TASK 27

Performance of Solar Facade Components

Performance, durability and sustainability

of advanced windows and solar components for building envelopes

Final Report

Subtask A: Performance

Project A2: Switchable glazing

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Project A2: Switchable glazing

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Abstract

Over the last couple of decades there has been a trend to use more glass as façade elements in large office blocks. This inevitably leads to overheating in the summer even in a northern climate, unless careful solar shading is included in the building concept. Unfortunately the easy way out is to install expensive and power consuming air-conditioning units. A better and more environmentally friendly way of reducing the over-heating problem could be to use efficient solar shading. A new and exciting concept of solar shading is switchable windows, also called smart windows. These are windows that can switch between high and low transmittance of solar and/or visible radiation. Thus, they can adapt to varying solar irradiation conditions and maintain high interior thermal comfort, as well as reduce glare. Owing to this ability to switch, these windows have a further energy saving capacity compared to static windows. Within the International Energy Agency, Solar Heating and Cooling Programme, task 27, the energy consumption of a standard reference office block has been evaluated using building simulation programs. The investigated office unit consists of two identical offices, one facing north and one facing south, both with two large windows, but not having a fully glazed facade. The results clearly indicate a large energy saving potential for switchable windows even compared to advanced static solar control windows. The simulations were carried out for three different European climates, Rome, Brussels and Stockholm. An especially interesting result was that the needed power for cooling can be reduced to almost zero in moderate to cold climates. Thus the need for power consuming air conditioning can be eliminated. This would reduce not only the energy consumption, but also the investment cost.

1 Introduction

In Europe about 40% of the total energy consumption is related to heating, cooling or lighting of buildings. This rather high fraction is to a large extend due to the fact that many buildings are not very efficient in their use of energy, and builders have been more concerned about reducing the investment cost rather than reducing the energy bill. Stricter national and international building regulations may change this in the future. A new European code for energy classification of buildings will come into force in 2006. This will make the energy consumption of buildings more "visible", just like the fuel consumption of cars has been a mandatory piece of information given to the customers for many years. In a building the weakest component of the climate shell from an energy point of view is usually the window. When it is cold outside heat losses through the glazed parts of the façade are generally much larger than the corresponding losses through the walls and roof, and in the summer the transmitted solar radiation often leads to overheating. Furthermore, the facades of modern office buildings tend to be more and more made up of glass. Architects seem to like the idea of the "transparent office building", even though this inevitably leads to problems with overheating in the summer and heat losses during the winter, unless special precautions are taken to prevent these problems.

Modern advanced glazing materials include products with optimised optical properties for different applications. In particular, recent developments in glass coating technology have led to a large number of coated glazing products with high light transmittance and low emittance of thermal radiation for energy efficient window applications. Using windows with such glazing products can lead to large energy savings compared to traditional windows (single or double pane with clear float glass), both in terms of reduced heating loads in the winter and reduced cooling loads in the summer. For heating dominated climates, windows with U-values (thermal conductivity) below 1.0 W/m^{2}K reduce heat losses through the windows drastically as well as improve the indoor thermal comfort. For cooling dominated climates windows with a ratio between light and total solar transmittance (T_{vis}/g) close to 2.0 reduce overheating caused by high solar heat gain without seriously affecting the light transmittance. Such windows are usually known as “low-e” and “solar control”, respectively. [1]

Another group of advanced windows are the so-called switchable windows. These are windows that can switch between high and low transmittance of solar and/or visible radiation. Thus, they can adapt to varying solar irradiation conditions and maintain a comfortable level of light and thermal transmittance. Owing to this ability to switch, these windows have a further energy saving capacity compared to static windows. The switching can be between high and low transmittance or between transparent and translucent states. This short presentation is limited to the high/low transparent case. Presently there are two possible technologies to achieve this switching. Either the switching is controlled by a low electrical voltage between transparent electrodes (electrochromic) or by the addition of hydrogen to a coated surface (gasochromic). In both cases the coatings become absorbing upon insertion of hydrogen in the film. Extracting the hydrogen leads to bleaching. In the electrochromic case hydrogen can be replaced by lithium. For a detailed description of the function of these surfaces the readers are referred to the literature. [2,3]

Switchable glazing products are not yet generally available on the market. Several manufacturers have developed prototypes which are currently being tested and evaluated. One of the major concerns is the durability of the switching capacity. This presentation is a short summary of the work conducted within the international collaborative project IEA Task 27. [4] One of the important achievements of this task has been to develop and evaluate methodologies for the testing and evaluation of switchable glazing products. Full scale prototypes have been tested in test sites both regards durability and optical performance. This presentation only reports on the efforts to perform energy simulations. When switchable glazing products can be introduced on the market it is important to be able to evaluate their performabne in a reliable way. The energy saving potential depends on how these window products are being used and also on the performance on static reference window products.

2 Simulated windows

Prototypes of switchable windows from three European manufacturers have been tested and evaluated within the task. The object has not been to compare products, but instead to evaluate energy performance and durability test procedures. The switchable prototypes are therefore not identified in this report, and the optical and thermal properties and the corresponding results are simply referred to windows A, B or C. Neither of the switchable coatings provides a surface with low thermal emittance. In order to get a window with a low U-value, the switchable panes have to be combined with a separate low-e coated pane in a double or triple glazed unit. The relevant optical and thermal parameters of the tested windows is shown in table 1. The task has lasted for 5 years and product specification has changed over these years. Building simulations performed by the different participants presented in this report may therefore have used slightly different input data. The data in table 1 can be said to be reasonably representative of the prototypes available during the task, but technically mature products and future products may have an improved dynamic range between dark and bleached states.

Table 1: Solar and thermal parameters for window simulations. TSET=g=Total solar energy transmittance (including absorbed and re-emitted energy), Tvis = light transmittance, U-value=thermal conductivity of window. A, B and C correspond to switchable windows and Ref is a static double glazed high performance low-e window.

Window	A	B	C	Ref
TSET (g)	0.30-0.10	0.48-0.18	0.40-0.16	0.62
T_{vis}	0.47-0.10	0.60-0.15	0.52-0.16	0.77
U value (W/m^{2}K)	1.2	0.93	1.2	1.3

3 Energy performance

The performance of a window depends on a large number of parameters and is in most cases difficult to evaluate. In the winter when it is much colder outside than inside the net energy flow through the window is going out and the room needs to be heated. In the summer it can be the other way around. It is often warmer outside than inside and then the net energy flow is going in. In addition to the thermal flow driven by a temperature difference, there is also the solar irradiation transmitted through the window. Inside the building, heat is generated by people, lighting and various electrical appliances as well as by the heating radiators. It is desirable to maintain an indoor temperature between 20 and 26 degrees. To achieve this we generally need both a heating and a cooling system. If it gets cooler we start to complain and if it gets warmer we loose concentration and become less efficient in our work. Since more than one third of the total energy consumption in Europe today is associated with temperature control of our buildings, it is easy to understand the importance of keeping the consumption down. In later years cooling has become more common and the summer of 2003 was very hot in Europe with temperatures exceeding 40 degrees in many places. The trend with an increasing use of air conditioning is alarming since it inevitably increases the consumption of and peak demand for electricity.

In order to be able compare results from different simulation tools a standard test office block has been identified. This office is oriented in the east-west direction with standard office modules facing north and south. Each office module has well defined dimensions and materials in walls, floor and ceiling. The adjacent offices are assumed to have the same temperature as the studied office and no heat transport takes place between these office modules. Heat can, however, flow between the north and south offices. The window size is fixed. A schematic picture of the office is shown in Fig. 1.

The simulations were performed for three different locations in Europe, representing Mediterranean, central European and northern European climate zones, Rome, Brussels and Stockholm, respectively. Climate data were generated by the program Meteonorm. The set points for heating and cooling were 20 and 26 degrees Celcius, respectively.

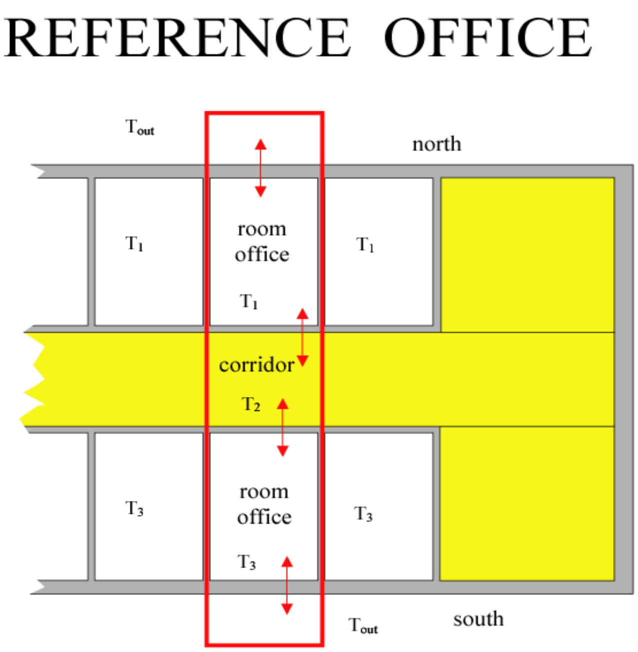

Fig. 1: Standard reference office

4 Energy balance simulations

In order to calculate the total energy balance of the offices as defined in Fig. 1, simulation tools have been used. They make it possible to simulate the temperature inside the rooms of a building hour by hour throughout the year. The physical properties of all building elements need to be known, together with the meteorological data for the location of the building and occupant behaviour. All simulation tools are based on models and simplifications of the building structure. The simulation tools so far used in Task 27 are TRNSYS [5], CLIM2000 [6], BSIM [7], DEROB-LTH [8] and WINSEL [9]. The reader is referred to the references for the details of these tools.

Switchable glazing needs a control strategy for when it should be in the dark state and when it should be in the bleached state. This strategy can be based on a number of parameters. Minimising power consumption is not necessarily what the occupants want. Glare reduction may be the prime factor for the staff who sit in front of computer screens, while temperature is more important to others. Physical parameters that can be used for the control are solar irradiation, outside temperature, indoor temperature, light level inside the office, occupancy, time of day and time of year. For each one of these parameters different set points and different control algorithms can be used. The switching time is of the order of several minutes so a time constant must be used to avoid too frequent switching. All this means that the simulation of the energy and power consumption of the office block is complex. For any control strategy it is important to be able to switch to manual control.

In order to evaluate the limits of the switchable window the simplest possible control strategy was used for some of the calculations. This means no control at all, i.e. having the switchable windows as two separate windows; always dark and always light. This is equivalent to having the window in the dark state whenever cooling is needed and in the light state when heating is needed.

5 Results and discussion

Only a small selection of the obtained results are presented in this summary report. These can be seen as examples of how data can be presented and give an indication of the results. In Figs. 2, 3 and 4 the DEROB-LTH results are shown for Rome, Stockholm and Brussels for two of the switchable windows together with the low-e reference window. The graphs show the energy demand for heating and cooling for the south and north facing office modules placed in the three climates. The switchable windows have been calculated as being always in the dark (colored) state and always in the light (bleached) state. In the comparison with the reference window the switchable window should be in the dark state for cooling and in the bleached state for heating. In the graphs heating is shown as positive values and cooling as negative values. As can be seen there is a considerable saving potential for the cooling load in all three locations. For the heating, when the switchable windows are in their bleached states, the optical properties are very similar to the static reference low-e window and the differences are quite small. Among the results, it is interesting to note the small difference in cooling load between Brussels and Stockholm. It is also clear that for the warmer climate in Rome a large portion of the cooling load is caused by high outdoor temperatures while in Stockholm and Brussels the solar heat gain contributes more to the cooling load. This leads to the very interesting conclusion that although the saving in units of kWh is larger for Rome than for Stockholm and Brussels, the cooling load can be more efficiently reduced by solar shading in the central to northern

European climates. By proper design of the building and by using night time ventilation efficiently, it should be possible to eliminate the need for air conditioning units completely.

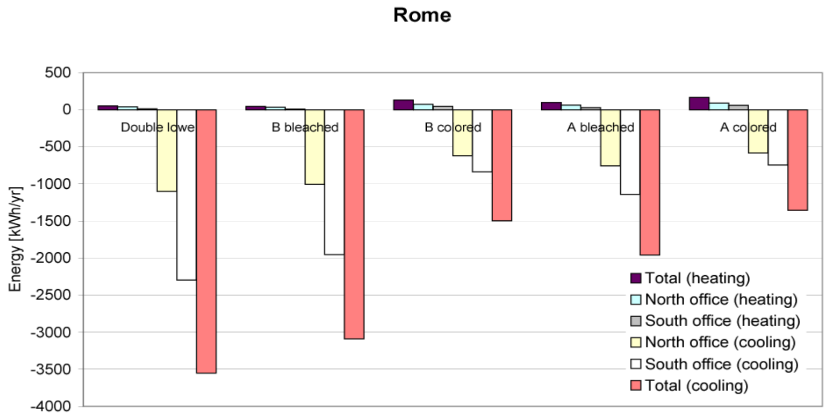

Fig 2: Heating and cooling loads for the north and south office modules equipped with two of the switchable windows (A and B) and the reference window (double low-e) in Rome

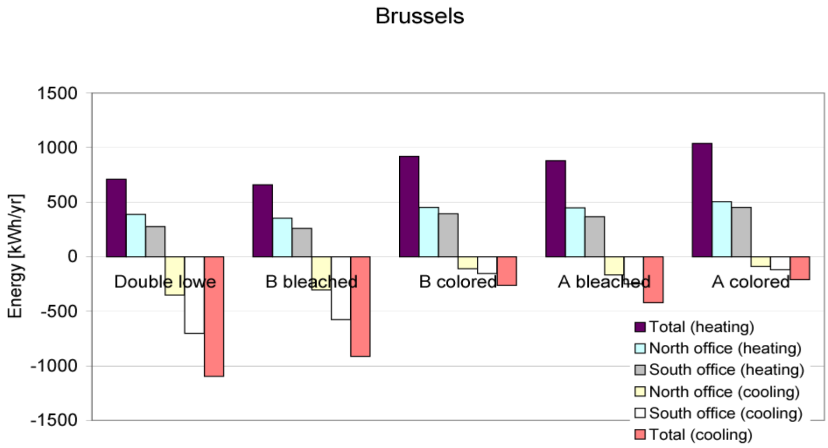

Fig 3: Heating and cooling loads for the north and south office modules equipped with two of the switchable windows (A and B) and the reference window (double low-e) in Brussels

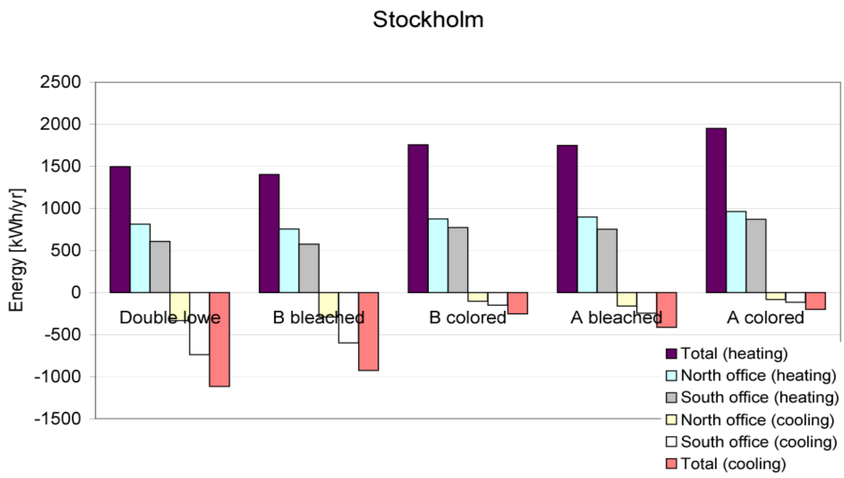

Fig. 4: Heating and cooling loads for the north and south office modules equipped with two of the switchable windows (A and B) and the reference window (double low-e) in Stockholm

In table 2, building simulation results are shown for Brussels for the different simulation programs used. As can be seen there are differences between different tools, although the energy saving potential is in agreement. The different tools give different levels for the heating and cooling demand, but the total energy consumption is very similar for all cases.

Another way of looking at the energy balance is to consider only the energy flow through the windows. This can be done with the window simulation software WinSel. In Figs. 5 and 6 the results are shown for each month of the year in Stockholm for the window in the south facing office module. No ventilation losses and no losses through the walls are included in these graphs. The building is only modelled with its balance temperature, which in this case is set to 12 degrees Celcius. In the graphs a positive heating balance means that the window contributes to the heating through the solar heat gain which in this

Table 2: Annual heating energy demand of the two office modules for a Brussels climate calculated with different building simulation programs

Brussels	< Heating - south office			>< Heating - north office			>
Window	clim	bsim	derob	trnsys	clim	bsim	derob	trnsys
Ref	499		277	374	596		389	614
A(bleached)	619	589	367		696	678	449	
A(coloured)	750	725	452		797	776	505	
B(bleached)	486	448	259	400	584	547	355	604
B(coloured)	709	651	395	627	763	707	452	729

case is larger than the thermal losses. Cooling is only needed in the summer. The small heating load shown in the summer is due to the fact that there are a few hours when some

Table 3: Annual cooling energy demand of the two office modules for a Brussels climate calculated with different building simulation programs

Brussels	< Cooling - south office			><	Cooling - north office			>
Window	clim	bsim	derob	trnsys	clim	bsim	derob	trnsys
Ref	328		703	410	226		351	171
A(bleached)	103	216	248		79	144	167	
A(coloured)	35	99	120		32	83	89	
B(bleached)	271	393	576	269	179	235	305	124
B(coloured)	46	118	152	63	40	95	109	42

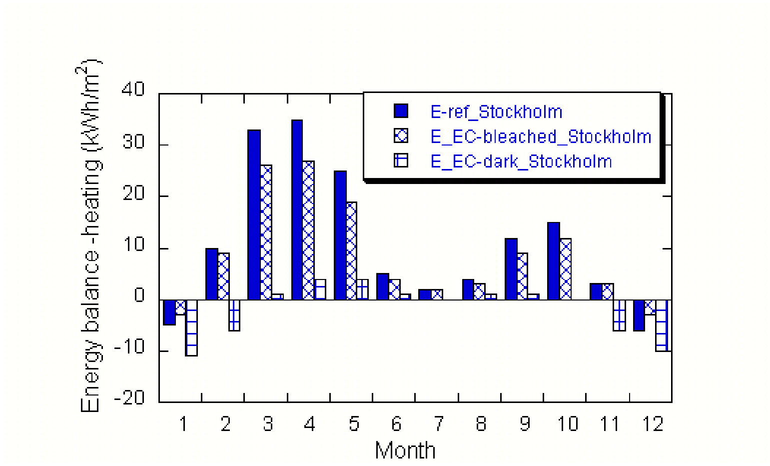

Fig. 5: Energy balance for heating for a south facing window in Stockholm. The energy balance is given in kWh per square metre of window area.

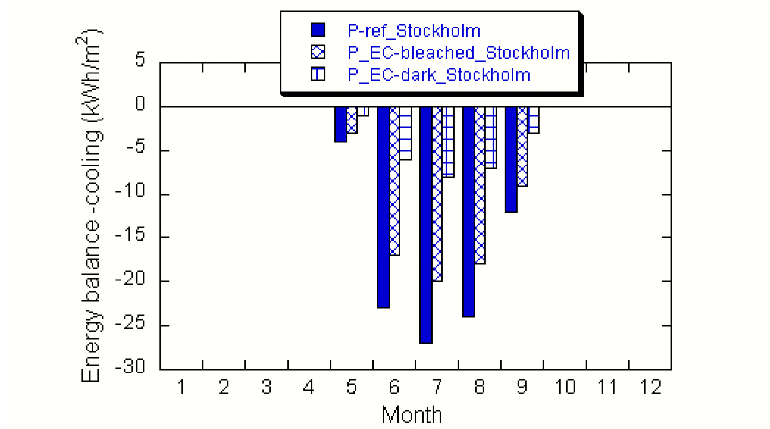

Fig. 6: Energy balance for cooling for a south facing window in Stockholm. The energy balance is given in kWh per square metre of window area.

heating would be required to maintain 20 degrees Celcius, although this is negligible and in practice no heating is needed in June – August. It can be seen that the switchable window in the bleached state does not perform as well as the low-e window during the heating season, but it reduces cooling considerably and the total energy balance is to the advantage of the switchable window.

It is apparent that according to these results the reduction in cooling load is substantial at all three locations. It must be pointed out that the reference case is a high performance low-e window. There are more efficient solar control windows on the market, with lower g-value (solar factor) than the used reference window, and such a window would be more similar in performance to the switchable window, for the cooling load. It should also be pointed out that the difference would have been even larger if we had used an uncoated double glazed window as the reference case. The energy “saving” is always related to a reference case and can thus vary depending on the conditions.

6 Summary

The results of the simulation work performed within Task 27 clearly indicate a large saving potential for buildings, especially in warm climates. An important result not specifically shown by the tables of data shown here, is that the cooling power is considerably reduced. This can help to reduce peak loads for the local energy system, and also in many cases make expensive and energy consuming air conditioning units obsolete. In central and northern European climates, these results indicate that buildings designed with proper solar shading and a controlled ventilation system can maintain a comfortable indoor climate throughout the year without air conditioning. In warm climates where the outside temperature often is above the indoor set temperature, it is not possible to maintain a comfortable indoor climate without using air conditioning, but on the other hand the energy saving is then larger than in cooler climates, and the air conditioning system can be operated with less power.

The results of these investigations are not fully evaluated. It is, however, of interest to compare different tools having different degrees of built in approximations and simplifications, using the same input parameters. We have noted considerable differences between simulation tools, although the main task was to investigate the switchable windows, not to evaluate different simulation tools. The correct answers will have to wait until switchable glazing is more readily available and can be installed in more than just a few test offices, but the results presented here gives a clear indication of the energy performance we can expect from switchable windows in the future.

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