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Investigating the impact of electrochromic glazing on energy performance in hot arid climate using parametric design

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Abstract. One of the most important functions for windows is to connect the interior space to the outside, as well as having a role in ventilation and natural lighting. However, as it is considered the weakest link in the building envelope, in terms of thermal insulation, designers in the areas with severe climatic factors, tend to minimize the window ratio, without taking into account the importance of the other functions, in providing the user's comfort. This research aims to investigate the ability of electrochromic glazing to solve limited ratio problem and give designers more flexibility. A case study located in a hot and dry area was compared with several scenarios where electrochromic glazing was used in various ratios. Simulations were made using parametric design tools based on Rhinoceros and Grasshopper, which are among the most used software by designers. The study concluded that electrochromic glazing was useful in increasing the window-to-wall ratio and improving the building opening on the outside without having a negative impact on building energy performance.
Keywords: Parametric simulation, energy performance, window-wall ratio, Electrochromic glazing, hot and dry climate

1. Introduction

For people who often stay indoors, windows can be considered as a way of accessing the outside world [1]. With technology development, the exterior wall has lost its structural role, and the architect can now design using high window-to-wall ratios. Nonetheless, in presence of extreme climatic factors design remain constrained by thermal insulation considerations.

With nanomaterial development, active dynamic windows can play a central role in improving energy efficiency [2], including the electrochromic, system that can be considered as an electrical battery consisting of five superimposed layers [3]: two transparent electrical conductors surround cathodic and anodic oxide films that are connected by an electrolyte [4]. The transmittance of this system could be switched in several different states between bleached and colored [5], through the application of small voltages with durable memory generally up to 48 h [6].

To manage these different states, electrochromic glazing requires a control strategy, which may depend on various parameters: solar irradiation, cooling and heating rate, illuminance, glare index, air temperature [7]. Several studies found that the control based on interior illuminance may be very advantageous compared to other strategies [8-10].

Several studies have investigated the impact of window-to-wall ratio (WWR) on energy consumption of buildings [11], Kim et al. [12] and Yang et al. [13], confirmed that the annual energy consumption increases as the window-wall ratio increases.

According to Alwetaishi [14], the window-wall ratio is recommended to be 10% in hot and dry climate. Hassouneh et al. [15] investigated the impact of type of glazing in different ratios in four orientations, and

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results showed that the flexibility to choose the window-to-wall ratio and orientation depends on the type of glazing used.

2. Research methodology

In the present paper, we have implemented a simulation procedure and protocol over a case study in a typical hot and arid region, situated in the northeast part of the Algerian Sahara.

2.1. Location and climate

Biskra is one of the 48 Algerian provinces, situated in the south of the country at latitude 34.80 °N, and longitude 5.73°E, altitude of 82 m [16]. The climate in Biskra is largely influenced with solar radiation, (9.32h average annual sunshine duration, and about 5545 Wh/m² of global irradiation incident on a horizontal plane) [17- 18], which leads to an increase in temperature. According to its geographical location, Biskra is considered as a desert area with a hot and arid climate (BWh according to Köppen-Geiger classification).

2.2. Study objectives

The main objectives are to investigate the performance and the impact of electrochromic glazing in a hot-dry climate, and to improve the opening of the building on the outside without having a negative impact on energy performance of the building.

2.3. Materials and construction

To carry out the simulation, a four-story building was simulated, in which the case study (Fig.1) was located on the ground floor. The case study was an apartment situated in Biskra city, consisting of three rooms, we have chosen the living room as the more preferred zone for outdoor openness, as well as for acceptance of a lower privacy level in case of larger windows.

The exterior wall consists of 0.02 m cement-plaster, 0.15 m hollow brick , 0.05 m air barrier, 0.1 m hollow brick and 0.01 m coated plaster and overall U=1.14 W/m^{2}K. The interior wall consists of 0.01 m coated plaster, 0.1 m hollow brick and 0.01 m coated plaster with U= 2.49 W/m^{2}K. The roof is composed of 0.02 m granite flooring, 0.04 m mortar, 0.16 m hollow concrete blocks, 0.04 m concrete, 0.01 m coated plaster with U=2.42 W/m^{2}K. The floor includes the following components 0.15 m clay, 0.15 m stones of valley, 0.04 m concrete, 0.04 m mortar, 0.02 m granite flooring with U=2.25 W/m^{2}K.

The dimensions and material characteristics are based on the existing building , that represents the most widely used type in Algeria's residential sector. The living room is oriented south-west, with an initial window-to-wall ratio of 8.5% and a laminated glass under reference conditions. As the electrochromic glazing is supposed to be applied to a double glazing, an intermediate case was also considered in which the laminated glass was replaced by a standard double glazing consists of two 5.7 mm clear glasses separated by 12 mm air gap . Finally, for the electrochromic glazing a commercially available solution was assumed, composed of 7 mm sage glass, 12 mm air space and 5.7 mm clear glass, characterized by high transparency in the “bleached” condition. All the glazing properties are calculated using LBNL Window 7.5 and summarized in Table 1.

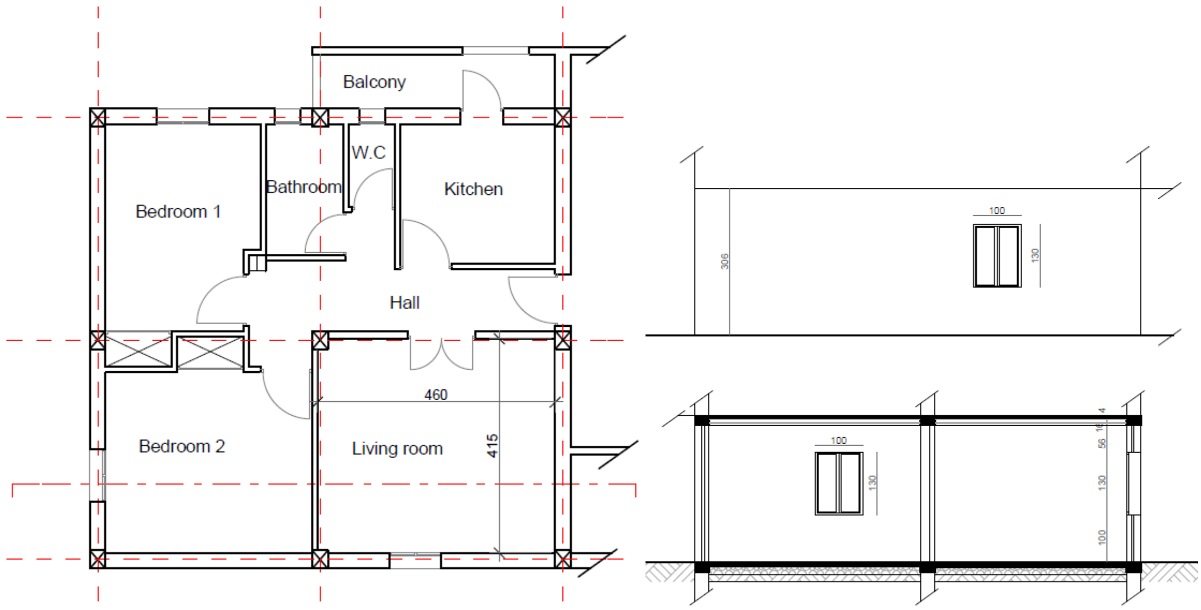

Figure 1. Case study plan, facade and cross-section

Table 1. Characteristics of glazings (values in brackets refer to colored state).

	Laminated glazing	Double glazing	Electrochromic glazing
U-value	5.64	2.70	1.84
SHGC	0.65	0.70	0.44 (0.10)
Tvis	0.68	0.78	0.64 (0.01)

2.4. Simulation conditions

Comparative annual simulations were performed between the case study and several scenarios that differed in the window to wall ratio from 8.5% to 90%, and in the type of glazing material.

The parametric simulations were carried out through the environmental analysis plugins for Grasshopper and Rhino. Ladybug used to combines geometry in Rhino and the parametric interface of Grasshopper with open-source weather data from IWEC (International Weather for Energy Calculations) database. Honeybee was used to connect Rhino geometry and Grasshopper energy modelling and simulation program, Open Studio [19]. Boundary conditions assumed to be 28°C for cooling, 18°C for heating and 300 lux for electric lighting. The room was assumed to be occupied from 7:00 to 23:00.The electrochromic glazing was controlled according to the interior illuminance strategy to ensure a 300-lux target over a virtual sensor located at the centre of the living room. Artificial lighting was consequently used at night and to compensate natural light in case illuminance fell below 300 lux. Heating and cooling energy was calculated assuming an "Ideal Loads Air System" object, and converting to equivalent electric energy .Ventilation was supposed to be 0.2 m /s. All results were finally normalized with reference to floor surface area.

3. Results and Discussion

For cooling, in the case of laminated glazing, it was observed that with an increase of 10% of the window-to-wall ratio, consumption increased by about 2 to 3 kWh/m² because of the increase in the sun rays entering the room combined with the increase in heat transfer from outside to inside.

For heating, consumptions were negligible up to a window-to-wall ratio of 40%, but for higher values, they showed a systematic increase with the window surface area, because heat transfer is increased from the inside out due to high transmittance of the reference window.

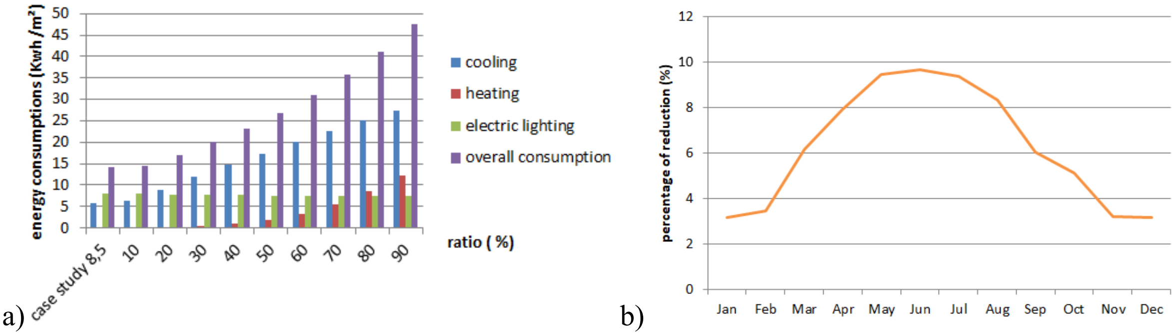

Figure 2. a) Energy consumption depending on Laminated glazing ratio (kWh/m²); b) Percentage of electrical lighting reduction between ratio 8.5% and 90%

For electric lighting results were substantially independent of the WWR, with only a slight decrease by about 6.4% in consumptions when moving from a WWR of 8.5 to 90, likely as a consequence of the fact that most of consumptions take place at night when the role of natural light is minimized. This is further confirmed by the fact that the improvement was generally larger in summer when daylight time is longer (Fig. 2b).
In overall consumption, an increase as a function of WWR was found, largely influenced by the increase in cooling costs.

3.1. The effect of different glazings
When double glazing was used (Fig. 3a), the most significant result was observed in terms of reduction of heating energy, as values were more than nine-tenths compared to single laminated glass. With reference to other aspects, a small reduction in cooling energy was also observed, particularly for higher WWR where the area of the window plays a major role in heat transmission. For lighting a slight decrease in energy demand, given the similarity in optical characteristics.

The use of electrochromic glazing (Fig. 3b) determined a significant change in results. In fact, cooling energy demand was more than 13 % at highest WWR when compared to double glass, and was two tenths of the value observed with laminated glass. Heating energy was also reduced to nearly zero, independent of WWR, as a consequence of the further increase in U-value showed by the selected glazing. Lighting energy is mostly unchanged, possibly because of the prevailing use of lighting during night hours, and of the limited effect of the reduced Tvis when EC glass was colored. Overall consumptions obviously benefit from the significant reduction in cooling energy demand.

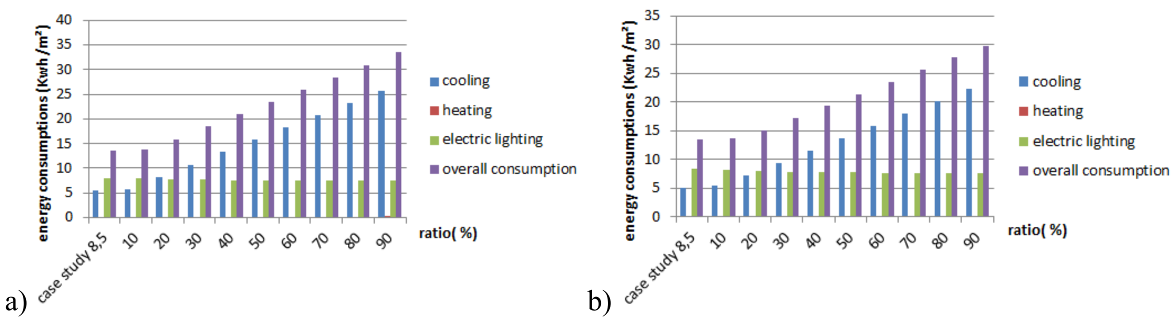

Figure 3. Normalized energy consumptions for different sources as a function of WWR for: a) double glazing window; b) electrochromic glazing.

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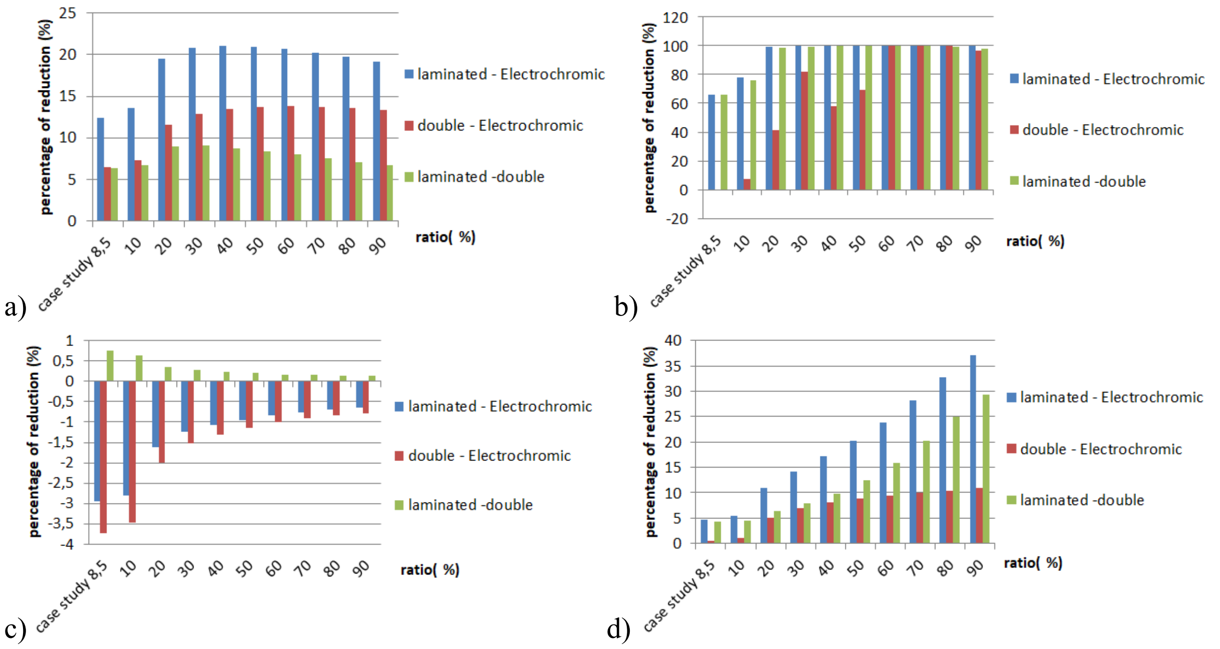

Figure 4. Relative variations of energy demand as a function of WWR for: a) cooling; b) heating; c) lighting; d) overall consumptions

In order to clarify the advantages of the different technologies in relation to the varying WWR, the relative variations between the analysed cases were plotted in Figure 4. As already observed, EC technology outperformed the others, under all circumstances, but it was with WWR higher than 50% that the variations showed the best reduction by about 20% to 37%. EC glazing ensured nearly zero energy demand for heating. For lighting, variations were typically small and negative, as expected because EC reduces the amount of light entering the room under "bleached" conditions, thus requiring, particularly when WWR is below 20%, a slight increase in energy demand. However, variations are largely negligible in absolute terms. The overall consumptions, consequently, reflect the positive trend that characterized cooling energy demand, as it is more clearly described by numbers given in Table 2.

Table 2. Improvement percentage of overall consumption %

Ratio %	8.5	10	20	30	40	50	60	70	80	90
A	4.6	5.4	10.9	14.2	17.1	20.2	23.9	28.1	32.6	37.0
B	0.4	1.1	4.9	6.9	8.1	8.9	9.4	9.8	10.3	10.8
C	4.2	4.4	6.2	7.8	9.8	12.4	15.9	20.2	24.9	29.4

A represent the variations from laminated glazing to Electrochromic glazing
B the variations from double glazing to Electrochromic glazing
C the variations from Laminated glazing to double glazing

4. Conclusion

The study investigated the improvement of window energy performance with different WWR in residential building in hot and arid regions, achievable through electrochromic glazing.
The methodology applied, based on comparative parametric study showed that:

Using laminated glazing, we must not exceed the 8.5% ratio. As the difference in consumption between 8.5% and 90% is equal to 70.23% increase in consumption, but in the case of an electrochromic glazing the difference between the same ratios is equal to 54.88%.

Heating energy demand is reduced to zero when using large WWR, thanks to increased radiation entering the space and higher U-value.

Electrochromic glazing proved useful in increasing the ratio and improving the opening of the building on the outside without having a negative impact on the energy performance of the building, as a laminated glazing covering 8.5% of wall area consumes the same as an electrochromic glazing covering a 20% wall area. A 60% WWR for a laminated glazing is equivalent to 90% WWR for electrochromic glazing and 70% WWR for double glazing in terms of overall consumptions.

Further investigations are under way in order to better understand the mutual interactions between the different parameters influencing the energy balance of the building, as well as to understand the influence of façade orientation on the collected results.

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