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# Case study assessment for natural ventilation performance of heritage buildings in the Mediterranean city of Alexandria (Egypt)

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**Abstract.** Historic buildings are an important aspect of any city in their capacity to provide cultural reference points. Demonstrating capacity for better levels of energy efficiency and thermal comfort has become a critical challenge to such buildings' survival. Wind driven natural ventilation in buildings is one way of reducing energy use by dependence on mechanical ventilation. This paper is a case study assessment of a nineteenth-century listed residential building located in the historic business district of the Mediterranean city of Alexandria (Egypt). From an architectural perspective, the European style courtyarded building offers good potential for healthy indoor air replacement, and the Mediterranean climate of the city provides enhanced possibilities for promoting indoor thermal comfort. Yet observation of the building today demonstrates that occupants rely heavily on mechanical ventilation (air conditioning). It is clear that the building's original layout has been modified. In this research, we use 3D RANS CFD simulation to investigate the potential for the original layout of the building to enable natural air flow patterns. Simulations are validated against air speed measurements in parts of the building. The results show a detailed natural ventilation deficiency performance in the case study building as modified today, and indicate potential for future improvement. This investigation can help in the understanding of conservation approaches that not only preserve the building's cultural value but also reclaim its natural ventilation performance.

## 1. Introduction

In seeking to establish the significance of heritage buildings, regarding their architectural, cultural historical and aesthetic values it is necessary to also fully understand the conventional or traditional technologies used for the operation of the building as it was intended to be used.

The conservation process is now considered as both an opportunity to protect heritage buildings, and also to respond to global environmental concerns through a better reading of passive design principles.

Current trends in research on the sustainable conservation of heritage buildings are often focused on the challenges and opportunities of thermally insulating heritage buildings (As they are considered leaky especially in cold climates) [1]. It is, however necessary to study how to target the environmental performance of such buildings in warmer climates.

This research aims to present an assessment of wind driven natural ventilation performance in a typical 19<sup>th</sup> century building in Mediterranean city of Alexandria (Egypt). The selected case study building is a listed building that was designed for passive energy use, yet it is observed that its occupants currently rely on mechanical ventilation (air conditioning). It is assumed that the energy consumption and thermal performance of a heritage building can be improved if it performs as it was originally designed.



Ventilation methods in buildings can play several roles including the enhancement of indoor air quality and thermal comfort in summer. Healthy indoor air movement provides sufficient air velocity to maintain an acceptable level of thermal comfort when local temperature and humidity require so [2]. In Mediterranean climates, natural forces can efficiently provide comfort and energy saving objectives without the need for mechanical energy consumption. For energy and health reasons, mechanical ventilation should be limited to situations when sufficient natural air flow cannot provide human requirements of comfort. [3] [4]

The influence of wind driven ventilation is related to the creation of pressure differentials on the different facades of the building which in turn drives the air movement indoors. [5-7] .

## 2. Description of Case study building

Alexandria is characterized by hot dry summers and mild wet winters. It induces specific energy needs in buildings, air conditioning needs being the most significant. Considering the climate during summer and its consequences in terms of thermal comfort is a characteristically Mediterranean problem [8]. Mean air temperature in the city ranges from 28.5°C in September to 32°C in August. Relative humidity typically ranges from 65% to 92% over the course of the summer months. Typical wind speeds vary from 3.4 m/s (light air to moderate breeze), and rarely exceed 5 m/s (gentle breeze), and the prevailing wind direction is strongly affected by the North-Western direction [9].

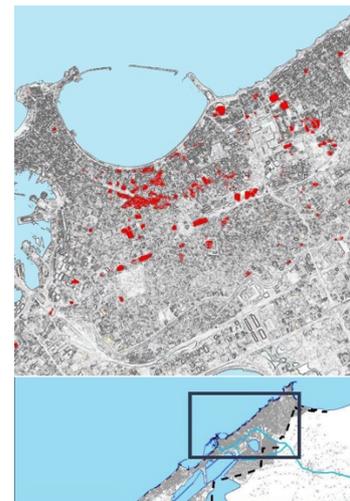
For this purpose, this research is focused on natural ventilation to investigate its potential to improve summer comfort in heritage buildings [10] [11].

The building selected for the study is a listed building which is sought to be a representative sample for the heritage buildings in Alexandria built during the same period and to same architectural style. The building was designed and built with traditional building materials and technologies as a residential four-story building located within the business district of Alexandria.

The eclectic Italian style building located in the heritage district of Alexandria, it is typical of the major part of the city's conservation area fig 1. [12] [13]

The building's design shows sharp juxtaposition to the construction typology of recent multi-story air-conditioned buildings in the city. Its inherent passive design features include large ordered openings, and an atrium and stair well which are thought to have cross ventilation and air buoyancy purposes. Figure 2

The typical floor plan according to the current layout of the building, composed of three flats. In order to analyze the airflow implications of the three different flats' layouts, inner spaces were categorized in a depth map according to their inlet position with the external environment. Where the zone labelled 'S1' has direct openings with the external environment, rooms within the zone denoted 'S2' have no openings to the external environment, by contrast, their openings are located on inner shafts, according to the architectural organization of the flats, the area labelled S2 is currently used to contain the main living spaces. In addition to specifying the auditing points used for physical and CFD results— Figure 3.



**Figure 1.** Heritage building map within the historic centre of Alexandria



Figure 2. Simulated building



Figure 4. Inner openings

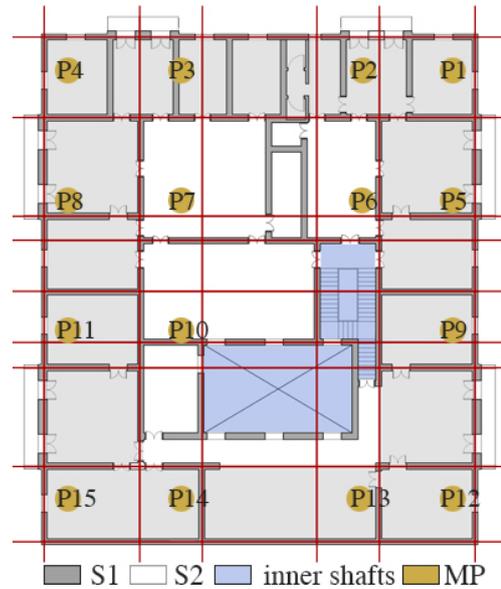


Figure 3. Typical floor plan

The block itself has the dimensions  $L \times W \times H = 34 \times 30 \times 22$  m, consisting of four floors with a footprint area of 1020 m<sup>2</sup>. The building contains a light-well (dimensions = 10.5 x 6 x 22 m). The building envelope is composed of different sized vertical windows with the percentage of opening in relation to inner spaces ranging from 10 to 17 percent. On plan, windows are positioned central to indoor spaces. Indoors all internal doors have high-level openings, yet site survey showed that they are permanently boarded by occupants. Figure 4.

### 3. Case Study Assessment

The assessment was conducted in three parts; (a) a detailed physical monitoring was conducted to measure air speed inside and outside the case study building. (b) Steady RANS CFD (computational fluid dynamics) simulation was conducted for the same building to expand on the measurement’s findings.

#### 3.1. Physical monitoring

Test was conducted using a hotwire anemometer, where air velocity was measured over different periods of time during the day over a period of 1 month of the summer July, averaged over two times a day (10 am, 4 pm) for three days a week (Sunday, Tuesday, Thursday) logged over 30 minutes. The monitoring specified fixed points P1, P2 within the second floor inner space of the case study building same as the simulation, and on the roof to calculate the U and the Uref speeds. Giving an average air velocity for P1, P2 and roof point of 0.59, 0.63 and 4.2 m/s respectively figure 5.

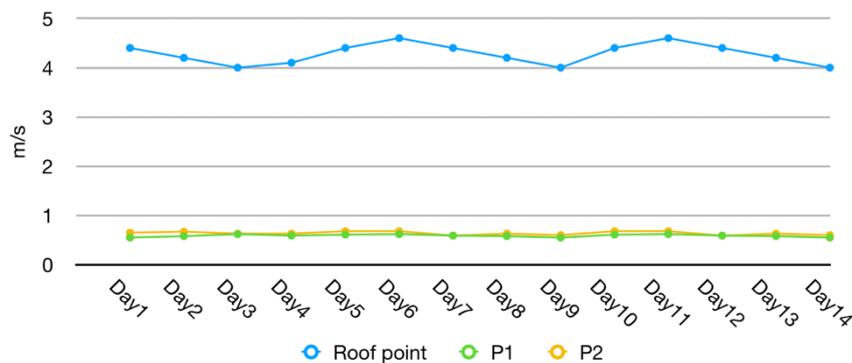
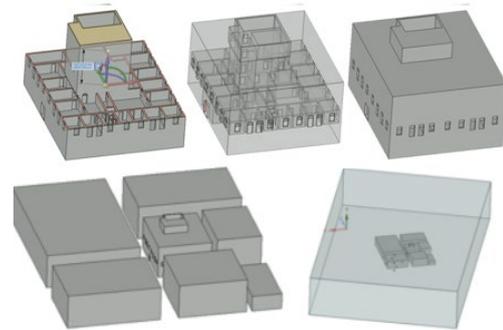


Figure 5. Hotwire anemometer readings (July)

### 3.2. CFD methodology

For the CFD simulation; the commercial numerical simulation code Fluent 18.1 is used to perform the computations for the assessment and evaluation of the air movement patterns in and around the case study building. Although it is recognized that CFD results are subject to uncertainties and approximations, the achievement of consistency is related to the control of a number of input parameters.

**3.2.1. Model, Domain and boundary conditions.** A model for the case study building and the surrounding building blocks were constructed. All surrounding blocks were modelled as solid blocks except for the monitored building which was detailed. Figure 6 shows that only floor two of the building was modelled including the openings and interior partitions/opening. All other floors of the case study building were modelled as solid blocks. The dimensions of the solution domain was set according to [14] dimensions of H inlet direction 5 H from the outflow direction and height, where H is the model height (560 x 365 x 100 m). The fluid was set for air at constant density (1.19 kg/m<sup>3</sup>) and viscosity (1.79e-05kg/m-s). the operating pressure conditions of the domain were kept at 101325Pa, the gravitational acceleration at -9.81m/s<sup>2</sup>.

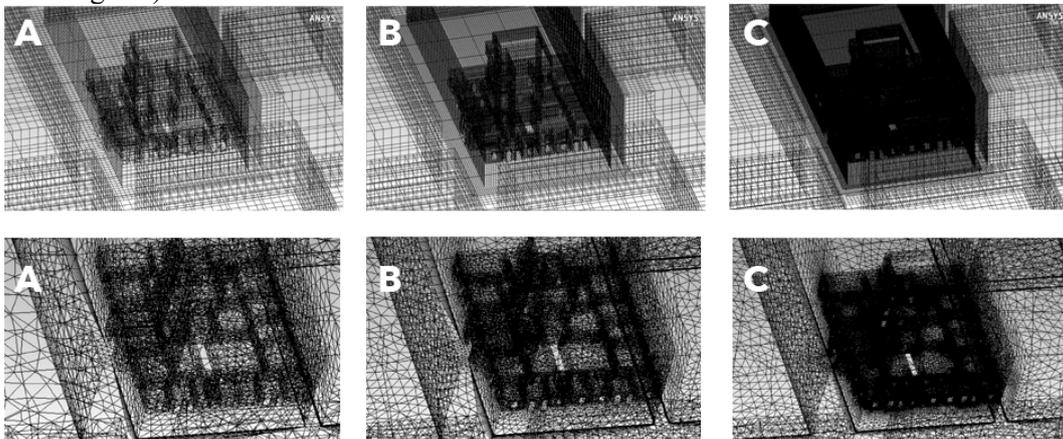


**Figure 6.** CFD modelling

The boundary types used are velocity inlet, interface, non-slip walls, and outflow boundaries [15]. The upstream boundary was set at 'velocity inlet', an ABL profile was imposed. Velocity was corrected to allow for terrain as per equation 1 [5].

$$U = U_{met} \cdot K \cdot z^a \quad (1)$$

In which  $U_{met}$  is the velocity of wind from the meteorological data,  $K$  and  $a$  are the coefficients of the terrain. The variables  $K$  and  $a$  were assigned the values of 0.21 and 0.68 for the dense urban site. Free wind at height 30m was set to 2.05 m/s after correction flowing from the north south direction (incident angle = 22 degrees).



**Figure 7.** Different mesh refinement for hexagonal (above) and tetrahedral (below) mesh type applied

**3.2.2. Mesh structure and solving parameters.** In order to achieve reliable results in the CFD, an initial group of CFD simulations were carried out and results were compared to field measurements collected at the locations P1, P2, P3. The aim was to assess the impact of mesh structure on the contour plot output and either tetrahedral or hexagonal meshes, coarseness/ refinement level influence on the results were utilized and all the CFD domains have been designed for minimum blockage, with an average value of 3.0% and a maximum of 4.6%.

Initial mesh (A) is too coarse and results are not accurate on both grid options (hexagonal, tetrahedral grids). After the first adaptation (B) the uneven cell distribution in the tetrahedral mesh solution becomes more apparent, impacting on the pressure distribution and later mesh refinement (C)

doesn't significantly improve the results, though increased simulation computer time. A sequence of two refinements proved to be enough to allow results become independent of mesh size.

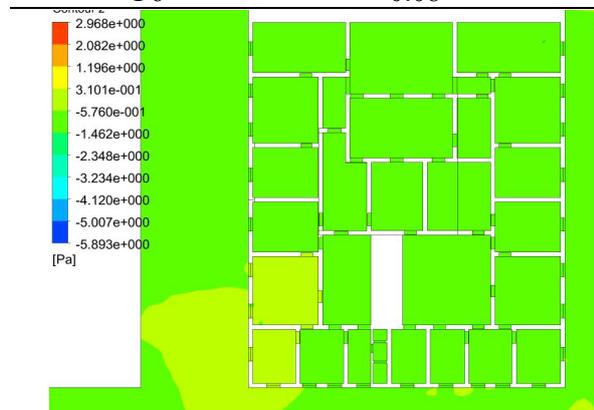
The solution solver was set as pressure based and was of implicit mode for steady-time problems. The turbulent viscosity model adopted for all the CFD simulations was K- $\epsilon$  RANS standard, in which average speed and turbulent intensity profiles were used.

#### 4. Results

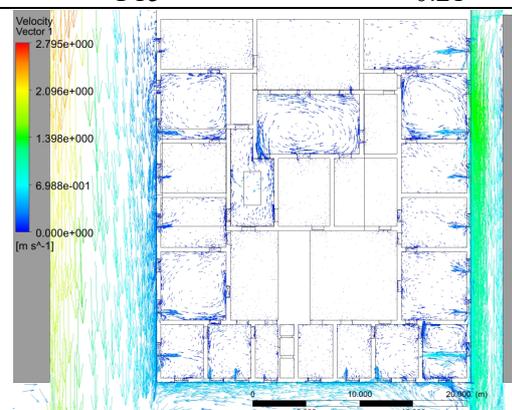
of CFD simulations was carried out and the results where compared to the actual monitoring data gathered from P1, P2 and roof point monitor table 3, by comparing the results of specified points on both simulation and monitoring with a factor error of 6 percent. Table 1 demonstrates the air flow at the different monitoring points specified in figure 3 attached with the physical monitoring performed by the hotwire anemometer (roof point, P1, P2) for results comparison and validation.

**Table 1.** monitoring points velocity acquired from the CFD model

Monitoring point	Airflow velocity m/s		Monitoring point	Airflow velocity (simulation) m/s
	(simulation)	actual		
Roof point	4.44	4.20	P7	0.03
P1	0.56	0.59	P8	0.21
P2	0.64	0.63	P9	0.17
P3	0.31		P12	0.09
P4	0.38		P13	0.01
P5	0.22		P14	0.08
P6	0.08		P15	0.21



**Figure 8.** pressure distribution inside the building



**Figure 9.** airflow pattern inside the building

The routes are created by the parallel nature of the arrangement of the blocks in the site, which in turn form straight higher speed streamlines for the airflow that penetrates the site between the rows of the blocks.

The maximum internal air speed reached is 0.64 m/s and an average internal speed of 0.28 m/s, which is lower than the intended benchmarks for passive cooling by natural ventilation, which was specified by Giovoni comfort ventilation is applicable, at any region 1.5-2.0 m/s when the outdoor maximum temperature doesn't exceed 32 °C [16]. According to the depth map categorization described in section 2, S1 spaces with direct openings with the external environment are single-side-ventilated with a maximum air speed reached is 0.64 m/s (P2) and an average internal speed of 0.28 m/s, which is lower than the intended benchmarks for comfort ventilation. While S2 spaces which act as the main living spaces don't have sufficient airflow with the velocity there being lower than 0.1 m/s (P6, P7, P10, P13, and P14) -table 1.

The occupant's changes in the original building design affected the different opposite and adjacent openings layout minimizing the pressure difference Figure 4 and affecting the air flow pattern inside the building.

The pressure difference across the internal layout is very low between the building's front and rear of 0.65 and 0.24-figure 8, leading to low airflow speed inside the building.

The airflow behavior demonstrated in figure 9 shows the inner spaces are depending on single side ventilation, where each space is isolated from the others and the internal inner shaft.

## 5. Conclusion

This paper provides a clear demonstration for the current natural ventilation performance for a typical heritage building located in the city of Alexandria. The principles of environmental design for these heritage buildings typology have indicated the potentialities for comfort ventilation in the case study building; the combined effect of the surrounding environment, inner space height, inner shafts and 17 % opening ratio.

The main aim is to reduce cooling loads and energy consumption in summer. However, in modelling and measuring the current occupation of the building the results obtained demonstrate unacceptable conditions for indoor comfort. This failure is evidently due to a combination of factors including occupants' behavior and modifications to the functional environmental principles of the building's original design. Alterations include the blockage of upper openings which have negatively affected the induction of cross ventilation and the stack effect throughout the building. Results show a detailed example of how a deficiency of performance in natural ventilation is created in the case study building.

This paper shows that the current user alterations to the building internal layout has led to poor U/Uref. This is an ongoing research, this paper begins an investigation into the case study building and future research is set to conduct a detailed analysis on the reasons behind the simulated natural ventilation deficiencies, and alternatives will be explored to assess how indoor air flow could be improved.

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