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# Integration of Wind Flow into the Bioclimatic Design in Djibouti

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*Abstract*—**East African countries are growing rapidly which significantly affect cities' climate. Such modifications negatively affect environment and inhabitant safety and comfort. Proper urban atmospheric planning and management are therefore key to making cities environmentally friendly and sustainable. Djibouti, in particularly, there is a need to integrate wind flow into the building design and to introduce the bioclimatic conception while improving the comfort of building occupants. Therefore, integration wind in building design known as a passive design strategy in buildings is one of the innovative techniques in modern building to reduce operation costs and energy consumption. This work provides an overview of the potential use of natural ventilation for free cooling applications and aerothermal analysis, by using the CFD (Computational Fluid Dynamics) applied on the building, for a local and sustainable development in Djibouti.**

***Index Terms***—**Computational Fluid Dynamics (CFD), airflow, simulation, natural ventilation, bioclimatic design, weather data, energy efficiency**

## I. Introduction

Economic growth, energy resources and the environment are highly related terms. Life improvement resulted from economic growth leads to excessive uses of depleted energy resources, but intensive use and often mismanaged energy endanger the stability of our ecosystems. The construction of low-cost buildings and reduction of negative impact of the environmental are priority to sustainable local development [1], [2].

In spite of the lack of access to the energy in developing countries, in Djibouti, one of the big sectors of energy consumption identified is the sector of the building[1] with 83% of the country's energy consumption. The lack of access to the energy accompanies a mismanagement of this energy. And this entails a useless and expensive overconsumption to vulnerable population. This observation must cause a substantial development of the energy research so as to strive towards an optimized conception of the building. The axes of research stretch from envelope (isolation, materials, glazing...) to different types of mechanical equipment and also the bioclimatic conception of the building.

The study aims to examine the potential benefits and feasibility of the natural ventilation and to investigate design and simulation methodologies.

## II. Climate Analysis and Site Description

### A. Climate Analysis and Site Description

Djibouti has a considerable wind potential which is not sufficiently exploited. As shown in Fig. 1, it characterized by a by high wind intensities with nearly 7 m/s in the capital where the study site is located.

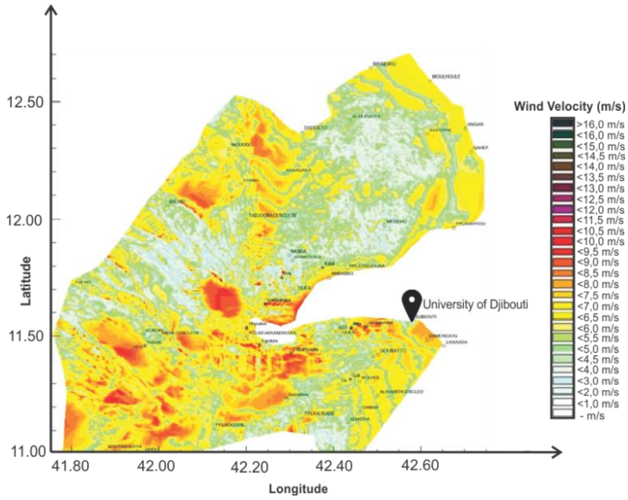


Figure 1. Geographic distribution of wind velocities of Djibouti at 60 m height (CERD) [3]

Furthermore, Djibouti has two clearly defined seasons:

- The cool season which starts from October to April, the wind blows from the Northeast to the Southeast. It comes from the Indian Ocean or the South of Arabia. This is the trade winds. The trade wind is cool and wet, never violent. It sometimes brings rain.
- The hot season starts from May to September and it is characterized by a violent and dry hot wind namely "Khamsin". It usually blows in the day and subsides at nightfall. It is then followed by a light east wind: the sea breeze. The Khamsin is a

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west wind coming from inland, the mountains of Ethiopia. It can raise the temperature to 47 ℃.

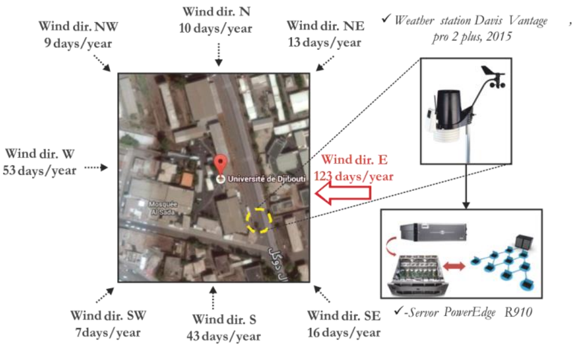


Figure 2. Airflow analysis at the university of Djibouti

The wind speed data were collected over a period of a year (July 2014 to June 2015). The wind speed measurements were made 8 m above ground level and recorded every five min at the station. The geographical location of the station is shown in Fig. 2. The data used in the study can be grouped into two classes namely: observed weather data, satellite observed data can be found in Solar and Wind Energy Resource Assessment (SWERA, [4]). The main limitation in the satellite data set is that the data is too short to conclusively correlate to the change in the climate parameters.

The weather station Davis Vantage Pro 2 measure weather data by a set of integrated sensors to the station and the measured data are displayed in a console. The connection between the external sensors and the console is via radio waves on frequency 868.0 - 868.6 MHz with a range of 300 meters maximum. The console is equipped with a large backlit LCD screen that views real-time information on weather conditions. A data logger connected to the console transfer data to a servor (PowerEdge R910) via an interface named Weather Link.

To better meet the objectives of the study, the data collected by the local weather station is analysed for a better use of natural ventilation.

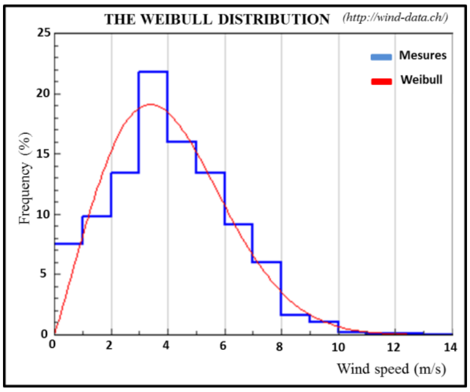


Figure 3. The Weibull distrubition

The frequency of wind velocity is divided by classes as follows (Fig. 3 and Fig. 4):

- The frequency of calm winds is 68%;
- The frequency of strong winds is 32%;

According to the wind rose at the University of Djibouti, prevailing wind direction is from the East with an average of 123 days/month and occurs primarily in winter. The wind rose also shows some contribution to the southerly flow. This analysis can be used to design the building in order to pick up maximum winds. In this study, the wind from the east direction is considered for the airflow simulation.

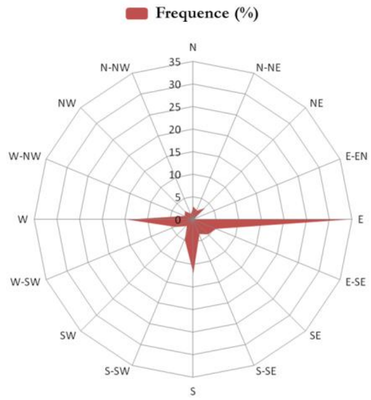


Figure 4. Wind rose at the University of Djibouti 2014-2015

Meteorological data concerning the average of temperatures is compared to the satellites data from the SWERA [5].

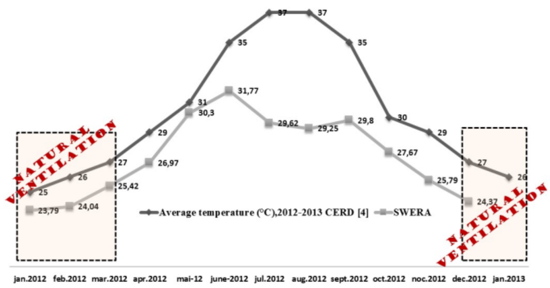


Figure 5. Average temperature (CERD 2012-2013, SWERA)

The most reliable data is obtained through collection of ground-measurement data at a specific site over the course of one year or longer. The data collected at University of Djibouti can be used to calibrate and validate national strategies for natural ventilation in building. Therefore, in winter, the use of natural ventilation is definitely an advantage with an average temperature of 25 ℃. In summer, as shown in Fig. 5, the outside temperature is very high and natural ventilation is to avoid.

Some difference, principally in the summer, was observed between our simulation and SWERA data. The SWERA uses data collected from geostationary satellites as a primary input into their models. The visible channel from geostationary satellites provides information on the reflection earth-atmosphere system. This method is used for estimating data over large geographic areas but impractical for local assessments. This explains the gap observed between the curves.

From the analysis above, air conditioned offices and living spaces are essential at-least in hot climate like Djibouti one. Yet only a part of the population can afford air conditioning which is extremely expensive for two main reasons:

- The high price of electricity
- Particularly bad thermal characteristics of the premises and accommodation.

However in cool season, it should be possible to dispense with cooling by improving the natural ventilation and thermal quality of the buildings.

*B. Principles and Elements of Natural Ventilation*

The wind is a natural phenomenon that involves the flow of a fluid (ρ=1.2 kg/m^3) at a certain velocity. Since the studied structures are found in atmospheric boundary layer, the air flow is turbulent. The wind speed is variable over time it is quite convenient to express it in a reference linked to the mean wind direction by the sum of an average component and fluctuations in the longitudinal, transverse and vertical. In atmospheric boundary layer, the average wind speed profile is not constant. Several models [6], [7] take into account the variation of the average speed based on altitude. The most common are the logarithmic profile as in (1):

$$\boldsymbol{U(z) = k_r \times U_{ref} \ln\left(\frac{z}{z_0}\right)} \quad (1)$$

where

**U(z):** The wind speed at a height z above the ground

$\mathbf{k_{r:}}$ Von Karman constant

$\mathbf{U_{ref:}}$ The wind speed at a reference height

$\mathbf{z_{0:}}$ Aerodynamic roughness length

The airflow simulation, in this work, is then based on the inlet conditions of the computational domain including modelling of flows in the urban boundary layer. Indeed, the computational domain is part of the urban boundary layer and must reproduce at best the soil roughness. Therefore, it was necessary to use local data of the site.

Due to the density and spaces between buildings at University of Djibouti, the wind on the site was considered a class 3 of Eurocode ($\mathbf{z_{0=}}$0.5 m and $k_r$=0.22), regardless of its direction according to the standards NF 1991 action of the wind and National.

The inlet conditions are define via a user define function that ensures the flow dynamics (velocity profile) and considers the turbulent characteristics of the boundary layer with a RANS-k-epsilon (Reynolds-average Navier-Stokes) model.

Natural ventilation is the movement of air through specific openings resulting from the natural forces produced by temperature differences and wind. The ventilation rate depends on the wind speed and direction, design and location of outlet and inlet openings. Natural ventilation differs from mechanical ventilation (air conditioner) in that the latter requires a mechanical energy input to produce the pressure differential necessary to cause air flow. Naturally ventilated buildings depend upon thermal and wind forces. Whereas thermal or buoyancy forces are present during the cooler season, the wind is the main ventilation force in the winter in Djibouti. This project will mainly deal with the wind effect because it is concerned with the optimizing building orientation for better winter ventilation [8]-[10].

The flow of air around a building caused by the wind creates pressure gradients between surfaces i.e transfer of dynamic pressure into static pressure head. It is basically the velocity of the wind which determinates the magnitude of the pressure exerted on the exterior of a building.

It is necessary to confirm that the incoming air could sufficiently ventilate the building. Therefore, CFD simulations [11], [12], provide data on the airflow features of the envelope, leading to better understanding of the ventilation conditions in its interior [13].

## III. Application: Evaluating Natural Ventilation Strategies

*A. CFD Description*

To better meet the objectives of the study, one of the University of Djibouti buildings was selected as shown in Fig. 2. This choice was largely motivated by the existence of weather station which facilitates the collection of the required data. This pioneering work provides an overview of the natural ventilation potential using CFD in order to make a major contribution to the development of energy efficiency in Djibouti.

CFD is a known computational method to study single and multiphase in laminar or turbulent flow. ANSYS Fluent 14.5 software was used in our simulations. The differential expressions of the Navier-Stokes equations for momentum, energy and mass balances were solved by the control volume approach [14].

A CFD problem is typically divided in seven steps:

- Geometry modelling which determines the geometry;
- Grid generation, where the geometry is divided into computational cells;
- Model definition that determines the models for turbulence;
- Properties setting, where the physical properties of the system are specified.
- Boundary and inlet conditions setting, where the initial conditions of the inflow, outflow and the states of the windows are clarified;
- Solution, where the solver, numerical method, transient or steady state and the convergence requirements are determined;
- Post processing, where the results are interpreted and evaluated.

Natural ventilation is more effective when the difference in altitude between the leads of fresh air and extraction is greater. Consequently, a change has been made to the original geometry of the building. To benefit from the pitch generated by the sheds, extraction openings are located in the vertical portion of sheds. Conversely, the supply of fresh air openings is located in the lowest part of the walls [15]-[17].

*B. Analysis and Results*

The wind conditions in the area of building is carefully analysed and consecutive simulations with CFD software made possible to understand the precise effects of natural ventilation.

The simulation is based on hypothesis for which the internal temperature is at 30 ℃. Initially the whole volume of air is at 30 ℃. The external fresh air is taken to 25 ℃.

Diagrams of external and internal airflow simulation studies with CFD software are presented next in a table.

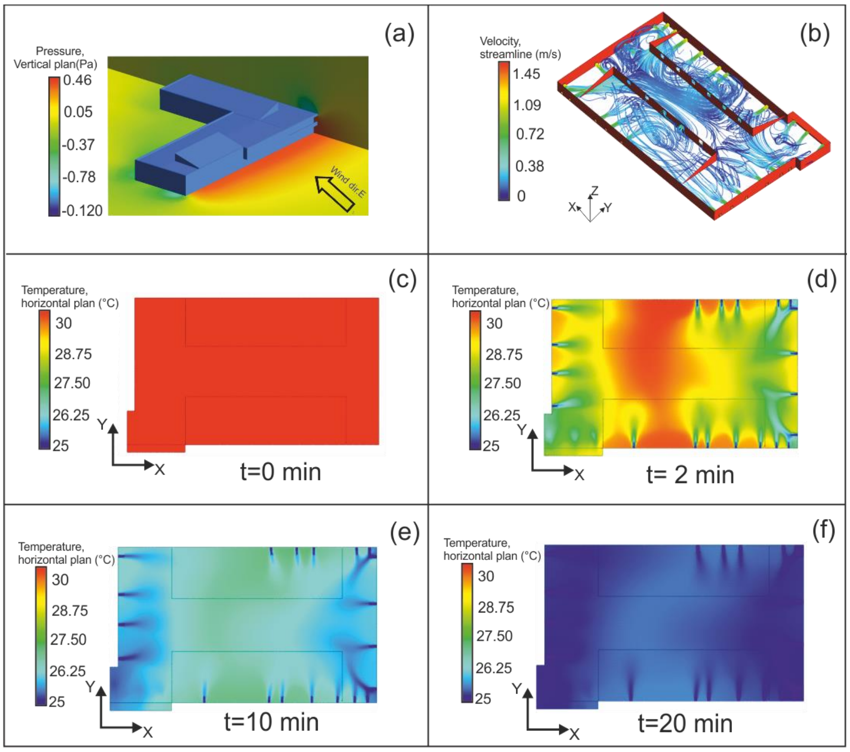


Figure 6. External and internal airflow simulation: (a) Pressure contours on a vertical plan; (b) Velocity streamline of the fresh air; (c)-(e) Temperature on a horizontal plan.

Just like the renewable high potential in energy, Djibouti has a significant potential in natural ventilation. In winter, the use of natural ventilation is definitely an advantage with the rising concerns regarding the cost and environmental impact of energy use. As shown in Fig. 6(a), the airflow simulations revealed pressure differentials between the walls of the building. The wind blows across a building fresh air will rush in the east wall facing the prevailing wind and exit the leeward wall opening to balance and relieve the pressures on the windward and leeward walls. It is thus possible to obtain through ventilation under the outside wind conditions studied.

The diagram of temperature in Fig. 6(c)-Fig. 6(f) show that at t=0 min, the whole volume of air is at 30 ℃. At t=2 min, the fresh air is diffused. It refreshes the air initially present. It is observed indeed that the red area of 30 ℃ greatly reduces. At t=10 min, the fresh air has brought down the temperature on the entire surface. The contours are blue to light green. So the refreshing air is important. And finally at t=20 min, the contours are blue (25 ℃). The entire surface is refreshed. This simulation shows that fresh air take up the building quickly when natural ventilation is active. The temperature of the inside air will be equal to the outdoor temperature.

The recirculation air of interior volume in Fig. 6(b) shows that fresh air circulates throughout the volume. No dead spaces is identified. In addition, the air velocity peaks near the fresh air supply with 5.26 km/h and the mean velocity is at 0.68 km/h. Heat exchange by convection and are promoted by a recirculation of the air in the entire volume. This point refresh the thermal mass as a whole, which contributes to the effectiveness of natural ventilation.

These results help and guide for country like Djibouti to optimize technical and architectural solutions using the maximum of natural potential.

## IV. Conclusions

The variation of ventilation rate in passive cooling on the basis of the local climate at the University of Djibouti permitted to reach very good internal conditions for building in winter. There were some limitations to our study. The study remains theoretical and the results are location dependent. The implications of these data regarding energy are potentially intriguing. To make best of this study, the concept of natural ventilation in hot climate must extended and coupled with the economic and energy consumption parameters. In the current Djiboutian regulation environment and energy economics it is too far to apply the natural ventilation.

We spend 80% to 90% of our time in our home or in an enclosed space. The Bioclimatic design is therefore essential for several reasons:

- Provide thermal comfort and create a feeling of freshness inside buildings.

- Provide the comfort and hygiene of our building. Poor air quality and thus poor ventilation may cause some damages such as headaches, fatigue, and breathing difficulty for occupants.
- Eliminate excess humidity and bring fresh air and thus supply our oxygen needs.
- Reduce the energy consumption of buildings to low levels.

Furthermore the GRE-team is the bearer of a plan under the call for projects launched by the University of Djibouti. This project “Development of a demonstrator of a Passive Building and Energy POSitive” (BPEPOS) incorporates the theme "Renewable Energy" [18]. To act in this field, this study is a first step of the bioclimatic design of the prototype house using CFD software. The originality of this research is that the presented CFD simulations provided a test bed during the design development phase of the house. This prototype house will be in Djibouti, an example of environmentally responsible architecture that points to certain visionary technological possibilities.

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