Study of the effects of daylight on optimum dimension of windows in hot climate

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***Abstract*— The optimization of energy consumption in hot climate is complex, for this climate daylighting can be used as passive strategy to reduce energy consumption. The window as sensible thermal load element in building is also a source of daylight. To avoid problems of glare and overheating the window size should be limited. ASHRAE proposed a Window to Wall Ratio (WWR) which is considered as the optimal window size that ensures minimum annual thermal loads. Unlike the WWR which is considered as optimal for the whole year, this study shows that the optimal window size varies with day time and depends on: type of glazing, the orientation and the variation of solar radiation intensity. In the present work Genetic Algorithms are used to optimize window size taking into account the daylight. A typical office room located in hot climate, in this case Ghardaia, Algeria, is selected as a case study. The results show that the daylight is a key factor to limit the window size in hot climate for minimum thermal loads.**

***Keywords*— Energy consumption, Window size, Optimization, Daylight, Hot climate.**

I. INTRODUCTION

Energy consumption of buildings has a negative impact on the environment as they are responsible for approximately 40% of the total world annual energy consumption [1]. Most of this energy is for the provision of lighting, heating, cooling, and air conditioning. Increasing awareness of the environmental impact of CO2 and NOx emissions and chlorofluorocarbons triggered a renewed interest in environmentally friendly cooling and heating technologies [1]. Windows are generally the weakest link of buildings in terms of energy conservation. Approximately one-third of the energy loss from a typical house occurs from windows [2].
In many countries there are codes regulating minimum window size to provide problems of glare and overheating, this window size are generally defined as a WWR which is related to an annual thermal loads calculation. However, this coefficient neglects several parameters that have a direct influence on thermal loads such as the orientation. Alan Pino and al [3] analyzed the thermal and luminous behavior of an office building in Santiago, for different design conditions through a year, by changing four architectural parameters that are the window to wall ratio (WWR), the outdoor solar protection devices, the type of glazing and the orientation. In winter, the window is considered as a thermal losses element and also a source of thermal gains due to solar radiation. Taking into account this thermal gains reduce heating loads, this is why the window tends toward an optimal size. In summer, the window is considered only as a thermal gains element, this means that the optimal window size tends to 0m². Consequently, the WWR can not be considered as optimal for the whole year. This implies that the optimization of the window size is much complex for cooling-dominated climates (hot climate).
The window as a thermal loads element is also a source of daylight, according to Scartzzini and al [4] daylighting strategies can contribute to curb the energy consumption of buildings, as well as the related carbon emissions, by reducing their electric lighting and cooling needs.
In this study the effect of using different types of glazing taking into account the daylight on optimized window dimensions in an office room (for 4 different orientations: North; South; East; West) is investigated. The Algerian Regulatory Document (DTR) [5] and the Hourly Analysis Program (HAP software) are used to calculate the required hourly cooling loads in July (the hottest month) for different types of window glazing as for new sustainable buildings, external surfaces are of different glazing. To carry out this study, Genetic Algorithm is used to determine the optimal size of the windows. The results of the hourly optimization are analyzed to evaluate the impact of a proper window optimal glazing area in a typical office room in Ghardaia, Algeria and to minimize the energy impact of windows.

II. DISCRIPTION OF THE MODEL ROOM

As this study is a part of ongoing research work, a typical room already considered with an area of 25.9 m² located for this purpose in Ghardaia, Algeria (32.49° N latitude; 3.67°E longitude) is selected as a case study. Figure 1 shows the schematic design of the office room. To carry out this study the room is studied for different orientations (North; South; East; West). The dimensions of studied room are 5.18 m long, 5 m wide and a height of 3m. This room has one window placed on external wall of 15m². For the analysis, all opaque building components of the reference room are considered as adiabatic, with the exception of one wall where the window is placed (the external wall)(Figure 1). The external wall transmission is of 1.14[W/m².°C]. Four orientations that are South, East, North, and West are considered and the whole building is rotated accordingly toward the desired orientation.

TABLE I
GLAZING TYPE CHARACTERISTICS

	Glazing type	solar factor SF [%]	Heat transmission coefficient U [W/m². C°]	Visible transmittance τ [%]	Thickness [mm]
Type 1	*Simple glazing*	83	5.8	87	4
Type 2	*Double glazing classic*	75	3.3	81	4(6)4
Type 3	*Double solar control glazing **Air***	47	2,8	41	6 (12) 6
Type 4	*Double solar control glazing **Air***	12	2,3	7	6 (12) 6
Type 5	*Double glazing (Reinforced Thermal Insulation) and solar control **Air***	8	1,4	7	6 (16) 6
Type 6	*Double glazing (Reinforced Thermal Insulation) and solar control **Argon 85 %***	37	1,2	40	6 (16) 6
Type 7	*Double glazing (Reinforced Thermal Insulation) and solar control **Argon 85 %***	8	1,2	7	6 (16) 6
Type 8	*Double glazing (Reinforced Thermal Insulation) and solar control **Argon 85 %***	17	1,1	18	6 (16) 6
Type 9	*Double glazing (Reinforced Thermal Insulation) and solar control **Argon 85 %***	8	1,1	7	6 (16) 6

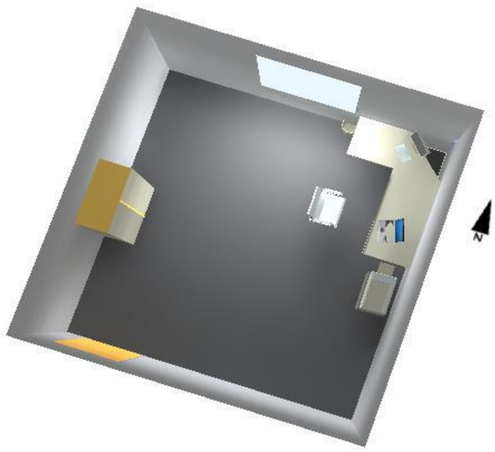


Fig. 1 Schematic design of the office room.

The optical properties of glazing are shown in Table 1. The same products have been studied by [6].In this study, the cooling set point is considered equal to 26ºC. Only cooling load of the glazing, the luminaires and the external wall are considered. The internal illuminance level is provided by daylight and artificial lighting. In the present case for an office room, the internal illuminance level must be equal to 500 lux. A typical luminaire has a unitary luminous flux 1300 lm and unitary heat released by the luminaire of 11,6 w.

III. Methodology

In this work, The ASHRAE [7] method is used to calculate solar irradiation intensity. To define the total thermal loads, two methods are used, the method given by the Algerian regulatory technical document DTR [5] and the method given the Hourly Analysis Program (HAP). For accuracy purposes, the obtained optimal total thermal loads will be corrected using HAP software. The objective function to optimize is the total cooling loads through glazing, the external wall and the electric light installation, while satisfying an equality constraint which is expressed as follow:

$$E_{electric} + E_{natural} = 500 \text{ lux} \qquad (1)$$

$E_{electric}$ is the illumination level ensured by the electric light installation, $E_{natural}$ is the natural illumination level ensured by the daylight. The performance evaluation of daylighting in the building was carried out theoretically using the daylight factor (DF) formula. The daylight factor method has been adopted by the C.I.E. (International Commission on Illumination) and is, therefore, internationally used in over 100 countries [8]:

$$DF = [(Ag \times \tau \times M \times \theta \times OF) / At \times (1-R^2)] = (Ei / Ee) \times 100 \qquad (2)$$

Where Ag is the glazing area of the window,τ is the Transmittance of glazing, M is the maintenance correction factor M=90%, θ is Vertical angle of visible sky from the center of the window θ=90°, OF is orientation factor for glazing, At is the total area of room-surfaces, R=0.707 is the average reflectance of all room-surfaces R^2=0, 5, Ei is the required illuminance (500lux), Ee is the outside illuminance on horizontal surface. The flowchart of solution methodology used in this research work is illustrated in Figure 2:

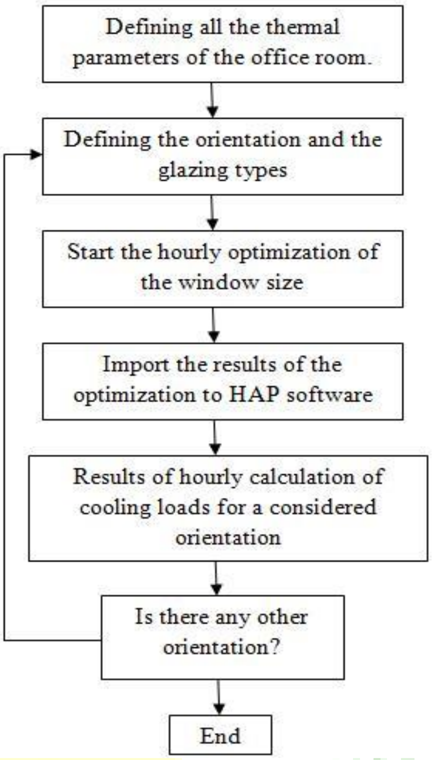


Fig. 2 structure of the proposed methodology

A. *Results and Discussions*

Results of this optimization are presented in the following figures:

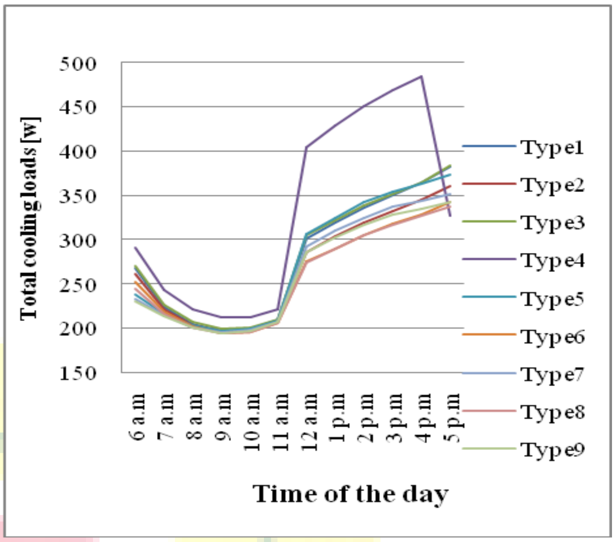
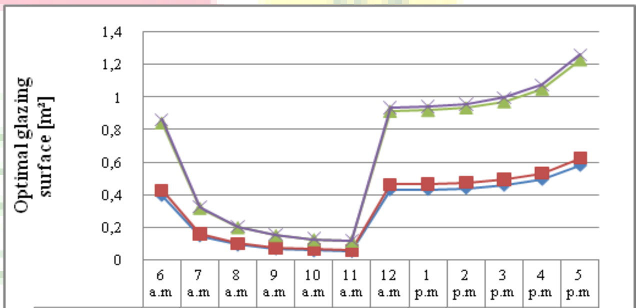
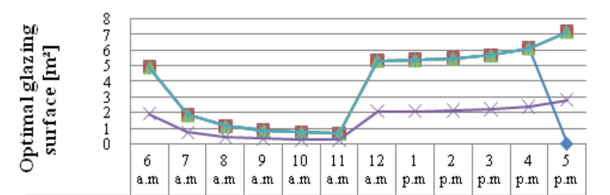


Fig. 3 The variation of total cooling loads for each type of glazing (for East orientation).



	6 a.m	7 a.m	8 a.m	9 a.m	10 a.m	11 a.m	12 a.m	1 p.m	2 p.m	3 p.m	4 p.m	5 p.m
Type1	0,39	0,15	0,09	0,07	0,06	0,05	0,43	0,43	0,44	0,45	0,49	0,58
Type2	0,42	0,16	0,10	0,07	0,06	0,05	0,46	0,46	0,47	0,49	0,53	0,62
Type3	0,84	0,31	0,2	0,15	0,12	0,11	0,91	0,92	0,93	0,97	1,05	1,23
Type6	0,86	0,32	0,20	0,15	0,13	0,12	0,93	0,94	0,96	0,99	1,07	1,26



	6 a.m	7 a.m	8 a.m	9 a.m	10 a.m	11 a.m	12 a.m	1 p.m	2 p.m	3 p.m	4 p.m	5 p.m
Type4	4,94	1,86	1,17	0,88	0,74	0,68	5,36	5,39	5,48	5,70	6,15	0
Type5	4,94	1,86	1,17	0,88	0,74	0,68	5,36	5,39	5,48	5,70	6,15	7,21
Type7	4,94	1,86	1,17	0,88	0,74	0,68	5,36	5,39	5,48	5,70	6,15	7,21
Type8	1,92	0,72	0,45	0,34	0,29	0,26	2,08	2,09	2,13	2,21	2,39	2,80
Type9	4,94	1,86	1,17	0,88	0,74	0,68	5,36	5,39	5,48	5,70	6,15	7,21

Fig. 4 The variation of the optimal glazing surface for each type of glazing according to the time (for East orientation).

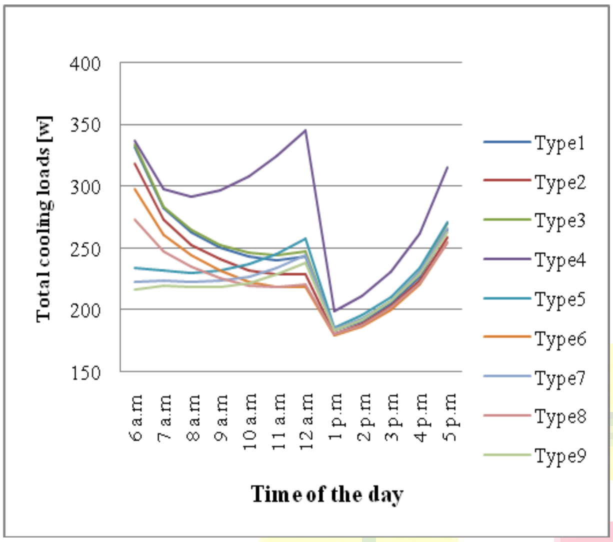


Fig. 5 The variation of total cooling loads for each type of glazing (for West orientation).

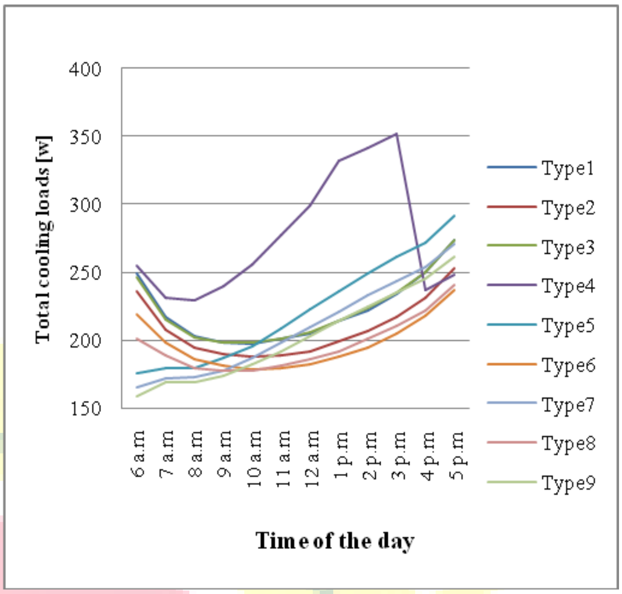
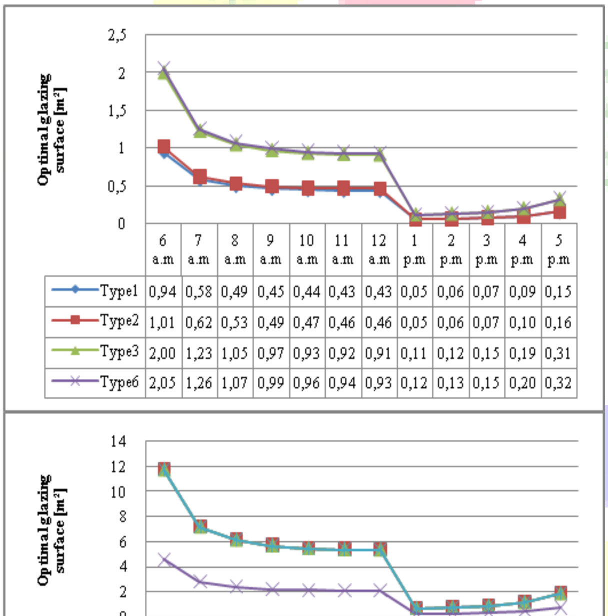


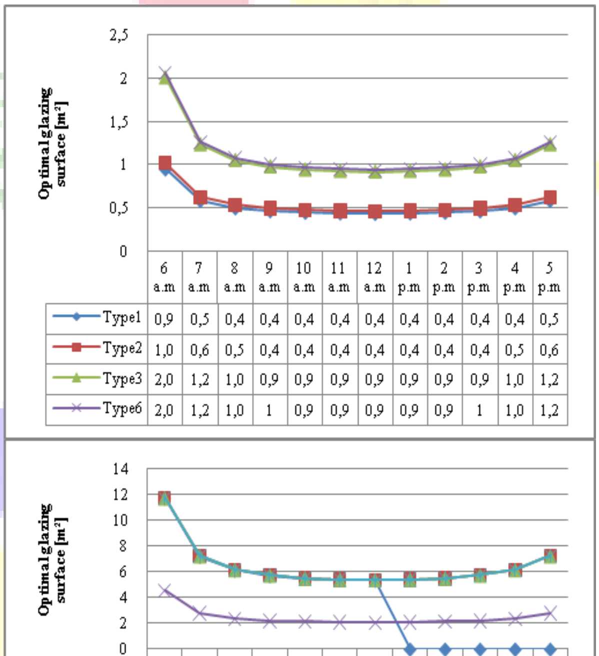
Fig. 7 The variation of total cooling loads for each type of glazing (for North orientation).



	6 a.m	7 a.m	8 a.m	9 a.m	10 a.m	11 a.m	12 a.m	1 p.m	2 p.m	3 p.m	4 p.m	5 p.m
Type1	0,94	0,58	0,49	0,45	0,44	0,43	0,43	0,05	0,06	0,07	0,09	0,15
Type2	1,01	0,62	0,53	0,49	0,47	0,46	0,46	0,05	0,06	0,07	0,10	0,16
Type3	2,00	1,23	1,05	0,97	0,93	0,92	0,91	0,11	0,12	0,15	0,19	0,31
Type6	2,05	1,26	1,07	0,99	0,96	0,94	0,93	0,12	0,13	0,15	0,20	0,32

	6 a.m	7 a.m	8 a.m	9 a.m	10 a.m	11 a.m	12 a.m	1 p.m	2 p.m	3 p.m	4 p.m	5 p.m
Type4	11,7	7,21	6,15	5,70	5,48	5,39	5,36	0,68	0,74	0,88	1,16	1,86
Type5	11,7	7,21	6,15	5,70	5,48	5,39	5,36	0,68	0,74	0,88	1,16	1,86
Type7	11,7	7,21	6,15	5,70	5,48	5,39	5,36	0,68	0,74	0,88	1,16	1,86
Type8	4,57	2,80	2,39	2,21	2,13	2,09	2,08	0,26	0,29	0,34	0,45	0,72
Type9	11,7	7,21	6,15	5,70	5,48	5,39	5,36	0,68	0,74	0,88	1,16	1,86

Fig. 6 The variation of the optimal glazing surface for each type of glazing according to the time (for West orientation).



	6 a.m	7 a.m	8 a.m	9 a.m	10 a.m	11 a.m	12 a.m	1 p.m	2 p.m	3 p.m	4 p.m	5 p.m
Type1	0,9	0,5	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,5
Type2	1,0	0,6	0,5	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,5	0,6
Type3	2,0	1,2	1,0	0,9	0,9	0,9	0,9	0,9	0,9	0,9	1,0	1,2
Type6	2,0	1,2	1,0	1	0,9	0,9	0,9	0,9	0,9	1	1,0	1,2

	6 a.m	7 a.m	8 a.m	9 a.m	10 a.m	11 a.m	12 a.m	1 p.m	2 p.m	3 p.m	4 p.m	5 p.m
Type4	11,7	7,22	6,14	5,72	5,50	5,40	5,35	0	0	0	0	0
Type5	11,7	7,22	6,14	5,72	5,50	5,40	5,35	5,40	5,50	5,72	6,14	7,22
Type7	11,7	7,22	6,14	5,72	5,50	5,40	5,35	5,40	5,50	5,72	6,14	7,22
Type8	4,57	2,80	2,39	2,22	2,14	2,10	2,08	2,10	2,14	2,22	2,39	2,80
Type9	11,7	7,22	6,14	5,72	5,50	5,40	5,35	5,40	5,50	5,72	6,14	7,22

Fig. 8 The variation of the optimal glazing surface for each type of glazing according to the time (for North orientation).

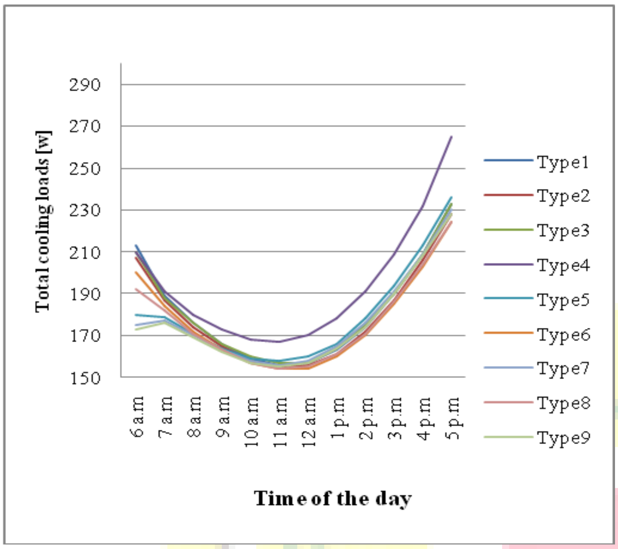
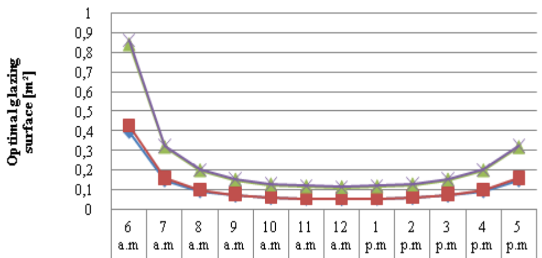
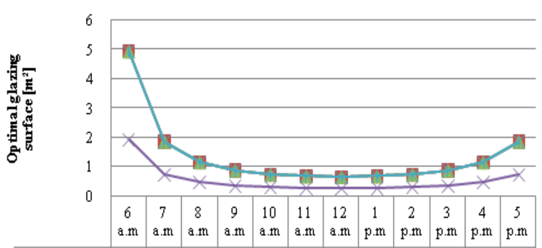


Fig. 9 The variation of total cooling loads for each type of glazing (for South orientation).



	6 a.m	7 a.m	8 a.m	9 a.m	10 a.m	11 a.m	12 a.m	1 p.m	2 p.m	3 p.m	4 p.m	5 p.m
Type1	0,39	0,15	0,09	0,07	0,06	0,05	0,05	0,05	0,06	0,07	0,09	0,15
Type2	0,42	0,16	0,10	0,07	0,06	0,05	0,05	0,05	0,06	0,07	0,10	0,16
Type3	0,84	0,31	0,2	0,15	0,12	0,11	0,11	0,11	0,12	0,15	0,2	0,31
Type6	0,86	0,32	0,20	0,15	0,13	0,12	0,11	0,12	0,13	0,15	0,20	0,32



	6 a.m	7 a.m	8 a.m	9 a.m	10 a.m	11 a.m	12 a.m	1 p.m	2 p.m	3 p.m	4 p.m	5 p.m
Type4	4,93	1,86	1,17	0,89	0,74	0,68	0,66	0,68	0,74	0,89	1,16	1,86
Type5	4,93	1,86	1,17	0,89	0,74	0,68	0,66	0,68	0,74	0,89	1,17	1,86
Type7	4,93	1,86	1,17	0,89	0,74	0,68	0,66	0,68	0,74	0,89	1,17	1,86
Type8	1,92	0,72	0,45	0,34	0,29	0,26	0,25	0,26	0,29	0,34	0,45	0,72
Type9	4,93	1,86	1,17	0,89	0,74	0,68	0,66	0,68	0,74	0,89	1,16	1,86

Fig. 10 The variation of the optimal glazing surface for each type of glazing according to the time (for South orientation).

From figure (3, 4, 5, 6, 7, 8, 9 and 10) it can be seen that:

- The optimal window size varies with day time unlike the WWR method.
- The optimal window size depends on solar radiation intensity, the more solar irradiation intensity increases, the more the optimal window size decreases.
- The optimal window size depends on the orientation. For North orientation the optimal window size is larger than East, West and South orientation.
- The totality of the internal illuminance level (500 lux) is insured by the daylight which means that the luminaires are considered as unfavorable thermal loads. In other words, the window insures much illuminance with minimum thermal loads than the electric light installation.
- The optimum window size depends on glazing type. The more the transmittance (τ) of glazing is less the more the optimal window size increases while insuring minimum thermal loads and the required internal illuminance level (500lux). However, the glazing type 4, for North orientation case from 1p.m to 5p.m and for East orientation at 5p.m, the optimum window size is equal to 0m², even if this glazing type has a low transmittance and the solar radiation intensity is low. This is due to its height thermal transmission coefficient U [w/m².°C]. The window in this case is considered as a source of heat not as a source of daylight. This means that the window is considered as unfavorable thermal loads. In other words, electric lighting installation insures much illuminance with minimum thermal loads than the window.

IV. Conclusion

This study evaluates the influence of daylight on optimized window dimensions in an office room. The results show that daylight is a key factor to limit the window size by having the required internal natural illuminance level and a minimum of cooling loads. Unlike the WWR, this study using the Optimization of Window Size method (OWS) shows that the optimal window size varies with daytime and depends on the orientation, the glazing type and solar radiation intensity. The choice of an adequate glazing type allows reducing cooling loads (in hot climate) meanwhile increasing the window size. This result indicates the significant effect of daylight on optimizing window size for the purpose of reducing energy consumption.

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