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Research Article

THE EFFECT OF BUILDING HEIGHTS ON OUTDOOR WIND ENVIRONMENT OF THE RESIDENTIAL SECTOR / CAS OF EL EULMA CITY, Algeria

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ABSTRACT

The residential open spaces microclimate especially the wind environment, is widely affected by its surrounding buildings. This paper aims to assess the influence of residential buildings on urban microclimate in the North Est region of Algeria. This assessment performed using the in-situ measurements of different microclimate's settings, during summer and winter. Comparing between two existing city housing blocks, the present study showed that, the higher one result lower temperatures outdoor spaces in winter and summer. Furthermore, the passage under the building improves the accessibility, the ventilation in the inside corner of the city block, but may increase the wind speed so it causes pedestrians discomfort and safety issues.

Keywords: residential buildings; city housing block; urban microclimate; wind comfort; urban open space.

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1. INTRODUCTION

In addition to the percentage of discomfort hours in Sétif is 59,4% in winter (Semahi, S., Zemmouri, N., Singh, M. K., & Attia, S., 2019), the high-speed construction in Algeria during the last two decades, has resulted in the neglect of pedestrian comfort in the open spaces. Henrique Andrade et al (2010) showed in their study that 65% of pedestrians indicated different types of bioclimatic discomfort [1]. Most building makers unlike the scientific researchers, are poorly informed about the relationship between the urban configurations and wind comfort [2], which modifies our activities and qualifies the open spaces, especially the residential ones [3]. The low quality of outdoor spaces affects widely the health and the comfort of its users [4], as well as the social interaction between the residents of the city [5].

The urban microclimate settings defined and modified by the urban configurations [6], can make the residential open spaces either comfortable and usable, or abandoned [7,8]. This abandonment is a psychological stress reaction, caused by poor microclimates conditions, in order to achieve physical or mental balance [9]. The urban complexity can not only increase or decrease wind speed, but make the direction of the wind unpredictable as well [10,11]. The high-density interconnected spaces lead to differentiation in thermal comfort between streets and squares. The walkability and the urban morphology diversity, increase this differentiation. [12].

The manipulation of urban configuration parameters (street width, building shapes and height, vegetation), ameliorates pedestrians wind comfort in outdoor spaces [13]. In the case of canyon streets, at night the wind penetrates and evacuates the heat towards the atmosphere by convection, the evacuation speed depends on the length of the street (the longest the slowest) [14].Buildings heights are one of the morphological factors that define and influence outdoor wind environment [15,16,17].These high buildings which bloc natural views and increase pollution are the results of the increasing housing demands, population growth, as well as the lack of land and its increasing price [18].

Wind speeds affect pedestrian's thermal perception in open spaces [19]. During cold days users of outdoor spaces prefer low wind speeds with the change of clothing, unlike hot seasons [20]. This thermal sensation varies from cool" or "cold, depending on the air speed and the cloud cover of the sky. These two parameters are dependent on the building's heights [21]. At this point, a question arises: what is the influence of the height of the buildings on open spaces natural ventilation? The main objective of this present study is to assess the wind comfort and to verify the influence of building's heights on the urban microclimate, by analyzing two different existing urban residential city blocks of El Eulma city, in the North Est of Algeria.

2. CASE STUDY AND CLIMATE CONDITIONS

On the North East Algerian highlands, lies the city El Eulma. Distant 97km from the Mediterranean coast (See Fig. 1). Situated between the Tell Atlas and Saharan Atlas, two main mountain ranges, on an area of 74.20 km². According to the National Statistics Office (ONS), Currently its population is around 180,000 inhabitants, with a density of 2089h / km² [22].

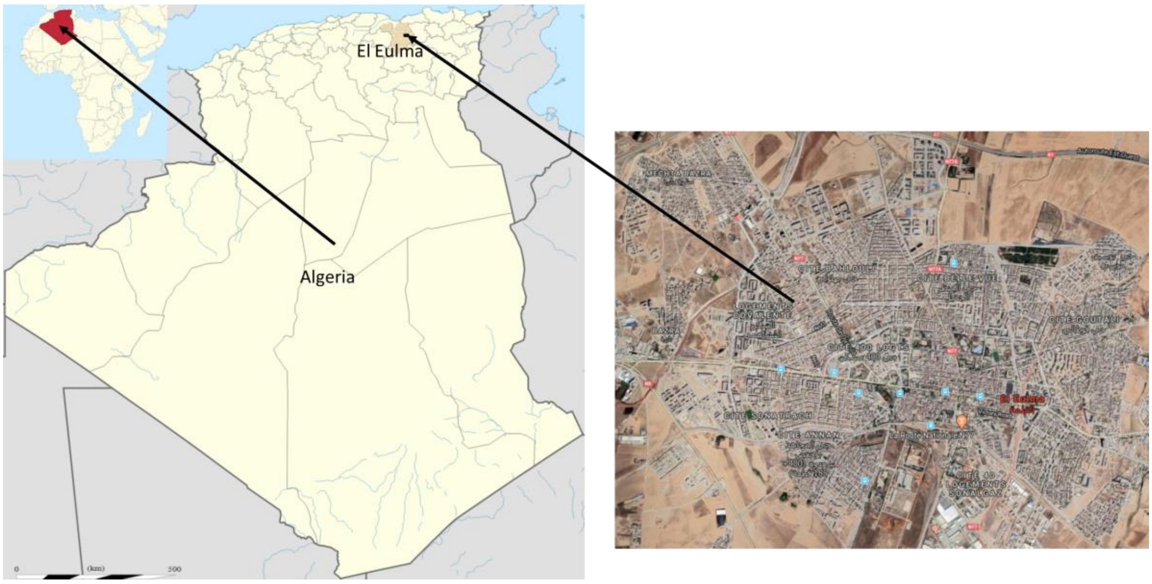

Fig.1. Location of the chosen city (El Eulma)

Source: www.Google.com

The city of El Eulma was chosen as a study case because it's highly seasonal winds which may cause discomfort to pedestrians, especially with the flourishing commercial activity that this city is experiencing [23]. The climate of this city is semi-arid continental, with an aridity index of 15,8 hot and dry summers, and rainy and cold winters, and an average rainfall of 400 mm [24]. The climate data (2004-2018), were provided by Algerian ONM (National Office of Meteorology), and made available online by the US energy department [25]. Figure 2 shows that, the coldest period is from November to March with a minimum average temperature of 0,6 C°, while the hottest season is from June to September, with a maximum average temperature of 34,4 C°. The temperature increasing is moderate from January to July; however, the decrease is faster from September to January.

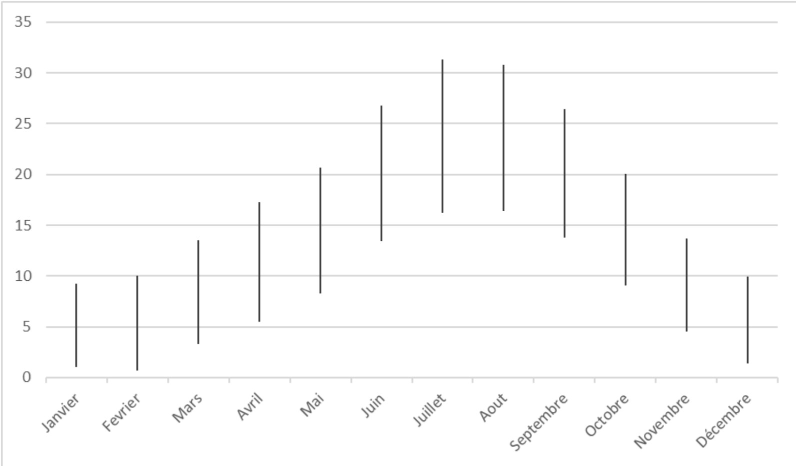

Fig.2. Minimum and maximum average temperatures in El Eulma, (period 2004-2018)

2.1.Wind potential

North and South winds are the most dominant, North and NNE winds blow more than 1000 times a year, with variable speeds between 8 m/s and 1,5 m/s, from November to February and the beginning of March (Fig. 3). This type of wind is loaded with humidity since it comes from the Mediterranean, favouring snow and rain falls.

The Sirocco winds (which come from the South), are hot and less violent than those of the North, blow more than 1000 times per year, during the months of June, July and August. Its speeds are variable between 5m/s and 1,5m/s. Those generally carry quantities of sand, cause the soil to dry out and increase the evapotranspiration of the plant species.

Secondary winds are less frequent, about 500 times a year come from the western part of the city (NNW and SSW).

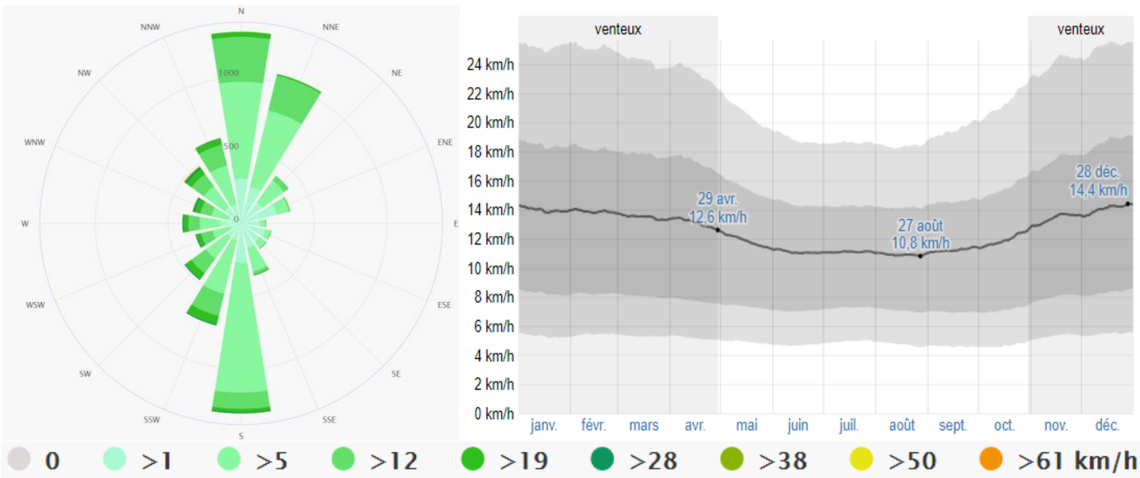

Fig.3. Wind speed and directions in El Eulma (period 2004-2018)

3. ARGUMENTS OF CHOICE

For this study, we have chosen (02) two different urban fabrics. These two existing housing blocks were built during different periods after Algerian independence; Located in different parts of the city. Their low floor area ratio resulting in large open spaces.

3.1.City block housing Kahoul Rachid (case 1)

The Housing Improvement and Development Agency, has built two housing blocks of collective dwellings, in the eastern part of the city, as part of the hire-purchase program for the year 2001/2002, in an area of 3,4 hectares (33,852m²), with a floor area ration of 0,2 (Fig. 4). The two housing blocks are separated by a 30m wide street. The main entrance to the first one on the north side is exclusively for pedestrians, passing between two high towers of 10 levels. Each housing block open space, contains playing areas, parking areas and water tanks.

Fig.4. housing blocks Kahoul Rachid (case 1), Situation in the city

The residential buildings are built around a large semi-public central space, forming a triangle shape. These dwellings blocs ensure the limit between public and semi-public spaces. An under-building passage was created, in order to improve pedestrian and cyclist accessibility between the two sides of the housing block. This passage brings fresh air and accelerate natural ventilation, as well as the dispersion of pollutants inside the housing block. [26].

The two housing block heights are between 06 and 14 levels, the first two levels are dedicated to the commercials and administration activities on the outside. The levels contain from 2 to 6 dwellings. The vertical circulation is assured by stairs and elevators.

The vegetation is present at three outsides (North, Est and Ouest) as well as in the central open spaces.

3.2. City block housing Boussouf Abd El Hafidh (case 2)

Located in the western part of the city, on an area of 24 hectares (Fig.5). Over 20 City housing blocks of collective dwellings were built as part of the PSH program in 2008 (participatory social housing), financed by both the government and owners.

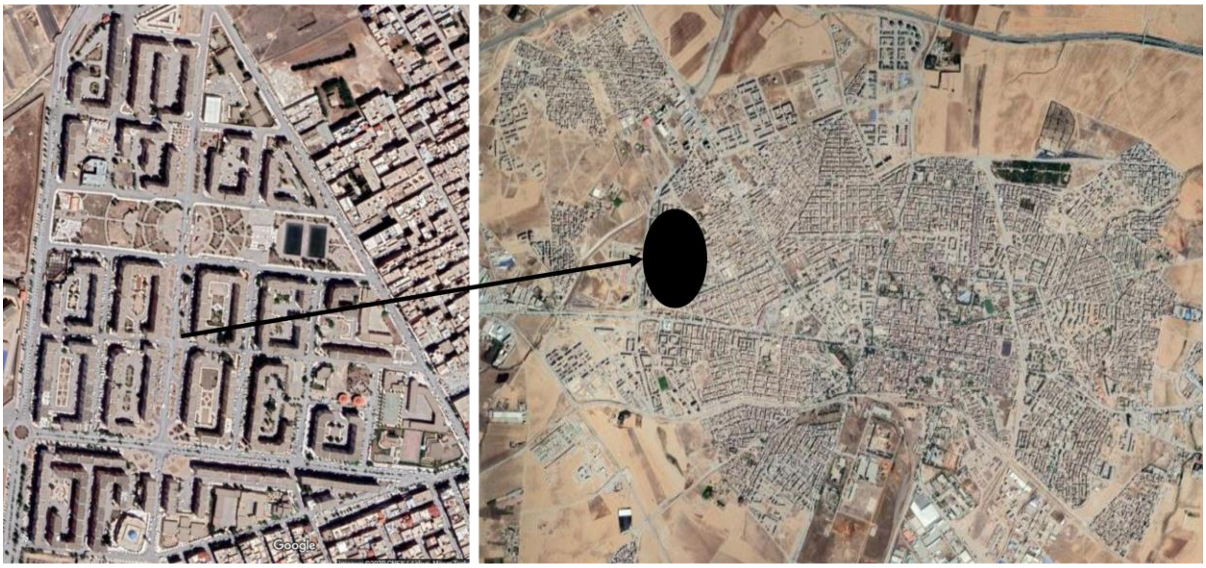

Fig.5. City block housing Boussouf Abd El Hafidh (case 2), Situation in the city

The tracks layout is regular, the main streets are of different orientations (North-South, East-West) with 11m width, the secondary streets that lead to the housing block are 6m width. The units (L and straight shapes) are located around a large semi-public central space, forming a closed block. This typology ensures the boundary between public and semi-public spaces.

Each core of the housing block contains: playing areas for children and private parking areas, which allows users to meet within the neighbourhood. The buildings have six levels, this level number is fixed by the water tower height, since water adduction is only by gravity. Each residential building level has two dwellings. The first level is dedicated to the commercial activities on the outside of the urban block. We opted for two typical residential blocks, which are the most exposed to the prevailing cold and hot winds. (Fig.6).

Fig.6. views on the opted City housing blocks

4. RESEARCH METHODOLOGY

This study is based on a comparative analysis of the two chosen case studies.

In order to verify the impact of a residential building's heights on the open spaces wind environment, which affects the pedestrian thermal comfort in turn. In-situ measurements of urban microclimates settings, were carried out in 8 stations distributed in the two typical city blocks housing (Fig. 7), using a calibrated multifunction device model TESTO 480. The use of this tool makes it possible to provide reliable and adequate data, with each existing urban configuration [27].

In accordance with previous studies [20,28], this research was based mainly on the study of air temperature (A_t, °C), relative humidity (R_h, %) and wind speed (W_s, m/s), since these three parameters must be combined for a better description of the perception urban microclimate, instead of giving just the air temperature [29]. The evaluation criteria for comfort and safety, relative to the wind environment, used in this research are shown below in Table 1. This evaluation is based on various information available in the literature and established practices. The NEN8100 code defines the threshold value of comfort mean W_s is 5m/s, and 15m/s for wind danger, although gustiness isn't [3]. More detailed criteria are explained in Willemsen and Wisse (2007) [30]. However, there is no universal or unique agreed Algerian criteria, to evaluate the pedestrian comfort level at outdoor residential spaces, for wind environment.

Table 1. Comfort criteria used

Wind speed	Comfort evaluation
$W_s < 5m/s$	No human discomfort
$5m/s < W_s < 10m/s$	Human performance affected by an unpleasant feeling
$W_s > 10m/s$	Human performance strongly affected by a seriously unpleasant feeling

The three settings were measured in the pre-set stations (Fig.7), the selection of these stations was based on-site observation of the most used open spaces. The measurement is established at the pedestrian's height (1,60 m above the ground level), during the month of December for the winter period and August for the summer period of the year 2019, which represent the most critical periods of the year. The measurements were made every two hours from 8 a.m. until 6 p.m.; this interval represents the peak hours of use.

a) b)

Fig.7. Locations of the different measurement stations: (a) City block housing Boussouf Abd El Hafidh (case 2), (b): housing blocks Kahoul Rachid (case 1)

Table 2. Measurements location

	Location	Heights	H/W ratio	Vegetation	Passage under building	Shape
S1	**Entrance between two towers**	**10levels**	**1,39 (32,80/23,64)**	**absent**	**absent**	**Triangular**
S2	**Near the inside angle**	**10levels**	**0,26 (32,80/125,72)**	**absent**	**present**	
S3	**Playing area**	**10 levels**	**0,26 (32,80/107,35)**	**present**	**absent**	
S4	**Entrance between buildings**	**07 levels**	**1,94 (22,61/11,63)**	**present**	**absent**	
S5	**Playing area**	**06 levels**	**0,37 (19,55/52,50)**	**present**	**absent**	**Rectangular**
S6	**Near the inside angle**	**06 levels**	**0,37 (19,55/52,50)**	**absent**	**Absent**	

S7	**Entrance between buildings**	**06 levels**	**1,7 (19,55/11,50)**	**present**	**Absent**
S8	**Playing area**	**06 levels**	**0,37 (19,55/52,50)**	**present**	**Absent**

5. RESULTS AND DISCUSSIONS

5.1. Analysis of urban microclimate

The in-situ measurements were carried out under well-defined conditions. The wind speeds were fluctuating in the studied days during the two months (December and August). With a partly clouded sky during the month of December and clear during the month of August.

5.1.1. Case 1 (Kahoul Rachid City housing block)

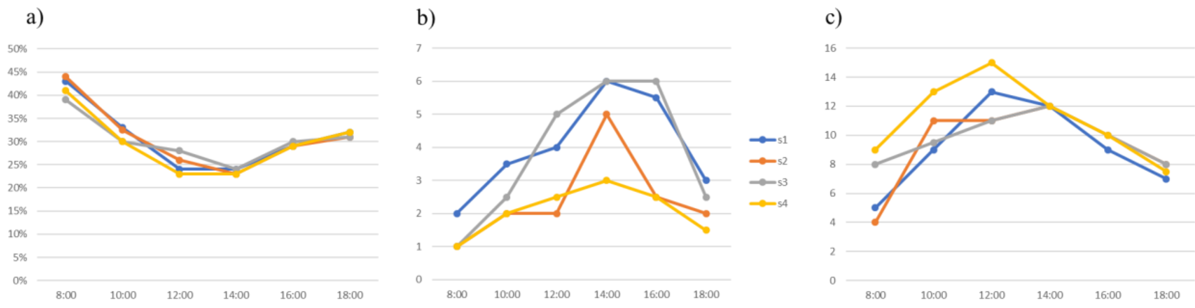

Fig.8. (a) Rh, (b) Ws and (c) At, recorded values during December 2019

The daily fluctuation of the urban microclimate settings, were recorded at various stations of the outdoor spaces during the month of December, and illustrated in figure 8.

The R_h levels measured at the stations (Fig. 8 (a)), are very close (maximum deviation of 5%) and important in all the stations from 8 to 10am and 4 to 6pm, unlike the A_t (Fig. 8 (c)), due to the presence of buildings masks during sunrise and sunset (07 to 10 levels). These masks block the direct component of solar radiation and extend the duration of the famous freeze-thaw phenomena, during sunrise and sunset.

The triangular shape of the city block housing, the orientation of the station (Est-Ouest) despite its ratio (1,7), results from the lowest W_s, R_h unlike the A_t. Figure 8 (b). The highest W_s values are present at stations 1 and 3 since the two stations are exposed to the prevailing north winds, its locations create the channelling effect for S1 which is between the two towers (10 levels, ratio 1,37), and the effect of the courtyard for S3 in playing area (ratio 0,29). The W_s fluctuation at 2 p.m. in station 2, is due to wind direction change, which creates the effect of the passage under the building.

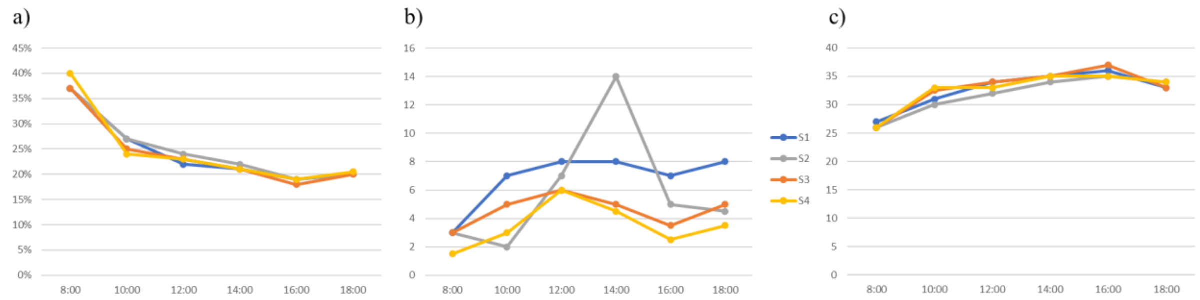

Fig.9.(a) Rh, (b) Ws and (c) At, recorded values during August 2019

The graphs above (Fig. 9. (A), (c)) show that the R_h levels are close (with a deviation of up to 3%). The humid and relatively cold air masses of the overnight, cause high R_h and low A_t until 10 am, unlike A_t, because of. The decrease in R_h levels as well as the increase in A_t until 4 pm, is due to the continuous change of dry and hot prevailing winds coming from the south. In addition to the significant heights (07 to 10 levels) of the residential buildings, creating immense drop shadows. These drop shadows reduce the transpiration of the vegetation and in turn the relative humidity.

The lowest A_t are present at station 2 due to the covered pedestrian passage under the building, which eliminates the direct component of solar radiation inside the passage, and cools the air. This station records the highest values of W_s between noon and 4 pm., due to changes in wind direction sometimes and the corner effect.

Figure 9 (b) reveals that the highest W_s are recorded at station 1, which is located at the pedestrian entrance to the city between the two towers (10 levels, ratio 1,39), which generates the Venturi effect during the summer. The lowest is recorded at station 4 where the area is protected in summer. This protection is the result of the triangle shape of the housing block and its orientation (Est-Ouest), despite the height of the entrance (07 levels, ratio 1,94).

5.1.2. Case 2 Boussouf Abd El Hafidh City block housing

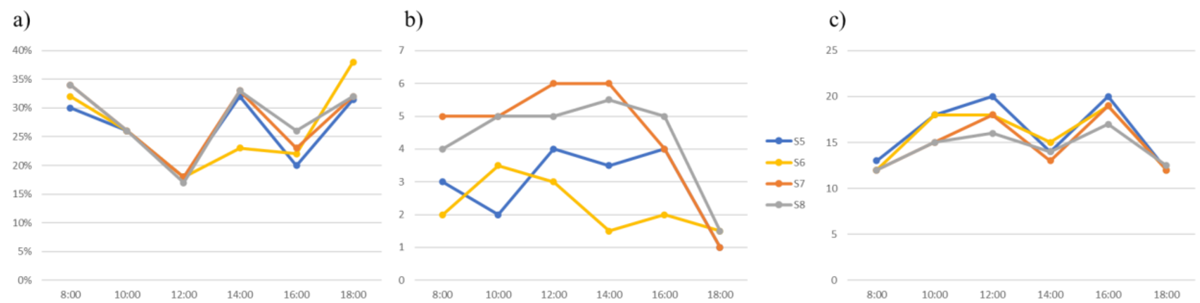

Fig.10. (a) Rh, (b) Ws and (c) At, recorded values during December 2019

Figure 10 represents the daily evolution of the urban microclimate recorded in different open spaces during the month of December. Figure 10 (a, c) illustrates that at 8 a.m. and 6 p.m., unlike A_t levels, R_h levels are high in all stations. This is due to the presence of masks created by buildings during sunrise and sunset. These masks decrease the solar radiation direct component, and extend the freeze-thaw phenomena. The change in cloud couverture at 14h, results A_t drop un increase in R_h due to transpiration of the tree leaves. The location of station 6 in the protected area, the absence of vegetation and the decrease of W_s at 14h, gives it the lowest R_h and moderately high temperature.

Figure 10 (c) shows that, station 8 in the playing area, records the lowest A_t with moderately high R_h, this is due to exposure to the solar radiations. This is favoured by building heights (06 levels, ratio 0,37) and vegetation presence, which in turn increases the transpiration, as well as the high W_s of the passage of cold air

As for the A_t maximum values (which reach 6m/s at noon), stations7 and 8 records them during the whole day of measurement. This is due to the mesh effect created by the rectangular shape of the city housing block. The corner effect which is present at station 7 (ratio 1,7) created by the street intersection, results in high values of W_s. Fig. 10 (b)

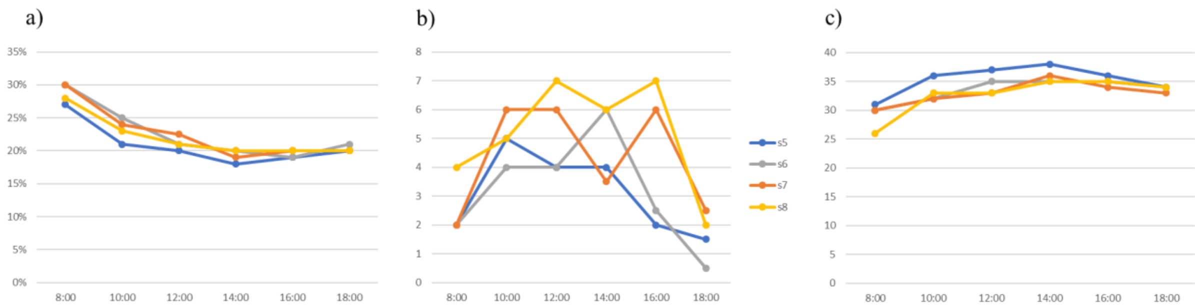

Fig.11.(a) Rh, (b) Ws and (c) At, recorded values during August 2019

The daily evolution of the urban microclimate settings, which were recorded in different outdoor spaces during the month of August, is shown in Figure 11.

Figures 11 (a, c) reveal that contrary to A_t levels, the R_h levels during the morning are higher than those of the afternoon. This is the cause of the humid and relatively cold air masses that existed overnight. Station 5 in the playing area, records the highest A_t values and the lowest R_h levels, due to vegetation and the low W_s coming from the south, which prevents the renewal of air. Fig. 11 (b)

The building's cast shadow, decreases the A_t from 2 p.m. to 6 p.m. by 4°C, despite the decrease in wind speeds. Station 8 exposed to high values of W_s (up to 7m/s), due to the Wise effect. This ventilation speed and direction (South), decreases the air temperature (up to 4°C at noon), compared to station 5(06 levels, ratio 0,37). As well as it causes pedestrians' discomfort.

5.2. Comparison between study cases

Comparing the results obtained from the two cases, we found that the influences of building heights on urban microclimates Settings during the winter and summer are significant in both residential configurations studied, illustrated in fig. 12 and 13.

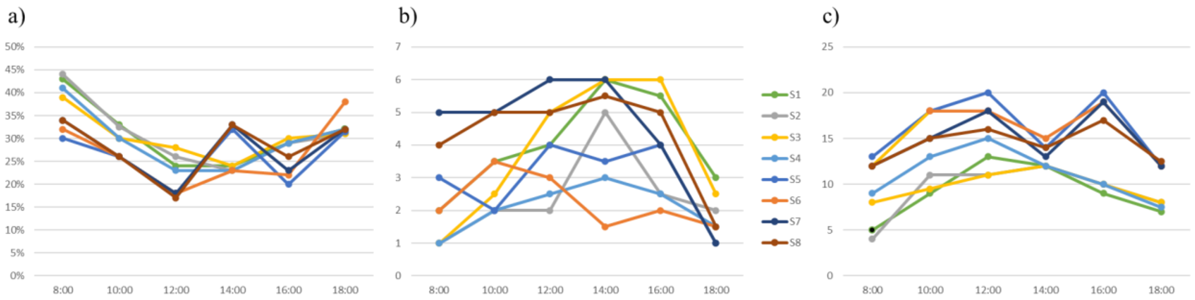

Fig.12. Winter results from comparison for Kahoul Rachid and Boussouf Abd El Hafidh city housing blocks

In winter, the case1 buildings whose heights are higher than those of the case 2 city housing block, results from colder open spaces and more humid (higher R_h levels) (Fig. 12 a, c). This is because of the pedestrian passage between the two tall towers (10 levels, ratio 1,39), which creates the Wise canalization effect and increasing W_s. Figure 12 (b). At this point, the playing area (station 3, ratio 0,26) of case 1, is directly influenced, since it is located on the axis of the prevailing winter winds from the North. Contrary to station 5 (case 2), which heights are lower (06 levels, ratio 0,26). Even though the mesh effect created by these lower buildings heights at station 8, and the location of prevailing wind axes, result from high values of Ws, in the station. Station 7 of the collective housing (POS2), which has building heights lower than the first one (06 levels, ratio1,7), exposed to high W_s, this is the result of the corner effect, created by the street intersection, compared with station 4. The orientation of this station (Est-Ouest) despite its heights (07 levels, ratio 1,9).

Unlike station 6, the passage under the building at station 2 (Fig. 7), improves pedestrian and cyclist accessibility between the two sides of the city housing buildings. However, it causes pedestrian discomfort (up to 5m/s) despite its perpendicular orientation to the direction of the prevailing winter winds.

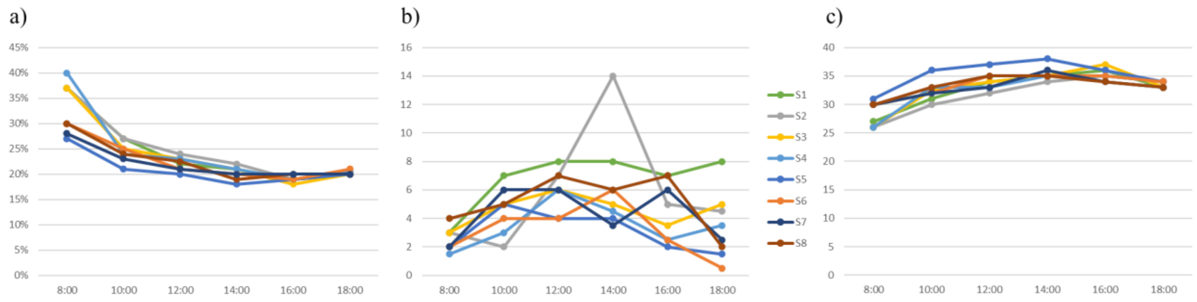

Fig.13. Summer results from comparison for Kahoul Rachid and Boussouf Abd El Hafidh city housing blocks

In summer, as shown in the figure above (fig.13). The case 1 open spaces (Kahoul Rachid city housing blocks), are colder than those of case 2, which has fewer building heights (Fig.13, c). Since the residential buildings block the prevailing South winds, the station 5 at the playing area records the highest At with low Ws. The At at station 3 in the playing area, are lower than those of station 5, even though the station 3 is more exposed to the hot dry South prevailing winds. This is because the case 1 buildings are higher.

As for the air velocity Fig.13 (b), the venturi effect created in the pedestrian's passage between the tall towers (10levels, ratio 1,39), resulted in the highest values of Ws, on the contrary to station 7 (06 levels, ratio 1,7). The playing areas in both configurations are directly exposed to prevailing south winds. However, the Wise effect created by city block housing shape at station 8 results in more severe Ws than those at station 3, despite of the hights.

For the protected area's station 2 and 6 at the inside corner, the presence of under building passage may create unsafe conditions for pedestrians once the winds change direction (case station 2, Ws up to 14m/s at 2pm).

6. CONCLUSION

This paper shows the effect of residential buildings heights on wind environment, which need to be safe and comfortable for pedestrians. The research was carried out in both winter and summer seasons, which represents the extreme seasons of the year in the studied region. We used the in-situ measurements of urban microclimate settings to proof this effect.

The following conclusions in accordance with previous studies, confirm the effect of the urban configuration (Height, shape, ratio and space location) on the urban microclimate parameters. The higher City bloc buildings seem to provide colder and higher wind speed in their outdoor spaces, than the lower ones in both seasons. The passage between buildings increases the wind speed and leads to human discomfort when it is orientated is by the prevailing winds. Therefore pedestrian entrance should be perpendicular to the axis of prevailing winds. The city block inside the corner is a protected and warm area during the winter, only if there is no passage under buildings. Its existence results from unpleasant and sometimes unsafe conditions of users. The location of playing areas in the axis of the prevailing winds and entrances, needs to be avoided in order to decrease prevailing wind speed and modifying its parameters. The study should help the designers and the deciders to improve future urban configuration design and should serve as a guideline for a sustainable urban future. Another implication of this research is the need for new design strategies, considering the existing effects on the open spaces.

The role of buildings in pollutant dispersion of the open space microclimate needs further studies.

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