The assessment of natural ventilation performance for thermal comfort in educational space: a case study of design studio in the AAST-Alexandria

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Abstract. Through the last decades, the impact of thermal comfort on the working performance of users and occupants of an indoor space has been a concern. Research papers concluded that natural ventilation quality directly impacts the levels of thermal comfort. Natural ventilation must be put into account during the design process in order to improve the inhabitant's efficiency and productivity. One example of daily long-term occupancy spaces is educational facilities. Many individuals spend long time receiving a considerable amount of knowledge and it takes additional time to apply this knowledge thus, this research is concerned with user's level of thermal comfort in design studios of educational facilities. The natural ventilation quality in spaces is affected by a number of parameters including orientation, opening design and many other factors. This research aims to investigate the conscious manipulation of space physical parameters and its impact on natural ventilation performance which subsequently affects thermal comfort of users. The current research uses inductive methods to define natural ventilation design considerations, which are used in a field study in a studio in the university building in Alexandria (AAST) to evaluate natural ventilation performance through analysing and comparing the current case to the developed framework. Also, the study conducts a computational fluid dynamics simulation. Results have proved that natural ventilation performance is successful by only 50% from the natural ventilation design framework, these results are supported by CFD simulation.

1. Introduction

Education is one of the major sectors of national development [1]. People dedicate their time in educational buildings which must be constructed to shelter inhabitants against any unfavourable outside conditions and to offer them a healthy, comfortable and sustainable environment. Learning and Studying is a very concentrated and complex procedure which requires a lot of mental work. Students spend major time in educational buildings; consequently, thermal comfort is a huge problem in the developed countries and more evident in developing countries. According to several studies people devote their time in indoor environments with an average percentage of 80–90% [2]. Therefore, thermal comfort and air quality are vital factors to control the quality of indoor air environment. A previous study showed that indoor air quality (IAQ), ventilation and building-related health problems in schools are related to insufficient ventilation in many classrooms and were found to be the main cause of health symptoms [3]. When it comes to design of educational buildings, architects most commonly rely on fulfilling the functional requirements. However, for a sustainable educational environment, natural ventilation design measures must be taken into account. A healthy and comfortable indoor condition heavily depends on the design and operation of the natural ventilation system which comply on international standards.
2. Natural Ventilation and Thermal Comfort

Thermal comfort has been always linked with natural ventilation, as, it is now concerned with reducing the dependence on mechanical systems and depending more on passive strategies of natural ventilation [4]. Same reference said “utilizing natural ventilation can achieve a comfortable indoor thermal environment while reducing building energy consumption”. Based on the body of research and the references concerned with human thermal comfort; natural ventilation induces air velocity that affects the users’ perception of thermal comfort. Sensation of cooling can be reached by increasing air velocity to certain limits and that is due to the decrease in the rate of evaporation from the surface of the skin [5]. Air velocity, along with air flow patterns, are associated with air movement which is promoted by ventilation [6]. Ventilation is found to improve indoor thermal comfort [7]. Therefore, this paper will focus on natural ventilation design measures which have an impact on airflow and its relation to thermal comfort in a private educational building in Alexandria, Egypt. The research will use CFD “computational fluid dynamics” analysis to evaluate the natural ventilation potential in educational building.

3. Designing with Natural Ventilation

Designing with natural ventilation consists of two stages which are conceptual process and design consideration process respectively. Conceptual process presents the related science to natural ventilation that is categorized to natural driving forces, ventilation strategies and ventilation principle [16]. This paper will focus on design considerations that are involved with architectural aspects which are sorted into two main factors which are site characteristics and building characteristics.

3.1. Assessment Criteria Numbering

Preparation for the case study assessment through the evaluation of Cross ventilation, and the design measures that support it.

3.1.1 Ventilation principle. The study will focus on the cross-ventilation principle which is a two-sided control of air flow method that is applied to the room. The main driving force is the wind-induced pressure difference between the face-to-face openings as seen in [8]. Circulation of air flow rate for cross ventilation equation is [9]:

\[ Q = C_d x A_w x (2\Delta P/\rho)^{0.5} \]  

where Q is the air flow rate, C_d is the coefficient of opening 0.6, pressure coefficient which differs according to building form, A_w is the average window area, \( \Delta P \) is the pressure difference in Pa Where \( \Delta C P = (0.5 \times C_d \times \rho \times V^2)/\rho \), \( \rho \) is the air density and \( V^2 \) is the air velocity.

Architectural Design Considerations

Natural ventilation design reviews the architectural design considerations and their parameters influencing air movement in and around the buildings. The following summary is applicable for moderate climate only.

- Macro level:

The macro level design is linked with site characteristics and design considerations for natural ventilation are summarized below in (Figure 1). Site landform, heat sinks urban form and streets design are the site characteristics that affect natural ventilation in a certain fashion. Concerning site landform, it was found that in moderate climates, the best location varies between the middle and upper part of the slope to deliver better exposure of the sun and wind as well as receive protection from the high wind speeds at the peak [10]. The design building on site is near heat sinks, for instance the large water bodies (sea, lake, nile, etc.) as they create a cool breeze and offer a cooling sensation through evaporation. Site layout and street design are significant as they work together to give full protection from wind or...
in wind induced ventilation. Dispersed and clustered urban form are ideal to natural ventilation as they provide better potential for air movement between the buildings and the wind force (Figure 1).

- Micro level:

To Design a building with optimum natural ventilation, several factors related to the airflow movement around and within the building into consideration. These factors can be assembled based on their relation to Building mass, Building Form and Shape, building orientation and building envelope. The aspect ratio volume, area, and dimensions are the building mass configurations that have a significant role in managing airflow. Thus, they influence natural ventilation potentials. Building Aspect ratio, (Length/Height) should be kept low to achieve a large decrease in pressure at the middle of the windward façade and a suction aftereffect at the boundaries. To mention that, “if the volume is the same by either a small number of large volumes or many small volumes. Different arrangements of these volumes could present variance in air flow pattern”. [10]. According to building forms such as atriums, courtyards, etc. Each one has a certain principle. Concerning the building shape, it was found that irregular and corrugated shapes are ideal for moderate climate as they give larger surface areas and better ventilation [11]. The building should be oriented 45° towards wind direction to enhance air flow entering the room. The building envelope air inlet area should be around 20% of the floor area to achieve an acceptable comfort level and the total inlet area should be 15-20% of the façade area (Figure 1).

![Figure 1. Technical guideline for macro& micro level design in moderate climate (researcher, 2018)](image)

4. Case study

A case study is conducted in an architectural engineering and environmental design department, AAST, Alexandria, Egypt, in order to assess natural ventilation potential in studio hall, room 288 (Figure 2).

4.1. Architectural Design Considerations Assessment

In terms of the landform of the case study site, it is flat with no vital difference in levels. Concerning heat sinks; they are found near the site within a radius of ranging from 1 to 1.8 Km. Thus, the site is in the active zone of the sea breeze phenomena due to the pressure of heat sinks with an average radius of 1.4 km (Figure 2). It is believed that the compact urban fabric site layout is dense, it consists of high rise, medium rise and low-rise detached buildings with relatively minimal distances in between them. This leads to poor air circulation between buildings; hence it will not give the best potential for ventilation. In terms of Street design there are no street canyons on the site (street canyons are streets flanked by continuous lines of buildings) and no urban configuration in the site is present as well (figure 2).

![Figure 2. shows macro and micro analysis on case study building by (researcher, 2018)](image)
Concerning micro level the building is relatively wide deep mass along the wind direction and low buildings are built on the site with low to medium area density with a dimension of L= 162m, W= 93 m and H= 19 m and a L/W ratio of 1.7 as previously shown in chapter 3. L/W must be kept low to maintain a strategic distance in pressure at the centre of the windward façade with a suction impact at boundaries. The building is formed of six identical square blocks that consists of 4 floors high blocks and 1 rectangular block having 5 floors high all connected with a total footprint area of 7966 m² and a volume of 151368 m³. Area density is ab/as= 0.32 (Figure 3).

Each of six square blocks have a building form atrium with dimensions of 10 m*10 m which allows access for daylight and air thus, increasing the potential of using wind and stack driven natural ventilation within their buildings. In terms of shape the building form is defined as an irregular shape that resulted from a number of connected squares and a rectangle that can provide large surface area and better potential for natural ventilation (Figure 3). In terms of building orientation, the whole building is oriented to the north-west while the architecture block is oriented south west with an angle of 90o clockwise from the prevailing wind direction which is slightly connected to the building orientation design measure in the micro-level category. Not to mention that, the blocks have the same rhythm in elevations, thus the architectural department block will be occupied to measure the total façade area and assess building inlet and outlet dimensions. In the architectural department block, most of the rooms are cross ventilated except the toilet and service zone which are single sided. In the studio, ratio of area of the inlet window over area of floor area was found to be 14 % (area of the inlet window 49.4m² and area of the studio 352m²), (Figure 3). While total inlet area is 39% from total facade area. The size of openings for best ventilation performance was reported in previous studies to be 20% of the served floor area to achieve acceptable comfort level through ventilation [10].

4.2. CFD simulation
Cfd is known as computational fluid dynamics which is used in many approaches for natural ventilation as the uncertainty of the pressure coefficient for wind-driven flow calculations, also it helps in the measuring the exact values of air supply and extract openings (dependent on wind direction, turbulence, temperature difference, etc.). To add more, Cfd calculates the different wind directions as classical methods cannot accurately assess the effect of wind direction. Besides, technologies can be employed to improve the relations between a building and the other aspects such as the project site, surrounding buildings, prevailing wind direction and building clusters, hence to increasing natural resources, enhance a better potential in natural ventilation conditions and ultimately generate an outdoor wind environment that is comfortable and safe [9]. A CFD simulation software ANSYS/Fluent 19® is used to conduct the
analysis for evaluating the layout of the engineering building to be constructed. The drawing considers
the environmental wind flow and pattern distribution over the architectural block. CFD is used to also
velocity and its results on air movement patterns in and around the block assuming the is velocity is
4m/s. Thus, permits in knowing the significance of the airflow contour and assists in justifying some
monitoring consequences. It is clearly seen from (figure 5, (a)) that it has a random form of a low-
pressure distribution which in turn forms low air flow patterns around and inside the whole building.
Even Blocks A, B, C and D which are oriented to the wind direction have a low-pressure distribution
from (figure 5, (a)). Building G showed the lowest pressure distribution. The architecture studio has a
window inlet area of 9.36 m² and velocity at the mid of the inlet opening was found to be 0.92 m/s which
was taken from the CFD results consequently, show that the air flow rate is 8.61m³/s using equation (1)
and the air change rate using equation (2) is 21.9 ACH.

\[
ACH = \frac{Q \times 3600}{V}
\]

(2)
Where ACH is the air change rate per hour, Q is the air flow rate and v are the volume of the rooms.
Inhabitants can have an ACH starting from 5 however, they will not feel thermally satisfied. For an ideal
air quality and to achieve thermal satisfaction, the room should have between 40 to 50 air change rates
while for a good air quality internally 15ACH [12].

4.2.1 Manipulating parameters: Comparative analysis. As stated previously; the case study’s analysis
met only 50% from the design framework, consequently, in this section, specific parameters will be
under comparison to test its impact on ventilation performance, mainly; the atrium void, the building
envelope inlet area as well as the building’s orientation in respect to wind direction. Computational fluid
dynamics (CFD) simulation software will be used in simulating those alterations and finding the air
change rate aiming for a better sustainable and comfortable environment.

- Case 3 (22% building envelope) resulted in lower wind velocity value (0.75m/s) than case 1 (atrium + 14% building
  envelope (original case))(0.92m/s) and case 2 (court + 14% building envelope) resulted in (0.95m/s), yet it achieved higher ACH value (59.8) than both case 1 ACH(21.9) and case 2 (Figure 5). It is believed that case 3 despite the low wind velocity (0.75m/s) had an adequate ACH(59.8) value because its parameters met the conditions of the framework conducted previously more than cases 1 and 2 that had higher wind velocity.
- Case 4 (court + 22.2% building envelope) had the highest wind velocity value (1.2 m/s) that resulted in the highest ACH value (95) yet concerning the thermal comfort requirements. In this case the ACH value is higher than the adequate range which is believed to cause thermal
discomfort. In contrary to Case 3 that had lower value of ACH, yet it falls in the adequate range that leads to comfort. The only difference between both cases is that case 3 has an atrium, while case 4 has an open court. Case 6 (45 degrees orientation + atrium case and inlet surface area 14%) had lower ACH value (17.9) than case 5(original case of the building) ACH(22) although it met the angle of wind direction 45 degree from the framework. Although case 6 had the adequate angle of wind direction, it had the lower ACH and air velocity as it is a non-stand-alone building that is attached to other masses that affects the simulation results (Figure 5).

5. Conclusion
The case study was performed in AAST, Alexandria, Egypt in terms of classifying the design measures that can affect natural ventilation performance and air movement. This study was conducted on two phases: assessment of the framework and CFD simulation. The analysis was based on the macro and micro level design assessment which stated that the results of the case study analysis concludes that 50% were successful from the design framework. CFD verified the results of the framework due to the presence of low velocity and random pressure difference along the building. Air flow rate was found to have a good potential but air change rate (ACH) is low by comparing the ideal standard in order to achieve cooling effect. This leads to low chances in achieving thermal comfort. As a conclusion, assessment framework was applied on the case study of AAST and results was relatively poor according to framework indicating that the ventilation is not optimum. Then, a comparative analysis between different cases with manipulated parameters was conducted to investigate a better set up for enhanced natural ventilation quality than the one in the original case of the case study, which, will initially lead to better thermal comfort. After conducting simulations and calculations for the previously stated 6 cases the following was deducted: The higher ACH of case 3 with lower wind velocity than case 1 and 2, shows that manipulating the parameters regarding framework mentioned previously will enhance the natural ventilation quality. The space location in regard to the cluster of buildings attached to it may lead to variation in simulation results that can contradict with the results of the assessment of the framework. In general, consciously manipulating the parameters of the spaces will enhance the natural ventilation quality which leads to better thermal comfort.

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