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Energy Demand Reduction Applying Different Window sizes for an office building in semi-arid climate

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A B S T R A C T

Previous studies have shown that the glazing is responsible for the most part of the heat gains and losses in the buildings. Glass has been progressively more used in Algeria. In this country, the building sector is the largest energy consumer. It is responsible of more than 41% of the overall energy consumption, with an annual increase rate of 10.8%. Consequently, glazing is an important factor in determining building energy consumption. From the point of view of aesthetics and visual comfort, great glazed surfaces are desirable. However, in semi-arid climates, like in Constantine city (Algeria), internal spaces require both cooling and heating demands. Yet little is understood about the performance of large glazed façade in such climate. The study aims to investigate the effect the contemporary facade of tertiary buildings in Algeria has on internal temperatures, and to find out the most energy-efficient fenestration system that suits offices under a semi-arid climate by the data- processing software Pleiades comfie.

Keywords: Glazing, WWR, energetic performance, overheating, power consumption

1. Introduction

In Algeria, the building sector is the largest energy consumer. It is responsible of more than 41% of the overall energy consumption, with an annual increase rate of 10.8% (N.M.E, 2014). Among aspects of energy design, office buildings offer significant possibilities in order to reduce the power consumption and its environmental impact. However, a detailed attention must be given to its outer envelope, because of its transparency. Windows are important in the workplace for both environmental and psychological reasons (Menzies, et Wherrett, 2005).

These building features combine many functions (daylight, thermal comfort, protection against noise, sun, cold and wind, aesthetics, provision of view to the exterior and safety (Tsikaloudaki, Theodosiou, Laskos & Bikas, 2012). Consequently, selecting appropriate windows is important in terms of occupant comfort and energy savings (Haglund, 2015). In terms of heating needs, glazed surfaces contribute positively to the space heating by collecting solar energy (Tsikaloudaki, Theodosiou, Laskos & Bikas, 2012). However, they are the crossing point of significant solar energy which contributes in warming the space and causes summer overheating. This is the effect of its capacity of solar radiation transmission (Binarti, 2009). The cooling needs are usually resolved with the proper design of the outer envelope, in particular, the glazing part (Hilliaho, Mäkital & Lahdensivu, 2015).

The transparency ratio of facades is defined as the window-to-wall ratio (WWR) which is the net glazing area to the gross exterior wall area). Several studies showed that WWR is an important parameter in determining the energy requirements of buildings (Binarti, 2009) (Bektas & Aksoy, 2008) and in achieving the indoor thermal comfort. Kontoleon and D.K. Bikas (2002) found that the selection of glazing type, as well as its size, is very important towards achieving a desirable indoor environment. Jaber and Ajib (2011) reveal that the most influential factor on energy demand (heating and cooling) is the size of glazed surfaces.

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Efficient WWR depends on climate conditions. Consequently, each climate needs a proper fenestration design. Binarti (2009) investigated the optimal window area for a classroom in a tropical zone. He found that a window with a WWR of 20% can be considered with regard to energy-efficiency, and for maintaining proper view to outside. In another work undertaken for hot climates, Inanici et Demirbilek (2000) showed that a building that has conventional (25%) south window area is preferable for residential buildings. However, in cold climates, larger window sizes are preferred for increasing heat gains in winters. From an investigation carried out for Turkey climate, Eskin and Turkmen (2008) found that total energy demand of the office buildings increases significantly with high surface of glazing as compared to the buildings with lower glazing surfaces. In a study reported by Waheeb (2010) the author explained that the amount of saving in cooling loads increases with the increase of the window glazing ratio.

Many other studies investigated the performance of the facade configuration in a considerable number of cities in the world; however, the bulk of research is carried out in moderate, cold climates and hot climates. Little is understood about the performance of large glazed facade in predominantly semi-arid regions like Constantine, which requires both cooling and heating demands.

2. Objectives

There is a great potential for energy savings on air heating and conditioning when using the ideal Window Area (WWR) in offices, depending on orientation and glazing types. Energy efficient window design should limit both cooling and heating demands. The brief addressed by this study was to evaluate internal conditions in an office space that have large glazed area in Constantine city, and to define an efficient window in terms of heating and cooling. This work intends to provide guidance to building designers with regard to the thermal performance of office buildings.

3. Methodology and Description of case Study

The control of the indoor environment and its requirement is important for office buildings in terms of energy. This work presents the results of a post-occupancy study based on quantitative measures of internal and external air temperatures and humidity. It aims to study the effect of the glazed facade of an office building on the internal environment, in Constantine city. In a second step, a detailed study of energy consumption of an office space is performed with the data- processing software 'Pleiades comfie 2.8.6.13'. The simulation considers the glazed openings percentage (WWR) in four orientations (South, East West and North). Other parameters are considered; type and number of layers; single glazed, double glazed, and double glazed with low e film.

3.1 *Introduction of Climatic Condition in the Studied Area*

The office room studied in this paper is located in an office building representative of contemporary buildings in Algerian country. It is situated in Constantine city at (36°, 17 N and 7°,23'E), 675m altitude. Its climate is characterized by great temperature oscillations, very cold and wet winters (2.6°C is the minimal average temperature,) and hot summers, where average air temperature presents a value of 25.5°C at the hottest month of the year (Figure1).

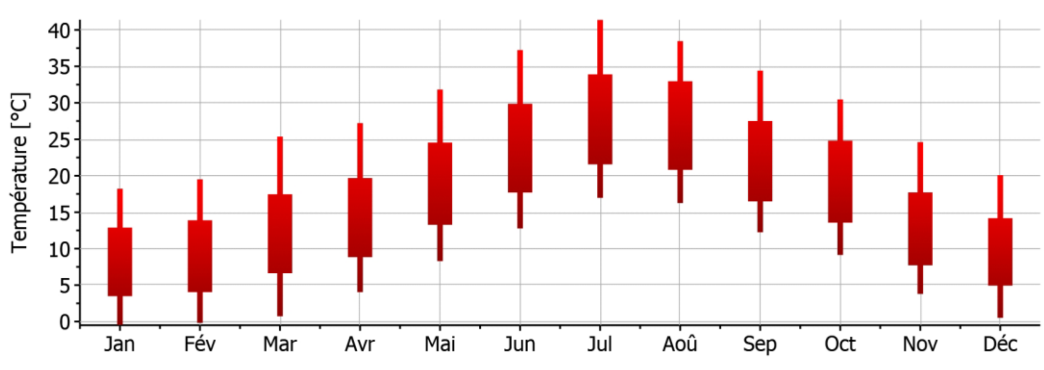

Figure1. Monthly average temperature in Constantine (Meteonorm. 7)

The average intensity of solar radiation in this city is significant, as it is about 4230 W/m ² / day on a horizontal surface, according to the National agency of weather data (2014). Total solar radiation on a horizontal surface reaches its maximum value of 337 w/h/m ² in July (Figure 2).

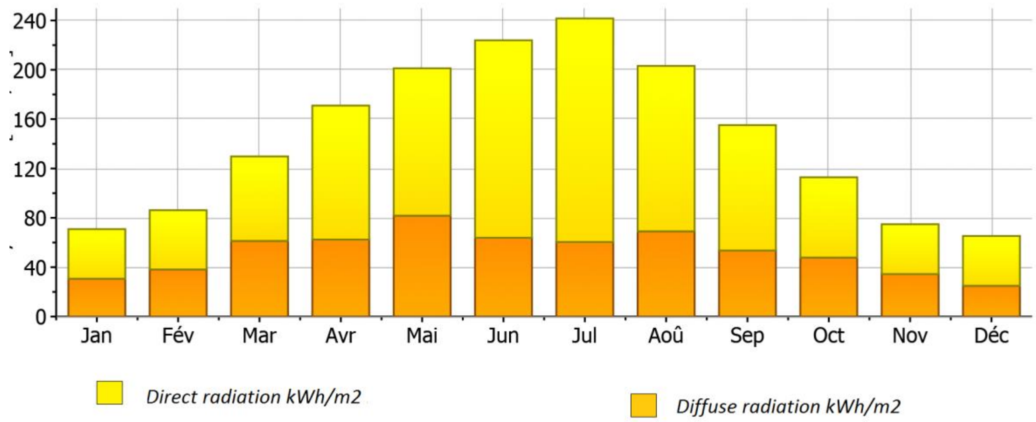

Figure 2. Monthly Average Radiation in Constantine (Meteonorm.7)

3.2 *Description of the building Case Study*

The ABAM building (Agency of Building Advancement and Management) which is an office building is selected for the case study. It is built in 2010 and located in Constantine. The ABAM building consists of a ground, underground and 4 storeys. Its long axis is oriented in the east west directions. The envelope has large glazing ratios of exterior façade around 40% to 50%. An office space situated in an intermediate floor of this building is selected for the field measurement. The studied office space shown in Figure 3 has a floor area of 16 m² (3.28m wide, 4.87m long and 2.70m high.) and two façades in contact with the exterior. The fenestration areas are identical Double-Paned Windows located in two exterior walls, towards the north-east and south-east directions. The windows are composed of a 5 mm external sun protection glass pane, 12 mm of air and a 5 mm internal clear glass pane. The frame is of aluminium. The window-to-wall ratio is 40 % exterior wall in each direction.

Figure 3. External and internal views of the monitored office building

4. The in-situ measurements

As a first step, to deal with the comfort problem, and to analyze the thermal performance of the space and the effect of glazed area on thermal environment, in real conditions, measurements were undertaken in the selected office space, during the hottest month characterized by highest amount of solar radiation. 7 full consecutive days representative of the hot season (from 03 to 10 august) were selected.

A data logger PCE-HT71 was designed to collect data. It has an accuracy of ±1°C. Internal measurement point has been situated at a height of 1.20m above the floor level, and near the centre of gravity of the space. The Oregon station WMR200 was designed to collect external temperatures, humidity, and air speed with an accuracy of ±0.5°C. Outdoor climate is also completed from the meteorological station of the National agency of weather data (N.A.W.D, 2014) for the same measurement period. All measurements were performed with a scan rate of 10min.

4.1 *Results and discussion of in situ measurement*

The weather over the 7 measurement days was generally hot and sunny. To allow air entering in the space, the windows were fully opened during the occupation hours (from 8:00am to 12 am and from 13pm to 16:30 pm). Since the office space did not have significant thermal storage or conditioning equipment, indoor environmental conditions of this office room followed closely the outdoor conditions with the expected attenuation of temperature extremes. The curves in figure 5 indicate that the outdoor temperature had a maximal diurnal variation of 24°C, from 14°C to 38°C while the simultaneous indoor temperature was varying from 23.2°C to 33.0°C, showing a maximum diurnal variation of about 9.8°C. The average indoor temperature of the space was approximately 2.6 °C higher than the average outdoor air temperature for the measurement period.

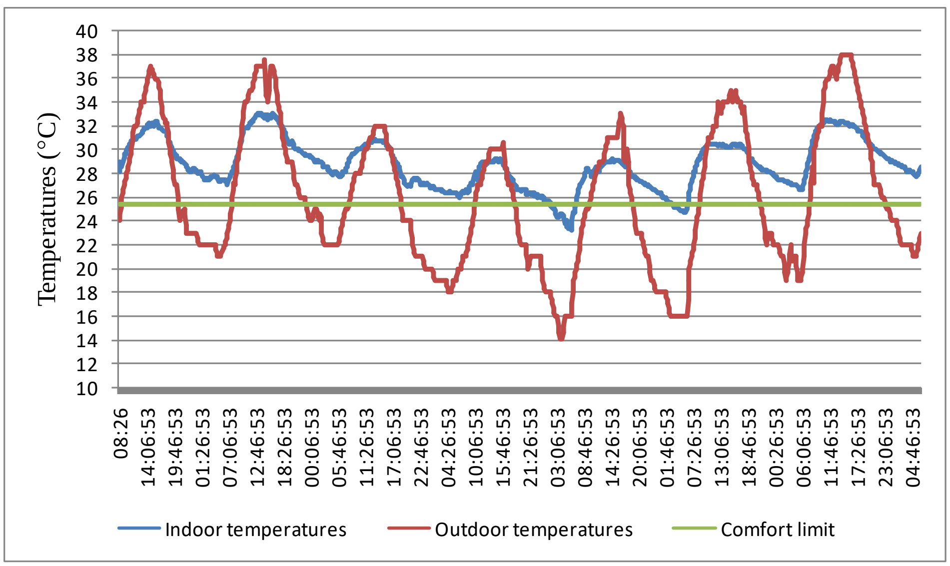

Figure 4. The variation of air temperature in the monitored office from 03 to 10 august 2014

The examination of the curves shows that the maximum temperatures in the office room occurred during midday periods, regardless of the solar heat gain and the poor control measures applied. In occupied hours and in addition to dependence of indoor temperature on the amount of solar energy received by the glazed part of the envelope, occupants open the operable window to generate an air movement to improve their comfort. The office room was consequently exposed to a high overheating risk.

The large temperature difference between the two curves is observed in night time period. The external temperatures fall considerably in night time while internal ones remained higher, well above the comfort limit (Tc=25.42°C) calculated for Constantine with Auliciems formula for the hot season in Constantine. It is clear that night ventilation is not envisaged because windows were often left closed, to prevent drafts that may disrupt papers on desks within the office area. As a result, excess heat is accumulated in the space the following day.

The temperature recorded inside the office room is found to be higher than the comfort limit, for 96 % of all measurement period and 100% of occupied hours (figure 6). From the analysis of the above referred literature and the result of the in-situ measurement, it is clear that the extent of glazed areas in building facades, are directly affecting the indoor temperature. Moreover, this fenestration system is not recommended for summer time in the city of Constantine. It is evident from the results that the energy loads to achieve thermal comfort will be great.

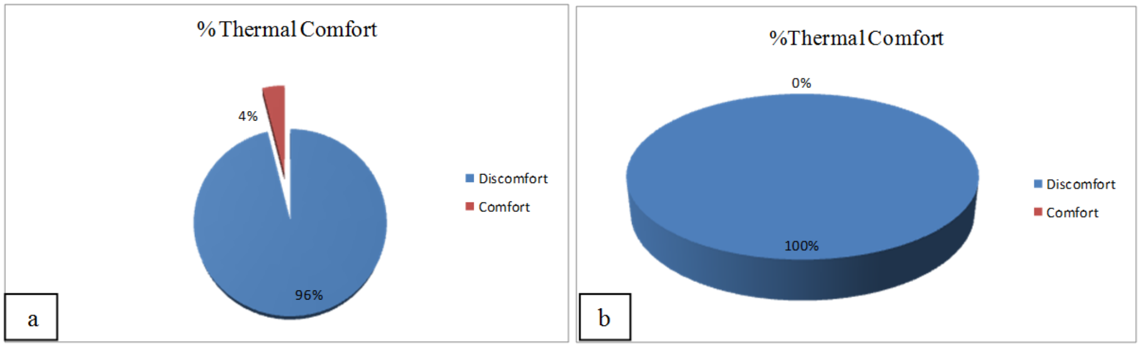

Figure 5. The Percentage of thermal comfort duration: a. from the total measurement period, b. from the occupied hours

5. Simulation

In order to find out the optimal window area in terms of heating and cooling loads, simulation is performed for all year round, using the simulation program 'Pleiades comfie 2.8.6.13'. The office room monitored and described in the first section is selected for simulation. The office room characteristics of building materials are described in table 1, and the simulation results are presented and discussed in this section.

Table 1. Characteristics of building materials used in simulations

	External opaque walls		Slabs		windows	
	Thickness (mm)	Type	Thickness (mm)	Type	Thickness (mm)	Type
components	20	mortar cement	13	Plasterboard	6	Single glass
	150	Hollow brick	200	Hollow body slab		
	100	Air gap	50	mortar Cement		
	100	Hollow brick				
	20	Plaster				
U-value (W/m^2K)	0.3		3.33		5.10	
Solar heat gain coefficient					0.90	

5.1 *Simulation variables*

There are many parameters in the design of windows in terms of thermal comfort, the most important are:

- The Window size expressed as the window-to-wall ratio (WWR) is one of the most important parameters for improving thermal conditions in the building;

-Window orientation is a significant design consideration, with regard to solar radiation;

- Selection for appropriate windows glazing.

So, the energy performance of different types of glazing used in buildings in Algeria has been investigated: A one pane glazing, a double glazing and a double glazing with low-emissivity (low-e). Different WWR expressed as Window-to-Wall ratios (WWR), 10, 20, 30, 40, 50% were studied and the building was rotated in the four main orientations (N, E, S, W). Table 2 gives details of the studied glass types, including their thickness and thermal characteristics.

Table 2. Types of the glazing studied and their thermal characteristics.

Glazing Type		Thermal characteristics	
Type	Composition	U- value (W/m^2. °K)	SHGC
a	One pane glazing (6mm pane)	5.10	0.90
b	Double glazing (6mm pane/12mm air gap/6mm pane)	2.80	0.72
c	Double glazing (6mm pane/12mm air gap/6mm pane and low-e film)	2.80	0.40

5.2 Occupancy and operation schedules

The internal loads in the office room consisted of the heat generated by one computer (450 W) and 3 peoples (80 W each). The thermostat setting was 27°C for cooling, and 19°C for heating during occupation hours. The ventilation rate was 57 m^3/h per Person. Determination of energy loads in the modeled office space, for all cases is given by kilowatt hour/m^3.

5.3 *Results and discussion*

5.3.1. The effect of window-to-wall ratio on heating and cooling loads

In order to select the most effective WWR, each glazing type has been varied by a step of 10% in the four principle orientations. It was found that when using a single glazing (type a) in the southern orientation, a WWR of 30% performs better. However, when using a glass (type b) or (type c), the window with more glazing surface in contact with exterior (a window-to-wall ratio of 50%) is the most energy efficient for South direction (figure 6). This is understandable considering that South orientation receives a great amount of solar energy in cold season, and a lower solar energy in hot season.

The risk of overheating in the Western orientation is avoided because the great amount of solar energy is received out of the occupancy hours. Subsequently the increase of the window area has a positive return on saving energy for heating and has no penalty on cooling energy demand. Therefore, for both heating and cooling loads, energy demand decreases with increasing WWR to 10% in Western orientation. In contrary when using a glazing (type a) in Northern and Eastern orientation, the reduction of window size from 50% to 10% leads to a quick decrease of energy loads by approximately 8%. The decrease of energy loads is less affirmative for the glazing (type b), and (type c) by a ratio of 3%.

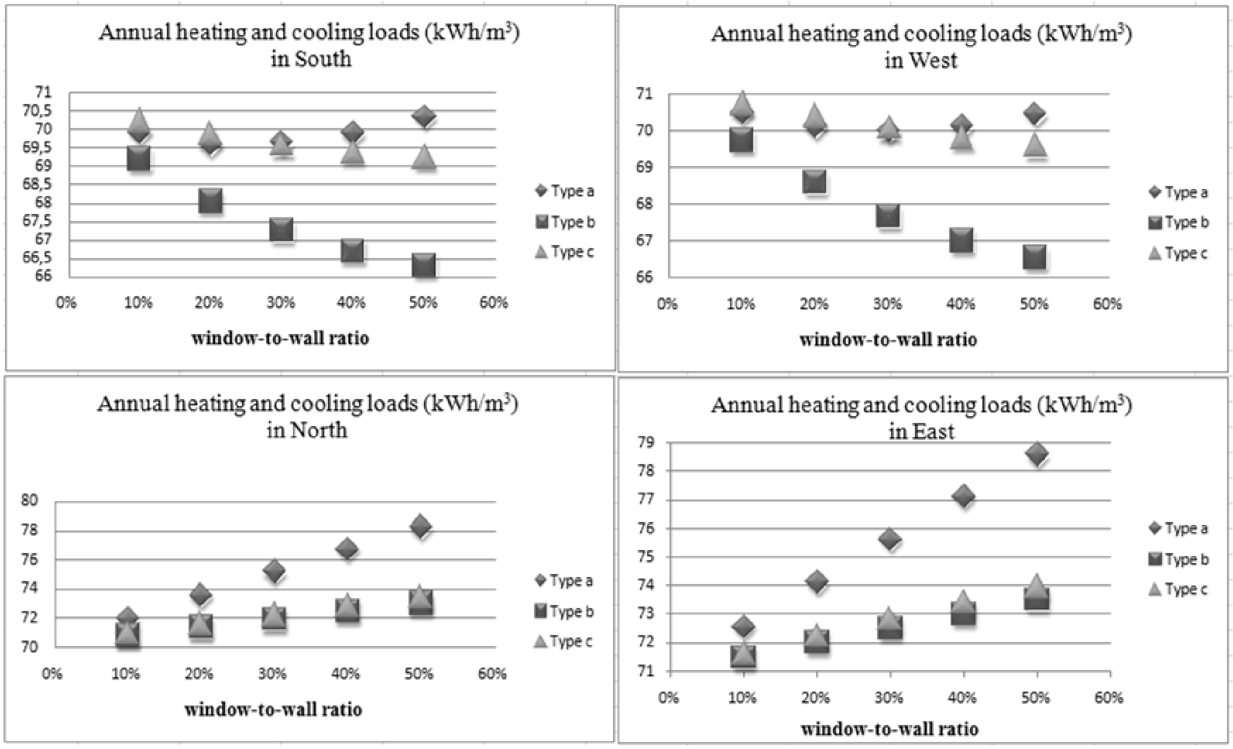

Figure 6. Annual Heating and cooling loads for different orientations when varying the glazing size (WWR).

5.3.2 The effect of orientation

The building was rotated by 90°. The office room energy use is affected by orientation changes. Simulation results indicate that the orientation is another fundamental variable which can strongly influence the energy savings of the glazed façade, as it may be mounted in the South, West, North or East faces of a building. Results for window use in the four main orientations are shown in Figure 7.

For energy savings where both heating and cooling are concerns, the South face is an efficient direction with total annual heating and cooling loads between 67.25 and 70.33 kWh/m^3. This is understandable considering that South orientation receives lower solar energy in hot season. Positioning glazed spaces in the South face can reduce the total energy load, because solar heat gain has a positive effect by increasing the indoor temperature in cold season and reducing it in hot season. Also, in non-residential buildings, the North orientation which allows relatively low solar heat gain seems to be a beneficial window location for energy savings. Simulation indicates a total annual heating and cooling loads between 69.9 and 70.3 kWh/m^3 in this direction. The East is the less effective orientation with regards of total heating and cooling loads (between 71.92 and 78.57 kWh/m^3).

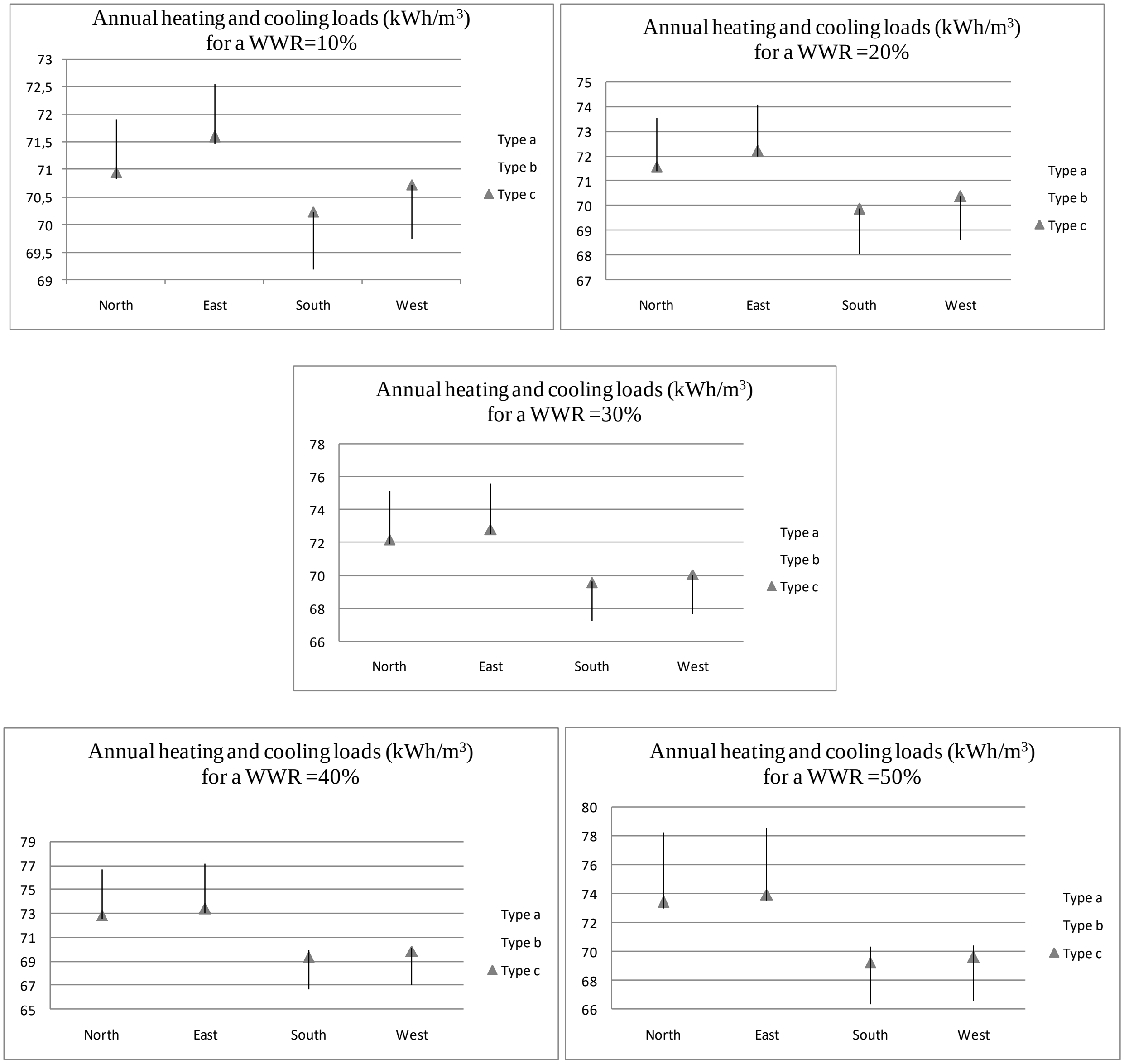

Figure 7. The effect of orientation on heating and cooling load.

5.3.3 The effect of glazing types

The energy demand for heating and cooling seasons resulting from the use of the three glazing types described above was compared. It has been found that the type of glazing materials used in building construction makes a significant contribution to the annual energy consumption.

In Northern and Eastern orientations, the single Glazing (type a), with the higher U value (5.10 $W/m^2.°K$) allows heat transferring between inside and outside. Therefore, it is the less efficient in this study, particularly when great WWR is employed in external wall (Figure 8). Total annual heating and cooling loads can reach 78,6 kWh/m^3 in the Eastern orientation. The double glazing (type b) is the most promising case. It failed to produce acceptable results. The use of glazing (type b) leads to better energy performance than the other options in all the studied orientations. By minimizing the heat transfer through glazing, it aims at the reduction of the heating demand. While the glazing (type c) allows optimizing solar protection and reducing heat transfer. Its Low emissivity coating and gas fillings are important topics here. It performs better than glazing (type a).

Figure 8. Heating and cooling energy demand for glazing Type (a), Type (b), and Type (c) for all the studied orientations.

5.3.4 Ideal WWR for the office room model

The findings from investigating the effects of individual parameters (orientation, glazing type, and WWR) have been combined to formulate a glazed façade that has the low heating and cooling loads in constantine. Table 3 indicates optimal combinations of design measures represented by the ideal WWR for all orientations and glazing types. From this table we can see that energy loads increase as the window area increases. Reducing WWR leads in reducing annual energy loads for glazing (type b), and (type c) for Eastern and Northern orientations. The Southern and Western orientations admit a larger WWR (50%) by using a glazing (type a, and b), in fact of their capacity to admit solar thermal gains in cold period. In contrary, in hot season the space is protected from solar rays.

Table 3. Ideal WWR for the modeled office room

	Ideal WWR (%)		
	Glazing Type a	Glazing Type b	Glazing Type c
South	50	50	30
East	10	10	10
North	10	10	10
west	50	50	30

6. Conclusion

The investigation of an office room located in Constantine city has shown a discomfort and an overheating in a week representative of the hot period. The energy potential of employing glazed facades in office rooms is examined. Design variables such as WWR, glazing types and orientation were evaluated with the assistance of Pleiades comfie program. This analysis defined the most efficient window area (WWR) in an office building, in a semi-arid climate characterized by summer intense solar radiation and cold winters. Thus, a careful design is needed when selecting the window to wall ratio to ensure low energy use for both cooling and heating spaces and good thermal comfort. The maximum reduction of energy loads was achieved by using double glazing window which is more effective in achieving high energy performance of the window than double glazed low e and single glass, especially for highly glazed office buildings.

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