Figure 4: Window types.

ronment. With low heating loads, but the control system of the window, which was beforehand selected.

Before proceeding with the winter period results, it should be mentioned that the selected control (strategy 6b) gives priority to the solar radiation incident on the facade. The evaluations for the energy consumptions of the winter period for the 4 types of windows that were examined are illustrated in Figure 5. The window with the smallest area, (window 1) gives the lowest energy consumption while the window with the largest area, (window 2) gives the highest value. Windows 3 and 4, which have approximately the same surface area, have very similar performances. This remark indicates that the geometry of the window under the conditions does not significantly affect the power consumption. On the contrary for the summer period, (Figure 6), the cooling loads are very similar for all windows. However, the window with the smaller area (window 1) and with the largest surface, (window 2), indicates the worst and the best behaviour respectively.

Here, the influence of the electrochromic glazing and the control system becomes obvious. Lastly, for the two other cases of openings the results are almost identical and they are approximately on the level of windows 1 and 2 mean level, (glazing 1: 15583.14 Wh/m2, glazing 2: 15455.75 Wh/m2, glazing 3: 15366.58 Wh/m2 and glazing 4: 15443.01 Wh/m2).

However, to facilitate the comprehension of the results, a table indicating the sum of the hours for each state of the window is given, (Table 2).

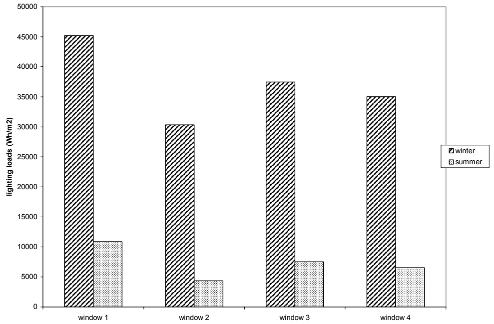


Figure 5: Heating and cooling loads calculated for the two periods (geometry).

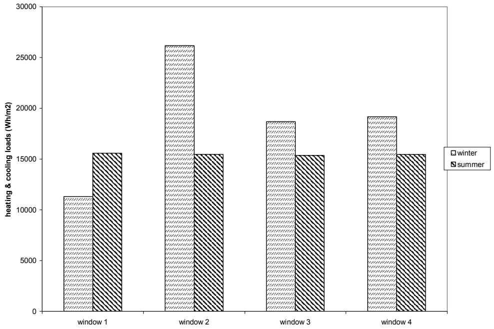


Figure 6: Lighting loads calculated for the two periods (geometry).

3. CONCLUDING REMARKS

The results presented here lead to the following conclusions.

In the case of winter the optimal orientation of the cell is the southern, which present very low heating loads. The heating loads for the remaining orientations are larger. For the eastern orientation the calculated heating loads are increased by approximately 27% while for the western and the northern orientations the increase is approximately 33% and 50% respectively. This constitutes the northern orientation as an unfavourable case. It is of great importance to note however that the lighting loads for the western and the southern orientations are very decreased while for the eastern and the northern orientations are increased by 15 and 32 % respectively. However for the summer period the northern orientation is the optimum as it presents the lowest cooling loads. For the other

Table 2: Indicator of the hours during which the window was in each state (4 types of glazing).

	Summer (Hours of operation for each state)				Winter (Hours of operation for each state)			
State	Window 1	Window 2	Window 3	Window 4	Window 1	Window 2	Window 3	Window 4
P1	1130	1122	1115	1123	1562	1412	1468	1398
P2	49	48	63	54	103	132	107	112
P3	69	71	56	65	105	178	155	157
P4	63	73	81	76	109	100	95	86
P5	850	847	846	843	282	339	336	408

orientations the calculated cooling loads are increased by 40-50% approximately. As far as the lighting loads are concerned the western orientation was found to have very low electric consumption while the other orientations present an increase of 23, 53 and 60 for the southern, northern and eastern orientation respectively.

The scenario corresponding to the basic case (window 1) for the geometry of the window is the best alternative for the particular configuration of the test cell during winter. This choice on average reduces the heating loads roughly by 45% compared to the other scenarios. For the summer period, however, each window type produces similar cooling loads with very small differences of the order of 5% or less. This was expected since the angle of incidence of the solar radiation is very large and the double window thermally insulates the test cell.

The lighting loads calculated for the two periods present the lowest value in the case of window 2 which has the greatest area of all. However, it can be seen that during the winter the windows that have larger length present lower lighting loads, while for the summer period the windows that have greater heights present lower lighting loads. This can be explained by the angle of incidence of the solar radiation, which during winter is 70° while during the summer it does not exceed 30°.

ACKNOWLEDGMENTS

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