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Passive Strategies of Promoting Outdoor Air Quality in Microclimate

Ashraf Abdel Fatah El Mokadem¹, Osama Mahmoud Abo Eleinen², Naglaa Ali Megahed², Asmaa
Mohammed Hassan³

Professor, Department of Architectural Engineering and Urban Planning, Faculty of Engineering, Port Said, Egypt¹

Associate Professor, Department of Architectural Engineering and Urban Planning, Faculty of Engineering, Port Said, Egypt²

Associate Lecturer, Department of Architectural Engineering and Urban Planning, Faculty of Engineering, Port Said, Egypt³

ABSTRACT: The world nowadays is facing a great phenomenon associated with the ongoing growth in the proportion of people living in urban areas, which causing major problems in urban areas, like poor air quality, which leads to several series effects on the human being, and environment. Consequently, the approach of promoting outdoor air quality is often proposed in general by controlling the air emissions. However, regarding with urban and design field, passive strategies can be used to reduce air pollutants' concentrations, hence promote outdoor air quality. Such passive strategies demonstrate the ability of urban and building morphology in reshaping the air pollutants dispersion. Therefore, the main objective of this paper is to present the passive strategies, aiming to outline a reference matrix for the urban planners, and architects to promote outdoor air quality. Furthermore, the microclimate factors will be also analysed to investigate their influence on outdoor air pollutants dispersion and on the proposed reference matrix.

KEYWORDS: Outdoor air quality, Passive strategies, Air pollutants dispersion, Urban morphology, Building morphology, Microclimate factors.

I. INTRODUCTION

Owing to the modernization, industrial revolution, and economic growth, urbanization phenomenon has increasingly caused various social, health, economic, and environmental impacts [1]. As a result, high concentrations of outdoor air pollutants, which lead to associated threats, not only in several megacities, but also in many medium-sized, and large cities [2, 3]. Moreover, Stauffer [4] has confirmed the ability of outdoor air quality to inflict harm on public health, and environment through the degree of ambient atmospheric pollution in both microclimate, and global level [5]. the World Health Organisation (WHO), has considered outdoor air pollution as the main indicator to the indoor air quality, especially in highly ventilated homes, or in homes near pollution sources [6]. Consequently, many researchers have extensively discussed outdoor air quality issue, and how can promoting outdoor air quality.

Emitted outdoor air pollutants can be dispersed from their sources to even a long distance in different urban settings through explicit phases, which specify their dispersion characteristics. In this context, Kumar et al. [7] have determined four phases to describe outdoor air pollutants' life cycle through; fumigation, vertical mixing, horizontal dilution, dry or wet deposition. As outdoor air pollutants can be dispersed over a wide range of horizontal length scales (L) through many dispersion scales; mesoscale, local -scale, and micro-scale dispersion.

On the other hand, Salem et al., [8, 9] demonstrated that microclimate, factors; including pressure gradient, inflow conditions, typography, thermal stability, relative humidity, besides rainfall can influence the dispersion of air pollutants, hence promote outdoor air quality. Therefore, the need for promoting outdoor air quality through the dispersion of air pollutants within microclimate scale has become even more critical issue. In this context, this research focuses on how passive strategies could modify the dispersion of air pollutants and analyses the correlation between these passive

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strategies, and microclimate factors through the proposed reference matrix. Consequently, the paper is organized as follows. Section II describes the strategies that promoting outdoor air quality in general either active or passive. After the discussion of these strategies, passive strategies will be investigated in Section III. Section IV analyses the influence of microclimate factors on promoting outdoor air quality. In addition, correlated relation between such passive strategies, and microclimate factors will be outlined by a proposed reference matrix in Section V. Finally, Section VI presents the study conclusion.

II. STRATEGIES OF PROMOTING OUTDOOR AIR QUALITY

A number of strategies can be promoted outdoor air quality (Fig. 1), which expands from control the air emissions to dilution and purifying air pollutants [10]. On one hand, air emissions' control presents active strategies, including industry, transport, energy and waste management, as illustrated in Table 1, which provide its own benefits, and challenges. However, on the other hand, the dilution, and purifying of air pollutants present the passive strategies through urban, and building morphology, besides surface deposition, and photo-catalysis reactions [2, 11, 12].

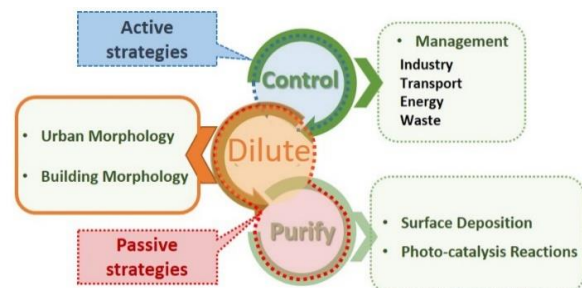


Fig. 1 Strategies of promoting outdoor air quality. Source: the authors based on [10].

Table 1: Active strategies of control outdoor air emissions. Source: the authors based on [10-14].

Active strategies	Industry	- Reduce industrial smokestack emissions - Improve management of urban, and agricultural waste
	Energy	- Use low-emissions fuels, and renewable combustion-free power sources - Improve the energy efficiency of buildings and making cities more green and compact
	Transport	- Shift to clean modes of prioritizing rapid urban transit, like Personal Rapid Transit (PRT) unit at Masdar city - Use clean heavy duty diesel vehicles, and low-emissions vehicles - Implement a series of temporary traffic management procedures in China have principally contributed 24–65% reductions of the emission inside the sixth-ring road region in China
	Waste management	- Recycle and improve methods of biological waste management such as anaerobic waste digestion to produce biogas

Subsequently, the following section emphasizes the ability of the proposed passive strategies in modifying air pollutants concentrations with emphasizing on dilution outdoor air pollutants in microclimate. The dilution strategies aim to control air flow, and air pollutants dispersion as a primary sequence. However, the purifying strategies based on removing or decreasing air pollutants by surface deposition, besides photo-catalysis reactions.

III. PASSIVE STRATEGIES OF PROMOTING OUTDOOR AIR QUALITY

Promoting outdoor air quality presents new challenges for urban planners and architects to enhance air pollutants dispersion. Therefore, the passive strategies can be integrated as a part of a holistic strategy to promote outdoor air quality, hence minimize the health risks through either dilution or purifying strategies, as presented in Fig. 2. Based in these strategies, the current study presents and analyses the ability of urban and building morphology in reshaping the air pollutants dispersion due to the containing of the main variables and parameters related to the initial phases of the planning and design processes.

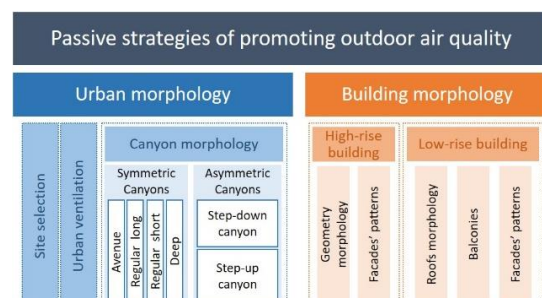


Fig. 2 Passive strategies of promoting outdoor air quality.

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1) Urban morphology

Urban morphology has a significant role in enhancing the dispersion of air pollutants [13, 14], which help urban planners to take into account several variables, which affect the air pollutants dispersion and air quality issue as described in the following points.

Site selection

Increasing the distance between any pollution source, and existing sensitive uses enables air pollutants to disperse, hence dilution of air pollutants' concentrations [15]. It is worth mentioning that continuous streets and parks oriented parallel to the wind direction will tend to channel winds [16, 17], which provides air pollutants dispersion.

Urban ventilation

Urban ventilation in street canyons depends mainly on the flow structures; separation, circulation, and reattachment, which produce vortices [15]. Hence, urban ventilation can be considered a significant passive strategy to reduce air pollutants' concentrations. Furthermore, Wang et al. [17] have demonstrated that urban ventilation depends on two factors; the orientation of street canyons grid to the prevailing wind directions, besides Air Exchange Rate (AER) of street canyons, which strongly influenced by the buoyancy force.

Canyon morphology

The morphology of symmetric canyons depends on the dimensions of street canyons; length, width, and height, which present the key geometric parameters affecting the air pollutants' dispersion in a street canyon. An aspect ratio can be calculated by two methods; firstly, dividing the height (H) of the canyon by the width (W), which classify symmetric street canyons into avenue, regular and deep street canyons. The second method divides the length (L) of the canyon by the height (H) to distinguish between short, medium, and long street canyons, as shown in Table 2. However according to asymmetric canyons, step-up, and step-down canyon can describe the morphology of street canyon. Whereas, the step-up canyon refers a street canyon, where the Height of the Upwind Facade (H_u) is less than the Height of the Downwind facade (H_d), on the contrary with the step-down canyon [18].

Table 2: Influence of canyon morphology on the dispersion of outdoor air pollutants. Source: the authors based on [2, 13, 19-22].

Canyon morphology		Remarks
Symmetric Canyons	Avenue canyon $H/W < 0.5$	Ventilation has enhanced as H/W reduced
	Regular long canyon $H/W = 1, L/H > 7$	Pollutants' concentrations had mostly accumulated at the center ground of street canyon, and were reduced in the windward side
	Regular short canyon $H/W = 1, L/H < 3$	Pollutants' concentrations were uniformly distributed on the ground, with lower pollutants' concentrations compared to long canyon
	Deep canyon $H/W > 2, L/H > 7$	The maximum pollutants' concentrations were at the bottom corner of windward wall, and decreased along the lower half of windward wall The concentrations were three times the concentration in a regular canyon
Asymmetric Canyons	Step-down canyon	Pollutant concentration near the windward wall is greater than leeward wall
	Step-up canyon	Pollutant removal is enhanced, owing to the main vortex extends above the shorter building leading to a secondary vortex

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2) Building morphology

The morphology of buildings can be considered an innovative method to change the human perception of heat and humidity [23, 24], besides improving air quality through effect the capacity to disperse pollutants in street canyons [24, 25]. Consequently, Bitsuamlak et al. [25], and Oke [26] demonstrated that the total array of buildings (roughness elements) modifies the velocity field close to the façades, hence mass and momentum transfer, aerodynamic characteristics, and the production of mechanical turbulence. Therefore, the morphology of buildings can be formed as passive methods to reduce air pollutants' concentrations, which can be varied based on the following classification.

High-rise building

High-rise buildings provide wind flow separation and cause periodic shedding of vortices. Such periodic vortex shedding exerts crosswind forces on the body by creating fluctuating pressures [27]. Accordingly, morphological modifications to the external shape of a building, through geometry morphology or facades Patterns, can significantly alter the air pollutants dispersion around high-rise building [27], as discussed in Table 3.

Table 3: Influence of high-rise building on the dispersion of outdoor air pollutants. Source: the authors based on [27-30].

Building morphology		Remarks			
High-rise building	Geometry Morphology	 Tapering Affecting the vortices to become incoherent, and shed at different frequencies at different heights	 Twisting Reducing vibrations along the building height	 Varying cross section size vortex-induced	 Varying cross section shape Affecting the vortices to shed over a broad range of frequencies
	Facades Patterns	The patterns of facades reflect new ideas of the morphological concept. These patterns can be catalogued, as a type of manual algorithm, hence can be translated to parametric models in order to enhance environmental behaviour of both high, and low-rise buildings, for instance, the patterns of Spiderweb Tower, which was inspired by the behaviour of spider silk fibres.			

Low-rise building

Simple morphological modifications to low-rise buildings can change the flow patterns around the buildings. Such modifications can be entitled vortex suppression techniques; provide straight sharp edges, enhance the vortex formation, and deflect the vortices to deflect vortex generation through architectural shapes and configurations [41]. These previous techniques depend mainly on building morphology; roof shape, balconies, and patterns of facades (see Table 4).

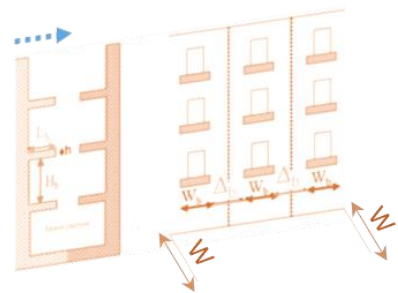
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Table 4: Influence of low-rise building on the dispersion of outdoor air pollutants. Source: the authors based on [27-30].

Low-rise building	Roof shape	Roofs can provide vortex suppression techniques. The slanted roof shape can be more effective compared to a pitched roof due to the turbulent shear intensification.  Roof shape promotes better air quality compared to pitched or flat roof. Roof shape yields the highest pollutant accumulation along the leeward. Roof shape presents the worst shape and yields the highest pollutant accumulation. Pitched upwind roof showed that the pollutant dispersion pattern increases. Pitched backwind roof showed that the pollutant dispersion pattern decreases.
	Balconies	Balconies can modify the flow field, and affect the pollutants' transfer rate, besides air quality in the street canyon. In a deep street canyon; with $H/W = 3$, with perpendicular flow, the presence of balconies limit pollutants' mass transfer from the bottom volume to the roof top level when $L_b / W_b < 0.3$ $L_b / W > 0.05$ 
	Facades Patterns	The patterns of low-rise buildings can create slow wind speeds, and turbulence, for better distribution of pollutants across the patterns, for example the outer façade of Manuel Gea González Hospital, which depends on patterns' design to improve outdoor air quality in Mexico City, and the urban forest façade's patterns of Palazzo Italia in Italy Pavilion at Expo Milan 2015.

IV. MICROCLIMATE FACTORS

After presenting and indicating the passive strategies, the microclimate factors will be discussed to complete the reference matrix which will guide urban planners, and architects to promote outdoor air quality.

Park et al. [2] declared that the flow of air pollutants generally depends on three laws, which reflect mainly microclimate's factors; mass transfer, momentum transfer, and heat transfer. Consequently, the Institute of Air Quality Management [31] has classified microclimate factors according to their significance in air pollutants dispersion (see Fig. 3), as illustrated in the following points.

1) Pressure gradient

While the pressure change in rate and direction between areas of high and low pressure is called the pressure gradient (see Fig. 4). Such pressure gradient presents wind speed enough to disperse air pollutants in a local area (as described in the next factors).

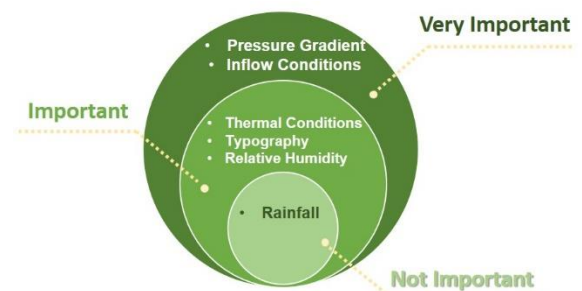


Fig. 3 Classification of microclimate factors. Source: the authors based on [31].



Fig. 4 Pressure gradient. Source the authors based on [32].

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2) Inflow conditions

Air pollutants dispersion in a street canyon mainly redirect the flow patterns [15], which depends on the synoptic wind through three main features of inflow conditions; wind direction, wind speed, and turbulent flow as clarified below:

Wind direction

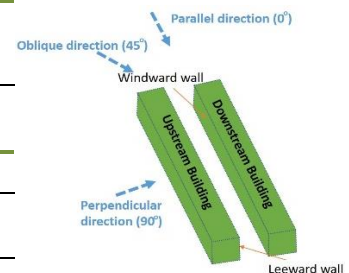
The wind direction can modify the structure of the wind, besides the dispersion of air pollutants in street canyons, hence, the concentrations of outdoor air pollutants [33]. As, Huang et al. [34] have proved, by experimental results, that average horizontal, and vertical profiles of pollutant concentrations based on wind direction at the roof level within street canyons (see Table 5).

Wind speed

Wind speed can affect pollutant dispersion in street canyons. For instance, perpendicular wind direction, low wind speed does not produce the typical vortex in a regular canyon, hence the pollutant will remain near the source [35].

Table 5: Influence of wind direction and speed on the dispersion of outdoor air pollutants. Source: the authors based on [15, 21, 33, 34].

Wind variables		Remarks
Direction	Perpendicular	The short canyon is much more preferred layout for the reductions of the pollutants
	Parallel	
	Oblique 45°	Helical vortex indicates an enhancement of air ventilation, and enhances the air quality inside the long street canyon
Speed	<1.5: 2 m/s	The central vortex has disappeared, and the air is stagnant
	≥ 2 m/s	Intensification of the primary vortex, and enhanced overall air quality near the leeward building in particular
	2: 4 m/s	Pollutant concentration dispersion between leeward and windward wall has increased



Turbulent flow

Turbulence can modify the velocity field close to the façade primarily, and heat exchange due to the wind convection [36]. In addition, turbulence flow can modify mass, and momentum transfer of air pollutants, which affect the urban ventilation, and the aerodynamics of the building due to vortex shedding at the upwind corners [15, 28]. All of this can increase turbulence flow through increasing surface roughness to create a narrower pressure, hence decreasing pollutants concentrations in windward walls (see Fig. 5).

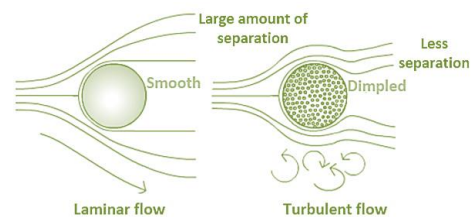


Fig. 5 Flow field around a dome. Source: the authors based on [36].

3) Typography

Topography plays an important role in air pollutants' patterns synoptically through the relation between inflow conditions, and the phenomenon of the valley breeze, which restricts vertical air movement and traps pollutants [37].

4) Thermal conditions

The thermal stability can be categorized into three sections; stable, neutral, and unstable. Different thermal stability regimes depend on wall temperature, and wind speed [25]. The stable case accumulates pollutants at the windward wall, whilst for neutral and unstable cases, the accumulation of pollutant is higher near the leeward wall. However, Habeebullah

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[38] has determined that the impact of the unstable case depends on the type of pollutants; as a positive correlation with NO_x, CO, SO₂, and PM₁₀, with contrary to ozone pollutant.

5) Relative humidity

Relative humidity plays an important role in photochemical reactions with many substances. In this context, NSCEP [32] declared that water molecules attach to substances via two cases. Habeebullah [38] has reported that relative humidity is positively correlated with particulate matters, and negatively correlated with the rest of the air pollutants.

6) Rainfall

The rainfall dissolve only specific outdoor air pollutants owing to the presence of the cations of the particulate matters of the industry activities [39].

V. PROMOTING STRATEGIES MATRIX

Owing to the previous demonstration of passive strategies, which promote outdoor air quality, this section presents the reference matrix. This matrix mainly shapes the correlated relation between the passive strategies, as the horizontal axis, while the vertical axis identifies the microclimate factors affecting air pollutants dispersion. Due to some relations are strong while others are weak, these relations demonstrated with different weights, which requires giving every strategy its own weight in the proposed reference matrix, as illustrated in Table 6.

Table 6: Weighted relations between microclimate factors, and promoting strategies.

No Relationship			Urban Morphology					Building Morphology																		
Secondary Relationship			Site selection	Urban ventilation	Canyon morphology						High rise buildings					Low rise buildings										
Medium Relationship					Symmetric canyons			Asymmetric canyons			Geometry Morphology				Facades Patterns	Roof Morphology								Balconies	Facades Patterns	
Primary Relationship					Avenue	Regular	Deep	Step-down	Step-down	Tapering	Twisting	Varying cross section size	Varying cross section shape	Flat		Arched	Pitched			Sawtooth		Semi shaded				
																	Triangle	Slanted	Wedge-shaped	Single span	Multi span					
Pressure Gradient				●					●	●	●	●	●		●	●	●	●		●	●	●	●	●	●	●
Inflow Conditions	Wind direction	Parallel	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
		Perpendicular	●	●	●	●	●	●	●	●		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
		Oblique	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	Wind speed	<1.5: 2 m/s	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
		≥ 2 m/s	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
		2: 4 m/s	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
		Turbulent flow			●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Typography			●	●					●	●	●	●	●													
Thermal ISO 7	Thermal stability	Stable	●	●	●	●	●		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	
		Unstable	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	
	Walls heating conditions		●	●					●			●					●	●	●	●	●	●				
	Relative Humidity			●	●																					
Rain Fall			●																							

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VI. CONCLUSION

The ongoing impacts of poor air quality need passive strategies to enhance the reduction of outdoor air pollutants. Consequently, this research presents and analyses the ability of urban and building morphology in reshaping the air pollutants dispersion due to the containing of the main variables and parameters related to the initial phases of the planning and design processes. However, promoting strategies face group of possibilities related to microclimate factors as air pollutants dispersion in a street canyon mainly reflect the flow patterns, which depends on microclimate factors; pressure gradient, inflow conditions, thermal conditions, relative humidity, and rainfall. As a result, the proposed reference matrix outlined the interrelationship between passive strategies, and microclimate factors to guide urban planners, and architects to promote outdoor air quality.

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