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LUMINOUS EFFICIENCY STUDY IN RESIDENTIAL BUILDINGS UNDER SEMI-ARID CLIMATE. CASE OF THE CITY OF BATNA.

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Abstract:
With a view to greater energy efficiency, natural lighting should be used to facilitate the execution of visual tasks while ensuring the general well-being of the occupants of the space. Indeed, an illuminance level that complies with standards (or recommended values) allows good productivity through good visual performance [1]. In the concept of sustainable lighting, it is obvious that daylighting allows less use of electric lighting and therefore, greater energy saving [2].

This article presents an investigation of daylighting in a sample of domestic spaces with a view to gauge the impact of orientation on the design of openings, based on the same window when it is oriented towards three directions (South, North and West) on three levels. However, only the study carried out on the living room (generally a multi-purpose space with prolonged occupation) is reported below for the winter season (being the most unfavorable period in terms of light deposit**)** in order to bring a contribution to better define the capacities and limits of typical windows widely used in residential buildings (dwellings) in the city of Batna, which is characterized by a semi-arid climate with a clear and sunny sky for a large part of the year. This study was carried out through a field measurement campaign to determine the levels of illuminance in the domestic spaces concerned, the majoraim of which is the objective assessment of the luminous environment.

At this level of the investigation, a comparison of the results with international standards [3, 4, 5] was carried out in order to determine the aperture whose characteristics optimize indoor light performance in the domestic spaces investigated. The analysis of all the measurements of illuminance levels on horizontal work plan that were obtained for the nine rooms clearly demonstrates their differences. The results presented below highlight the influence of the type of sky, the orientation, as well as level (height) on the quantity of light received by a room. They revealed that for the winter period: the south-facing room ensures sufficient amounts of natural light needs, and values of average illumination levels sufficient for accomplish domestic activities for the west, while the living room oriented to the north is in an unfavorable situation.
Keywords: Window, Orientation, luminous efficiency, domestic space, daylight, illuminance.

INTRODUCTION

Today, the focus on energy consumption in buildings and its saving by reducing the energy used for electric lighting, related to the recognized benefits of daylight for occupant well-being and productivity, has revived the attention paid to natural light. It is recognized that optimizing the use of daylight in interior spaces can significantly reduce electric lighting, and therefore energy consumption [6].Good daylight provision is now considered a highly desirable mode of sustainable daylighting in terms of occupant well-being and productivity [7]. However, the objective of good use of daylight must be accompanied by the necessity of avoiding the appearance of visual discomfort as well as overheating problems [8]. Knowing that in climates where clear sunny sky is the most typical; the design of windows becomes more complex: The reason is that, unlike overcast sky, clear sky is much more variable and dynamic depending on weather, day and year.

Domestic spaces should meet the needs of the occupants, promote their harmonious development and achieve optimal conditions of comfort for categories of individuals varying in age and sex. Daylight should, as well, be adapted to the nature of the work to be carried out. Before moving on to the realization of the project, it is possible to proceed with a precise calculation of the daylight illuminance generated by the elaborated design in order to be able to estimate the distribution of this daylight illuminance inside the different spaces, especially on the working plane[9].

Generally, good visibility is defined by the presence of an adequate quantity of light allowing the occupant to accomplish his tasks, an even distribution of daylight illuminance and luminance, and the absence of glare. [10] Activities in a living room require a good level of illuminance as well as a good distribution of daylight without strong contrasts that tire the eyes.

We can emphasize that the priorities of the luminous requirements are very complex and difficult to define especially in residential environments and in living rooms to be more specific, because they vary according to the tasks of activities practiced in these spaces, and according to the culture of the occupant. These priorities are perfectly related to the openings. In addition, the configuration of the window as well as its orientation often depends on the luminous performance of the building; which can change the intensity and distribution of daylight to create appropriate luminous environments [11, 12, 13, 14].

However, the published literature focuses more on workspaces and very few on residential buildings. Especially in Algeria, a country where daylight is abundant, research in this field is of paramount importance.

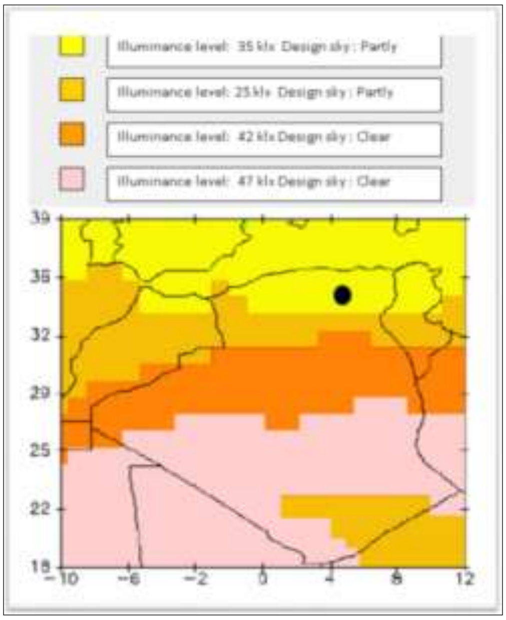
This paper specifically studies the impact of orientation on windows design in residential buildings based on three orientations (South, North and West). The analysis is confined to the study of the living space for the winter season (being the most unfavorable period in terms of light deposit or light source in order to make a contribution to better define the capacities and limits of typical windows widely used in dwellings in the city of Batna.

The objective of this research is to optimize window efficiency to achieve the optimal levels of illuminance daylight in the spaces with respect to the orientation of the buildings. It is a question of favoring a global approach to the energy efficiency of housing so that the windows, being elements of comfort, become energy saving factors.

The experiment is carried out through a measurement campaign to indicate the role of the window in each case in terms of daylight distribution and visual comfort.

1 / CLIMATE CHARACTERISTICS AND LUMINOUS DEPOSIT

The corpus of study is located in Batna, a city in the highland region of the Aurès, north east of Algeria. With an area of 12,038.76 km^2, it is located at a latitude of 35°45' North, a longitude of 06°19'East, and an altitude of 821.29m [15]. The climate is semi-arid, with four distinct seasons. Summers are short, very hot and mostly clear; the winters are long, very cold, and partly cloudy; and the climate is dry throughout the year. During the year, the temperature generally varies from -0°C to 37°C and is rarely lower than -3°C or higher than 39°C.



The average illuminance in the city of Batna is estimated at around 35.000 lux based on the results provided by N, Zemmouri (Fig n°1) [16].

From the climatic data collected at the level of the meteorological station of Benboulaid Airport of Batna relating to the duration of sunshine in the city of Batna for the years 2017/2018, the months of December and January are the least sunny months. On the other hand, the months of June, July and August are the sunniest of the year with a duration varying between 309 ; 328 and 363 hours. Table No. 01. Fig n°1. Daylight availability in Algeria. [16]

Table n°1 Sunlight duration in total hours. [17]

Y/M	01	02	03	04	05	06	07	08	09	10	11	12
2017	148	165	289	246	309	328	363	322	278	256	175	165
2018	233	154	204	253	251	344	344	281	236	217	201	202

The percentage of nebulosity (cloudiness) undergoes considerable seasonal variation over the course of the year. The clearer part of the year in Batna begins around June 14 and lasts for 2.8 months, ending around September 8. On July 31, the clearest day of the year, the sky is clear, mostly clear or partly cloudy 93% of the time, and overcast or mostly cloudy 7% of the time. **(Fig n°2)**

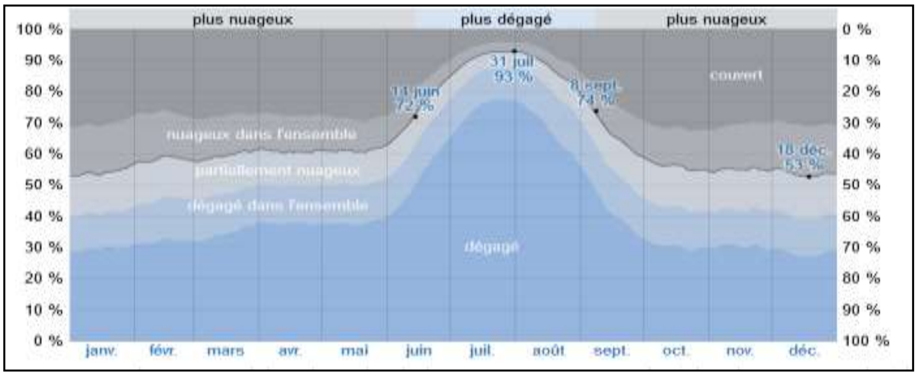


Fig n°2. Illustration of the frequency of clear sky, partly cloudy and cloudy sky conditions in Batna. [17]

The cloudiest period of the year begins around September 8 and lasts for 9.2 months, ending around June 14. On December 18, the cloudiest day of the year, the sky is overcast or mostly cloudy 47% of the time, and clear, mostly clear, or partly cloudy 53% of the time. [17]

2/ PRESENTATION OF THE CASE STUDY

The study site is located in Bouzourane a residential district with a high-density area, presents a contemporary structure split according to the new urban regulation; which once was an old slum, of Batna: a large city located in the east of Algeria. Fig. 3

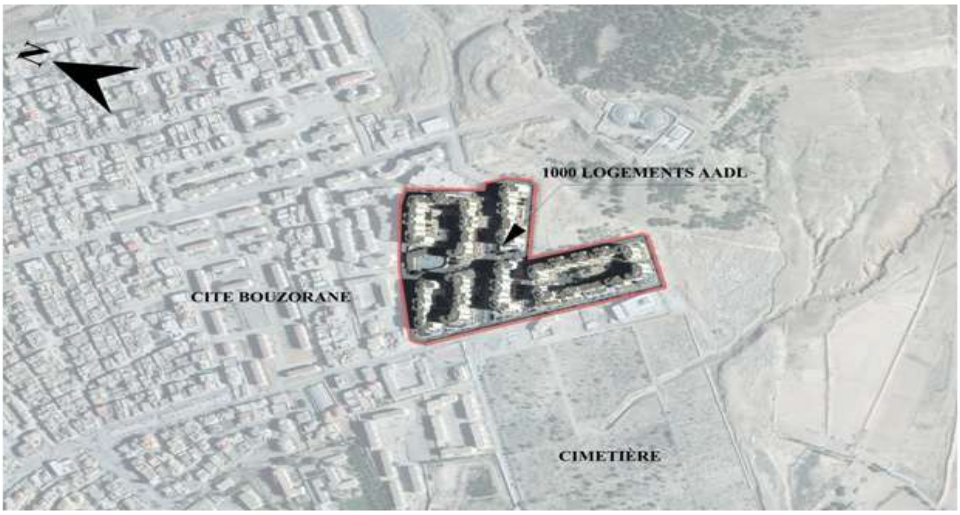


Fig n°3 Location of the study area.

The city is formed by a set of blocks designed in repetitive elements of simple shapes separated from each other and arranged over vast spaces. Two or three traffic lanes, 16m wide, cross the site and divide it into parts.

The buildings seem to be arbitrarily implanted without taking into account the climatic and environmental characters, which results in a diversity of orientations. The district consists of 32 buildings ranging from 5 to 11 floors.

The facades have a special treatment that stands out from the other units. A full and empty play, advance and retreat, shape of openings, and the dryers vary the appearance of the buildings and enhance the urban landscape Fig. n°4. The treatment adopted constitutes an obstacle for any possible transformations by the occupants.

Fig. n°4 overview of the city.

3/ CHARACTERISTICS OF THE STUDY SPACE

The domestic space that is the subject of the present study is the family living room wich consists a particularly significant "living space" from the point of view of its occupation by family members; a space used during the day for the accomplishment of very specific tasks such as receiving, eating, reading, praying, meditating, embroidering , resting, etc.

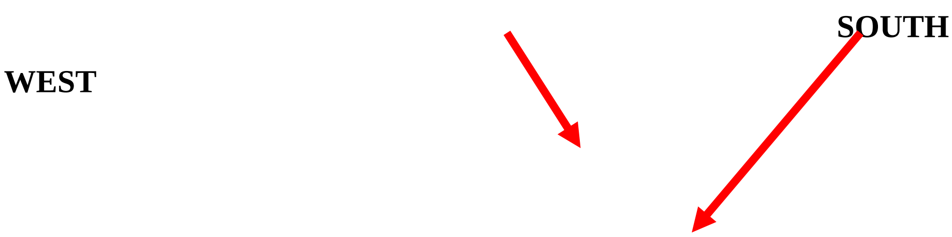
Rectangular in shape (3.50mx5.65m) with a height of 2.80m and side-lit by a square window (1.20mx1.20m) with simple and clear glazing on a sill of 0.90m. Fig. n°5.

Fig. n°5 plan view and section of the living room subject of this study.

Activities in a living room require a good level of daylight illuminance as well as a good distribution of light without strong contrasts that tire the eyes. We can point out that the priorities of the daylighting requirements are very complex and difficult to define especially in residential environments and particularly in living rooms, because they vary according to the tasks of activities practiced in these spaces, and according to the culture of the occupant. These priorities are perfectly related to the windows.

4/ PRESENTATION OF THE STUDY

The objective or quantitative assessment of the luminous environment in the spaces studied (09 rooms) is based on an in-situ measurements campaign during the winter of 2017-2018, on the basis of static indicators which are: the interior horizontal illuminance **E_i**, measured on a useful working plane, the daylight factor **DF**, and the uniformity ratio **I_u**. These parameters will be compared with the values recommended by international standards. The study, which based on three directions of the window (North, South and West) at different levels (**Fig. n°6**), will allow us to determine the needs, control and conditions of the luminous environment.



NORTH

Fig. n°6 Identification of the living spaces covered by this study.

For the study of the quantitative data relating to daylight illuminance distribution, an in situ analysis was carried out using the luxmeter (table n°2) measuring the illuminance levels in the representative family living-spaces in order to accommodate the measurements recorded in three periods of the day (08h00-12h30-16h00).

Table 2. The instrument used: lx1330B luxmeter).

Type of equipment		Précision
	Digital luxmeter LX1330B 0-200000 Lux	± 3%

The illuminance data was measured at 0.80m from the ground (Fig. 7).This height represents the useful working plane assumed to be the normal activity level of the space (because it is suitable for the conduct of several activities).A grid method was used to make various point illuminance measurements in the room (Fig. 8), and then establish an arithmetic mean.

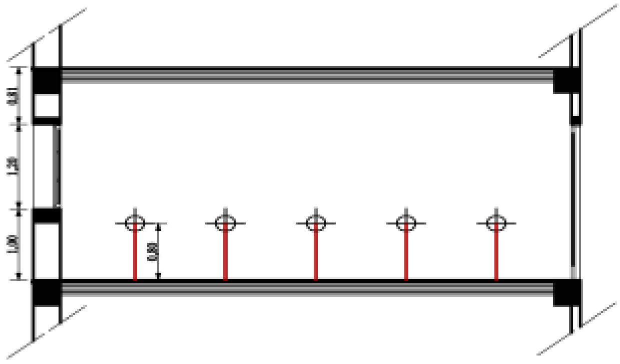


Fig. 7 Section indicating the level of measurement

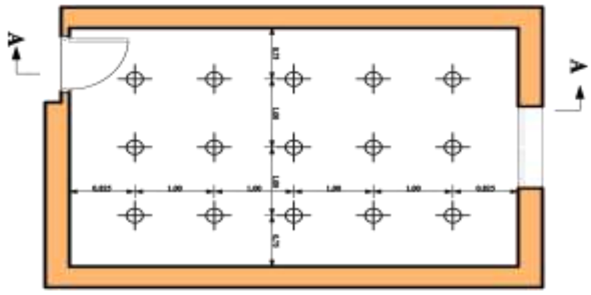


Fig. 8 Grid selected for measurements

All electrical lights were switched off during the measurements, the internal and external daylight illuminance readings were taken simultaneously, and the state of the climate is also recorded. [18, 19, 20, 21]

5/ STANDARDS AND RECOMMENDATIONS

In living rooms, with prolonged occupancy of a dwelling, daylight illuminance levels between 100 Lux and 500 Lux are considered effective for residential activities [**22, 23**]. In the absence of references in local studies and Algerian regulations concerning recommended daylight illuminance levels or daylight factors in residential building, 300 lux is chosen as the reference. This level is adopted from the British regulatory standard: the average daylight illuminance on a useful work surface required for the living room is 300Lux [**4**].

Despite its limitations, the DF is retained in this study since it is internationally accepted and well known. It measures the quantity and quality of light present in a space, while assessing the effectiveness of a room and its window as a daylighting system [**23**]. Bülow-Hübe (2001) proposes a classification of daylight factor (DF) values to assess the quality of a naturally lit space (table 3). The desired DF is between 2% and 5% [**24**].

Table No. 3 Classification of DF values according to Bülow-Hübe (2001) [24]

DF ‹ 1%	Insufficient for most tasks.
DF = 2 %	Minimum required.
2% ‹ DF ‹ 5%	Considered acceptable.
5% ‹ DF ‹ 10%	The space looks substantially illuminated by light, which translates into lighting autonomy.
DF ›10%	Possibility of glare.

The luminous distribution or the uniformity of the illuminance levels characterizes the variations of the level of daylight illuminance. The uniformity ratio $\mathbf{I_u}$ corresponds to the ratio between the minimum and the average value of illuminance observed in the work area [25]. This static parameter provides an indicator of the daylight distribution in a room. Its value ranges from 0 to 1, where 1 represents an optimal and homogeneous distribution of light. Some standards suggest values of the order of 0.3 to 0.4 for side-lit rooms [5].

6/ RESULTS

The results presented below illustrate the values of the illuminance **Ei**, the daylight factor **DF** and the uniformity ratio $\mathbf{I_U}$ as static indicators. These measurements are assessed on a useful work plan for the entire surface of the space. They are then translated into graphs then compared on different variations, which offers a more detailed view of the luminous environment in the spaces studied.

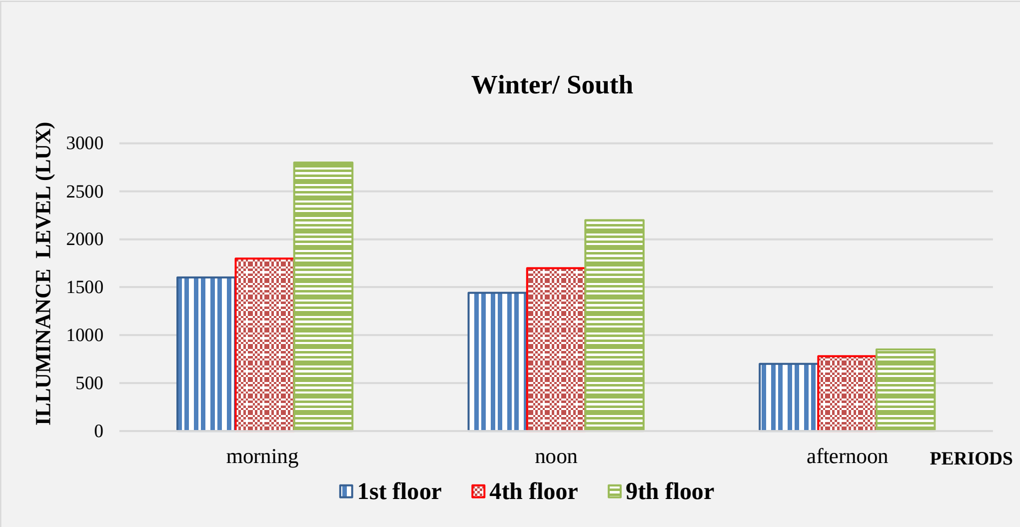
In winter, solar radiation is much less intense than in summer, but penetrates deeply into the room. Measurements of horizontal daylight illuminance on the working plane showed that under almost clear sky (without sun) on December 24, 2017, the orientation of the window influences, directly, the amount of light captured. The difference in the distribution of light is so marked for the nine cases investigated **(Graph n°1, 2, 3)**.

The large difference in horizontal illuminance values created illuminated areas near the window which contrasted with the area of the second row. Nevertheless, the average of the uniformity ratio for this day shows that the general lighting is uniform, except for the two spaces located on the first floor South and West where the values of $\mathbf{I_U}$ are found to be below the recommended standards as shown in table 4. However, the in-situ measurements show that the living room reaches an average **DF** in line with the recommendations for all the cases studies.

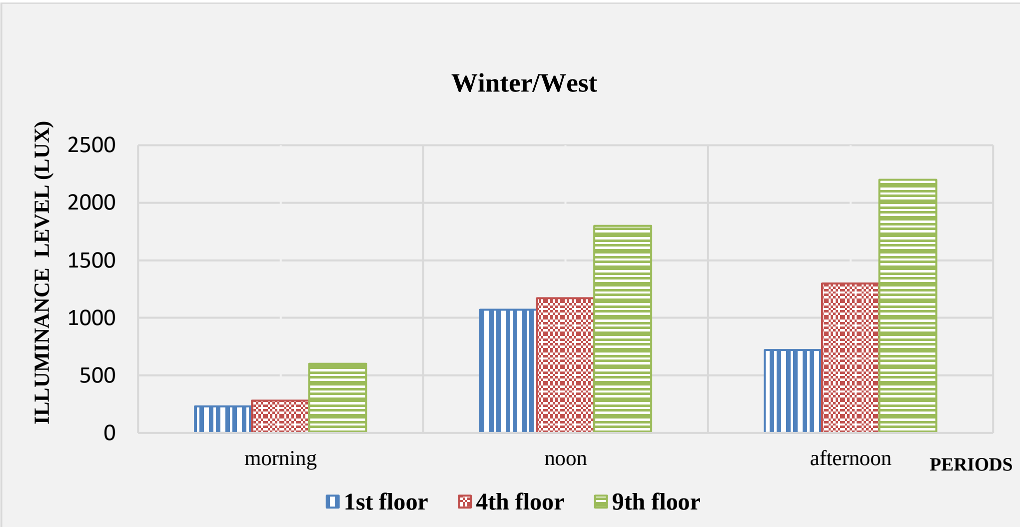
Table n° 4 Results of the in-situ measurements for the nine spaces.

Static metric	Standards [3, 5, 24]	1st FLOOR			4th FLOOR			7th /9th FLOOR		
		South	West	North	South	West	North	South	West	North
E_{aver} (Lux)	300	347	202	82	480	309	109	627	489	154
DF_{aver} (%)	2% ≤ DF ≤ 5%.	2.50	2.50	3.71	2.00	2.00	3.20	2.60	2.60	3.64
I Uniformity	0.3 ≤ I u ≤ 0.4	0.2	0.2	0.3	0.3	0.3	0.4	0.3	0.3	0.4

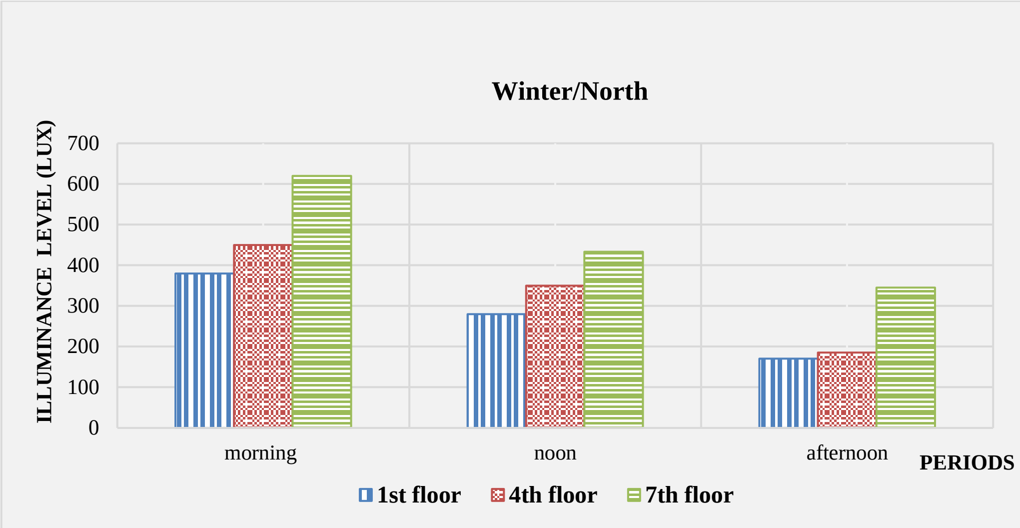
The measurements indicated in table n°4 were taken with closed windows (with clear and simple glazing); shutters and canvas blinds are completely open.



Graph n°1 Variation of daylight illuminance levels in southern room.



Graph n°2 Variation of daylight illuminance levels in the western room.



Graph n°3 Variation of daylight illuminance levels in the northern room.

7/ DISCUSSION

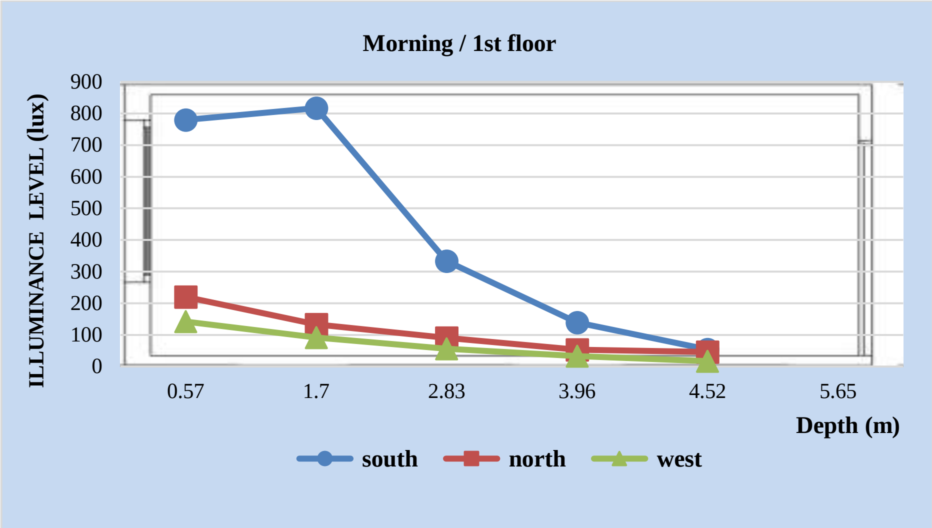
The analysis of all the measurements of the levels of illuminance on the horizontal working plane collected for the nine rooms clearly demonstrates their differences, as illustrated in table n°4.

The diffused light from the sky is available in all directions, with the maximum contribution on the South facade in winter. Measurements of horizontal illuminance levels on the working plane showed that under almost clear sky conditions (without sun) on December 24 the room located on the first floor facing south has much higher levels of illuminance near the window than at the back of the room. The luminous distribution of this space is asymmetrical for the three measurements taken on this day (The presence of a tree at about 2m from the window has radically transformed the daylight in the room). The maximum illuminance values (E_{max}) recorded near the closed window without blinds reached high figures (1600 Lux at 8:30 a.m. – 1440 Lux at 12:30 p.m. to drop to 700 Lux around 3:40 p.m.). The minimum illuminance values Were picked up from the back of the room and showed very low figures during the day as indicated in graphs n°4, 5, 6. For the South orientation, the living room offers satisfactory coverage of the quantitative needs in daylight based on the considerations described. The average illuminance on a useful working plane for this space is 347Lux. For this day, the average DF shows 2.5% which is acceptable.

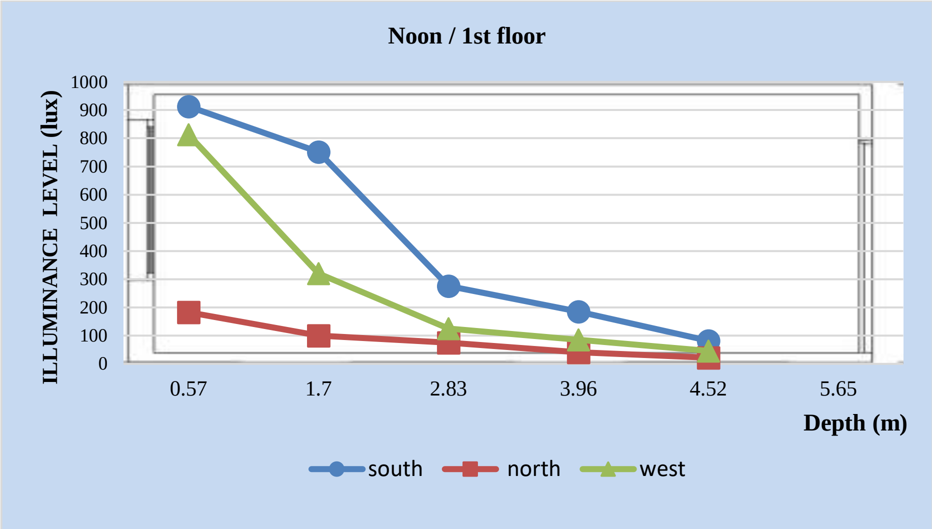
For the West orientation, the value of the average illuminance for the day in question is quite sufficient for the accomplishment of the activities with E_{moy} equal to 202 Lux. The measurements indicate that the sample located on the first floor is poorly lit in the morning with an average level of illuminance of 68Lux and the maximum value does not exceed 230

Lux near the window. At noon, in the afternoon the levels of illuminance approach the reference value as shown in graph n° 5. The uniformity ratio for this sample (0.20) is lower than it is recommended.

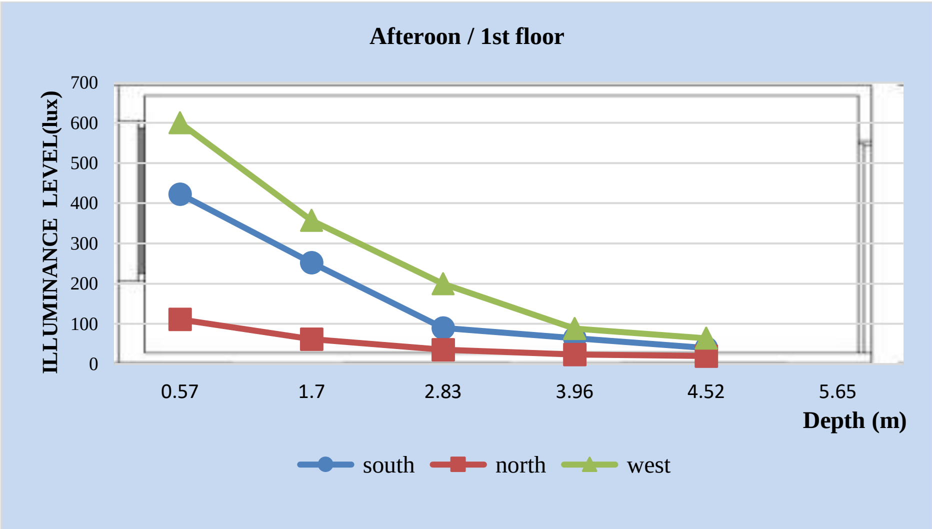
The calculations show that the daylight distribution is far from optimal for the north-facing window. The living room located on the first floor is in an unfavorable situation with an average daylight illuminance value E_{moy} of 82Lux due to the fact that it benefits little from direct solar radiation in winter in addition to the presence of a tree of about 7 m in height located at a distance of 5 m from the window which intercepts the sun during this period. Graphs n°4, 5 and 6 show that more than half of the room surface (central and deep zone) is dark for most of the day, which necessitates the use of electric lighting in this room. Nevertheless, the average uniformity ratio for this day (0.3) shows that the general lighting is uniform with the average DF showing 3.71%.



Graph n°4 illuminances profile for the three orientations of the first floor in the morning.



Graph n°5 illuminances profile for the three orientations of the first floor at noon.

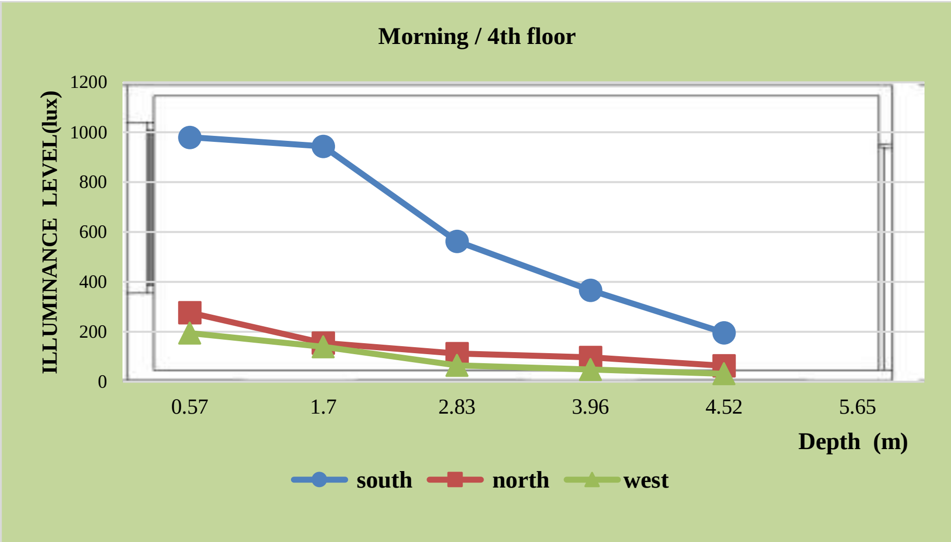


Graph n°6 illuminances profile for the three orientations of the first floor in the afternoon.

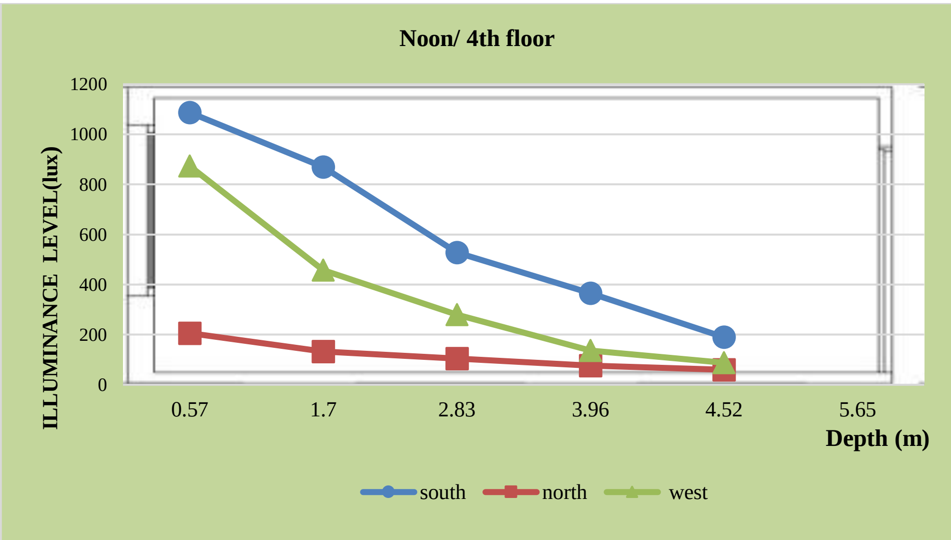
For the living room located on the fourth floor (South), it appears that the general lighting of the room is uniform with a ratio Iu equals to 0.3, and an average daylight factor (DF) of 2%. The average Illuminance values for the morning and at noon are similar (610Lux), exceeding the standard. Nevertheless, in the afternoon (3:40 p.m.) the E_{moy} approaches 300Lux, which makes the luminous space optimal for users. Graphs n°7, 8, 9.

The amount of daylight distributed in the living room located on the fourth floor (West) is sufficient with an average illuminance of 309 Lux. The maximum values of illuminance near the window reached very high figures, especially at noon when the average illuminance reached 1170 Lux, whereas in the morning the illuminance value is lower than 100Lux. The average DF for this sample is at a lower limit of 2% while the uniformity ratio (0.3) is satisfactory.

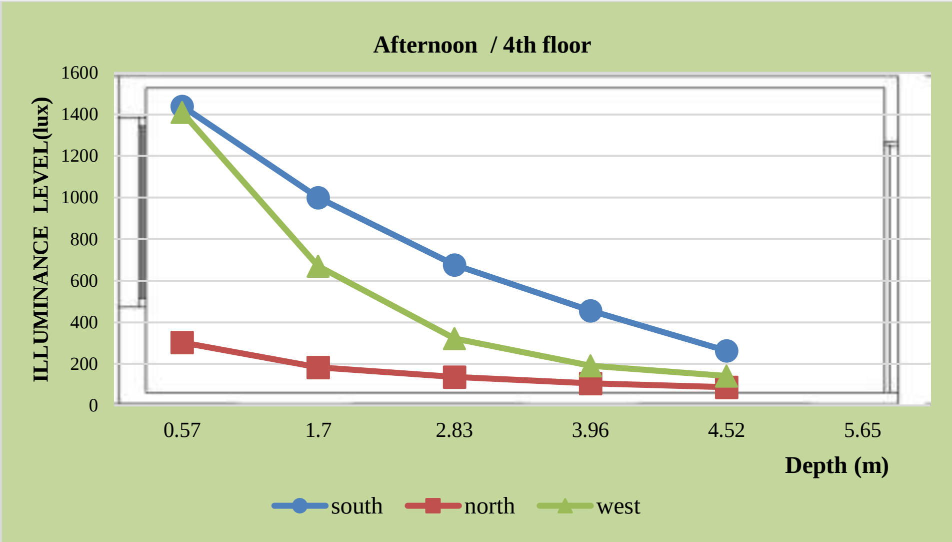
For this winter period, the value of the level of horizontal illuminance recorded in the space located on the fourth floor (North) is 109 Lux, which is why users opt for the use of combined lighting (natural and electric).The average illuminance values fluctuated between 142Lux at 8h32mn and 116Lux at 12h45mn up to 68Lux in the afternoon. Graphs n° 7, 8, 9. Nevertheless, the uniformity ratio displays a value of 0.4 wich is within the recommended range for such spaces. The average DF (3.20%) is in line with the recommendations.



Graph n°7 illuminances profile for the three orientations of the fourth floor in the morning.



Graph n°8 illuminances profile for the three orientations of the fourth floor at noon.

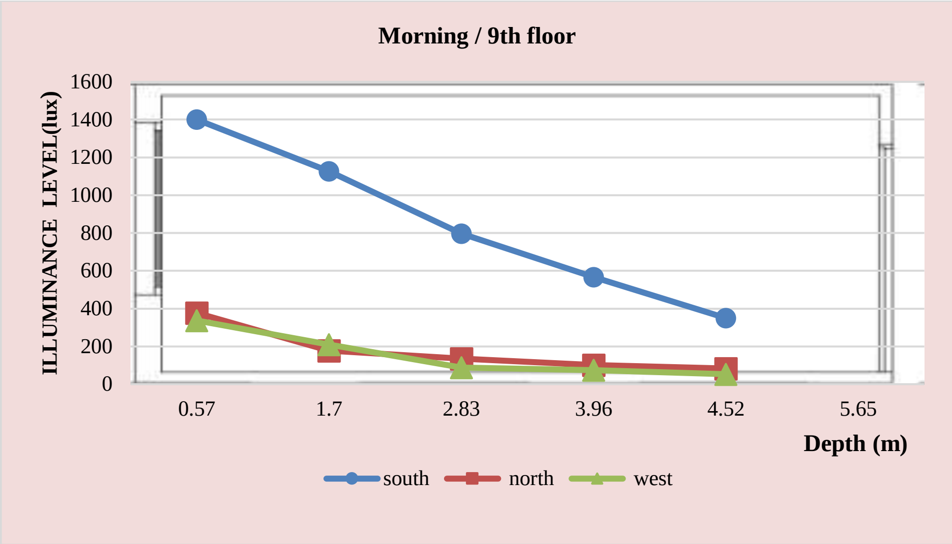


Graph n°9 illuminances profile for the three orientations of the fourth floor in the afternoon.

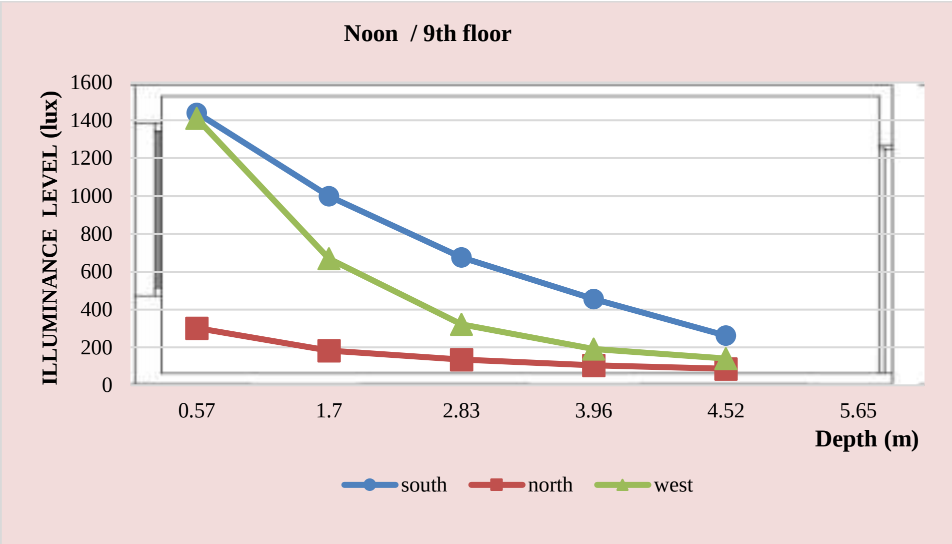
It appears through this study that the depth of the room has a major impact on the luminous environment. Graphs n°.10, 11, and 12 show that there is a large difference or a sharp drop between the values recorded near the window and those taken at the back of the room on the ninth floor (South). The maximum illuminance value recorded near the window is 2800Lux due to the presence of a sunspot at the time of the measurements, while the minimum value of 80 Lux is recorded at the back of the living room at 3:44 p.m. The recorded average illuminance value is 627 Lux (higher than the standard). Nevertheless, the uniformity ratio (I_U=0.3) indicates that there is a good luminous distribution as well as the average DF(2.60%).

The room located on the ninth West floor offers satisfactory coverage of the quantitative needs in daylighting for this day with an average illuminance value of 489 Lux, a uniformity ratio of 0.3 and an average DF recording a value of 2.6%. Exposure to direct sunlight in the afternoon of this space generated excessive illuminance of around 2200Lux near the window around 3:50 p.m.

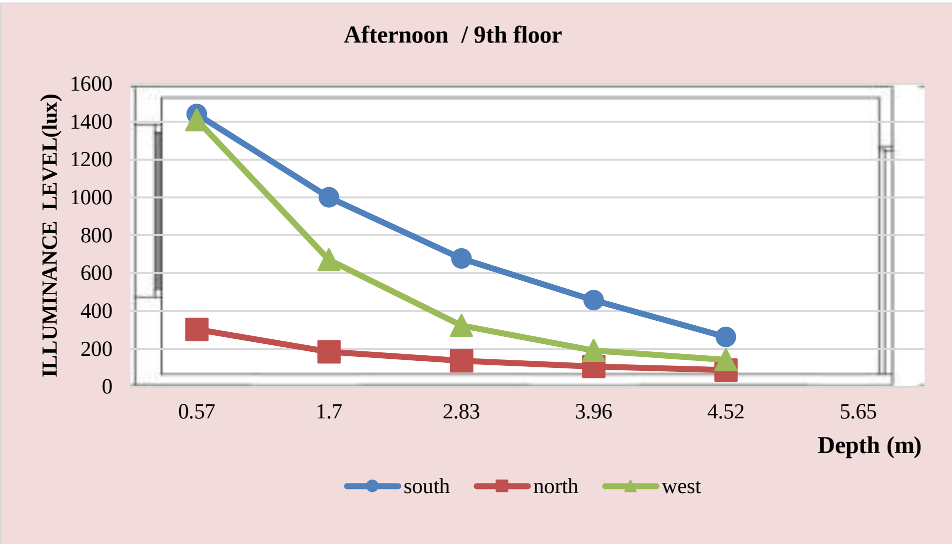
The results of the measurements showed that the room facing north is poorly lit despite its location on the seventh floor. The distribution of the illuminances recorded on the various points of the measurement grid indicated that the value of the average daylight illuminance is lower than the standard, which is 154Lux for this day, whereas the average of the uniformity ratio (0.4) as well as the average DF (3.64%) show that the general lighting is uniform for this day.



Graph n°10 Illuminances profile for the three orientations of the ninth floor in the morning.



Graph n°11 Illuminances profile for the three orientations of the ninth floor at noon.



Graph n°12 Illuminances profile for the three orientations of the ninth floor in the afternoon.

CONCLUSION

The importance of daylighting is essential because it allows a significant reduction in the consumption of electrical energy in the building [26,27]. The design of the openings is intended to satisfy the crucial need for daylight while avoiding overheating problems. In several countries, regulations have taken into consideration the need for buildings in natural light and which has been expressed in the right to the sunlight [28, 29, 30]. In Algeria, there is still a lack of regulations relating to daylighting adapted to the climatic specificities of the country, despite several steps taken in this sense. [31, 32]

In order to assess the conditions of daylight in the collective housing in Batna, one of its main rooms was examined to assess the effect of the window and its orientation on the luminous distribution and consumption of energy in the domestic space. The analysis of all the illuminance measurements collected for the nine rooms clearly demonstrates their differences. It reveals an optimal distribution of daylight in the living room oriented towards the South, and average illuminance values sufficient enough for the accomplishment of domestic activities for those oriented towards the West. Calculations show, however, that the distribution of daylight is far from optimal for the north-facing window; the living room is in an unfavorable situation which requires the use of electric lighting during the day, and this is the emblem of the current dwellings.

The main findings clearly indicated that the orientation of windows significantly influences illuminance levels. Therefore, daylight studies are very important for the early stages of environmental analysis when designing a building.

Further research through the examination of different window configurations for the same orientations is to be encouraged in order to obtain more optimal results. An optimized opening shape can increase the quality of natural lighting by limiting the effects of contrasts and shadows. Additional studies can include the impact of the texture of the interior walls and the type of glazing on the luminous performance; so as to make of research a useful directive tool for the production of well-lit domestic spaces, on the one hand, and, on the other hand, can contribute to the proposal of an efficient window generating a sustainable built environment.

If daylight is not properly merged with the project (design), it will turn the best-sculpted space into a negative environment [9].

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