Assessment of Façade Opening Impact on Energy Performance in School buildings Using a Parametric Design Tool, Case of a Hot and Dry Climate

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***Abstract*— Building sector holds a significant part in the world's total energy use. It accounts for about 40% of the world's annual energy consumption and up to a third of greenhouse gas emissions (United Nations Environment Program, 2007). In Algeria, building-related energy consumption accounts for almost half of the total country consumption. As a result, the architecture and construction framework is one of the key areas where action can be taken to produce fast and sustainable changes. For this reason high performance design is becoming more desirable in the field of architecture. This study aims to evaluate the effect of opening ratio of the facade on the total energy consumption of a classroom. The investigation concerns a secondary school located in Biskra which is characterized by a hot and dry climate. In this respect, various opening ratios and different orientations have been tested to achieve optimal lighting with a low level of energy consumption. The goal is to provide architects with simple operational recommendations for the choices they make in designing school facades. The parametric study used the Grasshopper program for Rhinoceros which is one of the most popular parametric platforms today. Experimental results are evaluated in terms of monthly and annual energy consumption and optimal values are determined. Simulation tests indicated that any design modification in opening ratio and orientation has a significant effect on energy consumption for heating, cooling, and electric lighting. Thus, an appropriate choice made at the glazed surface of the facade can significantly reduce the building's total energy requirements.**

***Keywords*— Energy consumption, school buildings, window to wall ratio, parametric design tool, hot and dry climate**

I. INTRODUCTION

With the growing global concern for sustainability, the development of high environmental performance of buildings is becoming a topic of interest for research. Maintaining a comfortable and healthy indoor environment with minimal energy consumption is a challenge for architects especially in areas with a hot and arid climate. In these regions, designing naturally lit buildings that are thermally comfortable while consuming as little energy as possible is almost a paradox. However, the design of the facade and especially the appropriate choice of the transparent surface seem to be decisive to meet such a challenge and ensure buildings with "zero energy" [1]. The problem is even more complex in school buildings where it is imperative to ensure both light and thermal comfort in the classroom. Solving this problem requires the development of a multi-criteria approach that integrates climate, formal and functional data.

The main objective of this study is to initiate such an approach that will highlight the impact of the opening ratio and orientation of windows in the energy consumption required for heating, cooling and lighting in classroom.

In Algeria, the realization of schools had to cope with the urgent demand for the lack of infrastructure resulting from escalating demographic and the institutionalization of the right of education. The construction was governed by standard plans largely reproduced to meet the criteria of economy and speed of execution. However, the consequences resulting from this strategy proved to be catastrophic from the point of view of the quality of the spaces produced. Often, the constructed buildings did not provide the minimum required in terms of thermal comfort and level of illumination, which made their operation highly dependent on the electric energy.

Indeed, school buildings by their function and tenure are distinguished by a particular architectural design. Thomas-Releau (1999) [2] states that schools and office buildings require precise levels of illumination and natural ventilation. These requirements have repercussions on the morphology of such buildings since they often appear with articulated shapes allowing large surfaces of external walls and a maximum of glazed surfaces.

However, window design has a direct impact on energy consumption for heating and cooling because. It is responsible for much of the heat loss (or gain) that occurs at the same time on the building envelope. As a general rule, natural lighting performance is better when the window-to-wall ratio (WWR) increases, at the same time solar heat gains will be increased as this ratio increases [3]. In other words, the higher the opening ratio of the facade is, the more heat will be exchanged between the environment and the building, and the building will consume more energy to regulate the indoor environment [4]. According to a study conducted by Inanici and Demirbilek [5] in five cities in Turkey with different climates, it has been shown that optimizing window sizing and reducing energy

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consumption while ensuring visual comfort, goes through an optimization of the ratio of the length of a building to its width, with an optimal dimensioning of the south window. Muhaisen and Dabboor [6] investigated the impact of the orientation, size and glassy material of the window on the heating and cooling energy demand of Gaza's residential buildings which is characterized by a hot and humid climate; it was found that the energy load decreases when the glazing thermal transmission U value is minimized. The optimal size for all facades is the minimum (10%) that provides sufficient daylight for most scenarios. In addition, it is considered the best option for saving energy in construction. The southern orientation considered the worst because it causes great energy consumption and that the energy consumption is not influenced by the vertical or horizontal shape of the window. On the other hand, the study pointed out that the use of low transmission specific glazing materials has important factor in reducing the energy demand. Wang et al. [7] explored the optimal size of windows and ways to reduce energy consumption of buildings using computer simulation.

In the same context, Alwetaishi [8] carried out a study on the impact of the window ratio of the facade of school buildings in various climatic regions in Saudi Arabia. The results obtained showed that it is more advantageous to have a larger glazing surface in a humid climate than in a hot and dry climate. Similarly, the East and South orientations are the most unfavorable in terms of undesirable calorific gains, since they cause overheating in all the cases studied. Regarding the ratio between glazed area and façade wall (opening ratio), it seems that the ratio of 10% is recommended both in a hot and dry climate and in a hot and humid climate. This ratio ensured a dry indoor temperature of 37 ° C and 38 ° C respectively in Jeddah and Riyadh. On the other hand, a ratio of 20% is recommended in a temperate climate.

In Amman, a study was conducted by Hassouneh et al. (2010) [9] in a school building to investigate the impact of glazing types. The results suggest that choosing a large area of south, east and west facing windows saves more energy and reduces winter heating costs. On the other hand, a north-facing classroom is better for saving energy in the summer.

In the hot and dry climate a study was done by El-Deeb in 2013 [10]. on the combined effect of the window to wall ratio and the composition of the walls on the energy consumption of a residential building been made in a hot and arid climate (Egypt) which characterized by a hot summer for four cities: Alexandria, Cairo and Khargah, and the fourth was Berlin's temperate climate for comparison, after a simulation work by Energie Plus to study the effect of WWR and the composition of the walls on energy consumption, and define after which degree the thermal insulation of the envelope does not represent a significant benefit. WWR from 0 to 100% (0%, 10%, 20%, 30% .... 100%) and wall compositions with and without thermal insulation layers vary from 1 to 10 cm (0.1.2 , 3, ... .10cm), the results shows that thermal insulation is not useful for all desert climates, It was of great importance in extreme hot and cold climate, the insulation shows a significant effect in small ratios up to 30%, and it was only useful with the smaller ratios (WWR 0% and 10%) and it was not useful for WWRs greater than 30% in the South and West orientations. Other research was done in same climate by Zekraoui to study the effect of glazing type, orientation and the size of the opening and type of glazing on total energy consumption, the investigation focused on three types (single, double, triple), and different ratios of (25%, 50%, 75%, 100%) proposed, the results shows that the use of double and triple glazing offers a significant reduction in energy consumption, the energy consumption in heating and cooling decreases according to the type of glazing and the best orientation is North / South and the worst is East / West in terms of energy consumption [11]. In recent years, research oriented towards the parametric design approach, Labib and Mayhoub search for the optimal solution to use the glazed facades in arid regions in office buildings using Grasshopper platform with Honeybee and Ladybug Plug-ins, a number of facade alternatives have been examined for better performance. In the first phase, a more efficient glass was examined. In the second phase, lights have been added. Then, in the third phase, a second perforated facade layer was applied. For the last two phases, a parametric design has been applied to obtain the best thermo-visual performance, the results showed that in a hot climate, the glazed facade is an undesirable source of heat gain as well as the uniformity of lighting and glare, on the other hand it can also be a source of cold which causes the increase of the energy consumption [12].

II. METHODOLOGY

In school buildings, classrooms consume most of the energy which is estimated according to Muhaisen (2007) to 70% of the total amount of energy consumption [6]. The present study takes into account the climatic conditions of the city of Biskra. It aims to evaluate the impact of windows surface on the energy consumption in school buildings according to a parametric approach. Parametric design tools have become a strong trend in contemporary architectural design practice and education [14]. Design parametrically means to design a parametric system based on combination of parameters variations that can provides a design space [15].

Among several software used to simulate the energy performance of buildings, this study is mainly based on Honeybee and Ladybug which constitute an environmental and climate analysis toolkit for Grasshopper 3D. The latter is a "graphical algorithm editor" for Rhino. Honeybee uses a set of integrated software for simulation; DAYISM and RADIANCE for lighting, THERM, EnergyPlus and OPENSTUDIO for building energy, Ladybug imports EnergyPlus climate files (*epw) and provides a variety of interactive 3D graphics/ metrics, including: , wind roses, radiation roses, radiation analysis, shadow studies and view analysis. This tool is becoming more and more used by designers, architects and students [16].

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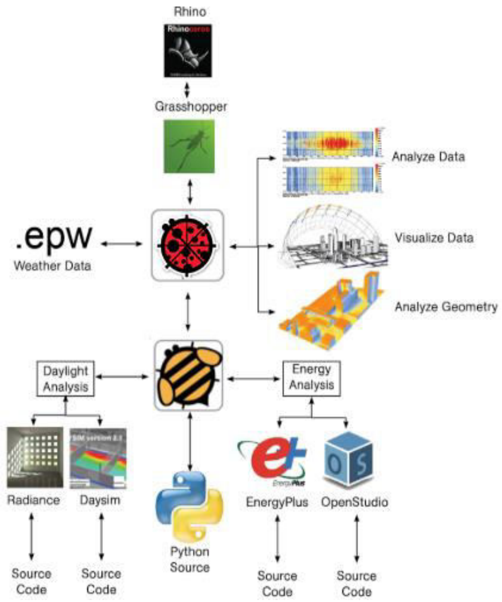

Fig.1 Honeybee &Ladybug plaguing for grasshopper 3D, Source: https://github.com/mostaphaRoudsari/honeybee/wiki

The research is structured in two parts: the first part consists in evaluating the thermal and luminous environment in a building taken as a case study (an existing middle school). The second part presents the parametric optimization process. The latter consists in tow steps: firstly, the orientation of the glass facade along the main directions East, West and North, was changed and then, the energy consumption of the block in the different orientations was compared to the 'reference' orientation which is the South. Secondly, the effect of the WWR on the energy consumption of the block was evaluated by changing the window ratios from 0.1 to 0.9 with a 10% increase in glass area. The Meteonorme software was used to select Biskra climate data [11].

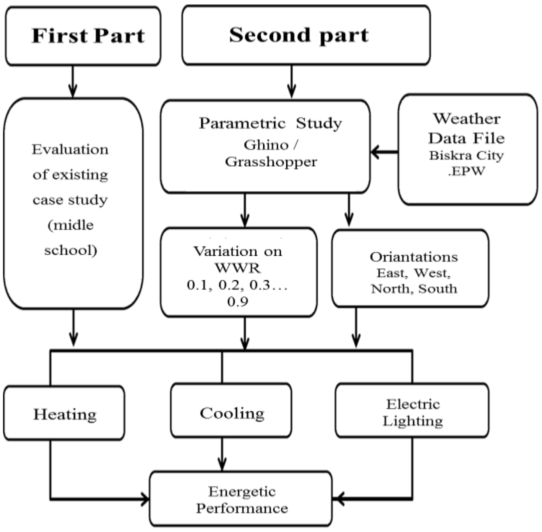

Fig.2 Research work methodology. Source: Authors.

III. CASE STUDY

A. *Location and characteristics of the existing building*

Biskra an Algerian city is located 470 km southeast of Algiers, with an area of 21 671 Km², latitude of 34.80 N, a longitude of 5.73 N, and an altitude of 86 m above sea level, With a hot and arid climate, this climate is found between 15 ° and 35 ° north and south of the equator. The city of Biskra is characterized by sunny clear skies most of the year, high temperatures caused by intense solar radiation and large amplitude between day and night. The relative humidity is generally low during the day and especially in the summer months, which it decreases at less than 19%. In winter, it is ranged between 46% and 55% during the day and is about 80% at night [17].

The analysed case study is a middle school, built in 1995 in the southern part of the city opposite to a public garden. The pedagogical block of the school building is a ground floor plus one floor; it has the shape of a rectangular bar oriented along the east-west axis (Fig.1). The classrooms are also of rectangular shape, about 8.75m long, 6.60m wide and 3.40m high. The block consists of 18 rooms, 9 rooms in each level. The walls are built with an ordinary concrete with a thickness of 35 cm; single glazed windows are arranged on one side and open to the south with an opening ratio of 23%.

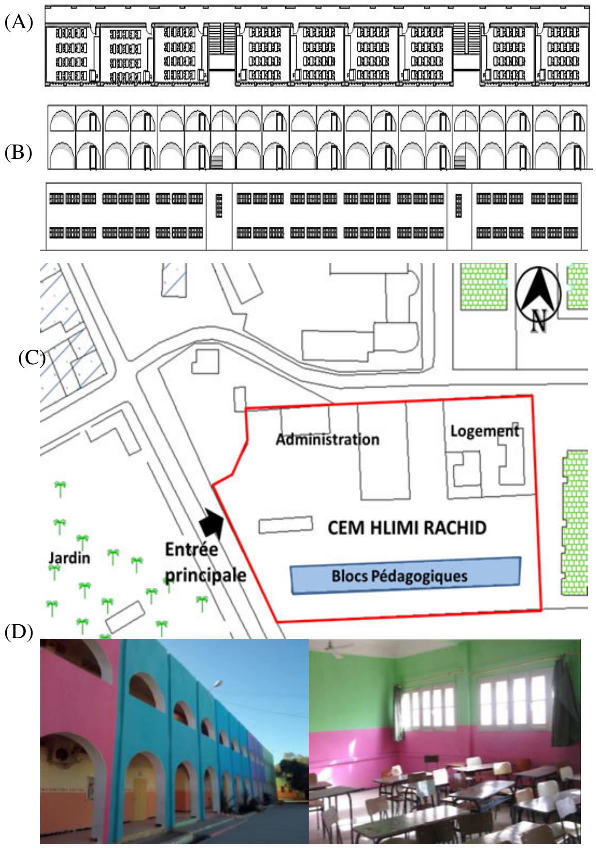

Fig.3 Presentation of the existing building (the case study) : (A) plan view, (B) North and South facades), (C) Pedagogical block situation, (D) Interior and exterior views, taken the 14th of July 2017. Source: Authors (2019).

B. Simulation parameters

The energy simulation in Ladybug and Honeybee run through several steps in which many factors should be specified. Cooling and heating set point which controls the running of HVAC system is set to be 28° and 18° respectively. The HVAC system is set to be packaged single zone AC. The number of people per floor area, lighting density per floor area are designed as 0.8 ppl/ m^2 and 8 w/ m^2 respectively, these values are referenced from ASHRAE base case model for a secondary school building.

C. Material characteristics of the envelope

The building materials used in this study are taken as they are in the case of study, they are ordinary materials marketed in the Algerian market (tab.1).

TABLE I
ENVELOPE MATERIALS AND THEIR THERMAL CHARACTERISTICS. SOURCE: KADRI AND MOKHTARI (2011)

Walls / Floors	Materials	λ Conductivity	Thickness (m)
Interior wall	Plaster	0,35	0,015
	Hollow brick	0,5	0,1
	Plaster	0,35	0,015
Floor	Plaster	0,35	0,015
	Hollow brick + compression slab	1,45	0,2
	Mortar	1,4	0,04
	Flooring	2,1	0,06
Roof	Plaster	0,35	0,015
	Hollow brick + compression	1,45	0,2
	Insulation	0,1	0,04
	Slope shape	1,15	0,04
	sealing	0,04	0,03
Glazing	Simple Clear	5,8	0,04

IV. RESULTS

The Rhino / Grasshopper program and Honeybee and Ladybug plug-ins were used to perform simulations tests on the pedagogical block of a middle located in Biskra. The characteristics of this control building are those defined previously. The objective of the simulation is to study the effect of varying the opening ratios of the facade in combination with different orientations on annual and monthly energy consumption for heating, cooling, and electric lighting in classroom.

A. Evaluation the classrooms energy consumption

Comparing the energy needs of the educational block, it appears that the energy consumption required for cooling is the most important. Indeed, the overheating period in Biskra is spread over 7 months, from April to October. During the three months of the Summer-June, July and August, the air conditioning system requires maximum exploitation; the values calculated for energy consumption are between 600 and 1000 KWh for each classroom (Fig. 4). On the other hand, the heating consumes less energy, the use is limited to the three months of the winter season (December, January, February), the maximum values reached are in January is 137 KWh. For its part, the monthly consumption in electric lighting is remarkable. During all the months of the year, the calculated values are of the order of 100 to 190 KWh. The maximum values are recorded during the winter period when the intensity of the solar rays is the lowest. These values are minimal during the summer period because of the considerable intensity of solar radiation. Figure 5 illustrates the distribution of total annual energy consumption for classrooms: 61% in cooling, 34% in electric lighting and just 5% in heating.

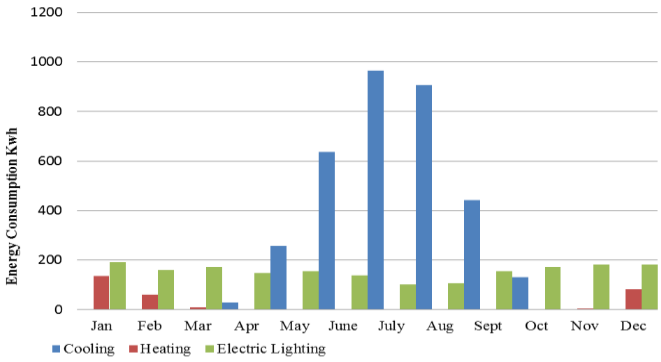

Fig. 4 Total monthly heating, cooling and electrical lighting for a classroom, Source: authors

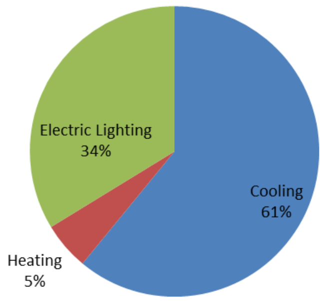

Fig. 5 Percentage of annual heating, cooling and electrical lighting consumption for a classroom Source: Authors

The distribution of the annual energy consumed in the classrooms was analysed according to their location in the educational block (Fig. 6). Thus, classrooms located on the first floor are more energy-intensive than those located on the ground floor. The values of the annual energy consumption are between 130 and 154 KWh / m^2 on the ground floor and between 186 and 210 KWh / m^2 on the first floor. This difference is the result of an increase in the area exposed to the outside and therefore an increase in the heat gains (or losses) that occur. In fact, the roof of the first floor is more exposed to the sun and therefore it receives more heat. The same phenomenon can be seen in the classrooms at the east and west ends of the block. These rooms consume more energy than

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those inside because of the difference in the surface of the walls exposed to the outside.

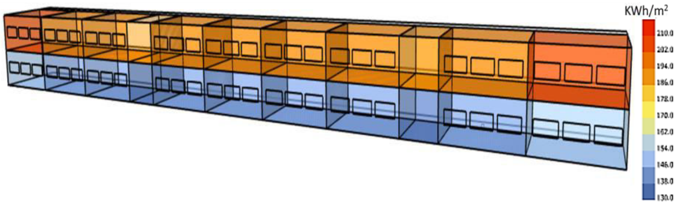

Fig. 6 Visualization of annual energy consumption in classrooms according to their location in the building, Source: authors.

B. *Impact of the orientation*

After analysing the energy performance of the control building, the second series of tests are designed to evaluate the impact of the orientation of the glass facade along the main directions on energy consumption in heating, cooling and electrical lighting. The opening ratio is kept constant at 23%. The results obtained are illustrated in the graphs below (Fig. 7).

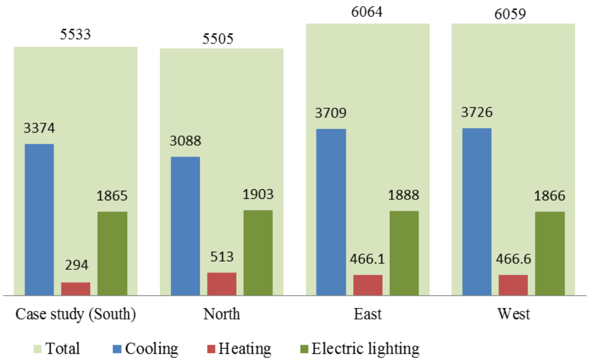

Fig. 7 Annual energy consumption in KWh according to the four orientations in a classroom, Source: authors

The Southern orientation which represents the orientation of the case study (control building) is the one that records the lowest values in terms of energy consumption for heating and electric lighting. The Northern orientation is optimal in comparison with all other orientations since the total annual energy consumption for this direction is the lowest for cooling (3088KWh). On the other hand, it represents the most energy-consuming case for heating and electric lighting because it is least exposed to sunlight. Finally, the East and West orientations are the most unfavorable, as they record the highest values in energy expenditure for both cooling (more than 3700 KWh) and heating (466 KWh).

C. *Impact of the window to wall ratio(WWR)*

For this series of tests, it is the opening ratio of the south-facing facade that will be varied to see the impact of the percentage change in glazed area on energy consumption. Thus, by maintaining classroom exposure to the South, the window opening ratio will be gradually increased from 0.1 to 0.9 with an increase in glass area of 20% each time.

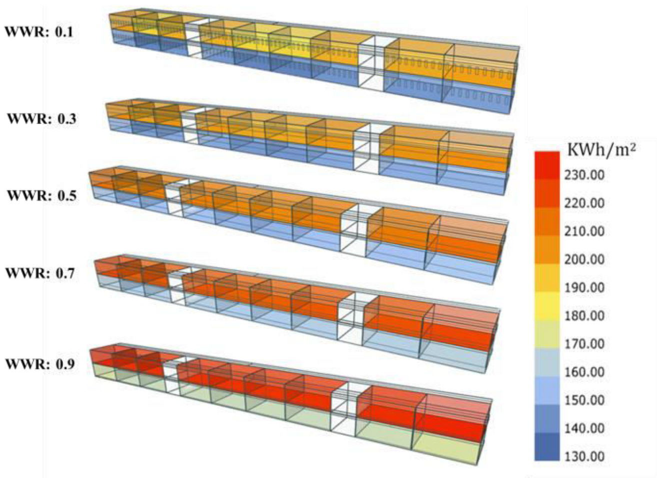

Fig. 8 Visualization of the impact of window to wall ratio on annual energy consumption in classrooms the building, Source: authors.

The visualization of the results obtained that represents the annual energy consumption in the educational building (Fig 8) indicates a proportional relation between the window to wall ratio and the energy consumption
The second series of tests represents the annual energy consumption in heating, cooling and electric light with an increase in glass area of 10% each time (Fig 9).

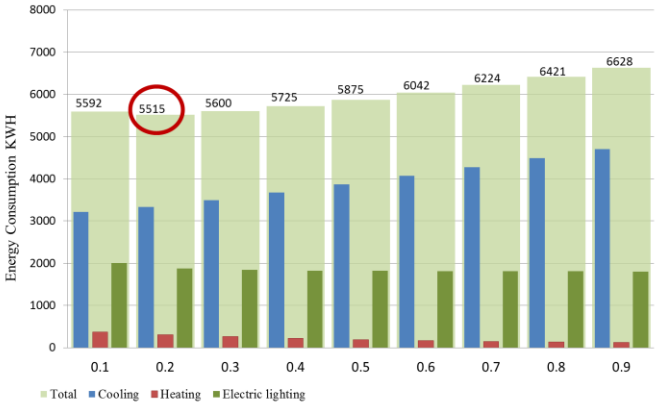

Fig. 9 Impact of changing window to wall ratio on energy consumption of the south façade, Source: authors

The results obtained indicate a proportional relation between the opening ratio and the energy consumption in air conditioning. Thus, the energy consumption for cooling increases as the opening ratio increases, the difference between the ratios of 0.9 and 0.1 is 1497KWh; it means a percentage of 32% increase in annual energy consumption for cooling needs. An inverse relationship is noted between the opening ratio and the energy consumption in heating. Indeed, as the opening ratio increases, the reduction in energy consumption in heating was reduced; the difference between the ratios of 0.9 and 0.1 is 190 KWh; it means 67% of reduction in annual energy consumption in heating. With regard to, electric lighting a remarkable reduction in consumption of electric lighting

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occurs when the opening ratio goes from 0.1 to 0.2; but beyond the ratio of 0.5, the increase in the glass area has no effect, since the values are almost identical.
From the results of the parametric study, it seems that for all the ratios proposed, the ratio of 0.2 is the most efficient from the point of view of the total energy consumption. Finally, the analysis showed that a 20% glass surface ratio of the South-facing facade is optimal for the total annual energy consumption for a classroom.

CONCLUSION

This study evaluated the impact of the WWR on the energy performance of a school building located in a hot and dry climate. Annual and monthly energy consumptions have been calculated based on the heating, cooling and electrical lighting requirements of the classrooms. The energy consumptions was calculated with the Rhino / Grasshopper simulation tool and using the Honeybee and Ladybug plug-ins. The results of a first series of simulations carried out to evaluate the energy performance of a control building, have shown that classrooms use 61% of the total annual energy consumption for air conditioning, 34% for electric lighting and just 5% for heating. In addition, the appropriate choice of aperture area reduces this annual consumption by 16.7%, while the appropriate choice of the orientation reduces the annual energy consumption by 9.2% per classroom. The results obtained also confirm the unsuitability of large glass surfaces for the hot and arid climate. The best open ratio is 0.2; this value represents a minimum consumption for the South orientation.

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