Switchable Façade Technology – Energy Efficient Office Buildings with Smart Facades

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Abstract – This paper describes describes the energy performance of switchable façade technology using electrochromic and gasochromic windows in a office environment. Heating, cooling and lighting energy are affected by the dynamically changing optical properties. Starting from angle-dependent laboratory characterisation, a validated façade model is being used in coupled daylight and energy simulations. The methodology and results for different European climates are presented. Switchable facades have a similar potential reducing cooling loads as external shading devices, however with different visual and practical consequences. User can always look through a deeply coloured glazing whereas for external solar protection the view can be obstructed. The solar protection function is integrated in the glazing in one single building element, and it cannot be affected by wind. Thus the emerging technology seems to have good prospects on a future market, provided the longterm reliability can be demonstrated soon.

1. INTRODUCTION

In the European project SWIFT (Switchable Facade Technology) elektrochromic and gasochromic glazings integrated into facades have been investigated. The work areas include the characterisation of the facades with respect to energy and daylighting performance, durability and reliability of the complete systems, technical and architectural integration of the components into the building, user evaluation studies and, last not least, on the investigation of market and energy savings potentials.
This paper concentrates on the application of optically switchable facades in office buildings, especially on the consequences on the primary energy consumption in dependance on the control strategy. In a first chapter the basic data of the two technologies will be presented. They are the basis of a simulation modell, which has been validated by outdoor experiments. The methodology and the results will be described in detail.
The work leading to this publication has been funded by the European Commission with the Framework Programme FP5 in the area of Energy, Environment and Sustainability. More information on the project content and the project partners are available at the website http://www.eu-swift.de. The author is responsibile for the content of the publication. It does not reflect the opinion of the European Commission nor is the Commission responsible for the further use of the presented data.

2. CHARACTERISATION OF SWITCHABLE GLAZINGS AND FACADES

2.1 Investigated glazing types

From the two German companies Interpane Entwicklung und Beratungsges. mbH & Co KG, Lauenförde, and Flabeg GmbH & Co KG, Furth i. Walde, prototype glazings having a optically switchable functionality have been delivered to the laboratory for characterisation including the necessary control equipment. These glazings modulated the solar absorption in the outer layer, thus providing an integrated solar protection function. The prototypes consist of an exterior functional unit which is different for the two technologies (see Figure 1 and Figure 2), an interior glass pane coated with a transparent low emissivity coating, having an gap filled with noble gas filling in between. Whereas the electrochromic functional unit is a laminated glazing with a thin layer system in between, the gasochromic functional unit consists of a double glazing unit with one pane covered with a layer system mainly based on tungsten oxide. The interpane layer is connected to a gas supply system with a noble gas as carrier gas.

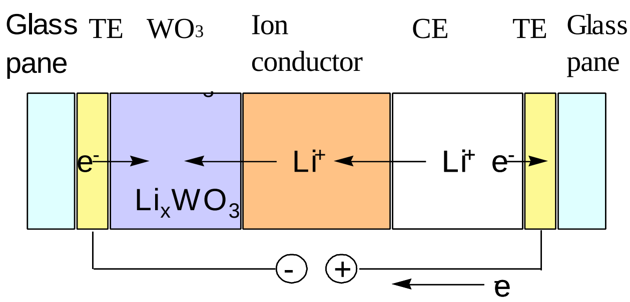


Figure 1 Schematic layout of the electrochromic functional unit
TE: transparent electrode; CE: counter electrode

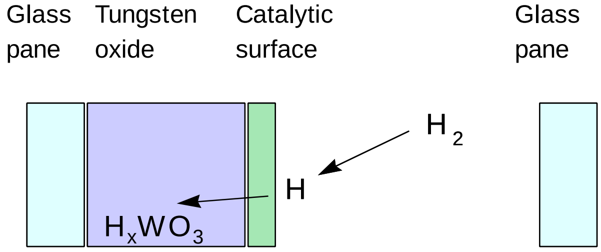


Figure 2 Schematic layout of the gasochromic functional unit

2.2 Laboratory characterisation

Visual transmittance τ_v and total solar energy transmittance g have been determined for different switching conditions and incidence angles in the laboratory. For direct transmittance a large integrating sphere equipment has been used, for energy transmittance a solar calorimeter developed to a very high standard (Platzer, 2000, see Figure 3). The U-value of the glazings were also determined with this device in the dark, non-irradiated mode. The electrochromic double glazing reaches a value of U=1.1 W/(m^{2}K), comparable to a modern low-e glazing, whereas the gasochromic unit, effectively a triple glazed unit with one low-e coating on position 5, reaches U=0.9 W/(m^{2}K).

Figure 3: View into cabin on the Fraunhofer ISE solar calorimeter (measurement of a solar protection device)

Table 1: Gasochromic glazing data

state	angle [°]	Interpane GC		
		g	τ_v	τ_e
bleachedl	0	0.48	0.60	0.40
	30	0.46	0.59	0.38
	45	0.46	0.59	0.37
	60	0.42	0.51	0.32
coloured	0	0.18	0.15	0.08
	30	0.18	0.14	0.08
	45	0.17	0.13	0.08
	60	0.15	0.11	0.06

Table 2: Electrochromic glazing data

state	angle [°]	Interpane GC		
		g	τ_v	τ_e
bleached	0	0.40	0.52	0.33
	30	0.37	0.51	0.32
	45	0.36	0.48	0.30
	60	0.33	0.41	0.25
coloured	0	0.16	0.16	0.08
	30	0.15	0.14	0.06
	45	0.14	0.13	0.05
	60	0.13	0.10	0.04

2.3 Dynamical façade testing and validation

A complete gasochromic façade system consisting of four glazings and a gas supply unit has been installed at the outdoor façade test site in Freiburg (Figure 4). Surface temperatures of the glazings and comfort and air temperatures in test room behind have been determined as well as visual transmittance. The façade has been switched according to control strategies also implemented in the simulation model TRNSYS. Using the lab data and THERM simulations of the frame profiles a simulation model for the complete façade including frame portions was developed. This model has been and validated using the time series of environmental data and test data in parallel (Figure 5).

Figure 4: View through the gasochromic facade from the test room to the landscape

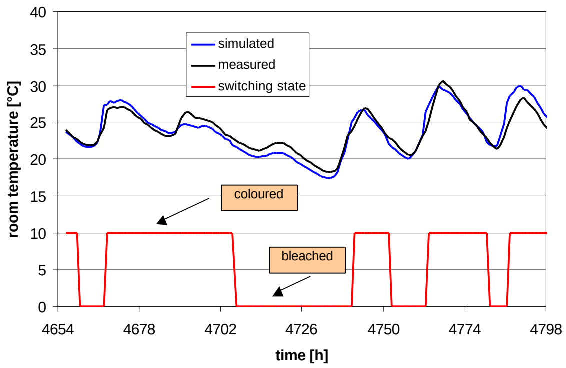
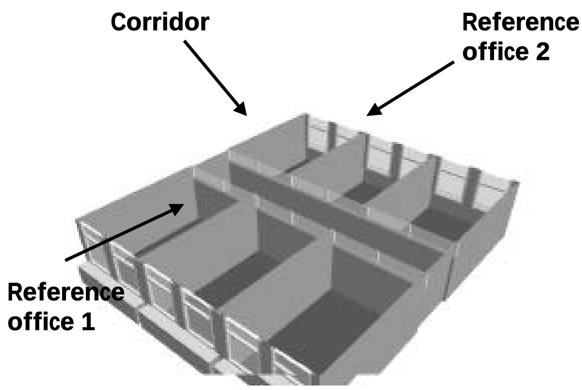


Figure 5: Validation of the gasochromic facade model using a comparison of simulated data with measured temperature dataover a week in July 2001 (red line shows switching state)

3. SIMULATION METHODOLOGY

An energy performance assessment of switchable facades has to quantify all influences with respect to primary energy consumption an relate that to alternative solutions. In principle this should include also the energy used for production, transport and disposal, i.e. the complete lifetime energy use. However, first investigations showed that the differences to conventional façade and glazing products are marginal in this respect, and on the other hand details are dependent on the final development process which is not finished for prototypes. Therefore this paper concentrates on the energy consumption during use of the product. To get representative data for heating, cooling and lighting energy, a so called reference office has been defined in cooperation with the IEA Task 27 "Performance of advanced building envelopes", which specifies building parameter and user data (Van Dijk 2001, see Figure 6). It is developed to represent a typical central European office with average technical equipment (internal loads), and describes two cell offices separated by a corridor cut out of a larger building. The base case considered here describes a hole in the wall façade. Well-defined variants allow also the investigation of other façades, e.g. completely glazed offices. Figure 6 shows schematically the office configuration.
Using this office and the façade models for TRNSYS and Radiance first the hourly daylight availability has been determined for several façade conditions. The method used here was the concept of daylight coefficients connecting a segment of sky luminance to irradiance on a certain point on the work plane. Using that hourly daylight autonomy can be calculated which in turn leads to lighting needs and corresponding internal loads, when the lighting system has been defined (Reinhardt, 2001).
Using the precalculated internal loads and window luminance for the bleached and coloured state of the glazings, both with and without a roller blind as additional glare protection, the building simulation was operated with different control algorithms. The switchable glazings were coloured or bleached depending on different control parameters like room temperature, irradiance on the vertical façade or window luminance. Depending on the glare conditions, in addition the internal roller blind was operated assuming that it had no influence on solar gains. Reading optionally internal loads from four different files thus guaranteed that the actual loads corresponding to the daylight and lighting conditions were used. This coupling of daylighting and energy simulations seems to be necessary to optimize control strategies for switchable systems.



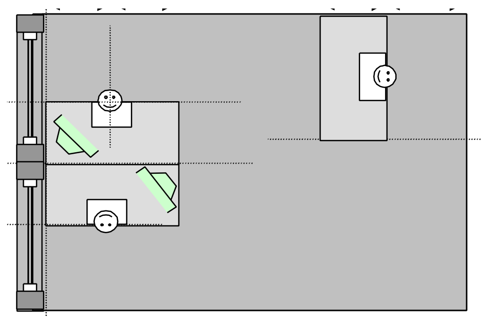


Figure 6: Schematical view of reference offices and floor plan of one office indicating the work positions

4. SIMULATION RESULTS

Simulating the heating and cooling energy demand using the program TRNSYS resulted in low energy consumption when compared to the case of low-e coated heat mirror or solar protection glazings with corresponding high or low total solar energy transmittance. This is not surprising, as in offices like that solar protection is absolutely necessary. Of course, effective external shading devices, if operated in cut-off position, would reach similarly low cooling demand, whereas internal devices with generally less solar protection would reach slightly larger cooling demand. The essence is, that switchable facades can reach as low cooling demand as facades with external shading devices, and a heating demand similar to a heat mirror glazing without shading. In addition the advantages of the switchable glazings are

- Permanent view through the window
- No restrictions to operation because of wind
- No mechanical device
- No external structure in front of glazed façade (appearance of building)

Table 3: Annual heating and cooling energy demand for different glazing options
HM: Heat mirror double glazing (U=1.3 W/m2K, g=62%)
SC: Solar control double glazing (U=1.1 W/m2K, g=33%)
GC : Gasochromic glazing (U=0.9 W/m2K, g=48%/18%)

	Heating energy q_H [kWh/m^{2}a]		
climate	HM	SC	GC
Rome	3.7	5.5	4.9
Brussels	16.6	20.3	17.2
Stockholm	33.8	39.4	33.1

	Cooling energy q_C [kWh/m^{2}a]		
climate	HM	SC	GC
Rome	45.5	24.2	15.2
Brussels	16.3	6.8	3.4
Stockholm	18.8	7.3	3.1

When the control strategies were optimized it could be shown that the switching according to room temperature would be the most energy efficient (Figure 8). Switching should occur about 2 degrees below the cooling set point Figure 7). However, because we assume that a user would manually operate a system according to visual comfort, i.e. glare, and glare from the direct sun cannot be reduced sufficiently, manually operable blinds are recommended for that case.

However, if automatically the façade would be operated using vertical irradiance or glare as switching criterium, only 10% increase in primary energy consumption (due to higher cooling loads) would result.

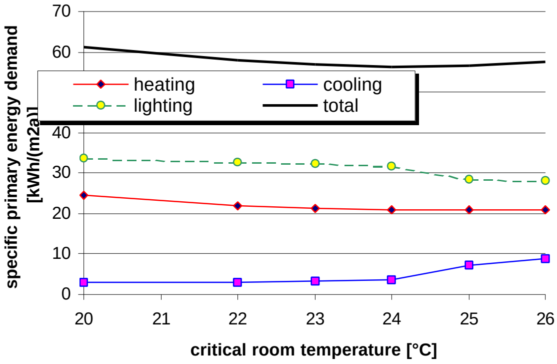


Figure 7: Primary energy consumption for the case of a gasochromic facade, reference office, Brussels, South-North orientation, switching according to room temperature set point (minimum consumption for 24°C set point)

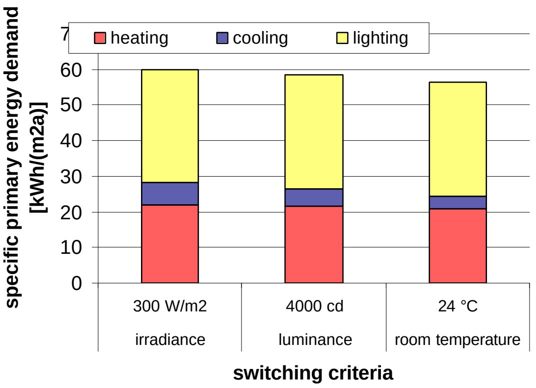


Figure 8: Primary energy consumption (conditions as in Figure 7) Different control strategies

As the cooling energy demand is small when the gasochromic façade is investigated, one might be interested whether natural or passive cooling could be sufficient to avoid overheating of the building. This is certainly not the case for Rome. In extreme periods the ambient temperature is very high even at night time. Thus cooling by nighttime ventilation is not effective. However, first simple strategies of increasing nighttime ventilation in Brussels or Stockholm reduced the number of overheating hours substantially with only a few hours above 27°C (for comparison: double low-e glazing without night time cooling around 700 hours above 27°C). For a real building project passive cooling options should be optimized of course, e.g. by increasing accessible ceiling mass, or by using earth-to-air-heat exchangers.

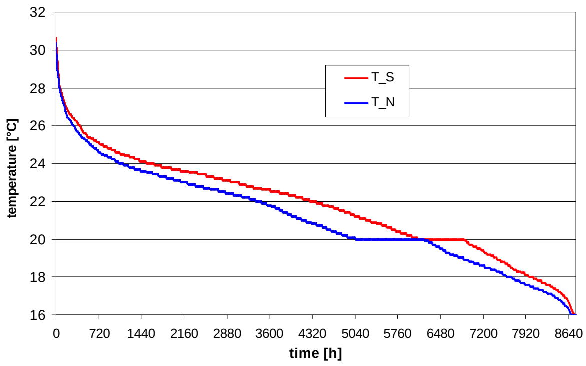
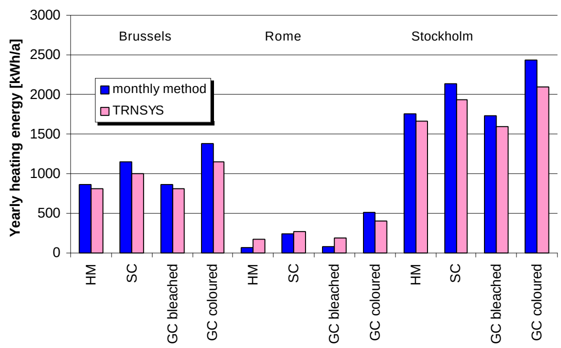


Figure 9: Distribution of room temperatures in reference office with increased night ventilation compared without cooling device (climate Brussels)

5. DEVELOPMENT OF SIMPLIFIED CALCULATION METHODS

When many alternatives shall be compared or, in an early design phase, when many details have not been fixed, a fast and approximate calculation methodology would be beneficial. Therefore a comparison of the detailoed simulation results with a monthly calculation method based on the standard EN 832 has been performed. The monthly methodology had been extended to include cooling energy also. Different usage patterns and phases had to be considered, e.g. the difference between working days and weekends. These phases have been considered using weighted averages of calculations using different boundary conditions. The overall comparison with simulation was fair in all three climates and all cases. However, the methodology is intended to be developed further to consider better transient and carry-over effects. This could be a possible way to calculate cooling energy loads in future thus following the reqauirements of the intended European energy performance standard for buildings.



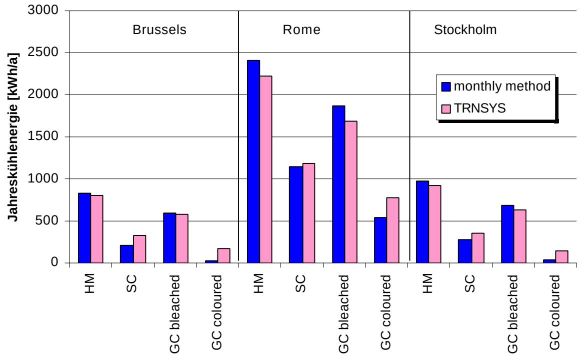


Figure 10: Yearly heating and cooling energy calculated with a simplified monthly method and with dynamical building simulation (TRNSYS)
- abbreviations as in Table 3

6. CONCLUSION

Optically switchable facades provide an attractive and energy efficient non-mechanical solar protection, which is combined with the glazing system. It allows a permanent view to the ambient environment parallel to a solar protection comparable to external efficient Venetian blind systems with having some of the disadvantages. However, it is clear that the prototype developments have to prove also the long term performance which is evaluated also at the moment. The properties of the prototype systems show the interesting potential, but should not be confused with future product properties.

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