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Airflow in Urban Environment: an Approach to Improve Egyptian Buildings Regulations

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1 ABSTRACT

Rapid urbanization among many factors contribute to elevate air temperature inside city's urban fabric that causes urban human discomfort. Natural ventilation in urban canyons is one of the measures that can limit that effect and minimize the air temperature of urban areas. Benefits range from pedestrian comfort in the urban environment, to efficiency of natural ventilation systems in urban streets. Studies have covered different urban forms and their impact on pedestrian comfort, others have investigated the role of built-up density on pollutants dispersion, some have studied the role of urban configurations on natural ventilation in buildings, while some studied different physical characteristics which also affect the urban heat island. What is yet to be defined is the effect of those physical characteristics on shaping the building regulations, especially in Egypt, and their efficiency regarding natural ventilation systems in urban canyons to eliminate the raised temperature. Spreading green architecture in Egypt requires reshaping current legislation and codes, starting by revising the existing local building laws and regulations. The aim of this work is to assess and analyse the main building code in Egypt by studying and analysing theories on natural ventilation and its physical characteristics.

Keywords: building regulations, urban canyon, pedestrian comfort, natural ventilation, urbanisation

2 INTRODUCTION

The world is currently experiencing the largest wave of urbanization in history. According to World Urbanization Prospects, by 2050, nearly two out of three of us will live in cities (Santamouris, 1997, Mei et al., 2018, Nazarian and Kleissl, 2016). Global urbanization includes the rapid growth of high-rise buildings, superstructures and increased buildings density. They continue to cause concerns about city breathability by blocking the prevailing wind and are associated with microclimate variations in urban districts. They are causing deterioration of pedestrian thermal comfort, increasing energy consumption and are causing several negative environmental impacts such as urban air pollution and urban warming (Juan et al., 2017, Omrani et al., 2017, Lin et al., 2014). For those reasons, we can easily notice the significant difference in microclimate when we are moving between urban areas and rural areas.

Outdoor urban ventilation is very important for a healthy and liveable urban environment -as it is one of the most effective passive cooling techniques- which is strongly affected by urban morphology (Ramponi et al., 2015, Santamouris, 1997). The interaction between urban morphology and airflows needs to be considered in new urban developments since their effects on human life may be beneficial or detrimental. Such effects do not only depend on the characteristics of the wind as a natural phenomenon – intensity, speed and direction- but also on the features of the obstacles and environments that the wind encounters along its path (Palusci and Cecere, 2022). Baruch Givoni states in (Givoni, 1989), that "Of all the climatic elements the wind conditions are modified to the greatest extent by urbanization". There is a clear need for basic scientific understanding of the airflow process in urban area morphologies for improving outdoor thermal comfort and lowering energy consumption (Mei et al., 2018).

Numerous studies have demonstrated that it is possible to improve urban air ventilation and urban climate by manipulating the building configurations during the early stages of planning and regulations. Countries such as United Kingdom, America, France, Germany and others made energy efficiency strategies a priority in building regulations (Omrani et al., 2017, Juan et al., 2017).

In recent decades, a large number of investigations have been conducted for the assessment of natural ventilation in urban areas. This paper aims to analyse the natural ventilation behaviour and its physical characteristics and assess the Egyptian regulations - Building Law No.119 of year 2008 – regarding natural ventilation aspects.

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3 NATURAL VENTILATION

Ventilation generally is the process of delivering fresh air. It could be natural, mechanical or hybrid. Natural ventilation relies on natural forces; it can be described as a process for providing fresh air movement. Natural ventilation can be used basically inside buildings to: improve indoor air quality (IAQ), achieve thermal comfort, reduce energy consumption and reduce pollutants inside spaces. Meanwhile, natural ventilation plays a very important role in the urban environment -as wind flow- to: control the humidity, adjust pedestrian thermal comfort, dilute pollutants and for summer cooling (Arup et al., 2002, Fordham, 2000, Krarti, 2018, Schulze and Eicker, 2013, McConnell, 1926).

3.1 Wind flow

The wind flow in the urban environment is complicated to follow. Small differences in land topographies cause irregular flows; as the wind flow is completely different in rural areas and urban environments (E. Bozonnet, 2006, Azizi and Javanmardi, 2017). Wind flow has many characteristics to be analysed and measured; its direction, velocity and pattern and all those characteristics change significantly from one place to another.

3.1.1 Wind direction

Wind direction is generally defined as where the wind blow or by the direction from which the wind originates (for example, a south wind blows from the south to the north). Any obstacles as buildings or land topography directly affect the wind direction ((NWS, 2021, Kutz, 2016, Serway and Jewett, 2018). Wind direction is usually reported in cardinal directions, or in degrees. A wind rose is a simple way to read wind direction as well as its velocity. For example, as shown below in Alexandria's wind rose (Figure 1), the prevailing wind direction -where the wind blows most often- is North North West (El-Geziry, 2013, (NWS, 2021). Wind direction can be measured by the windsock/wind vane or by ultrasonic Anemometer/thermal Anemometer (more sophisticated) (Hawkins and Sutton, 2009).

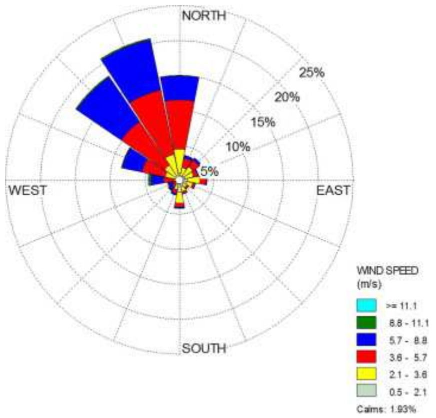

Figure 1: Alexandria's wind rose. (El-Geziry, 2013)

3.1.2 Wind velocity

Wind velocity (wind flow speed) is a fundamental atmospheric quantity caused by movement of the air from high to low pressure (Hogan and Monosson, 2010). Wind velocity is affected by a number of factors and at different scales as the pressure gradient. Where the air pressure differs between two points in the atmosphere or on the surface of the Earth the wind flow become faster or slower to balance out the variation in pressure (Chua et al., 2010, Garrison et al., 2002, Justus et al., 1978). The Beaufort wind force scale was known as the first measurement technique of wind velocity. Nowadays, meters per second (m/s) is the international system unit for velocity (Saucier, 1955, McIlveen, 1991, Hay, 2016). Wind speed could be measured with the same instruments that measure wind direction mentioned in the last section.

3.1.3 Wind flow pattern

Generally we can define wind flow pattern as how wind moves horizontally between different areas. The large global wind pattern is the result of the differential Earth's heating. This difference is created because of the uneven heat by the rays of the sun which happened because of Earth's rotation, its ellipsoid shape and its twenty three and half tilted axis (Dashamlav.com, 2021, Bu and Kato, 2011, Perry, 2004). When it is about cities and urban areas, wind interacts differently with the surrounding urban areas with different behaviour and characteristics that will be discussed in the next section.

3.2 Urban wind flow

Allard and Ghiaus, (2006) mention that the general aspects of wind patterns in the urban environment - as compared to those of undisturbed wind - are: mean speed due to differences in terrain roughness reduced by 20 to 30%; turbulence increased in intensity by 50 to 100%; and greater incidence (20%) of weak winds. It is also agreed that the mean wind speed above and inside the canopy height is closely related to certain urban dimensions. For roof-top speeds above 4.0m/s, mean velocity decreases by about 33%, while for speeds below 1.5m/s this coupling between the external main and internal secondary flow is considerably reduced or is lost. The centre of a city is warmer than its outlying areas. Daily minimum temperature readings at related urban and rural sites frequently show that the urban site is 6° to 11° C warmer than the rural site. This phenomenon called "urban heat island" (UHI) could be defined as the maximum temperature difference between the city and its surrounding area (Rafferty, 1998).

3.2.1 Urban wind flow pattern

Once the wind flow from the suburban surroundings reaches an urban area it tends to skip over the roofs and sides of buildings and its momentum is transformed into pressure on the windward surfaces of solids, creating several types of effect, such as acceleration, down-flow, flow detachment, low wind speed, high and/ or low pressure zones, sheltered areas and leeward wakes of turbulent vortices (as shown in Figure 2). This unsteady behaviour tends to diminish the flow's momentum due to the drag and viscous forces caused by the friction produced between surfaces and air flow. The Atmospheric Boundary Layer -the lowest 1 or 2 km of the atmosphere which is directly influenced by the presence of the earth's surface and responds to surface forces- is then set by the energy spent in overcoming the shear stress due to the roughness of the terrain, which is determined by the canopy height. Below this height, the free airflow momentum is transformed into wind pressure on vertical surfaces. Above this height the flow tends to stabilize slowly until reaching the gradient speed (Oke, 1978b, Oke, 1988, Cook, 1986, Faria, 2012).

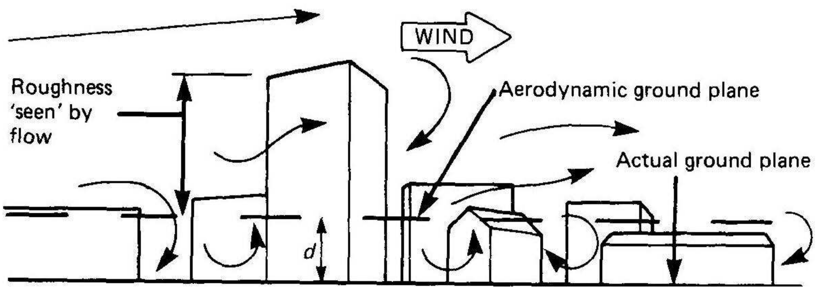

Figure 2: Flow in the interfacial layer (Both canopy layer and surface layer together create the interfacial layer which is extending up to one tenth of the total height of the ABL). (Cook, 1986)

3.2.2 Wind flow pattern around isolated structure

As shown in (Figure 3), when the wind is approaching a structure, it gradually diverges. At the windward facade a stagnation point with maximum pressure is situated at approximately 60–70% of the structure height. From this point, the flow is deviated to the lower pressure zones of the facade: upwards, sidewards and downwards. The upward and sideward flow separate at the upwind facade edges and create a separation bubble or recirculation zone characterized by a low velocity and high turbulence level intensity. Depending on the dimensions of the structure and the turbulence of the oncoming flow, the separated flow can reattach to the side facades and roof (as illustrated by the dotted lines in Figure 3). A considerable amount of air flows downwards from the stagnation point and produces a vortex at ground level. The main flow direction of the standing vortex near ground level is opposite to the direction of the approach flow. Where both flows meet, a stagnation point with low wind speed values exists at ground level, upstream of the structure. The standing vortex stretches out sideways and sweeps around the structure corners creating corner streams with high wind speeds. At the leeward side of the structure, an under pressure zone exists. As a result, backflow or recirculation flow occurs in a cavity zone that consists of vortices with horizontal and vertical axes. The mean cavity reattachment line downstream of the structure marks the end of the cavity zone. After this

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structure, the flow resumes its normal direction but wind speed stays low for a considerable distance behind the structure until the wake flow (Bert Blocken 2011).

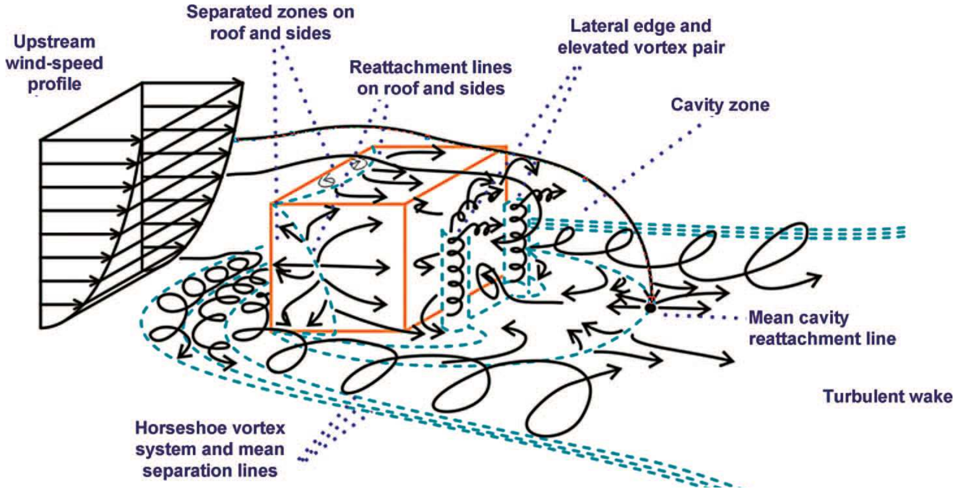

Figure 3: Schematic representation of wind-flow pattern around an isolated structure. (Hosker, 1985)

3.2.3 Wind flow pattern in urban canyons

Urban canyon is the volume lying between buildings, and the urban canyon volume is the volume between road surface and the roof tops of buildings (Figure 4) (Vardoulakis et al., 2003). Urban canyons are characterized by three main parameters: H, the mean height of the buildings in the canyon, W, the canyon width, and L the canyon length. (Georgakis and Santamouris, 2008)

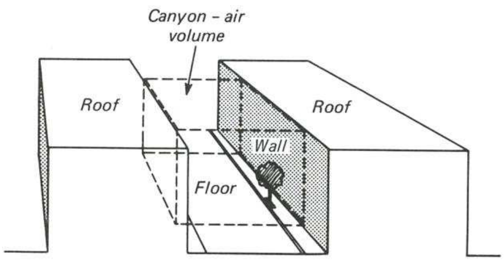

Figure 4: Schematic cross-section of an urban canyon-urban conyon's volume represented with doted line. (Oke, 1978b)

As shown in (Figure 5), Wind flow speed and direction modify as a result of the urban canyon's geometry; parallel, perpendicular or angled.

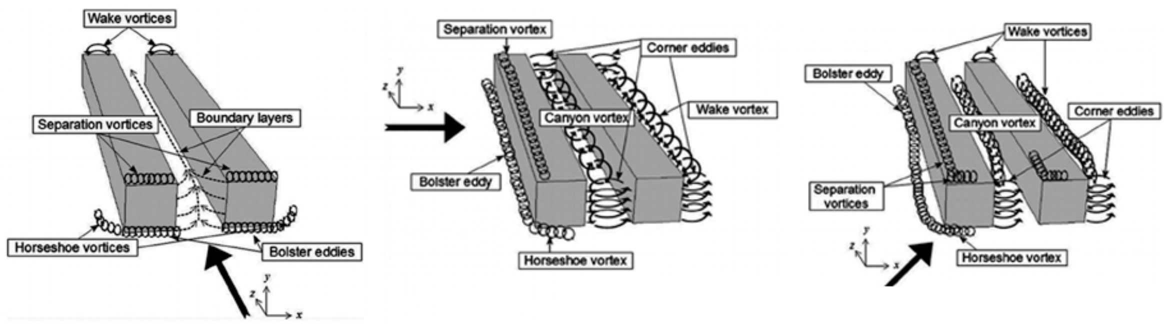

Figure 5: wind flow in different canyon's geometry; parallel (left), perpendicular (middle) and angled (right). (Yazid et al., 2014)

When the wind flow is parallel to the canyon's axis or nearly parallel (deviation of less than thirty degrees), a mean wind component is created along the canyon's axis. The wind speed is reduced due to friction and there is also a possibility of uplifting near the vertical and ground surfaces. In this case the vertical components of velocity tend to be much decreased and in the stream wise direction, if only wind drive forces are applied. Further, the flow inside the canyon is copying the free flow behaviour, but with reduced intensity (Nakamura and Oke, 1988).

An important aspect observed in the perpendicular wind flow is the production of vortices rotating in the mainstream direction below the canopy height and between the two structures shown in (Figure 5). The vortex occurs as a result of pressure differences between the leeward side of the upstream structure and the windward side of the downstream structure. The flow separates at the edge of the leeward surface creating a large wake of low pressure behind the front structure. Then the flow is diverted upwards due to its mass conservation and rises, though with a weaker vertical component. The vortex created in the canyon space therefore presents wind components near the surfaces but little air movement at its centre (Georgakis and Santamouris, 2008, Cook, 1986, Faria, 2012).

Skewed flows usually create a vortex alongside the main axis. The mean flow along the canyon axis presents vertical downwards components causing spiral vortices along the length of the canyon in the upward stream direction but with reduced velocity (Nakamura and Oke, 1988).

4 WIND FLOW PARAMETERS

Many parameters are affecting the urban wind flow. To define those parameters, this study analysed previous studies and the articles published in the field of natural ventilation in the urban environment, whether in individually published articles, or in previous review papers. Thr study investigated relevant publications in related journals regarding natural ventilation and the urban environment, including in particular: Building and Environment, Energy and Building and Journal of Wind Engineering and Industrial Aerodynamics. Among these numerous publications, this paper further focused on studies conducted in the years from 2008 to 2018 with the following keywords: natural ventilation, urban, canyon, airflow and air change rate (ACH). References are analysed according to: relations, methods, type of natural ventilation, wind direction, measurement unit, sensibility analysis, model and limitations of the study. As shown in (Table 1) studies are classified by building typology (high-rise, low-rise, compact, single block or others), scale (urban, canyon or building), measurement unit (Q, ACH, age of air or Cp), type of natural ventilation (pressure or buoyancy) and type of study (coupled or uncoupled). The next five graphs (Figure 6, Figure 7 and Figure 8) show the percentage of studies that discussed each type of classification.

Model					Scale of study			Measurement's unit				Type of NV		Type of study	
high-rise	low-rise	compact	single block	others	urban	Street canyon	Building	Q	ACh	Age of air	Cp	Pressure	Buoyancy	Coupled	Uncoupled

Table 1: previous studies classification. Source: the research

Figure 6: study's model (left) - study's scale (right). Source: the research

Figure 7: measurement unit (left) - type of natural ventilation (right). Source: the research

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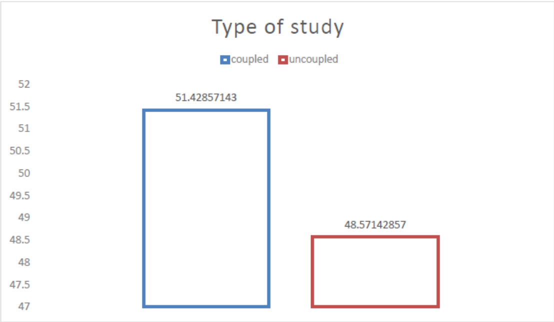

Figure 8: type of study. Source: the research

From previous studies a number of physical parameters were identified that affect the wind flow pattern in urban areas and related phenomena as urban temperature and pollution. The parameters are: Aspect ratio (AR), floor area ration (FAR), packing density (ʎP) and setbacks. The studied ranges of each physical factor are presented in (Table 2). Studied AR ranges vary from 0.5 to 6, FAR ranges vary from 1 to 4, ʎP ranges vary from 0.25 to 0.6 and setbacks were vertical or horizontal and their values depend on road width and buildings height.

Physical factor	Studied ranges
Aspect ratio (AR)	0.5 to 6
Floor area ratio (FAR)	1 to 4
Packing density ($ʎ_P$)	0.25 to 0.6
Setbacks	varied

Table 2: The four physical factors studied ranges. Source: the research

The four parameters and their definitions, importance and relation to urban wind flow will be discussed in next sections.

4.1 Aspect ratio (AR)

Generally as defined in Webster (1907), the aspect ratio is a ratio of one dimension to another. In urban studies, aspect ratios are related mainly to dimensions of urban canyons; they are H/W, L/H and W/L (Figure 9). Those ratios identifies the built aspect ratio and the type of volumetric canyon within it. It is expected that the resultant wind flow speed and direction below the canopy height are connected to variations in these aspect ratios (Hunter et al., 1990, Nakamura and Oke, 1988). A canyon can be considered accoroding to the mentioned ratios: for example, uniform or regular when its H/W ratio approximates to 1.0; deep or narrow when this ratio increases to 2.0; and wide or shallow when it drops to 0.5. Also, the L/H ratio is considered short, medium or long for respective ratios of 3.0, 4.5 and 6.0. Regarding the height, a canyon is considered symmetrical when height is relatively constant and asymmetrical when there is large variation in height (Vardoulakis et al., 2003, Nakamura and Oke, 1988, Oke, 1978a).

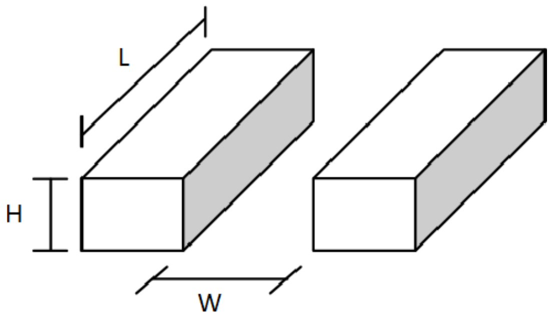

Figure 9: A simple urban canyon. Block's height (H), canyon's width (W) and canyon's length (L).(Afiq et al., 2012)

Comparative analysis of previous AR studies shows that wind speed inside a canyon does not necessarily increase with the increase of canyon AR. Apart from AR, there are other important factors governing the flow field inside a canyon. For example, thermal effects, finite length canyon effects, traffic induced turbulent effects and other physical parameters play important roles in shaping the flow characteristics inside a canyon (Ai and Mak, 2015).

4.2 Floor area ratio (FAR)

Floor area ratio (FAR) is the ratio of a building's total floor area (gross floors areas) to the size of the piece of lot upon which it is built. FAR is sometimes called floor space ratio (FSR), floor space index (FSI), site ratio or plot ratio. The difference between FAR and FSI is that the former is a ratio, while the latter is an index. Index numbers are values expressed as a percentage of a single base figure. Thus a FAR of 1.5 is translated as a FSI of 150% (Birch, 2009, Spikowski, 2006). FAR is often used as one of the regulations in city planning along with the packing density (ʎp) (block covering ratio BCR) as well as zoning to limit urban density. While it directly limits building density, indirectly it also limits the number of people that a building can hold, without controlling a building's external shape. (Figure 10) shows three different plot options with the same FAR (1); by decreasing the lot covering ratio and increasing number of floors. Thus, many authorities have found it unnecessary to include height limitations when using FAR calculations in building regulations. (Birch, 2009, Spikowski, 2006)

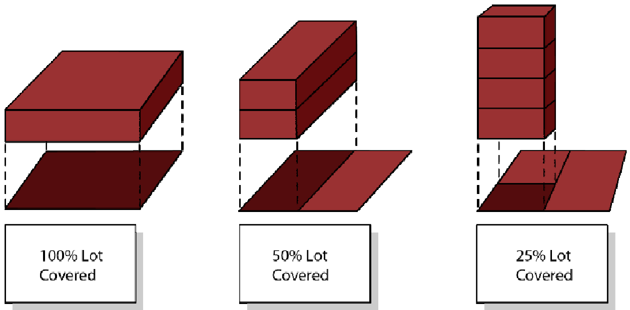

Figure 10: Floor area ratio (FAR=1). (DCOZ, 2022)

Previous FAR studies are wide ranging and vary from effects on environmental aspects such as solar radiation, day lighting. human comfort and natural ventilation, to business studies on land values, city character, regulations and laws.

4.3 Packing density (ʎP)

Packing density (ʎP) is the ratio between the block coverage area (ground floor area) and its total plot area (Hu and Yoshie, 2013). It is also known as; block covering ratio (BCR), plan area density, planar area density, building area density and building to land ratio (SÜMEGHY, 2007). Ramponi et al. (2015) agreed that urban density can be described with geometric parameters like the packing density (ʎP) and the frontal area density (ʎF) (the ratio of the frontal area- front façade that facing the wind - and the total surface area) (Figure 11).

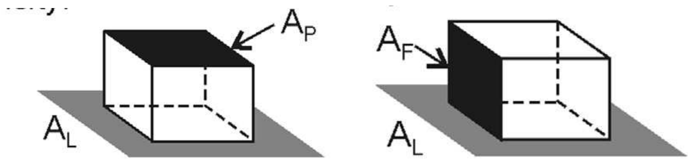

Figure 11: packing density (left) and frontal area density (right). (Ramponi et al., 2015)

Previous studies agreed that building packing density is the key factor to influence the flow adjustment and urban ventilation capacity in the city model; and that lowering the building packing density within a city could reduce the pollutant concentrations at street level and result in higher ventilation efficiency in most cases.

4.4 Setbacks

Setback in architecture, is a step-like recession in the profile of a block. Could be from a wall (other building frontage), a road or a water stream. In regulations, a setback is the minimum distance which a block must be set back from any place which is deemed to need protection (Davis, 1994, Allen, 1995). A setback as a minimum one-bay indent across all stories is called a recessed bay or recess and is the more common exterior form of an alcove. Setbacks were used by people to increase the height of masonry structures by distributing gravity loads produced by building materials. This was achieved by regularly reducing the footprint of each level located successively farther from the ground. The most marked example of a setback technique is the step pyramids of ancient Egypt (Figure 12).

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Figure 12: Djoser's Step Pyramid in Saqqara. (egymonuments.gov.eg, 2019)

In previous aforementioned studies setbacks are studied with different parameters to analyze how it could affect the natural ventilation efficiency. Pablo J. Rosado (2017) compared the change in solar flux reflected from the simple narrow (no setbacks) canyon to that of the simple wide (with setbacks) canyon. The simple wide canyon was able to reflect from 2.90 (summer) to 4.52 (fall) times more solar flux than the simple narrow canyon. These multipliers are the scaling factors for adjusting air temperature changes obtained with the simple narrow canyon to the simple wide canyon which directly affect the efficiency of natural ventilation.

5 EGYPTIAN REGULATIONS AND LAW

Law No.119 of 2008 (and its executive regulations) - called unified building law - is the only law used for planning and construction. The Egypt Green Building Council (EGBC) was established by 2009 and introduced a national green building rating system called the green pyramid rating system (GPRS) (Elfiky, 2011). Regarding the law and GPRS, we cannot find obvious planning criteria to be followed to enhance city breathability or outdoor air quality as a result of good natural ventilation penetration through the urban fabric. At present in Egypt, any new constructions are subjected to the proposed planning strategies (for example the proposed strategies of the city of Alexandria 2025, 2032 and 2050) and the unified building law. In the next sections, the unified building law (law No.119 for 2008) will be analysed, based on the four natural ventilation factors mentioned in previous sections.

5.1 Aspect ratio (AR)

In the Law No 119, aspect ratios are not mentioned directly. However, building height is defined as the distance between the surface of the sidewalk (from the centre of the frontal elevation) and the top surface of the concrete slab. Parapets and service rooms at roof level are not considered. The total building height is the distance between the surface of the sidewalk (from the centre of the frontal elevation) and the highest point in the building.

The law states that the building height shall not exceed one and a half times the width of road which means: AR=1.5- with a maximum height of 42 m, The legal rule for the height of the building on two different roads stipulates that: if the building is located at the intersection of two opposite sides with different width, the width of the building height is equal to one and a half times the width of the wider road with a maximum height of 36 meters.(Ministry of Housing, 2009).

5.2 Floor area ratio (FAR)

In the Law No 119 floor area ratio is defined as: the ratio of total built up areas of all floors to the total plot area. According to article 26, FAR is determined by the strategic plan for each part of the city with maximum FAR equal 4 in the case of absence a strategic plan.(Ministry of Housing, 2009).

5.3 Packing density (ʎP)

In the Law No 119 packing density ia defined as: the ratio of the ground floor built up area to the total plot area. According to article 26, ʎP is determined by the strategic plan for each part of the city (Ministry of Housing, 2009).

5.4 Setbacks

In the Law No 119 setbacks are mentioned in different terms and definitions.The Regulation Line is the line that defines the street and creates boundaries between public and private properties; it could be within, wider or narrower than the plot boundaries. The Construction Line is the line within which it is allowed to build on; it could be the street edge, the same as the Regulation Line or recessed from both. Finally, setbacks are mentioned in three other terms: frontal setback, side setback and rear setback which are defined as: the distance between the Property Line and the Construction Line in all directions (Ministry of Housing, 2009). Article 26 states that, in the case of existing streets, the Regulation Line is set back by half the difference between the width of the current road and the proposed width when building or reconstructing the plots (Ministry of Housing, 2009).

6 CONCLUSION

The rapid urbanization we are living nowadays is causing a number of problems, starting from pedestrian discomfort to the blockage of city breathability. Urban ventilation is strongly affected by urban configuration, therefore it is important to be considered as a mandatory element in building regulations and laws.

By comparing the building codes included in the Unified Building Law No.119 of 2008, and its executive regulations released in April 2009 by the Minister of Housing, and the GPRS document released by the HBRC in the same year; there are serious contradictions between both documents, as the Unified Building Law and its executive regulations allow building designs and procedures that do not comply with the GPRS. Moreover, there is no reference in the Unified Building Law to the GPRS or green building in general, nor is there any reference to the Unified Building Law in the GPRS documentation released by the Ministry of Housing, Utilities and Urban Development. Thus, it is clear that the GPRS is an isolated document that does not fit into the current building regulations, nor represent a law on its own (Ayyad and Gabr, 2012, Ammar, 2012). The most important thing - more than the relation between the law and the GPRS - is the existence of natural ventilation as concept, importance and consideration in the law. As studied and mentioned in the last section, when analyzing the law and the GPRS, there is no direct mention to natural ventilation related to the urban environment. Nor do the four main physical aspects affecting the natural ventilation have restricted requirements to enhace urban natural ventilation.

It is important to investigate urban ventilation further, its physical factors and its relation to laws and to specify the requirements in law to be followed to optimize urban natural ventilation and make it obligatory. Now that there are a lot of new developments in the construction field in Egypt, it is a perfect time to regenerate the building regulations to support the concept of natural ventilation in the built environment.

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