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This paper is part of the Proceedings of the 6th International Conference on Harmonisation between Architecture and Nature (ARC 2016)
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The assessment of natural ventilation potential in an affordable housing compound in Alexandria, Egypt

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Abstract

Affordable housing in Egypt is one of the critical policy means to control the housing market. It provides subsidised housing for newlyweds and low-income groups. For obvious and financial reasons, affordable housing sites are being developed for intensive use and high population densities. At the same time, the Mediterranean City of Alexandria has a sustained North–West wind that positively promotes natural ventilation probabilities.

With the purpose of development, affordability, running cost savings, and thermal and health targets, we enquire about the influence of intensive site use and urban configuration of an affordable housing compound in Alexandria on the natural ventilation potential? This is especially important when, paradoxically, affordable housing compounds' inhabitants in the city often use mechanical ventilation and complain about indoor overheating. In this paper, we study the challenge of assessing natural ventilation provision and potential in affordable housing buildings and its relationship to life cycle cost. Methods include inductive and deductive techniques to define the natural ventilation design rules and guidelines, which are then used to evaluate an existing case of affordable housing for young people in Alexandria. Also, a CFD package is used to simulate the air flow patterns developing in response to site organisation and the layout of buildings.

The study shows that excessive population cramming in the case study site, comes at the cost of poor pressure distribution, hence there is diminished natural ventilation potential, and imprudent energy use and operational costs.
Keywords: natural ventilation, affordable housing, high density, Alexandria, cost saving.

1 Introduction

Affordable housing in Egypt is one of the critical policy means to control the housing market, and provide subsidised housing for newlyweds and low-income groups. In a recent article [1], the Minister of Housing, Utilities and New Urban Communities states that in 2016 they are providing about 40,000 low-income housing units. Also in [2] the same ministry is targeting a new national goal of building a total of 500,000 low-income housing of different types and sizes. With a such large demand on subsidised accommodation for low-income groups, and with increasing land prices, current practices in the city of Alexandria are observed to show high land utility and sharp built-up density to provide housing compounds for a large number of disadvantaged families in as small a land area as possible.

It is important then to enquire about the environmental consequences of this form of site development. In this research, we investigate whether the upfront cost savings for creating a crammed housing complex can provide sufficient levels of natural ventilation? We also explore the operational ventilation cost implications for this urban form.

Bradshaw *et al.* [3] have shown that the goals of environmentally responsible buildings and affordable housing overlap to a large degree. As the building efficiency improves, the operating costs are reduced providing affordable living conditions for the compound future inhabitants. Environmental design is known to provide a healthier indoor environment. This leads to improved quality of life which is not exclusive to the rich [4].

This paper evaluates the natural ventilation potential in an existing affordable housing compound in the Mediterranean City of Alexandria. We assess the case study complex for comfort ventilation strategies through single sided ventilation. The methodology includes a theoretical assessment of the building's design as well as the site layout, and CFD simulations for air flow visualisation.

2 LCC and natural ventilation

Life cycle cost (LCC) is the assessment of financial viability through the evaluation of costs and savings across a building's entire lifecycle. Optimising the balance between construction and long-term operational costs. For example, the use of energy efficient design solutions helps provide best assets value for the owners and users. LCC according to Skanska [5] is a necessary tool to achieve and help communicate these shared value enhancements. Natural ventilation has an important role in reducing cost across specific phases of the building lifecycle. Successful natural ventilation strategies promote cooler building, thus reducing the use of mechanical ventilation which helps reduce capital costs, and hence reduce the operational and maintenance costs [6]. For this, the consideration of natural ventilation requirements in affordable housing is important in countries that face an annual increase in electricity costs. An example of such case can be seen in Egypt. According to the Egyptian Government [7], the cost of operating mechanical ventilation for 50KW.h/month or less is 0.075EGP/KW.h. For those who consume more than 200KW.h/month, electricity cost ranges from 0.16EGP/KW.h to 0.24EGP/KW.h.

3 Design for natural ventilation

The design for natural ventilation is classified into four essential aspects according to authors [8, 9]. First, driving forces and this could be achieved either through wind forces (pressure difference) or buoyancy (temperature differential). Second, ventilation principles' utilisation with the driving forces. These principles are single sided, cross and stack ventilation. Third; the design aspects where it explains the different rules of designing with natural ventilation on both site and building. Fourth, ventilation strategies as they are classified to comfort ventilation, night cooling, and evaporative cooling, where each is designed to suit certain climatic conditions.

3.1 Assessment criteria

In this section, we prepare for the case study assessment through the evaluation of single sided ventilation, and the design aspects that support it.

3.1.1 Single-sided ventilation

Single-side ventilation is an air flow control technique through one or more openings in the same wall. The airflow in the single side ventilation is a wind driven airflow where pressure difference is created around the building according to natural wind incident angel as defined by [8, 10] (fig. 1). The calculation methods of wind-induced single sided ventilation are stated in [9] (eqn (1)).

$$Q=0.025AV \tag{1}$$

where A is the area of opening and V is wind velocity.

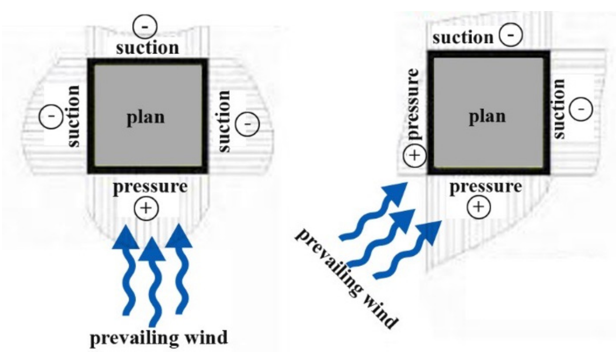


Figure 1: Changes in pressure created on building facade due to wind incident angles [9].

3.1.2 Design aspects

Design aspects are classified to site characteristics and building characteristics. Each of the site and building characteristics has different parameters that have been studied. Recommendations according to [9, 11] were concluded to achieve a successful naturally ventilated building/complex.

3.1.2.1 Site characteristics According to Brown and Dekay [12] and Osman [9] site landform, heat sinks urban form and streets design are the site criteria that influence the air flow. Each of these variables promotes and affects natural ventilation in a specific way. Flat sites are ideal in terms of air flow, yet also slopped sites could be utilised for natural ventilation. In such case, middle and upper part of the slope perform best.

Heat sinks such as waterfront zones, and green areas, provide a good opportunity for natural ventilation and locating the building near a heat sink provides better access to cold breeze.

The urban form is the most important factor to affect the air flow in and around the building. Disperse and clustered urban form are ideal to natural ventilation as they provide better contact between the buildings and the wind force. Canyons, on the other hand, are the worst in terms of natural ventilation in buildings (as shown in table 1).

Table 1: Natural ventilation design characteristics in site.

<table>
<tr><th colspan="2">Site characteristics</th><th>Studied parameters</th><th>Recommendations for Mediterranean climates</th></tr>
<tr><td colspan="2">Site landform</td><td>- Flat site, sloping site, undulating site</td><td>The best location is in the middle to upper part of the slope.</td></tr>
<tr><td colspan="2">Availability of heat sinks</td><td>- Near them or away from them</td><td>Near them to benefit from the cold breeze.</td></tr>
<tr><td colspan="2">Urban form</td><td>- Compact form
- Disperse form
- Clustered form
- Combined form</td><td>Disperse form used when ventilation has priority and clustered form used when shading has priority.</td></tr>
<tr><td rowspan="2">Street design</td><td>Street orientation</td><td>- Normal
- Oblique
- Parallel to the wind</td><td>20° to 30° oblique to wind direction.</td></tr>
<tr><td>Canyon geometry</td><td>- H/W < 0.3
- 0.3 < H/W < 0.65
- H/W =1
- H/W = 1.5</td><td>H/W ratio of 0.5 to 0.44</td></tr>
</table>

3.1.2.2 Building characteristics According to [9, 11] buildings' arrangement, mass, form, and shape, orientation and envelope are the design measures of building characteristics that control the natural ventilation performance. Arranging the buildings around a central open space was found to allow the best airflow when open towards wind direction. Building mass depends on aspect ratio and area density where plan should be narrow depth with low aspect ratio (l/w) and buildings should be wide and low with low to medium area density. There are several building forms as atriums, courtyards and pavilion block each server different purposes that vary between stack ventilation, energy performance, and airflow according to building height. As for building shapes they vary between Rectangular, U, L, T-shaped, square, irregular or corrugated shapes and it was found that irregular and corrugated shapes had best airflow as they build difference in pressure along building façade. The building should be oriented 45° towards wind direction to allow higher internal air speed. The building envelope area air inlets should be 20% of the floor area and total inlet area of openings should be 15–20% of the façade area (as shown in table 2).

4 Case study assessment

The case study complex building sits in the city of Alexandria, Egypt. Alexandria is a Mediterranean city, where the prevailing north wind, blowing across the Mediterranean, gives Alexandria a markedly different climate from that of the desert hinterland. The summers are relatively temperate, although humidity can build up in July and in August, the hottest month when the average temperature reaches 31°C. Winters are cool and invariably marked by a series of violent storms that can bring torrential rain and even hail. The mean daily temperature in January, which is the coldest month, is 18°C [13].

While the city's urban shape is linear with immediate proximity to the Mediterranean Sea, the case study complex's location is in the heart of the city about 1.50 Km away from the waterfront (fig. 2).

The site is a complex of 9 building blocks each 13 storeys high, that form an E shape and 3 separate rectangular blocks (fig. 3(a)). The building height is 34.45m as the height of 1 floor is 2.65m, the length of the building is 38m and width 25m (fig. 3(b)). The compound has two residential flat prototypes; A and B with surface areas $78m^2$ and $113m^2$ respectively (fig. 4). Each building has 11 flats, 10 flats type A and 1 flat type B. In prototype A, there are 2 bedrooms with area $10.5m^2$, living space with area $30m^2$, 1 bathroom, and 1 kitchen. Type B has 3 bedrooms with area $12m^2$, living space area $30m^2$, 2 bathrooms, and 1 kitchen.

Table 2: Natural ventilation design characteristics in building.

Building characteristics	Studied parameters	Recommendations for Mediterranean climates
Building arrangement	- Arranging small group of buildings	Arranging the buildings around a central space opened to wind direction
Building mass	- Plan aspect ratio (length/width) - Area density	- Narrow depth plan along with wind direction - Low (length/width) ratio - Relatively wide and low buildings built on a site with low to medium area density
Building form and shape	Form: - Atrium - Courtyard - Modern pavilion block	- Atrium: good for stack ventilation (low to medium rise buildings) Open courtyards are more energy efficient in smaller building heights, while, atrium buildings performed better at high building heights. (low to medium rise buildings) - Courtyard aspect ratio (0.3 < H/W <1) and (H/W= 0.25) - Porous pavilion block with 50% voids (high rise buildings).
	Shape: - Rectangular, U, L, T, square, irregular or corrugated shapes	- Irregular or corrugated shapes - Rectangular (centralising long façade 20-30° towards wind direction) - L-shape works as an air dam (when there is no known wind direction) - Square shape (suitable when providing openings in windward and leeward sides)
Building orientation	- 30° to 120	45°
Building envelope	Opening: - size - Position - Number	- Air inlet area = 20% of the floor area - Between 15% and 20% of façade area - For higher maximum internal air speed (Ao/Ai = 3) with oblique wind direction 45°. - Providing single or more openings in different or same external walls

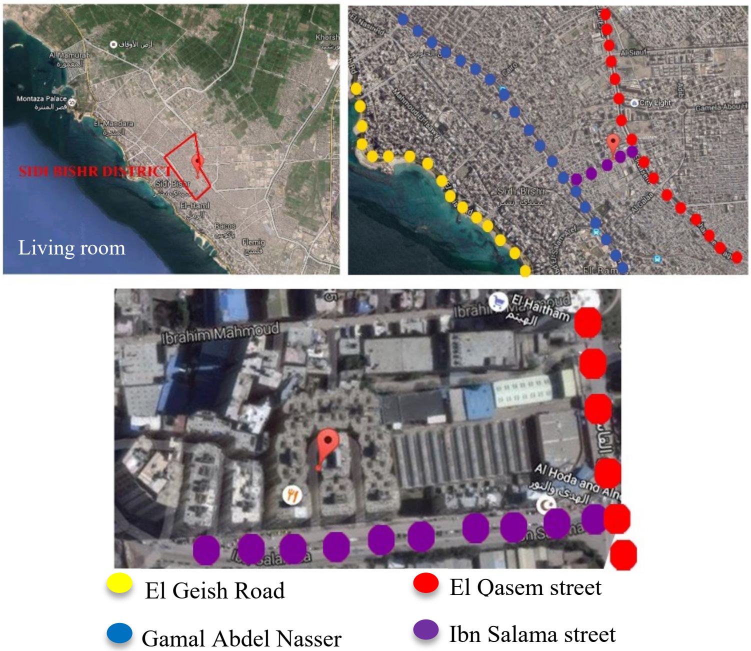


Figure 2: Case study location [14].

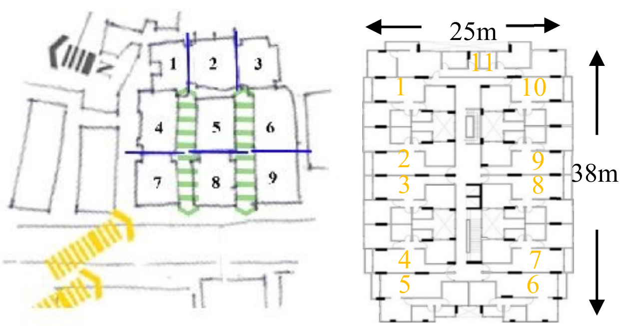
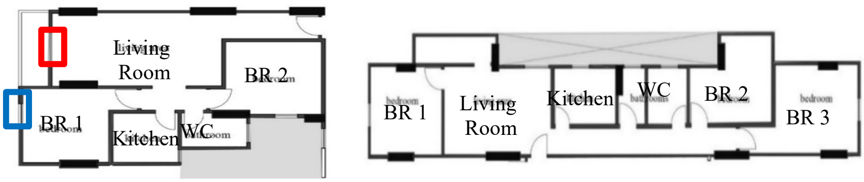


Figure 3: Complex arrangement (a), building dimensions and number of flats (b).

4.1 Natural ventilation analysis

The only possible mean of natural ventilation in the residential units in the complex is single sided. This is because, inside the large building blocks, there are small residential flats with rooms that connect to the outdoor through only single windows (fig. 4).



(a) (b)

Figure 4: Apartment type A (a), and apartment type B (b).

To calculate the natural ventilation air flow rate due to single sided ventilation in the case study complex, we isolate and study a typical residential unit type A. The living area has a window (W1) with Area 2.3 m², while each bedroom has only one window (W2) with an area 0.76 m² (fig. 4). Assuming that we use the prevailing wind velocity of 4m/s, and eqn (1), we therefor define the air flow rate for W1 and W2 as 0.23m³/s and 0.076m³/s respectively. The calculated air flow rates indicate that the air change rates which is calculated using eqn (2) are 10.4 ACH, and 9.8 ACH respectively.

$$ACH = Q \times 3600/ v \qquad (2)$$

where ACH is the air change rate per hour, Q is the air flow rate and v is the rooms' volume.

4.1.1 Design aspects

To evaluate the design aspects, we analyse both the site and building characteristics as follows

4.1.1.1 Site characteristics in terms of site landform, the compound is located in a relatively flat land plot with no significant difference in levels. The site, on the other hand, is located about 1.50 KMs away from the closest heat sink (Mediterranean Sea). The urban form is a compact form that leads to poor air flow patterns through the site. As for the street wind orientation, it is oblique 70° towards wind direction, where poor ventilation potential is found in the buildings on its sides. The streets formed between the buildings have H/W ratio of 2.3.

4.1.1.2 Building characteristics in terms of building arrangement, it is a complex of nine buildings in a clustered form around two streets. The building mass is a compact deep plan where L= 38 m, W= 25 m, and H=34.45 m. The block area is 950 m² and volume of 32727.5 m³. The nature of the deep plan design of the blocks along with their high density reduces the potential of using natural ventilation, which according to design rules should be kept low to avoid a large reduction in pressure in the middle of the windward façade with a suction effect at the edges. The area density: Ab /As= 8535 /1100=7.76, where Ab is total area of buildings and As is area of the site, with aspect ratio L/W = 1.52. Building form and shape, rectangular shape buildings arranged around two streets that were initially planned to be two linear open spaces, with high aspect ratio H/W of 2.3

(fig. 5). The building is oriented 70° towards the wind direction (fig. 6), this orientation leads to very poor airflow between the buildings and inside the apartments.

To evaluate the role of the building's layout on the natural ventilation strategy we conduct CFD simulation to provide visual evidence of the pressure patterns that shape in response to the sharp H/W ratio 2.3. The pressure distribution around the building, due to its form creates a constant low-pressure distribution of an average 4.2 Pa. The constant low-pressure distribution is a sign of very poor natural ventilation potential (fig. 7).

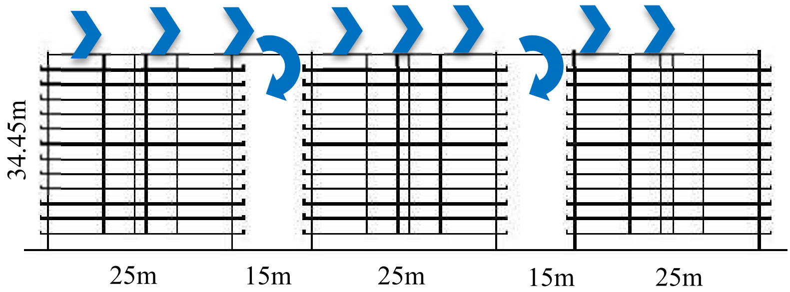


Figure 5: High aspect ratio courtyard.

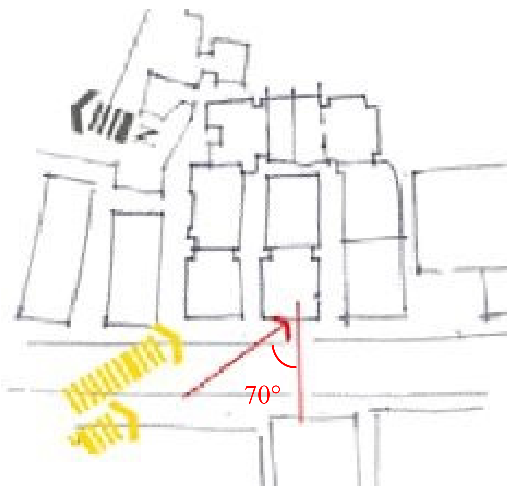


Figure 6: Building orientation 70° towards wind direction.

As for the building envelope, the openings' design in the façade according to its size, position and number. All rooms in all apartments are single-sided horizontal openings where the ventilation inlet is equal to the outlet. In apartment type (A) calculating area of window to floor area in living room, area inlet is 5% of floor area and area inlet in bedroom is 7% of floor area. As for apartment type

(B) area inlet of the living room is 4.5% of the floor area and the area inlet in bedroom is 7% as apartment A. The total façade area of one floor is L*H (38*2.65) = 100m² and the total area of air inlets are 12m², therefore, the total area of façade openings is 12% of floor area.

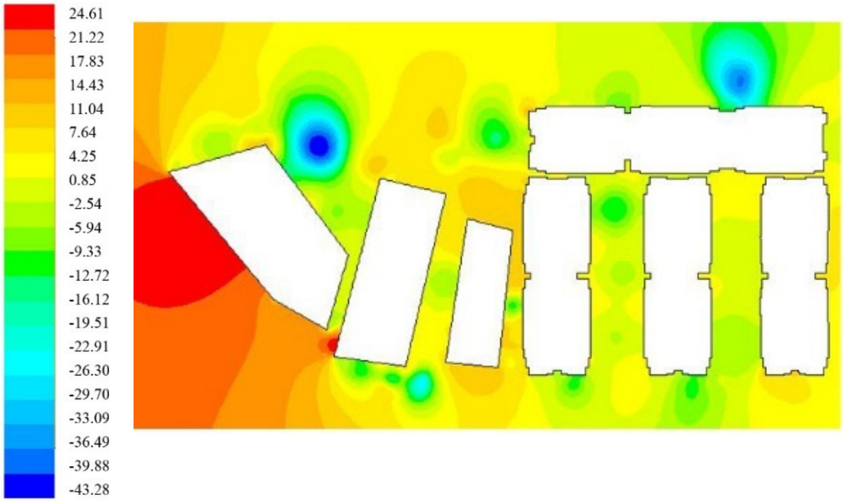


Figure 7: Complex total pressure contour simulation.

1.2. Impact of analysis on LCC of case study

The poor natural ventilation availability and potential has forced the users to use mechanical ventilation (air conditions) during 4 to 5 summer months each year. According to Egypt's annual electricity costs it was concluded that if:

Each apartment uses 2 air conditioners each is 1.25 HP which is 1kw, and assuming that air condition works 5hours/ day; therefore, each unit consumes 150kw.h; then 2 units consume 300 KW.h. According to price list after the Egyptian government [7] these air conditioners will consume 61 LE/month as a result 305 LE/5 months.

Since low-income families earn 2000LE/month [15] and spend 30% which is 600 LE [16] on their living in this apartment and spend almost 61LE/month only on electricity for mechanical ventilation.

5 Conclusion

This paper is a case study evaluation of a low-income housing compound in the Mediterranean city of Alexandria. The evaluation process is based on qualitative and quantitative methods, in which we assess the role of the site characteristics and buildings' design on the natural ventilation performance and thus the LCC. Results show that the case study is 99% unsuccessful with regards to natural ventilation.

This case proved to have very poor single sided wind-driven natural ventilation of $0.23 m^3/s$ and $0.076 m^3/s$. Analysis results were also evaluated by CFD simulation which indicated very low-pressure zones of 4.25 Pa surrounding the long sides of the compound resulting from the building shape. This, in turn, resulted in very poor airflow patterns around the site, thus causing poor ventilation inside the apartments and leading occupants to utilise mechanical ventilation.

The current trend of building low-income housing does not provide low cost for occupants. It only delays initial costs saved from the construction phase, due to inefficient natural ventilation design, to be later borne by the occupants during the operational phase.

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