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EFFECTS OF BUILDING MORPHOLOGIES ON CO_2 AIR POLLUTION
CASE STUDY: THE VERNACULAR URBAN FABRIC, CITY OF GHARDAÏA (ALGERIA)

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ABSTRACT

The present work investigates the CO_2 dispersion in micro-scale urban area, and its effects on air quality in old buildings in the city of Ghardaïa (M'Zab valley). The city of interest is located in the south of Algeria. Ghardaïa is characterized by its vernacular urban structure well adapted to local climate (hot arid) which is listed by the United Nations Educational, Scientific and Cultural Organization (UNESCO) as a protected city. Numerical simulation with CFD code was used in combination with measurement data in order to study the CO_2 air pollution levels in the selected area. The field measurements carried out for the two days: 5th and 6th July 2013, shows that CO_2 concentration in the street canyon reaches its highest level up to 400 ppm. Two numerical simulations were performed based on geometry changes and architectural propositions on the downstream buildings, to assess the effects of morphology on the CO_2 air pollution dispersion. The first improvement was made by increasing the street canyon width at the outlet side, which reduced the CO_2 concentration by 46%. In the second modification, which was made by changing the uneven building layout, this improvement decreased the CO_2 concentration by 36% compared to the real geometry. The results show the effect of weak modifications of the architectural fabric on the air pollution reduction, and therefore the participation in protecting old buildings heritage from air pollution effects.

Keywords: Old heritage; urban morphology; architectural propositions; CO_2 air pollution; Ghardaïa.

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1. INTRODUCTION

According to the World Meteorological Organization (WMO), the use of fossil fuels and human activities were the responsible of CO_2 emissions which causes the warming of our planet [1]. Carbon dioxide is the most important anthropogenic greenhouse gases (GHG) [2]. Its annual emissions have grown from 1970 to 2004 by about 80%, and represented 77% of total anthropogenic emissions in 2004 [3]. In urban areas, the source of CO_2 emission is the road traffic [4], according to Uherek et al (2010) the road traffic emissions were estimated by 72.3% in 2000, compared to rail traffic, navigation and airlines. CO_2 is one of the basic atmospheric pollutants due to its effect on human health, ecosystems and climate [5], [6], [7]. In addition, it plays a fundamental role in the creation of the harmful ground ozone gases [8]. As a consequence of previous researches, CO_2 pollutant is one of the real indexes of local and micro-scale air pollution. CO_2 air pollution levels from road traffic are usually measured either by using vehicle kilometers travel (VKT) or vehicle Miles Traveled (VMT) which combines the combustion factors and traffic flow [9]. It is important to notify that there are not industrial activities in the surrounding of the interesting city.

Besides the Urban Heat Island (UHI) intensity has a major effect on the street canyon ventilation and energy consumption for cooling. The buildings with low performance climatic quality consume a lot of energy for air conditioning and lighting [10]**.** Oke (1990) shows that the maxima of UHI can go from 2°C to 12°C as a temperature difference between the urban area and their surroundings, for towns of 1000 to 1.000.000 inhabitants respectively. For instance in 2003 at Paris, the heat wave that caused thousands of dead human, the UHI intensity was 8°C [11].

To investigate the change in complex fabric for the pollutant promotion dispersion in cities is not easy result in explicit rules, but there are many considerations that must be taken into account [12], [13] and other researchers define many factors that affect the pollution dispersion in street canyon, and affect the pollution dispersion in canyon street, and it is very difficult to distinguish the most important parameters, the relation of the outdoor thermal comfort into street geometry are treated by a very few studies [14].

The airflows in real urban canopies are more complex [15]. Urban geometry acquires complex aspects, by multiple designs and various parametric descriptions [16]. Many researches are not indicative of real situations of the air flow pattern, because the real urban flows are obviously more complicated. Most available studies are limited in an idealized system, that involved only very simple geometries, or isolated morphological cuboids .e.g. phenomena like city roughness effects cannot be captured from these idealized models [12].

Edussuriya et al (2014) have performed statistical analyses and field measurements findings, that the interaction between the air quality and the demarcation of the district are easy to distinct, by basically identifying namely the area density, roughness height, built volume, aspect ratio, distance between building and building height.

A canyon length should be split into sections, it is identified like a distance between two major intersections. The sections are identified like; Short (L/H= 3), medium (L/H=5), or Long L/H= 7, where L and H are the length and height of canyon [17]. The ratio of 5 can promote the airflow transition from wake flow to skimming flow [13] [18]. Intersections of street can provide low-pressure area, and potent mechanisms for dispersion. They promote a wind circulation. They can switch between the different streets [17], [19]. Intersections promote a complex combination of bifurcated channeled flows. Recirculation and corner vortices also influence the wind velocities and the pollutant concentration distribution in the street segment between two intersections and generate more vortices for better dispersion [20]. The corners can develop an intermittent vortices [21].

It is important to mention that the urban wind flow is characterized by the development of both; the Urban Canopy Layer (UCL) and Urban Boundary Layer (UBL) which extends above the roof tops [18]. According to Santamouris et al (1999), the airflow in the urban canyon has a strong relation with the flow above the buildings and the physics of urban air pollution in canyon and it depends on the physical profile of boundary layer [22], [13]. Local flows are the result of the interaction between wind flow field and the surrounding building-geometries, they create small-scale spatial variations, because the various configurations of the street canyons alter the airflows in the boundary layer [23], and the airflow in street canyons is originally discussed as in Oke's flow regimes [24], [18].

Different methods can be used to assess CO_2 pollution namely full-scale measurements, reduced-scale measurements, and CFD simulations. The latter is deemed to be the best approach for quick and economical strategy. The numerical simulation allow to parametric studies to evaluate alternative designs, especially when different configurations are included in the same domain and same calculation grid [25].

The methodological advance in the current study can be summarized; from one hand, the combination use of measurement data and numerical simulation in order to assess the effect of building morphology on CO_2 air pollution dispersion in urban micro-scale area. From the other hand, illustrate numerically the effect of weak modifications of the architectural fabric, on air pollution reduction, and therefore the participation in protecting old buildings heritage from air pollution effects. This manuscript aimed to study the CO_2 air pollution behavior in urban vernacular morphology, at a medium sized city in the south of Algeria (Ghardaïa Ksar). The main purpose of this research is to answer the contemporary needs of human life of M'zab with a minimal change on the old building fabric.

2. PRESENTATION OF THE STUDY AREA

The studies that treat the thermal comfort in the outdoor microclimate are rare [10]. In general, Mediterranean cities are alike. They have a particular microclimate and a common urban model by deep canyons with a higher aspect ratio of up to two [10]. The traditional city of the valley of M'Zab is situated in northern Sahara, 600 km south of Algiers and 464 m above the sea level. Ghardaïa has a big valley which crosses the cities from northwest to southeast as shown in Fig. 1. With the rhythm of this stream, the valley of M'zab became urbanized. It is along these sinuous courses and between the upstream and the downstream that the five cities of M'zab are spread [26]. The pentapolis marks out the valley to protect itself from floods and foreign attacks. Ghardaïa is a millennial penta-pole, it brings a special architectural authenticity, and since 1982 has become one of the heritages listed by UNESCO. Its architectural style is unique, distinguished by its majestic beauty and harmony with which many architects have greatly appreciated [27]. The Ksar of Ghardaïa is one of the five Ksour as shown in Fig. 1. In their spatial organization, cities are built around the mosque [28]. The general shape of the Ksar is radial, integrated into the hillock, where from the shape of the plan is radio-concentric. Streets are narrower at the top part, white in the bottom sometimes superior widths are registered.

Figure 1. Ghardaïa's Ksar before settlers [29]

The climate of the city is hot and dry, the wind is hot and sandy, the average winter temperature was 12.2°C and average summer temperature was 36.8°C [30]. It is particular, that which the shaded and narrow streets can offer comfort better than the open spaces .e.g. A 3K temperature can be reduced, by passing the aspect ratio from 4 to 0.5 [31]. In the old city, the passages are narrowing (deep and compact) with high aspect ratio, they aim to protect houses from solar radiation. Other important thing is the existence of the palm trees and oases between agglomerations (houses sets, or Ksar), this plant tissue decreases the heat intensity, and promotes freshness and nocturnal ventilation. According to Akbari et al (1997) [32], 30% of heat intensity may be reduced due to the existence of houses near threes. Concretely, 5° C to 10 ° C of heat intensity is reduced by the existence of palm trees [30]. According to Bouchair (2004) the recent urbanization in M'zab valley is increased illicitly, it is distinguished as the decline of traditional urban form and vernacular architectural values. The actual ecosystem at M’zab city is changing rapidly, and it knows great challenges, with unprecedented acceleration of urbanization on the oasis environment [33].

2.1 Street canyon

The street canyon is located in the southeast side of Ghardaïa Ksar, it was created during the colonial era, the canyon has a triangular shape with a length of 138 m, and variable widths ranging from 1.68 m up to 7.9 m as shown in Fig. 2.

The area is surrounded by natural morphologies uneven and unnatural morphologies. The former is surrounded by chain of mountains from south side, and the latter is surrounded by the Ksar from north and by urban extensions from the east side.

The maximum of the (UHI) intensity between the street canyon location and a meteorology station located at 20 km outside the city of Ghardaïa is +4.5°C, with 38 C inside the street canyon and 34°C registered at the station. This value is found to be very high, because it is taken at the beginning of July, where generally, the hot period and warm winds tend to be at the end of July (*Cf*. Fig. 10 (c and d)).

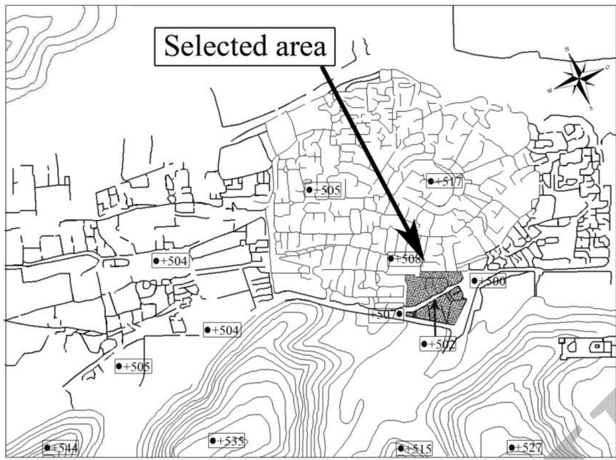


Figure 2. Location of the selected street canyon at Ghardaïa's Ksar

The chosen street canyon which was established at colonial period, represents the continuation of the historic site of Ghardaïa. This street canyon has a complex configuration, and has a significant unidirectional traffic. It is regarded as the only connection between the entire city of Ghardaïa and the Northwest side. It is used by different type of transportation, from cycling to heavy-duty. In addition, this boulevard is the destination for residents, traders and tourists as shown in Fig. 3.

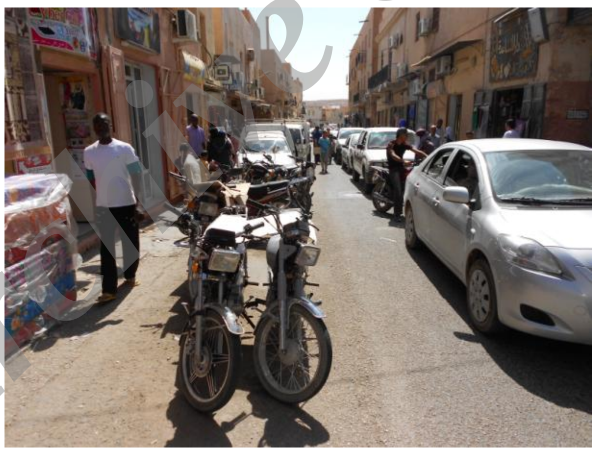


Figure 3. The street canyon with traffic movement (cycling and heavy-duty)

According to the measurement data in the street canyon, the average value of CO_2 concentration is 400 ppm. The street canyon is oriented from the north axe by an angle of (61°) and with a deviation at the level of the last island (272°). This canyon has a variable aspect ratio (H/W) of 0.88 at upstream and 1.34 at the downstream (Fig. 4).

The aspect ratio is approximately equal to 1. It is considered like a regular canyon (Table. 1) [17]. Theoretically, the street canyon has three kinds of winds namely;

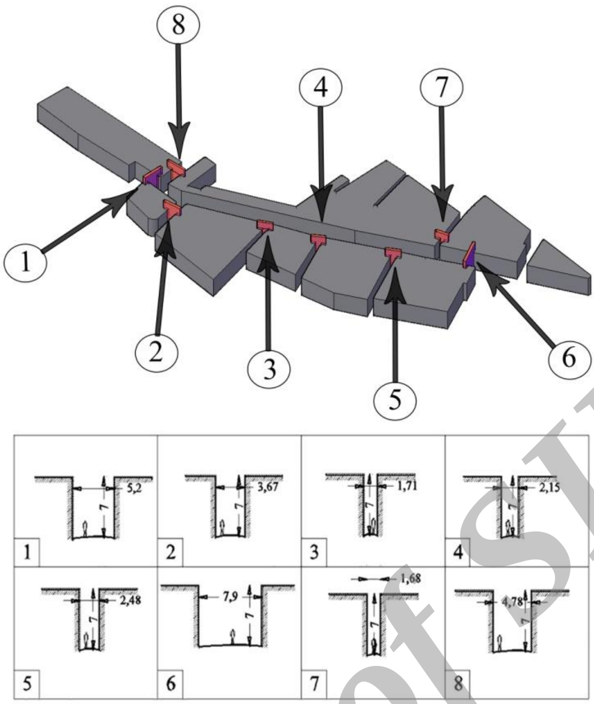


Figure 4. Existing cross-sections at the area of interest

Table 1: Characteristics of the main street and secondary streets (Fig. 4)

Points (Fig. 4)	Aspect ratio and lengths of alleys*			Characteristics of alleys			Values of the simulated CO_2 [ppm]
	W	L	H	Nature	Colors	Occult/ Shadowed	
1	5.2	138.64	7				1087
2	3.67	11.59	7			No	685.5
3	1.71	19.19	7		Yellow		
4	2.15	23.84	7	Rough		Yes	<300
5	2.48	29.05	7				
6	7.9	138.64	7				373.5
7	1.68	21.79	7		Pink	No	<300
8	4.78	12.31	7		Yellow		

* Width, Length, Height (m) Meter

I) The region of Ghardaïa undergoes cold and relatively wet winds of the Northwest during winter. This wind flow was neglected, because it blows during a period that is not hot. It is considered like perpendicular winds. It must be indicated that the perpendicular wind flow developed a shear layer is shed from the upstream building roof and one or more recirculation vortices may form in the street canyon with perpendicular wind flow above the roof [20], [19], perpendicular wind flow also provide clockwise and counter clockwise vortices with upwind flows along the warm façade and a downward flow along the opposite one [21].

II) Ghardaïa is exposed to violent winds (16 m/s and more) which blow approximately 20 days a year of the South-East especially in March, April and May. In this study case, the impact of these winds was also neglected, by its limited duration and for their blowing during a period that is not hot. These winds have the capacity to clear the pollutant by their important velocity [26]. The southeast winds have an oblique direction to the axis of street Canyon .i.e. with oblique wind flow above the roof, the wind within the canyon is a linear superposition of parallel and perpendicular winds [19]. The oblique wind flow developed a complex combination of interacting channeled flows, helical recirculation patterns, flow bifurcation and corner vortices [20], [19].

III) The integration of the canyon is with parallel airflow direction (northeast winds of the summer). The summer winds from the North-East are strong and warm, they are considered like parallel winds. Parallel wind flow above the roof developed a channeling phenomenon at the length of the canyon [20], [19], and a spiral flow [19], [17].

3. METHODOLOGY AND EXPERIMENTAL SETUP

3.1 Measurements

As described previously, in the present work, two classes of tools were used for the CO_2 air pollution evaluation, measurement data and numerical simulation. The field measurement data were took at different points in the street canyon for meteorology conditions and CO_2 concentration. In the meteorology case, values are measured for two days and compared next to available data provided by the Meteorology National Office MNO, located at 20 km outside of the city.

Three study zones: A, B and C were selected for taking measures along the street canyon, as illustrated in Fig. 5.

The study zones cover three parts of the street and fluid flow path: upstream, the middle part and downstream. Furthermore, measurements were unwound in the axis at a height of 1.5 m above ground level.

3.2 Numerical simulation

A numerical simulation was realized using the commercial CFD code. Fig. 6 illustrates the computational domain and buildings geometry and configuration. A CFD code configuration was made by creating the computational domain of 500 m in the x and y directions and 300 m in the z direction. The background CO_2 concentration and the initial conditions for meteorology in the domain were gathered from measured data (V=1.5 m/s, T_0= 311 K, CO_2 concentration 27,9g/s, pressure initial $p_s = 0$).

The entire domain was divided into regions named: inlet, outlet, opening (top, left, right) and domain ground where the buildings were constructed, and the cars inside them were considered as point sources of CO_2 pollutant. A uniform velocity at the inlet was considered, based on the measured data.

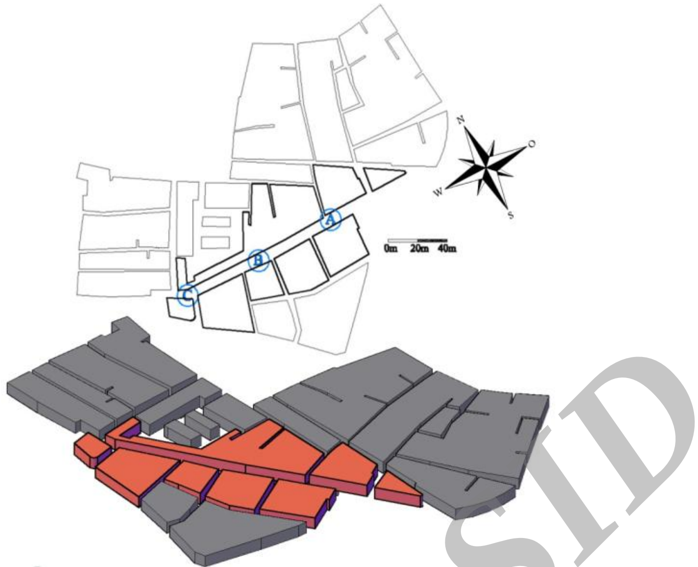


Figure 5. Selected zones (A, B and C) along the street canyon; 2D presentation (upper panel), 3D presentation (lower panel)

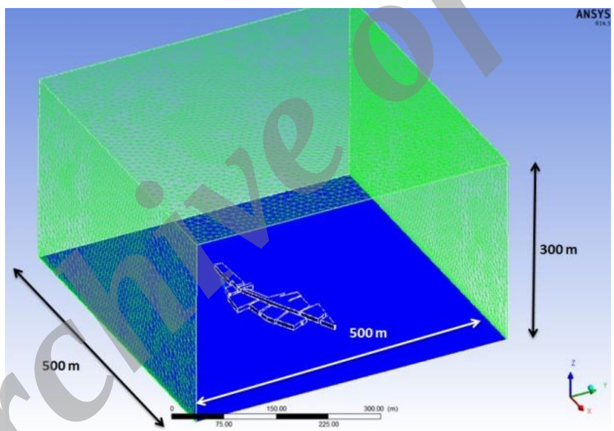


Figure 6. Computational domain configurations

Numerical simulation using CFD codes is based on the governing fluid flow and dispersion equations: The mass conservation (continuity) equation, the three momentum conservation (Navier-Stokes) equations and the transport equation for pollution concentration. A convergence criterion of 10^{-4} is used to insure the convergence of the dependent variables.

The air within the simulation domain can be considered as an incompressible turbulent flow, and the air and pollutants densities are assumed to be constant. These assumptions are reasonable for lower atmosphere environment as described by Sini et al (1996) [34]. The employed turbulent model in the current work and used in the CFD software (ANSYS CFX) was the k–ε model. The k–ε model was selected because of its good estimation of the atmospheric boundary layer [35].

The emission sources considered in this work was the traffic emission along the street canyon in the x direction, with 18 emission point sources (cars), with regular dimensions of 2 x 3.5 x 1.5 m and 5 m distance between each two cars. It is well known that vehicle emission factors depend on many parameters for example: Vehicle category (Gasoline, Diesel, light, heavy....); Season (Summer, Winter,.....); Vehicle speed (Highway road, urban road, rural road, ...).... etc. Due to the motorization diversities and the lack for circulation statistics of Ghardaïa city, in the present study a standard emission factors data for gasoline passenger cars was considered, for the computation of traffic source emissions as shown in Table 2.

Table 2: Characteristics of the CO_2 pollutant source [36], [37]

Total sources	27.9 g/s
Dimensions of a car (X,Y, Z) m	(1.68 * 3.99 * 1.42) m
distance between cars	5 m
Average speeds of cars	40 km/hour
Release of CO2/TRANSPORT	140 g CO2/km
Number of cars	18

The whole domain was discretized into finite volumes of tetrahedral elements and prismatic elements in the near wall layer with total elements number of 1416076 (Fig. 7). A grid independence test is carried out; the CO_2 concentrations at a given point are presented at Table 3 for various grid sizes.

Table 3: Mesh study

	Case : Reference	2nd Case	3rd Case
Number of elements in the Grid	1 410 659	1 806 920	2 019 379
Chosen point [ppm]: (X, Y, Z) m (181m, 192.1m, 1.5m)	1189 [ppm]	1183 [ppm]	1193 [ppm]
PRECISION OF RESULT		0.5 %	0.3 %

We can observe from the grid study table, that there is almost no difference between the results of the three grid size cases (0.5% and 0.3%). Therefore, the first mesh, with total number of element 1416076 was considered for the simulation.

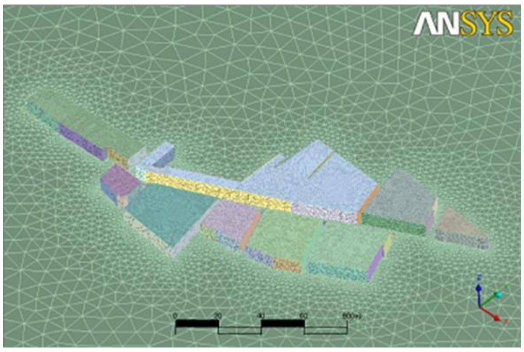


Figure 7. The geometry meshes

In the numerical simulation part, two geometry changes and architectural propositions were considered and examined. The modification was made on the downstream buildings, to assess the effects of morphology on the CO_2 air pollution dispersion. The first improvement was made by increasing the street canyon width at the outlet side, as described in Fig. 8.a. In the second modification, the last building at the left (Fig. 4) was modified by changing the uneven building layout (decreasing the building height) as can be shown in Fig. 8.b. It is noted that the weak modifications on the old building, were made from an architectural point of view in order to keep old buildings heritage design, from one side and from the other side to reduce the air pollution levels in the considered area.

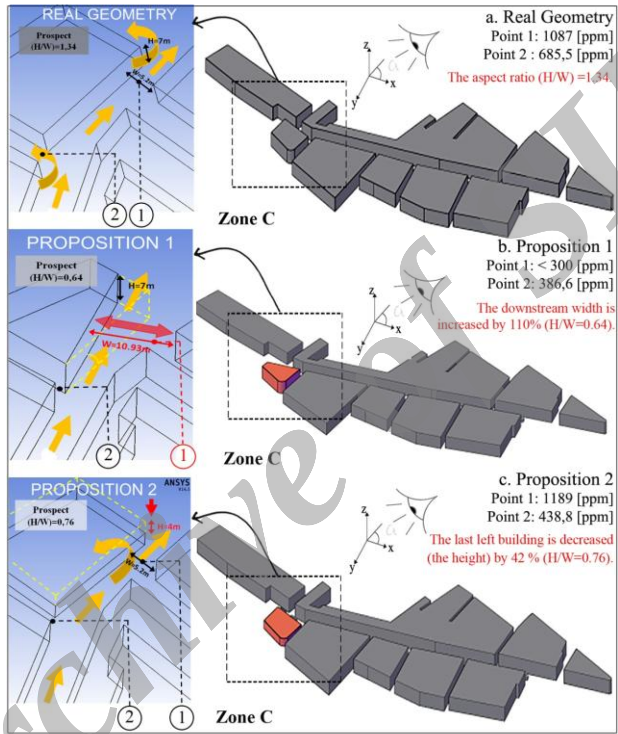


Figure 8. The real geometry (a) and the two architectural propositions, (b) Proposition 1, (c) Proposition 2

4. RESULTS AND DISCUSSION

4.1 Meteorology conditions

It is well known that, pollutants dispersion and therefore CO_2 concentration depend on meteorological conditions, such as: temperature, wind speed and solar radiation [38]. From a climatic point of view, the interesting street canyon suffers from unprotected exposure of strange effect of solar radiation and luminosity. This effect can be related to the street configuration, which is characterized by significant widths. In the historical Ksar at Ghardaïa city, the streets are narrow with the existence of many covered places, this practice allowed an adequate protection against any exposure during centuries (Fig. 9 (a,c)).

Figure 9. Example of the daily effect of solar radiation and illumination intensity on human activities; (a) 7720 lux, (b) 51800 lux, (c) 1632 lux, at 9 am, 3pm and 7pm respectively

Georgakis and Santamouris (2006) studied a field experience in Greece, where a street canyon was dominated by thermal phenomena, a difference of surface temperature between the inside and the outside of the street was found from 5°C, to 11°C. In our case, a difference of 2°C is measured between suburban station and the deep of the street canyon.

Based on the MNO measurements situated 20 km outside of the city, the month of July can be considered as the hottest in the year. The average temperature recorded goes from 29°C to 41°C (Fig. 10 (a, b)). While the average temperatures measured within the street canyon during the day are between 26°C and 36°C (Fig. 10 (c, d)). The recorded values of the Urban Heat Island intensity between the street canyon and surrounding are changed from -5°C °C to +4.5°C.

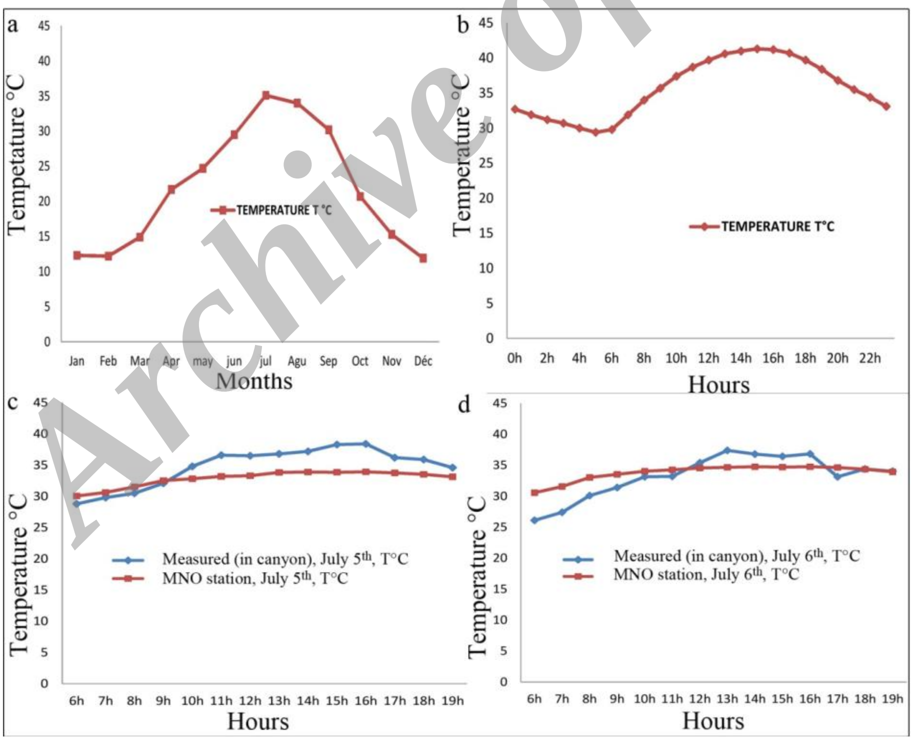


Figure 10. Meteorology conditions variations: a. MNO measurements of temperatures monthly variation (2010-2012), b. MNO hourly average temperatures variation in July (2010-2012), c and d. comparison between MNO measured temperatures and street canyon measured temperatures in July 5^{th} and July 6^{th} 2013, respectively

The wind speed values registered at the street canyon level are: 1m/s and 1.5 m/s. Whereas, outside the city the variations were rather important from 3 m/s till 4.5 m/s, it represents a gap of almost 50% as shown in Fig. 11 (a, b).

This important difference is essentially due to the roughness of the landscape bordering this street, like the surrounded mountains and the dense urbanizations on a hilly topography from north and northeast, which blocking flows coming from the Southeast (*Cf.* Fig. 2). According to Georgakis and Santamouris (2006) the airflow can be reduced from 68% to 82% due to roughness structure around a street canyon.

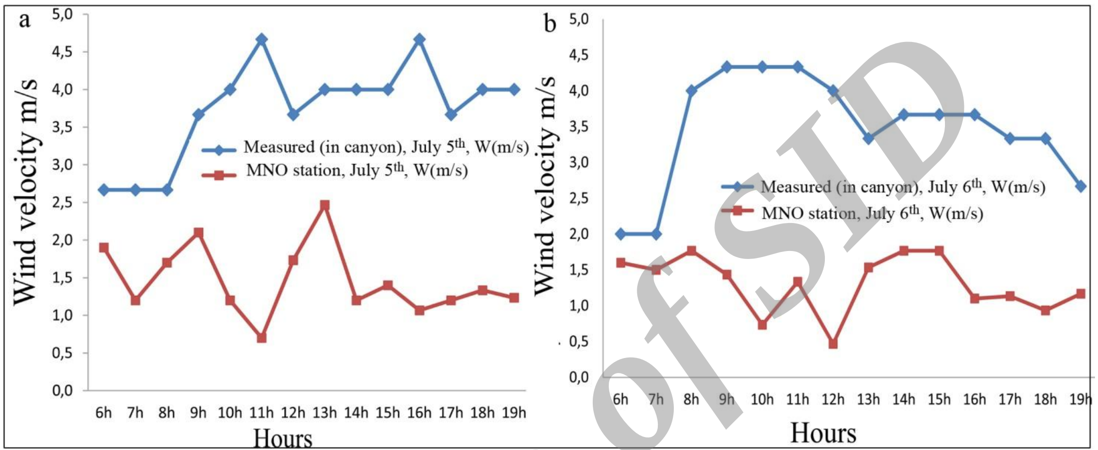
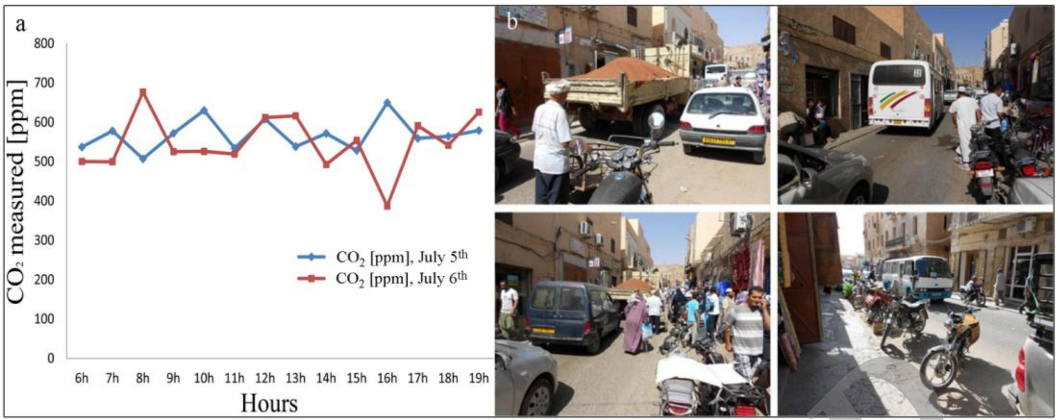


Figure 11. Comparison of measured wind velocity values from the MNO station to measured values within the street canyon: (a) in July 5^{th}, (b) in July 6^{th}

4.2 Results evaluation

Fig. 12 presents the hourly CO_2 concentration, measured at the street canyon axis during the 5th and 6^{th} of July 2013, the measured concentration varied between 500 and 700 ppm. As indicted by CO_2 NBN EN13779 [37], this interval is considered as average or acceptable air quality. It should be noted that; according to the European Standard index [37], CO_2 concentration values below than 400 ppm, corresponds to an excellent Air Quality. While values between 400 and 600 ppm agrees to an average air quality, CO_2 concentration values among 600 and 1000 ppm indicate an acceptable air quality. Finally, concentration values greater than 1000 ppm refer to a low air quality index.

Based on the measured data, the CO_2 air pollution level in the considered street canyon is important. Proceeding from this fact, the current numerical work is considered, using CFD simulation in order to study the CO_2 air pollution dispersion along the considered street, its levels and the different ways for its reduction. Therefore, air pollution source (cars) is simulated for the real geometry. In addition to that, geometry modifications are proposed and examined to the CO_2 air pollution accumulation (Fig. 8 (b, c) and Table 5). As it is described earlier, two geometries (proposition 1 & 2) were considered. The proposition 1 had the same structure of the real geometry, except the downstream width which increased by 110% (H/W=0.64). For the second proposition, the real geometry structure is kept too, except the decrease of the last left building height by 42 % (H/W=0.76) (Fig. 14 (a-c)).



Figuew 12. (a) Hourly variations of CO_2 concentrations within the street canyon, during the (5th and 6th) July, 2013. (b) Photos of the street canyon

In order to study and examine correctly the two propositions effects on the CO_2 air pollution, three study zones A, B and C are taken in account. Examination of the numerical simulation results, for the real geometry and the two propositions are performed for the whole region, with focus to selected zones.

Results of the analysis of CO_2 air pollution dispersion as simulated by the model are reported in Fig. 13, 14 and 15 and Tables 4 and 5.

Table 5: Characteristics and CO_2 concentrations at the points 1 & 2

Points Fig. 14 (a-f)		Aspect ratio	Characteristics of alleys			Values of the simulated CO2 [ppm]		
		H/W	Nature	Colors	Occult/ Shadowed	R.G*	Prop1	Prop2
1	R.G*	1.34	Rough	Yellow	Yes	1087	-	-
	Prop1	0.64				-	<300	-
	Prop2	0.76				-	-	1189
2		1.9				685.5	368.6	438.8

*Real Geometry

The arrangement of the real geometry and the two propositions simulation results in a single figure, aimed to simplifying the comparative study between the three cases (Fig. 13). Fig. 13, illustrates the CO_2 pollutant dispersion and concentration along the selected street canyon area. A first scientific reading shows to us the non-uniform distribution of the CO_2 concentrations, appeared clearly in the three considered zones. This figure shows that zones A and B provided identical dispersion behavior for the three geometries. However, various behaviors can be seen in the downstream of the street canyon (zone C). This area is located at the end of the street, and it has a significant CO_2 air pollution level, compared to other zones, either on building faces or within the street canyon. This pollutant concentration behavior at the downstream of the street canyon, prompted us to target this area and to intervene on urban configurations to improve air quality.

The main features appeared in selected zones, can be summarized as follow:

Zone A) From the upstream of the canyon which the Fig. 13 shows the zone A. The simulation of CO_2 dispersion gives the values 369, 455 and 386 ppm which correspond to the real Geometry, proposition 1 and proposition 2, respectively (Fig. 13). We note that the results are almost identical, with minimal gaps and differences.

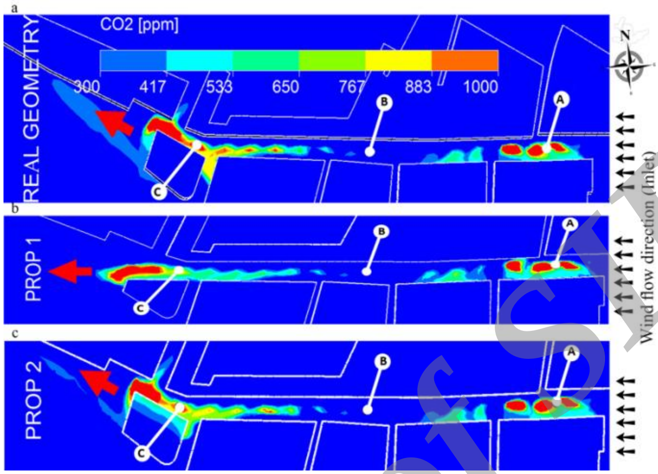


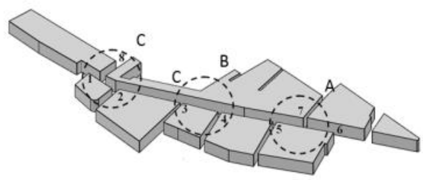
Figure 13. Global behavior of CO_2 concentrations along the street canyon; (a) Real geometry, (b) Proposition 1, (c) Proposition 2

Table 4 also shows an insignificant difference between the real valued measured and simulated values (difference of 207 ppm regarding the actual geometry).

Scientifically, these differences are considered insignificant because these differences are strongly related to: measurement conditions, perfect simulation of the real problem and weather conditions.

Table 4: Measured and simulated CO_2 pollutant at the considered zones

	Measured CO2 [ppm]	Values of simulated CO2 [ppm]		
		R.G *	Prop1	Prop2
A	576	369	455	386
B	800	<300	<300	<300
C	573	608.68	407.68	578.08



*Real Geometry

Zone B) At the center of street canyon (Fig. 13), almost the three geometries give similar values of the CO_2 concentrations, all of them are less than the zone A (Table 4), which is due to the discontinuity of the boulevard that releases the pollutant accumulated through the perpendicular alleys. The Fig. 14 (b) confirmed that there is a conflict between measurements data and numerical simulation values. The real measurement gives 800 ppm, but CFD simulation does not exceed 300 ppm for all geometries. This can be explained by the existence of temporaries occultation made by the storekeepers at the level of the perpendicular alleys (The Fig. 14 (c) shows the use of lightweight materials like natural cane or tissue). This practice which serves as protection against sunbeams has disrupted considerably the CO_2 dispersion through the discontinuity of the canyon. The comparative study shows a substantial gap between the real measured values and the simulated values ($\Delta d > 500 ppm$), remains to be said that this difference between simulation and real measurements are frequented, according to scientific literatures [15].

Zone C) Fig. 15 presents a complex pollutant concentration on downstream of street canyon at zone C. It demonstrates clearly that the proposition 1 can bring a considerable reduction of CO_2 air pollution of 46 % than real geometry (Table 4). While proposition 2 can also decrease the CO_2 concentration level at the downstream by 36% compared to real geometry (Table 4). To attempt to understand more, two study points (1 and 2) are considered in zone C, as shown in Fig. 15. At point 1, the values of CO_2 accumulation on proposition 1 are lower than both values of real geometry and proposition 2 (Table 5). Fig. 15 (b) demonstrates in detail, that proposition 1 has less than 400 ppm. However, the CO_2 accumulations is considerably raised (is upper to 1000 ppm) for both the real geometry and the proposition 2 (Fig. 15a and c). The point 2 is perpendicularly to the street canyon, the CO_2 accumulations are 685.5 and 438.8 ppm which correspond to real geometry conception and proposition 2, respectively. Nevertheless, proposition 1 has a CO_2 accumulation less to 400 ppm (see Fig. 15 a to c) and Table 5). This difference is justified by deflecting of street canyon on downstream area, where the last ilôt acts as an isolated building rounded by airflows. Wind-tunnel studies indicate that a relatively high pressure over much of the surface of the windward wall is generated by the wind flow [18], with maximum pressure at the upper central part by creating low pressure area near to the outside edges of the windward face. And the cavity zone (behind the building) is characterized by a double eddy circulation at ground-level which incorporates the side wall suction areas into a horseshoe-shaped pattern [18].

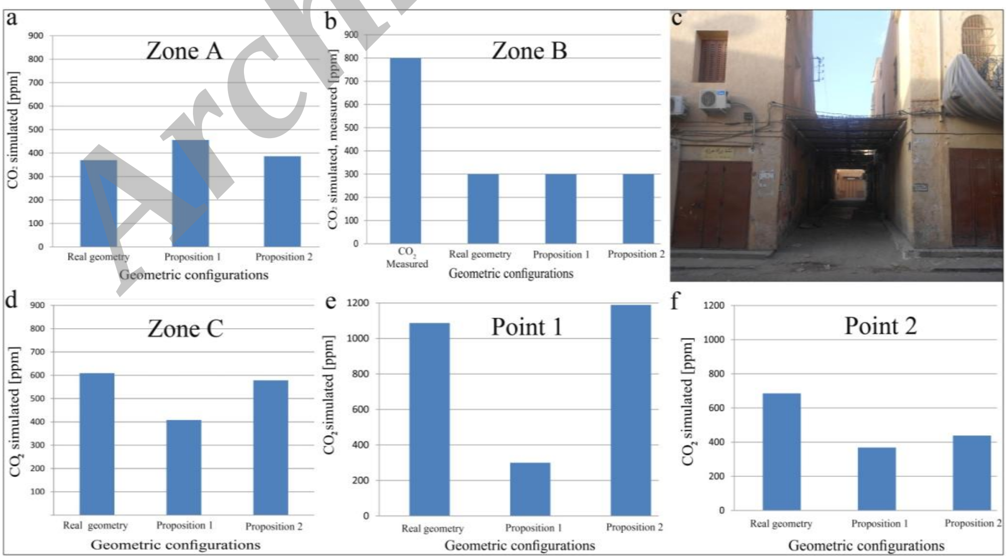


Figure 14. Simulated and measured CO_2 pollutant concentrations at the three study zones (A, B, C, point 1 and point 2) and for different geometries

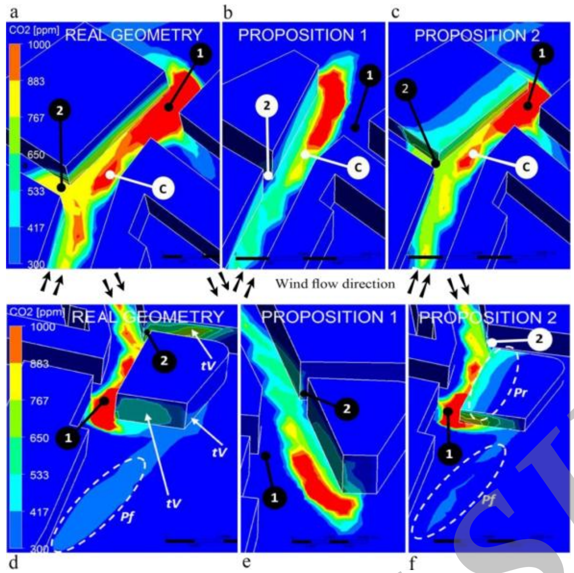


Figure 15. CO_2 concentration and dispersion at downstream area for three considered geometries: Real geometry (a and d), Proposition 1 (b and e), Proposition 2 (c and f)

The Fig. 15.d and f) shows that a turbulent Vortex *(tV)* may affect all building faces of real geometry by CO_2 air pollution, even the opposite blocks are affected by the pollutant faces *(pf)*. But on the proposition 2, turbulent Vortex (*tV*) do not affect all faces, and the opposite block is affected by weak degree. Additionally, Fig. 15 (d and f) confirms that proposition 2 can disperse the CO_2 better than real geometry and thus, decreasing the CO_2 concentration. This is observed by the concentration of the pollutant over the roof (*Pr).*

5. CONCLUSION

The Ibadite valley is a millennium civilization, and a Saharan region. In this inhospitable desert, the Mozabites knew how to adapt themselves with the region nature. They built Ksour with a harmony and high quality adaptation in an extremely arid environment. In the old city, the passages are deep and compact with high aspect ratio, to protect houses against exposure to solar radiation. Besides, the existence of palm trees and oases between agglomerations (houses sets, or Ksar), decrease the heat intensity and promotes freshness and nocturnal ventilation in the building plants tissue . Sadly, the new urbanization in M'zab valley increased illicitly, which declines traditional urban form and vernacular architectural values. The actual ecosystem at M’zab city is changing rapidly, and it knows great challenges, with unprecedented acceleration of urbanization on the oasis environment.

In the present study, CO_2 air pollution levels and its effects on air quality in old buildings was investigated. Numerical simulation with CFD code was used in combination with measurement data in order to study the CO_2 air pollution dispersion in the selected area, which is a vernacular urban fabric at the city of Ghardaïa, Algeria.

The area of interest is a group of buildings around a street canyon, which were established at the colonial period. They represent the continuation of the historic site of Ghardaïa. This street canyon has a complex configuration, and has a significant unidirectional traffic. It is regarded as the only connection between the entire city of Ghardaïa and the Northwest side. It is used by different type of transportation, from cycling to heavy-duty. In addition, this boulevard is the destination for residents, traders and tourists. Based on several measurements, the average value of CO_2 concentration in the street canyon is above 400 ppm, which can be considered as a high air pollution level.

A combination use of model numerical simulations and measurement data was considered during this study, in order to assess the effect of various building morphologies on CO_2 air pollution level in the interesting area.

Two geometry changes and architectural propositions were considered and examined. The modification was made on the downstream buildings, to assess the effects of morphology on the CO_2 air pollution dispersion. It is noted that the weak modifications on the old building were made from an architectural point of view, in order to keep old buildings heritage design, from one side and from the other side, to reduce the air pollution levels in the considered area.

A general scientific reading shows the non-uniform distribution of the CO_2 concentrations, appeared clearly along the street canyon, mainly at the downstream zone.

The two numerical simulations were performed based on geometry changes and architectural propositions on the downstream buildings. The first improvement was made by increasing the street canyon width at the outlet side, which reduced the CO_2 concentration by 46%. In The second modification, which made by changing the uneven building layout, this improvement decreased the CO_2 concentration by 36% compared to the real geometry. The results show the effect of weak modifications of the architectural fabric on the air pollution reduction, and therefore the participation in protecting old buildings heritage from air pollution effects.

An extended analysis, including more details about initial conditions of air pollution and meteorology, registered for long period, would be an important step to get a real simulation of the air pollution dispersion phenomenon. Besides, other alternative solutions and strategies such as: political approach to decrease air pollution in urban areas by reducing number of cars, and encouraging the public use of transport…, could be the key of air pollution reduction.

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