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EVALUATION OF AN URBAN AERODYNAMIC MODEL IN THE CITY OF FEZ IN MOROCCO "CASE OF THE CANYON STREET

Alaoui Sosse Jihad and Mohamed Tahiri
Department of Process Engineering, Mohammadia School of Engineers, Mohammed V - University of Rabat, Morocco
E-Mail: sys.energie@gmail.com

ABSTRACT

Constructions in the urban environment have a strong impact on microclimate parameters at local scale by modifying the distribution of wind flow between surfaces. This distribution directly impacts comfort or thermal discomfort in outdoor public spaces. This work aims to evaluate, through modeling and numerical simulation, an aerodynamic model for predicting aerodynamic atmospheres at the urban scale. To characterize the urban flow, we chose a semi-empirical one-dimensional model for the determination of urban wind speed profiles Nicholson (1975) coupled with the AROME model. The simulation results were compared with the measurement data obtained during an experimental campaign conducted in Morocco by Erik Johansson (2006), in order to validate the relevance and robustness of the numerical model under Moroccan urban climate.

Keywords: aerodynamic, AROME model, Moroccan.

INTRODUCTION

The design of buildings is often linked to the maintenance of a thermally comfortable indoor environment, defined mainly by hygrothermal parameters. However, the thermal and outdoor air environments also play an important role in the handling of the internal and external thermal stresses of buildings. Thus, the building, or even the cities itself, like the city of the Mediterranean type, have been adapted to respond to the demands of the local climate [1] [2] [3]. With the development of indoor climate control solutions, thermal constraints have gradually given way to economic, architectural or functional criteria. Subsequently, particularly as a result of improvements in heating and air-conditioning systems, building thermal studies have expanded and the energy crisis has intensified. Thermal insulation of buildings then became the subject of specific regulations for climatic situations.

Finally, more recently, the emergence of environmental concerns has led to more in-depth studies on the energy demand of buildings, mainly related to climate control systems. Thanks to computerization, these studies have been refined by the development of numerous computer codes for the simulation of outdoor environments allowing detailed calculations from the pre-project phase. However, the consideration of climatic conditions near buildings is often limited to data from reference weather stations located in rural areas, without considering the coupling between climate and buildings. In this context, this work will make it possible to choose an appropriate aerodynamic model for the prediction of wind speed profiles in the urban environment, and to evaluate it later in the Moroccan context. This model will play the role of a necessary sub-model for the global thermo-aeraulic model.

The modeling of dominant flows in urban areas is complex because of the heterogeneity of the urban environment. Scenarios in the literature, for the classic case of a canyon-type street, are defined. Several empirical or theoretical velocity field models are proposed for different configurations, Paul Arya *et al.* (1978) has established a model for calculating aerosol dry deposition velocity, this empirical model is based on similarity between flux and variance (Flux-variance similarity). It is a variation of the general equation of the turbulent kinetic energy allowing expressing in the surface layer the standard deviations normalized according to the cases of atmospheric stability. The measurements to establish these empirical laws are made from measurements of the fluctuations by anemometers arranged at different heights in the surface layer and over a horizontally homogeneous ground [4]. While for Nicholson (1975), in urban areas, the average profile of air velocity due to the prevailing wind is different from the logarithmic profile defined in a homogeneous site. The flow is thus strongly disturbed near the buildings. On the other hand, beyond an area called the mixing zone, the flow profile becomes similar to that of a homogeneous site. Empirical relationships establish velocity profile as a function of site roughness, often in logarithmic form [5] [6]. According to Rotach *et al* (1995), this profile depends very much on the dominant axes of the canyon streets, even far from the ground; the disturbed flow zone is also called the surface layer, and extends over several tens of meters above buildings. In the upper part, the inertial boundary layer is similar to the entire surface boundary layer for rural areas. In the lower part of the boundary layer, flow is disturbed and vertical or transverse secondary flows occur are observed, this zone is called the rough boundary layer or "Roughness Sublayer". In practice, the three-dimensional and highly variable flow caused by the high irregularity of the roughness makes it difficult to define in real scale this Zr limit in urban or suburban area [7] [8]. According to Grimmond and Oke (1999), the high roughness of urban surfaces is reflected in significant boundary layer heights, and the Zr coarse boundary underlain by various studies shows that it varies between 2 and 5 times the average height of buildings Zh, useful for defining the boundary layer. Near-ground flow, height displacement Zd and roughness Z0 can be estimated from characteristic values for different types of urban areas listed in the literature, in the absence of more accurate data. The different zones are characterized by the average level of the buildings as well as by the type of construction, industrial or residential for example, to which a typical morphology can be associated. Two types of approaches are therefore used to define these heights, one based on the morphology of the surface, and the other by microclimate observation and the identification of parameters with logarithmic profiles. The determination of these parameters from the surface morphology can be formulated more precisely from the definition of an average texture of a city or a district. The simplest morphological formulation consists in evaluating Zd and Z0 as a function of the average height of the obstacles Zh [9] [10]. To improve the prediction of meteorological fields within the street canyon with the town energy balance model (TEB), a new approach was developed according to the methodology described by Masson (2000). It solves the surface boundary layer inside and above the urban canopy by introducing a drag force approach. This new version is tested offline in a street canyon. The results are compared to the original single layer version of TEB and measurements in and above the street canyon. The results show that this new version produces profiles of wind velocity, friction velocity, turbulent kinetic energy, turbulent heat flux and potential temperature more consistent with the observations. In addition, this new version can still easily be coupled with mesoscale weather models [15] [16]. E. Bozonnet (2005) showed that for the case of a reference velocity between 0.5 m / s and 4 m / s, a model was established from the experimental data (Santamouris *et al*. (2001)), the model has been formalized in the form of a correspondence table between the order of magnitude of the reference speed and the speed at the lower and upper part of the canyon. When the reference speed is greater than 4 m / s, the use of an empirical model, gives satisfactory results, up to a limit of 7 m / s where the correlated velocity in the canyon can be highly overestimated. Thus, for the case where the incidence is substantially parallel to the canyon, at plus or minus 15 °, the speeds obtained by the Nicholson model are close to the measured values. When the wind is perpendicular or oblique to the axis of the canyon, the model of Hotchkiss *et al.* (1973) is then used [11] [12] [13] [14].We have chosen in this work to evaluate the aerodynamic model of the TEB model developed by Masson (2000) and based on the semi-empirical model of Nicholson (1975), this choice is due to the possibility of coupling the model with a mesoscale weather model, and who will be the model AROME in our case [17].

The city of Fez and the measurement sites

The city of Fez is situated in the northern of Morocco (33.1580N, 4.1590W), the climate of the city is characterized by a dry and hot summer and a cold winter, the summer temperature may exceed 40 °C and reached less than 0 °C in winter. Fez was chosen for this study because of the availability of experimental data conducted in 2001 by Erik Johansson.

Wind speed is measured during Erik Johansson's (2006) experimental campaign in 2001 in two canyons in the city of Fez, a site in the center of the new city of Fez (El Adarissa District) with a high aspect ratio (AR=10) and the other site is located in the old Medina (Seffarine District) with an aspect ratio of 0.6. See the following figures:

(a)

(b)

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Figure-1. City of Fez: (a) new town street (b) old media street [23].

Wind speed was measured by a hot wire anemometer. The anemometer was manually placed in the center of the streets at a height of 2 meters. The measurement is done 15 times divided evenly between morning, afternoon and the evening of the day studied. The variations of the wind speeds for the two canyons studied and for the two periods of the year 2001 are presented in the two following figures:

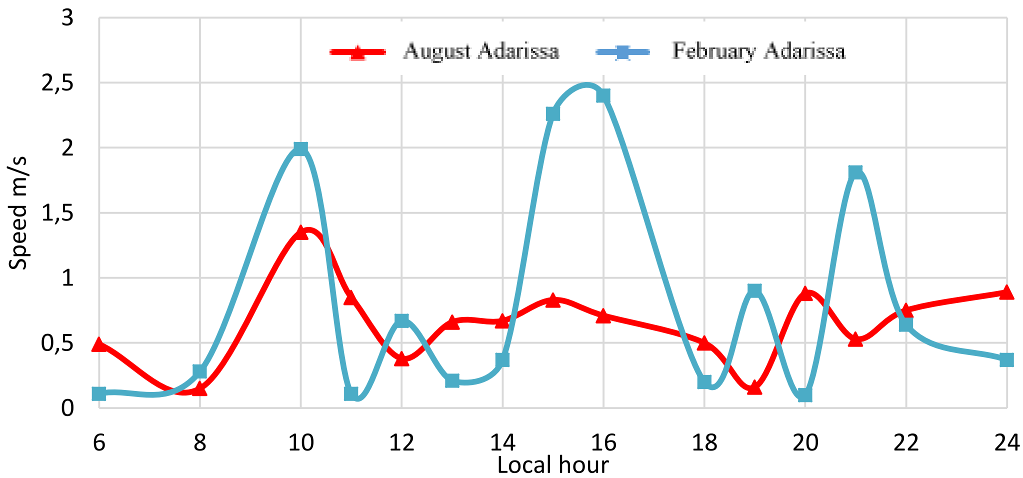

Figure-2. Variation in wind speed 2 meters above ground level in the Al Adarissa site during the summer day of August 6, 2001, and winter of February 7, 2000.

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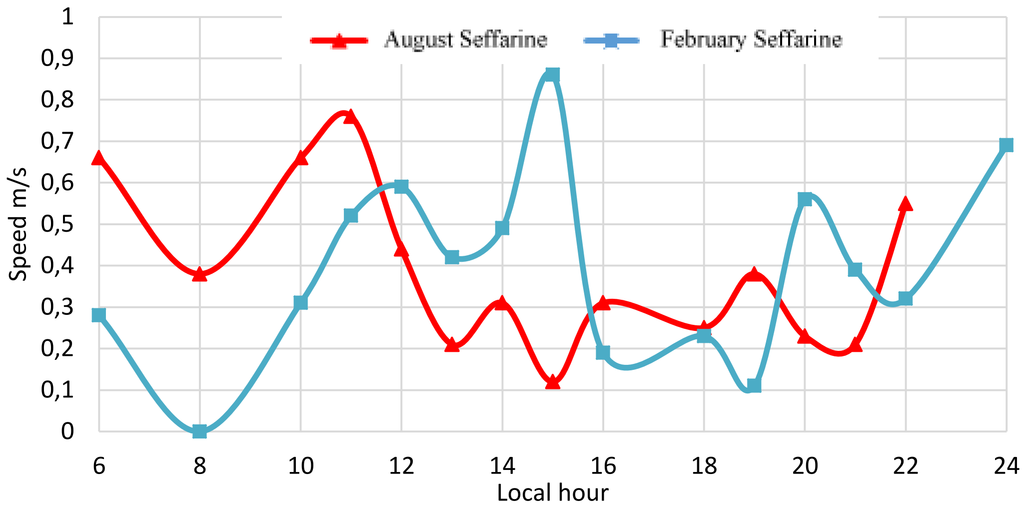

Figure-3. Variation in wind speed 2 meters above ground level in the Seffarine site during the summer day of August 6, 2001, and winter of February 7, 2000.

Due to the unavailability of data simulated by the AROME model in the year 2000, only the measurements made in 2001 will be investigated in this work.

METHODOLOGY

The comparison of the results obtained by modeling with the data obtained by the experimental campaign of Erik Johansson (2006) enables us to adapt and verify the validity of the approach proposed by the TEB model [16] which consists in determining the average of two vertical velocity components along the walls W '(z) and the horizontal velocity component U (z), as well as the velocity at the top of the canyon by empirical equations, a function of the geometrical characteristics of the computational domain.

The wind speed at the top of the canyon U (Zh) "Zh is the average height of the buildings" is used as a boundary condition for the wind speed profile, this boundary condition is derived from the atmospheric turbulence closure model AROME used by the Meteorological Agency of Morocco with a resolution of 2.5 km. The turbulence closure model is a 1Dprognostic-turbulence scheme on 6 vertical levels inserted between the surface and the lowest atmospheric model level. It should be noted that the velocity profile inside the canyon and at the top of the canyon is used to estimate the heat flux between the surfaces and the canyon in the TEB model, as well as the outside atmosphere and the canyon. An approximation of the wind at the top of the canyon can be given by a logarithmic profile (see Figure-4). The displacement height Zd is assumed to be 2 * Zh/3, that is to say, Zh/3 under the roofs (an approximation from the canopy of plants [18]). After 360-degree integration, to be able to take into account all possible directions of the canyon, the wind speed at altitude Zh is expressed in the form [16]:

$$U_{top} = \frac{2}{\pi} \frac{\ln(\frac{Zbat/3}{Z0})}{\ln(\frac{\Delta z + Zbat/3}{Z0})} \left\| \overrightarrow{U_{atm}} \right\| \qquad (1)$$

As Δz is the height difference between the first atmospheric level Zref (the altitude of the climate forcing data obtained by the AROME model) and the level of the roofs Zh, Z0 is the length of the canyon roughness. Empirical values of roughness length (Z0) can be imposed depending on the nature of the site of the model according to (Wieringa, (1993) [19]). The length of roughness of the canyon is supposed to be equal to 0.1*Zh, according to the works of Bottema (1997) [20] on several forms of buildings and positions, this correlation has the advantage to have lengths of roughness adapted to each architectural configuration. $\left\| \overrightarrow{U_{atm}} \right\|$ is the result of the wind speed at Zref.

To calculate U(z), a vertical profile of the wind in the canyon is assumed. An exponential form is chosen (see figure 4), with an analogy with vegetation cover, determined by Arya 1988 [18]. Such a profile applied at mid-height gives the profile of wind speed inside the canyon. At the height z=Zh/2:

$$U_{can}(\frac{Zh}{2}) = U_{top} * \exp\left(-\frac{N}{2}\right) \qquad (2)$$

N is determined experimentally according to the architecture of the canyon. Rotach (1995) [7] found from his case study (AR(Building Prospect Ratio) =1) that U(Zh/2) ≈0.75*U(Zh). Studies in maize fields (AR ~ 4), which could be likened to narrow streets, give U(Zh/2) ≈0.4*U(Zh) Arya (1988) [18]. Thus the parameter N=0.5*AR seems to be appropriate [16]. So, the wind speed at halfway up the canyon is:

$$U_{can}\left(\frac{Zh}{2}\right) = U_{top} * \exp\left(-\frac{AR}{4}\right) = \frac{2}{\pi}\frac{\ln\left(\frac{\frac{Zh}{3}}{Z0}\right)}{\ln\left(\frac{\Delta z+\frac{Zh}{3}}{Z0}\right)} * \exp\left(-\frac{AR}{4}\right) * \left|\left|\overrightarrow{U_{atm}}\right|\right| \quad (3)$$

However for prospects of higher buildings (deep street) taking into account the roughness of the site is important in the determination of the exponential profile of the wind speed within the canyon, so we use for an AR> 4 the expression of N empirically determined by (Nicholson (1975) [6]), namely:

$$\mathrm{N} = 0{,}1 * \frac{\mathrm{Zh}^2}{\mathrm{Z0}^2} \quad (4)$$

The wind speed in the middle of the street at a height of Zh/2 is used in the TEB model to determine the turbulent heat flux between the canyon air and the street surfaces (the walls, the road and the roof). The vertical velocity W 'along the walls is assumed to be equal to the friction velocityu_*, according to Rotach (1995) [7] who observed through measurements in the center of Zurich (Siegerland) that the vertical velocity of the wind is approximately equal to the friction velocityu_*:

$$\mathrm{W'}_{\mathrm{can}} = \mathrm{u}_* = \sqrt{\mathrm{C_d}} * \left|\left|\overrightarrow{\mathrm{U_{atm}}}\right|\right| \quad (5)$$

Where Cd is the drag coefficient that is a function of both the temperatures and humidity inside and above the canyon and the Z0 roughness length. In order to simplify the calculation of the friction velocity the formula of (Nicholson (1975) [6]) is used:

$$u_* = \frac{k * U_{atm}}{\ln\left(\frac{\Delta z+\frac{Zh}{3}+Z0}{Z0}\right)} \quad (6)$$

Where Uatm is the forcing velocity measured at a height of Zh+10 meters and k the constant of Von karman (k=0.41). This formula assumes that the friction velocity profile remains constant between the roughness layer and the boundary urban layer, this result is obtained from the results of Rotach (1995) [7], who observed that the vertical velocity in the upper part of the canyon is almost equal to the friction velocity, whatever the weather conditions (stable, unstable or neutral). For forcing data obtained at a higher altitude beyond the roughness layer, the application of the Monin-Obukhov theorem [21] is necessary, which is not the object of this work.

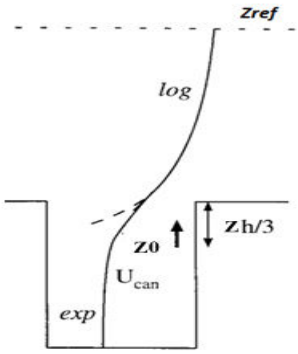

Figure-4. Representation of the wind above and inside the urban canyon (Lemonsu (2003) [22]).

The formulas used by Masson (200) [16] make it possible to obtain the wind speed at Zh/2 (7 meters from the ground for Al Adarissa and 5 meters for Seffarine), whereas the wind speeds measured by Johansson [23] are 2 meters above ground level. Masson's formulas are reworded as follows:

The wind speed at altitude Zh is expressed in the same form (equation 1), such that Δz=10 because the Uatm forcing speed data provided by the AROME model [17] are at a height of 10 meters above the roofs of the city. In the hypothesis of a neutral atmosphere, an exponential expression of the vertical profile of the horizontal mean velocity U(z) in the direction of the dominant flow inside the canyon is proposed, often used for the determination of the mechanical loads on buildings, this expression is valid from the urban atmospheric sub-layer above the zero-displacement plane (Nicholson (1975) [6]):

$$U(z) = U_{top} * e^{\left(\frac{Z-Zh}{Z0}\right)} \quad (7)$$

Where u_* is the friction velocity, it is expressed according to the reference velocity Uatm measured at Zh+10 meters (formula 6). In practice, this velocity in a neutral atmosphere (inertial sub-layer) is difficult to measure (Nicholson (1975) [6]). The overlap of the two exponential and logarithmic profiles is presented in the following figure:

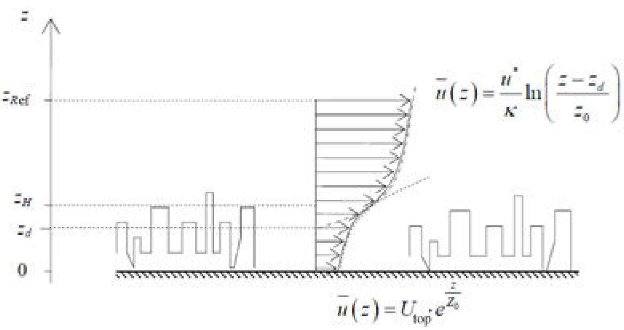

Figure-5. Representation of the resulting profile of the average wind speed in urban sites, according to (Nicholson (1975) [6]), an exponential profile in the canyon and a logarithmic profile outside until the reference height.

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RESULTS AND DISCUSSIONS

The validation of the aeraulic model consists in comparing the experimental results realized by Erik Johansson at the two sites of the city of Fez with the results of the correlations proposed by Masson [16], all based on the empirical formulas of Nicholson (1975) [6]. The following figure shows the variation of the wind speed at Zh + 10 meters of altitude simulated by the AROME [17] model of the meteorology direction in Morocco, for the two sites during the summer period of the year 2001.

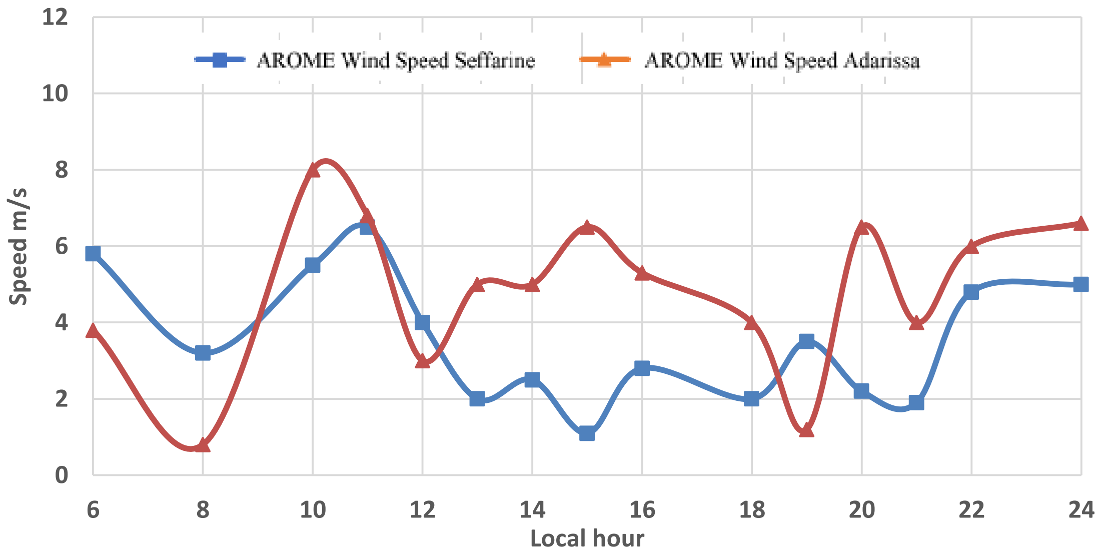

Figure-6. Variation in wind speed at Zh + 10 meters (Uatm) (AROME model source Seity *et al* (2011) [17]).

Figures 7 a and b and Figures 8 a and b are indicative wind speed profiles from the ground at an altitude of Zh + 10 meters for the canyon El Adarissa (a) and Seffarine (b) at two different moments of the day of August 6, 2001 (12:00 and 6:00 pm).

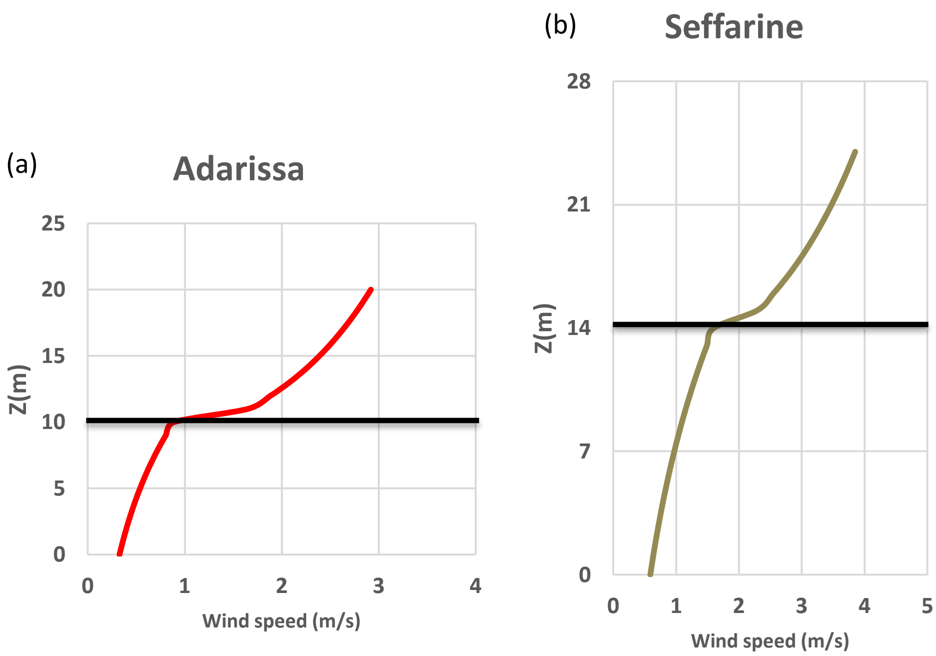

Figure-7. Calculated wind speed profiles from the ground at an altitude of Zh + 10 meters for the El Adarissa canyon (a) with Uatm = 3 m / s, and Seffarine (b) with Uatm = 4m / s at 12h: 00.

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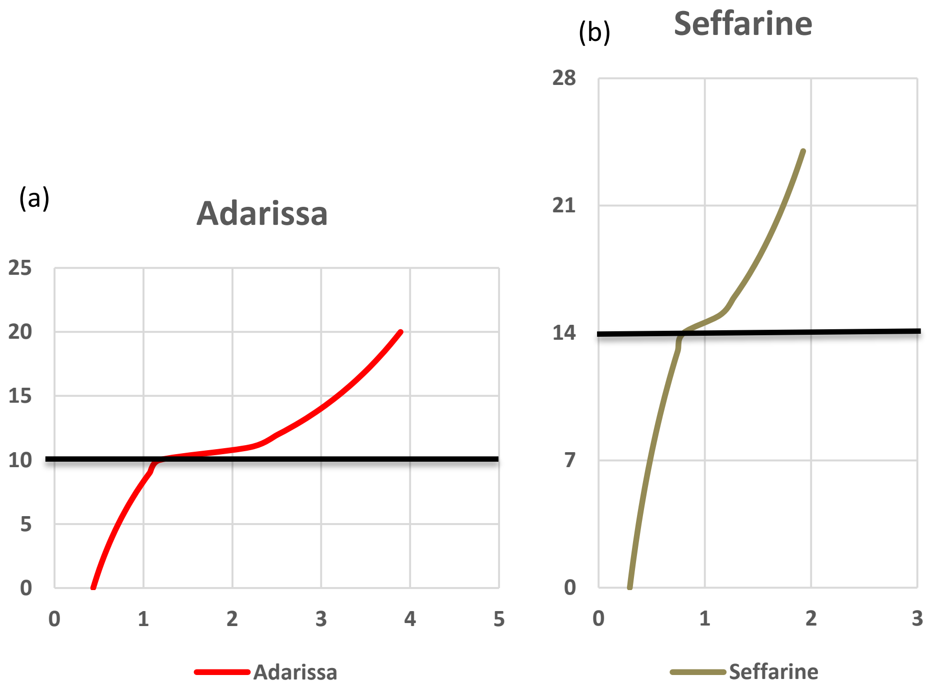

Figure-8. Calculated wind speed profiles from the ground at an altitude of Zh + 10 meters for the El Adarissa canyon (a) with Uatm = 4 m / s, and Seffarine (b) with Uatm = 2m / s at 18h: 00.

Figures 9 and 10 give the experimental results and predictions of the empirical formulas for the sites for the summer day of August 6, 2001. It should be noted that the data presented on these two figures correspond to Z = 2 meters. We used the average of the measured data for the evaluation because the exact interval between measurements is unknown, due to taking measurements on non-uniform intervals over the day investigated.

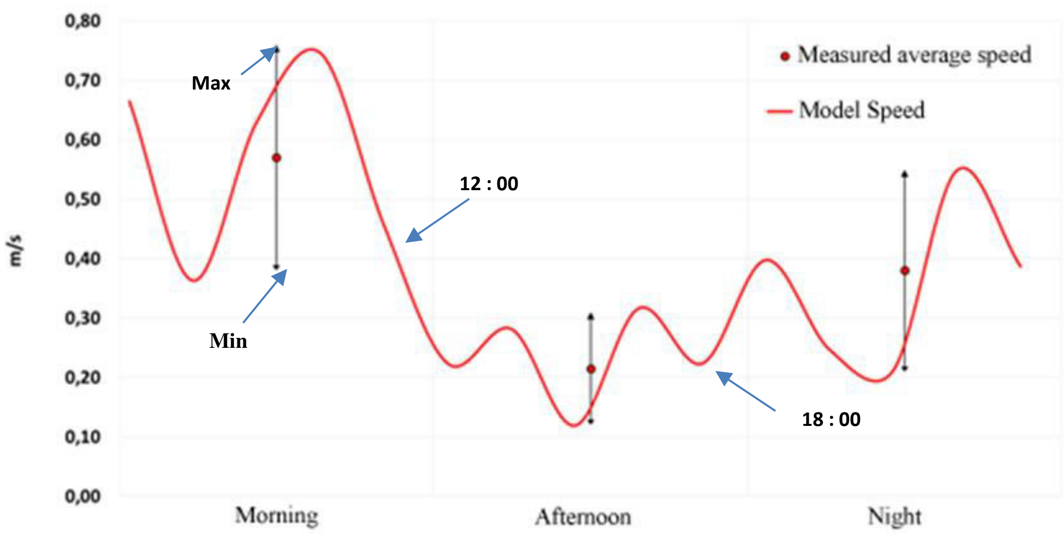

Figure-9. Variation of simulated and measured wind speed for the case of Seffarine deep canyon during the day of August 6, 2001 at 2 meters from the ground.

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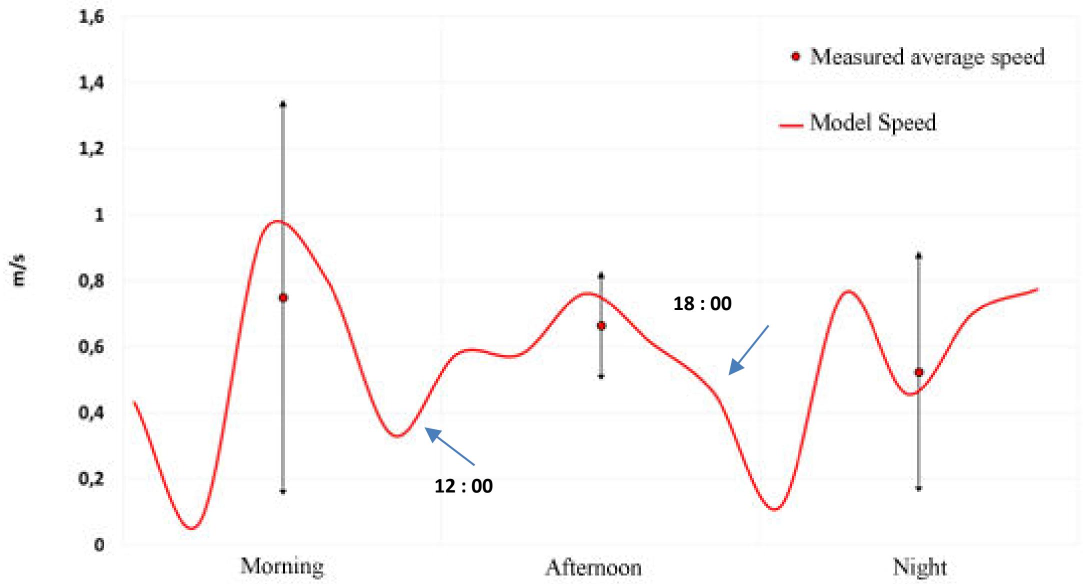

Figure-10. Variation of the simulated and measured wind speed for the case of the narrow El Adarissa canyon during the day of August 6, 2001, at 2 meters from the ground.

As a first observation we can notice the difference between the two canyons (El Adarissa and Seffarine) in terms of amplitude of the wind speed inside the street. Within the deep canyon, the wind speed is less intense than that in the narrow canyon; the compact form of construction in the old Medina of Fez makes the urban atmosphere less impacted by the winds at the top of the city. At the top of the streets at the first atmospheric level, the data simulated above the buildings by the AROME model in terms of wind speed for the case of El Adarissa street (New City), are higher than those determined for the old Medina this gradient is justified by the difference in altitude between the two sites which is of the order of 140 meters. So, the first atmospheric level of the new city is less impacted by the roughness layer than that of the old Medina.

For both streets, the comparison of calculated wind speeds and measured wind speeds show good agreement between the model and the measurements for the summer period. Deviations from 0.1 to 0.3 m/s are observed relative to the mean value of the measured wind speed. This difference may correspond to disruptive phenomena not considered or to a systematic error of the model for certain wind scenarios, or even thermal disturbances which become important with the presence of low wind speeds. For the impact of the orientation of the street in relation to the direction of the prevailing wind, taking into account the average wind speed at the top of the street in all possible directions, allows us to simplify the approach of determination of the wind speeds for all existing scenarios, there are algorithms for determining the velocity profiles according to the orientation of the street with respect to the incident wind ([6], [12], [13]) thing that it has been avoided by the use of the formula proposed by Masson 2000 [16]. The calculated values are close to the mean value, or oscillate for the three periods of the day (morning, afternoon and evening) in the interval between the maximum value and the minimum value of the wind speed. The results previously presented make it possible to conclude that the empirical formulas used, give acceptable estimates for vertical wind speed profiles in canyons with geometries specific to the context of Morocco.

CONCLUSIONS

In this work, we evaluated the semi-empirical model of Nicholson for the estimation of the wind speed within a canyon-type street, the evaluation is made based on the data measured by the experimental campaign of Erik Johansson in 2001, the model had given rise to a satisfying precision with a deviation varying from 0.1 to 0.3 m/s. However, when the wind speed at the top of the streets is greater than 7 m/s, the correlations of wind speed profiles within the canyon may overestimate the wind speeds inside the street, especially during the winter period when the wind speed at the top of the city becomes very important. This result was found by (E. Bozonnet (2005) [11]) in measurement campaigns carried out in the city of Athens. Therefore, it is important to simulate the winter periods with higher wind speeds, at the top of the canyons, but because of the unavailability of data at that time, we will be satisfied with the results of the summer period, which remain very representative. Future work should focus on data with larger wind speed amplitudes, to test the validity of the Nicholson model for extreme cases.
The studied model coupled with other radiative model will also make it possible to predict with high precision the urban climate, and thus to have a better estimation of the thermal loads of the constructions [24][25].

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