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An Experimental Cross-Ventilation Performance inside a Single Small Rectangular Room inHurghada, Egypt; As anExample ofWindy Hot Regions

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Abstract: *This Study Investigates The Effect Of Changing The Openings In Two Facing Opposite Walls,In A Single Room, On The Room Ventilation Under Wind-Driven Cross-Ventilation. Measurements Are Performed Inside A Selected Room In A Building Located In The Coastal City Of Hurghada, Egypt. The Cityis Selected As An Example Fora City In A Windy Hot Regionwith Wind Velocities Ranging From 4 M/S To 7 M/S. The Room Is 5 M Long And 3.5 M Wide. The Windwardfaçade Is 5 M Long Andhas A Sliding Door, Inlet Opening. The Leeward Façade Has Two Windows, Outlet Openings. The Position And Width Of The Inlet Opening Are Changed, While The Two Windows On The Back Are Fixed In Position And Width.Three Geometric Configurations Of The Façade Doorareexamined, (I) Configuration A, Where The Width Of The Inlet Opening Is 1/3 The Width Of The Outlet Opening And The Inlet Opening Faces One Of The Outlet Openings, (Ii) Configuration B,Where The Width Of The Inlet Opening Is 1/3 The Width Of The Outlet Opening And The Inlet Opening Faces The Intermediate Wall Between The Two Outlets, And (Iii) Configuration C,Where The Width Of The Inlet Opening Is 2/3 The Width Of The Outlet Opening And The Inlet Opening Partly Faces One Of The Outlet Openings. The Results Show That, Among The Three Configurations, Configuration B Presents The Best Ventilation Conditions. The Air Velocity In More Than 50% Of The Ventilated Space Area Is Within The Acceptable Limit Of 0.5 M/S To 2 M/S.*

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NOMENCLATURE

ΔT_{DR}	Diurnal temperature range [°C]
ΔT_{max}	Reduction of the maximum indoor temperature [°C]

ABBREVIATIONS

ach	Air changes per hour[1]
CFD	Computational fluid dynamics
LES	Large eddy simulation
SSV	Single-sided ventilation
WDCV	Wind-driven cross-ventilation

I. Introduction

Building ventilation is essential to maintain occupants' health and comfort, this can be achieved by mechanical and/or natural means. Natural ventilation has the advantage of low energy usage andlow operating costs[1]. Energy demands of naturally ventilated buildings can be 40% lower than air-conditioned buildings[2], [3]. Natural ventilation in buildings can be buoyancy-driven and/or wind-driven.Buoyancy-driven ventilation, or stack-ventilation, depends on the density difference between the inside and outside air due to the temperature differences. Stack-ventilation is characterized by larger air flows. Wind-driven ventilation, which can be single-sided ventilation or cross-ventilation, depends on the wind speed and the installed building openings.In single-sided ventilation (SSV) the ventilation is only limited to the zone close to the openings, while cross-ventilation covers larger areas.

Wind-driven cross-ventilation (WDCV) depends on ventilation openings on opposite walls of an enclosed space, external wind speed and wind direction[4], [5]. The architectural design decisions of the relative positions of openings and walls can achieve “stagnation” and “venturi” conditions which greatly affects the effectiveness of this method. Stagnation helps to reduce indoor air velocities in case ofundesirable high wind conditions. On the contrary, the venturi effect increases indoor air velocities in case of low wind conditions. Stagnation occurs when an indoor wall faces an inlet opening which decreases indoor air velocities or when wide inlet openings are used. The venturi effect occurs through narrow width openingswhen an inlet opening faces an outlet opening which increases indoor air velocities.

In natural ventilation, in warm and hot climates,thermal comfort inside indoor spaces is achieved via direct or indirect coolingeffects.In the first approach,sometimes referred to as comfort or daytime ventilation, comfort is achieved viathedirect cooling effect by increasing the air speed around the human body. This increasestheconvective heat loss from building occupants and increases the evaporation rates.The effectiveness of this approach depends on the air velocity within the ventilated space. For a humidity that is less than 70%, every 0.15 m/s can compensate 1°C in the indoor air temperature, [6], [7]. The acceptable indoor velocities are 1-2 m/s for temperatures up to 33°C, [6], [8]–[10]. As a rule of a thumb, Givoni[9] proposed that indoor air speeds at the occupants' level (1m above floor) should be within 35-50% of the outdoor wind speed. In the second approach, sometimes referred to as nocturnal or nigh purge ventilation, comfort is achieved via the indirect cooling effect by allowing the night cool air to penetrate inside the building to cool the building thermal mass. In this approach the indoor air temperature is reduced during the succeeding daytime [6], [9]–[12].The effectiveness of this approach depends on night ventilation rates, building exposed area, the thermal conductivity and heat capacity of building material, and the diurnal temperature range, ΔT_{DR}, [10], [7], [13]. As a rule of a thumb, Givoni[10]proposed that, for high thermal mass buildings and modest heat gains, the maximum indoor temperature could be less than the maximum outdoor temperature by 0.35-0.45ΔT_{DR}.For high thermal mass buildings, Shavivet al. [14] proposed Eqs.1-3 to predict the reduction of the maximum indoor temperature, ΔT_{max},for 20 ach, 5 ach and 2 ach night ventilation rates, respectively.

$$\Delta T_{max} = 0.810\ \Delta T_{DR} - 1.627 \tag{1}$$

$$\Delta T_{max} = 0.697\ \Delta T_{DR} - 1.722 \tag{2}$$

$$\Delta T_{max} = 0.599\ \Delta T_{DR} - 1.436 \tag{3}$$

There are several models in the literature that can predict ventilation rates through large openings. The ventilation rate through a building opening is estimated using the orifice equation [15] derived from Bernoulli’s equation.However, in the case of WDCV Per Heiselberg and Sandberg [16] pointed out that thissimple approach was not suitable for flow predictions through large openings. The available methods to analyse WDCV are either basedon (i) theoretical analysis or (ii) full-scale field experiments, or wind tunnel tests or (iii) computational fluid dynamics (CFD) modelling.

Yuan and Glicksman[17] studied analytically a single zone with two openings located at different heights. In their analysis they accounted for both wind-driven and buoyancy-driven flows. They pointed out that natural ventilation can be definedas multiple steady states. Lishman and Woods[18], expanded the work of Yuan and Glickman [17] and added transitional periods in between where either buoyancy or wind-driven dominate.Carrilho da Graçaet al. [19]presented a simplified analytical model for cross-ventilation flow with recirculation regions. Their model characterized the cross-ventilation flow as a result of a confined axisymmetric jet driving one or two recirculation regions. Each of the recirculation regions is modelled as a lid-driven cavity flow. Their model can deal with different angles of impingement and multiple inflow opening configurations.Lo[20], examined wind-drivencross-ventilation, experimentally and numerically. His experimental work included wind tunnel experiments and full-scale experiments.

Karava et al.[21] conducted wind tunnel experiments, with a two-opening scaled model,to study the effect of openings area on the internal pressure and discharge coefficientsforaWDCV configuration. The two adjacent walls had sliding window openings on each wall. Their study showed that the internal pressure coefficient varied with the area ratio of the inlet to outlet openings. Also, the inlet discharge coefficient varied with the inlet opening area and the area ratio of the inlet to outletopenings.LarsenandHeiselberg[22]performed wind tunnel experiments, with a single opening full scale model for a SSV. The goal of their work was to develop an expression for air flowrate that accounts for wind speed and direction and temperature difference. This is in addition to the unsteady effects from the wind near the opening. The developed expression was based on the equation presented by [23]. They observed that ventilation rate is sensitive to the wind incidence angle. Also, they found that the nature of the flow might change from being wind-driven to buoyancy driven, depending on wind speed and temperature difference. Chu et al. [24]ran wind tunnel tests,with a two-opening scaled model, to investigatethe effect of external turbulence intensity on the discharge coefficient and mean flow ratefortwo different WDCV configurations. The configurations studied were two opposite walls and two adjacent walls. The results of their experiments showed that the discharge coefficientwasinsensitive to the wind turbulence intensity,but only sensitive to the window area, window Reynoldsnumber,winddirection and type of flow whetherwind-driven or buoyancydriven.Chu et al. [25]ran wind tunnel tests to investigate the behaviour of WDCV of partitioned buildings. Their results showed that in partitioned buildings the ventilation rate was always lower that single-zone ones. This is due to the extra resistanceproduced by the internal partitions. Ji et al. [26] performed wind tunnel experiments to studythe effect of wind direction fluctuations on WDCV.

Hu et al. [27] used the large eddy simulation (LES) method to investigate the effect of the fluctuating flow rate induced by wind on the ventilation flow rate for a scaled model with two opposite openings. They carried their CFD simulations for two wind directions, normal and parallel to the opening. The results of their simulations showed that the ventilation rate was significantly sensitive to the flow pattern around the building. Bangaleeet al.[28]used the renormalization group (RNG) k–ε turbulence model to simulate the flow phenomena inside and around a full scale building to analyse the indoor air flow for the WDCV and SSV. They studied (i) WDCV for a room with two openings in each of the opposing walls, (ii) SSV for the room with two openings in the windward wall and (iii) SSV for the room with two openings in the leeward wall. The results of their simulations showed that cross-ventilationperformedbetter in all respects.Shen et al. [29] examined five two-equation RANS turbulence models for estimating ventilation rates through wind-driven ventilated buildings. Their CFD results were compared against wind tunnel experimental results. They conducted their experimental work on a building model with ridge openings of two sizes. Their results showed that, for small ridge openings, the standard k–ω model has the least deviation from the experiments. However, as the ridge opening increased the deviation between the numerical predictions and the experiments increased. They attributed this deviation to the lack of reliable technique to measure the wind pressure at the ridge opening.Shetabivash[30] used the k−ω model presented by Wilcox et al.[31]to investigate the effect of opening position and shapeon the natural cross-ventilation.

The aforementioned discussion shows that the design of WDCV is challenging due to the many factors involved. Theoretical predictions are based on over simplified conditions and simplify the design process. However, they may give erroneous predictions for complex buildings. On the other hand, CFD predictions are very detailed, but require expertise and code verification. In this investigation, experimental analysis is used since it provides accurate comprehensive information about the airflow around and inside buildings.

The main objective of the present study is to show how to architecturally adjust the indoor air velocity in the comfortable ranges from 0.5 m/s to 2 m/s. This is achieved by modifying the wall openings in two facing opposite walls, in a single room, under WDCV conditions. Measurements are performed inside a selected room in a building located in the coastal city of Hurghada, Egypt. The windward façade of the room is 5 m long and has a sliding door, inlet opening. The leeward façade has two windows, outlet openings. The position and width of the inlet opening are changed, while the two windows on the back are fixed in position and width. Three geometric configurations of the façade door are examined, (i) configuration A, shown in **Error! Reference source not found.**, where the width of the inlet opening is 1/3 the width of the outlet opening and the inlet opening faces one of the outlet openings, (ii) configuration B, shown in**Error! Reference source not found.**,where the width of the inlet opening is 1/3 the width of the outlet opening and the inlet opening faces the intermediate wall between the two outlets, and (iii) configuration C, shown in**Error! Reference source not found.**,where the width of the inlet opening is 2/3 the width of the outlet openingthe inlet opening faces partly one of the outlet openings.

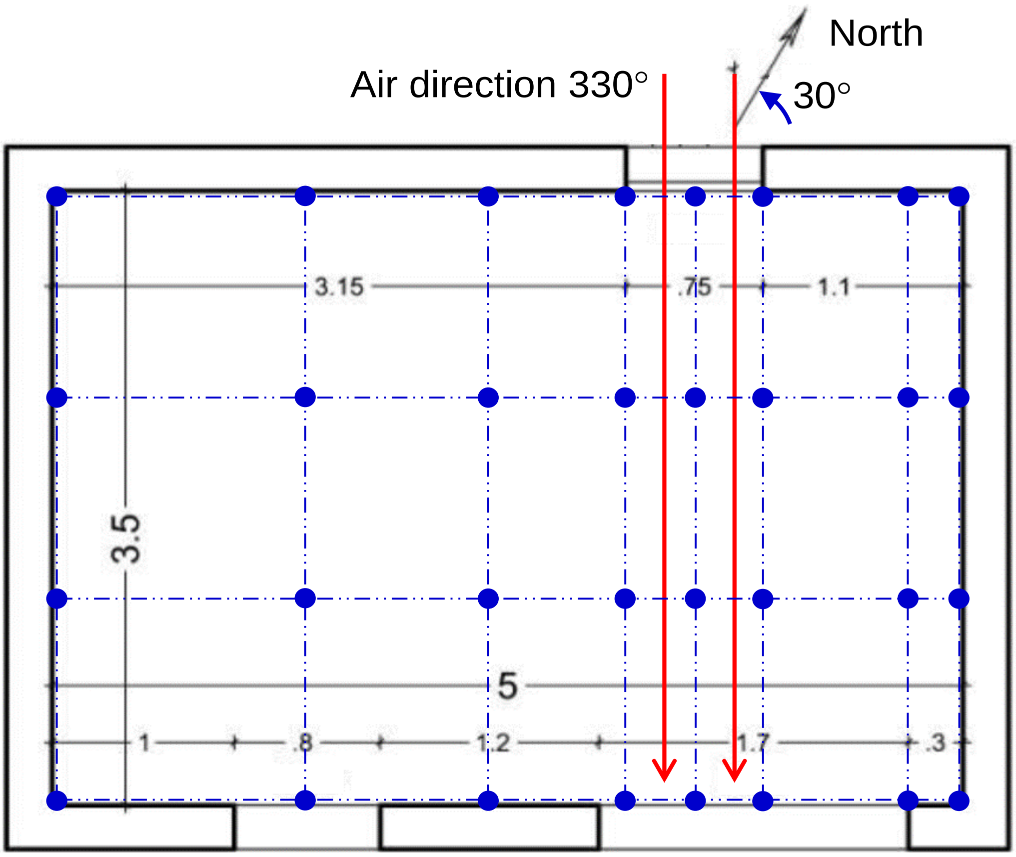


Figure1. Experimental indoor room, configuration A, Venturi condition.

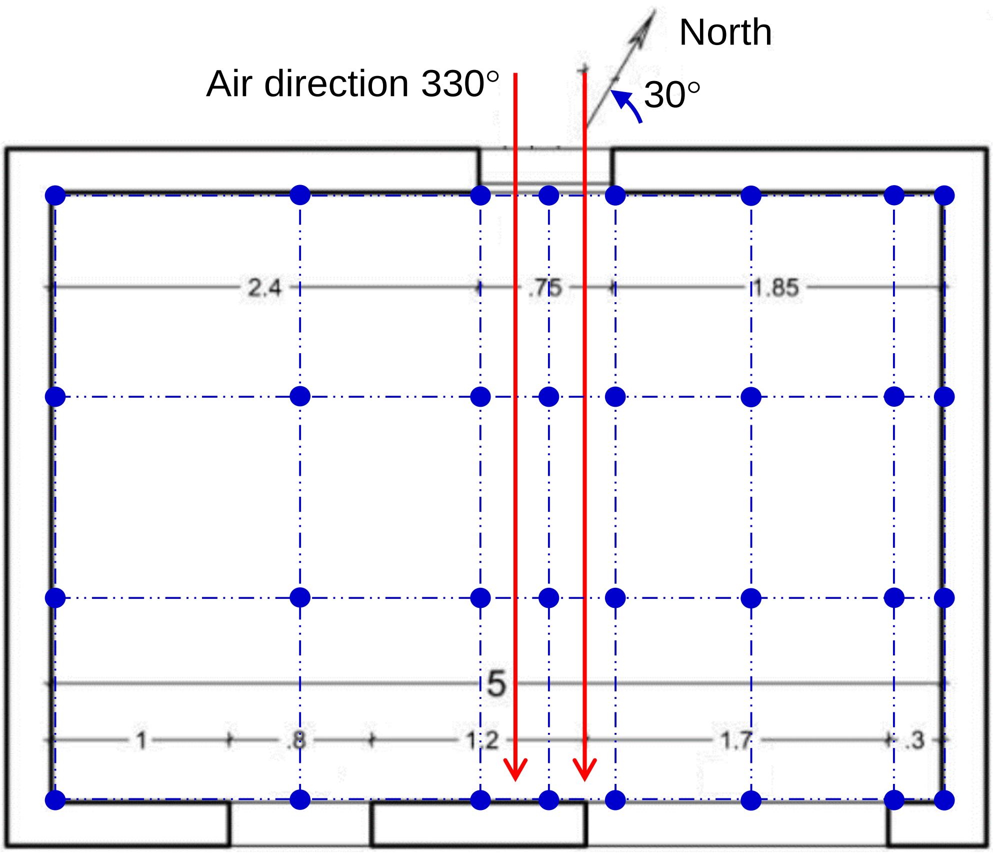


Figure 2.Experimental indoor room, configuration B, stagnation condition.

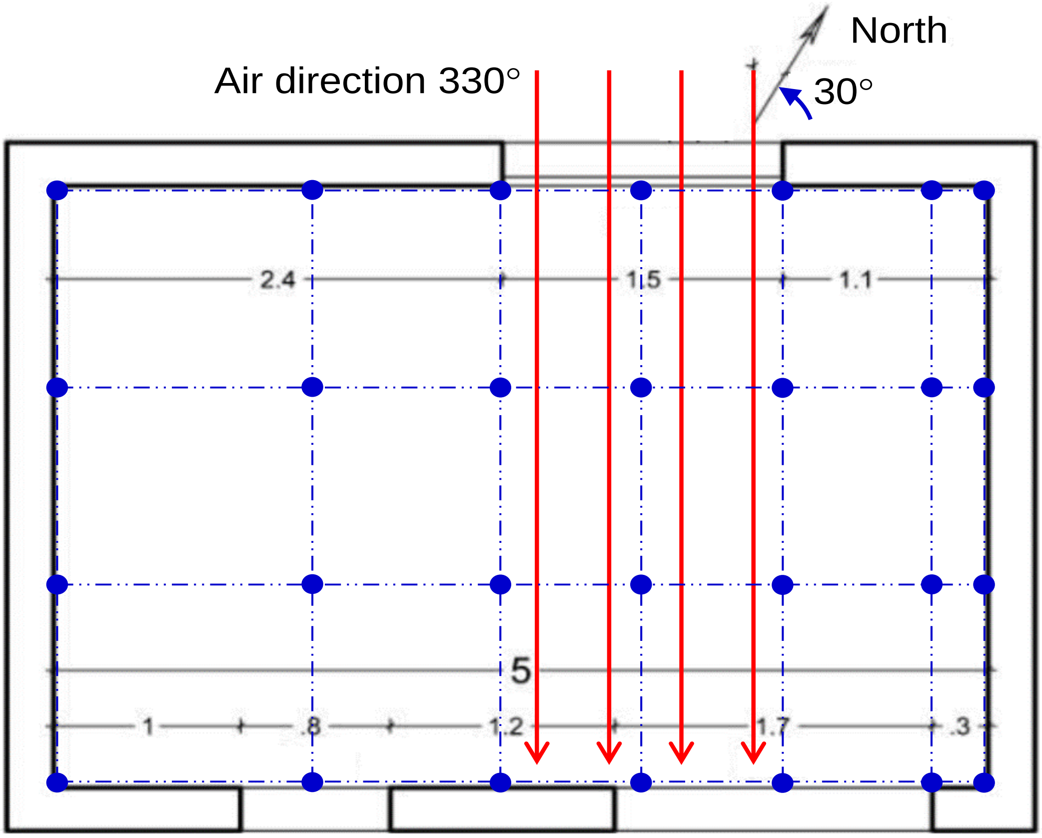


Figure 3.Experimental indoor room, configuration C, stagnation + venturi condition.

II. Method

2.1 Site selection

The city of Hurghada is a coastal city in Egypt on the Red sea coat, shown in **Error! Reference source not found.**. Itlies on the geographical coordinates of 27° 14' 20" N, 33° 50' 9" E.Hurghada, like other regions of Eastern Coast of Egypt, has the highest wind velocities [32]. Themean wind speedis6.7 m/s at a height of 24.5m above sea level[32]. The reason of this high wind velocity is due to the prevailing cool wind that comes from South Europe passes between two limitations; mountains and Red Sea. These limitations causes the constant direction of this prevailing wind; North West is the main direction of the prevailing wind through the year, as shown in **Error! Reference source not found.**,[33].Hurghada is seen to be one of the best examples of a windy hot region for the following reasons:

1. It is distinguished by strong wind 6 m/s or more in 70% of the daily time where a stagnation effect can be applied as an indirect cooling method; wind velocity ranges between weak wind 4 m/s or less in 30% of the daily total time where a venturi effect can be applied, as shown in **Error! Reference source not found.**and**Error! Reference source not found.**.
2. It is distinguished by a high diurnal temperature range, where the outdoor air temperature ranges between 33°C and 40°C in the day-time and 30°C in the night-time, as shown in**Error! Reference source not found.**. Consequently, a venturi effect can be applied as a direct cooling and a stagnation effect can be applied as an indirect cooling method.
3. It is distinguished by being humid at the rate of 50% of the time, as shown in**Error! Reference source not found.**; thus the two methods could apply to it i.e. direct and indirect cooling by ventilation.

Figure 4.Hurghada location, arrow shows prevailing wind direction, [36].

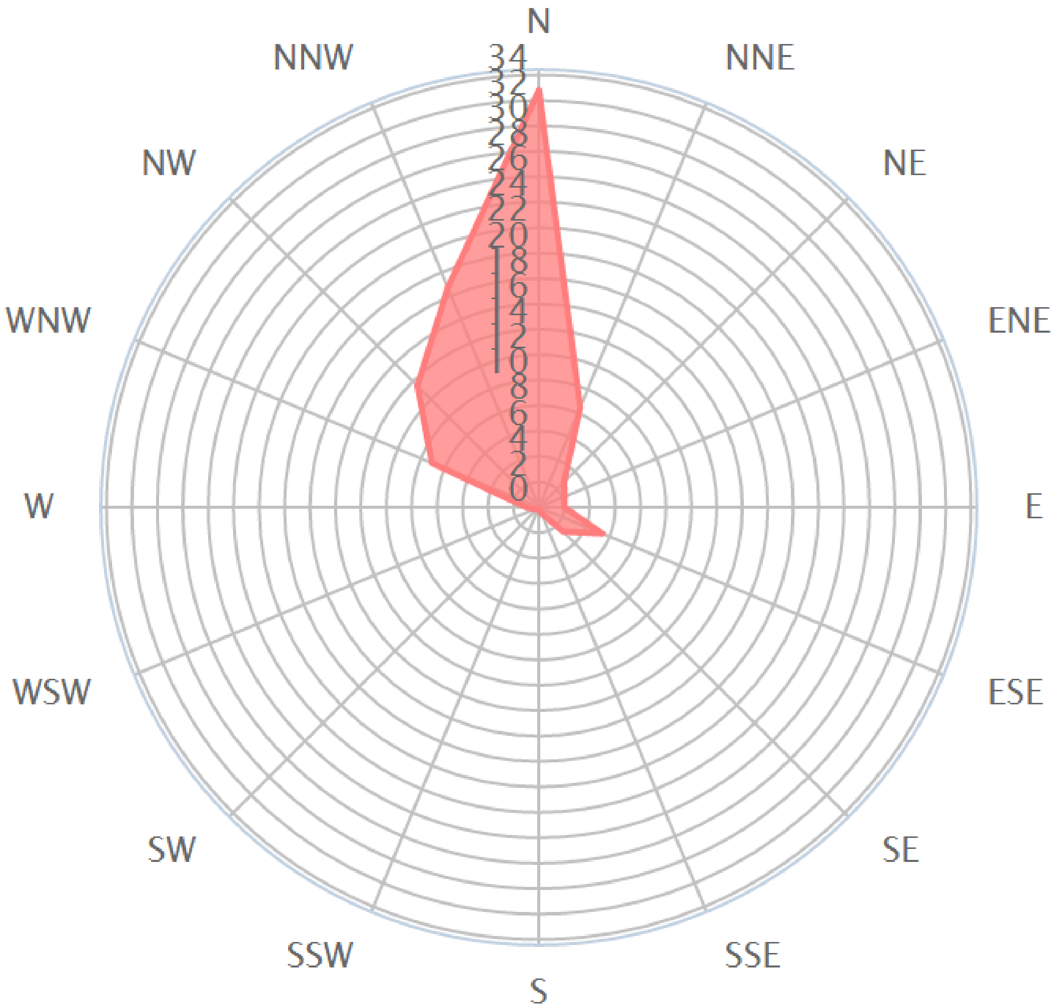


Figure 5.Annual wind direction distribution in (%), [33].

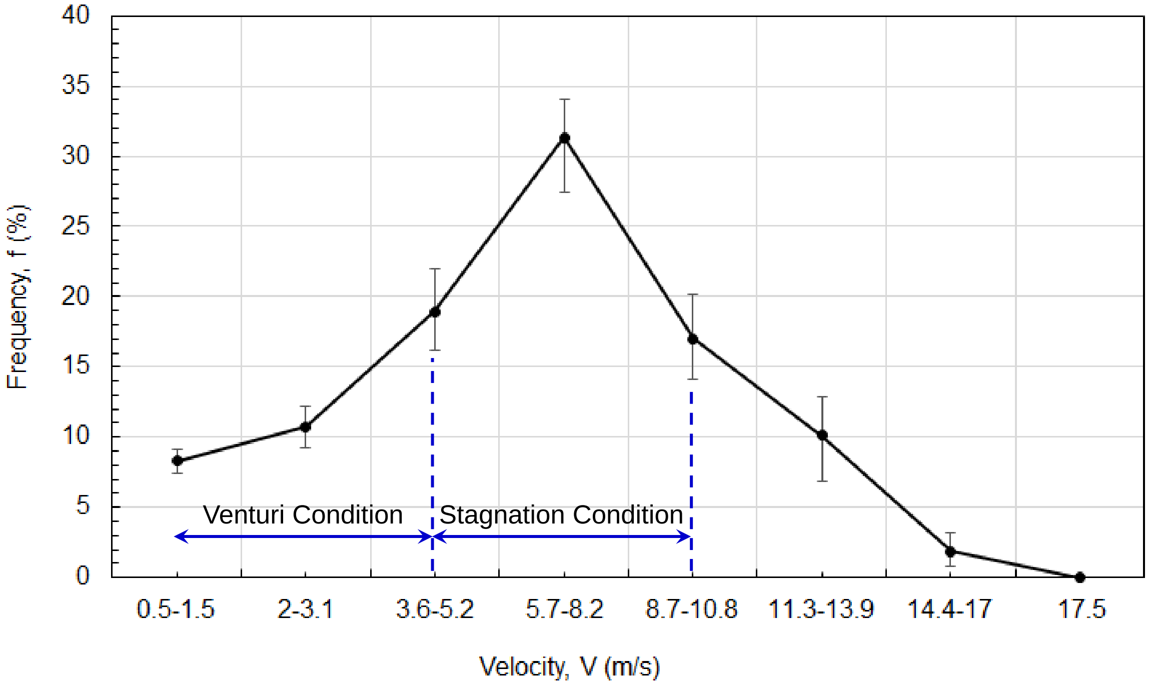


Figure 6. Measured annual mean frequency of wind speeds at Hurghada, bars show the maximum and minimum mean values, [33].

Month	0.5–1.5	2–3.1	3.6–5.2	5.7–8.2	8.7–10.8	11.3–13.9	14.4–17	≥17.5	Mean wind speed
Jan.	8.0	12.0	22.3	35.7	13.8	5.9	1.1	0.1	5.8
Feb.	7.3	11.0	21.3	30.8	15.9	9.6	1.8	0.2	6.3
Mar.	8.2	11.3	20.0	27.5	15.8	11.9	3.0	0.3	6.5
Apr.	11.3	12.0	18.2	25.4	15.4	11.6	3.3	0.3	6.4
May.	7.8	9.8	17.3	29.3	17.9	13.5	2.9	0.4	6.9
Jun.	6.0	7.5	15.0	30.6	21.9	16.0	2.2	0.1	7.4
Jul.	8.8	10.4	16.7	30.1	18.8	12.0	1.5	0.0	6.6
Aug.	7.8	9.8	17.3	31.5	19.9	10.4	1.3	0.0	6.6
Sep.	4.5	7.1	15.4	33.2	23.6	13.7	1.6	0.0	7.0
Oct.	10.4	11.6	20.1	31.4	16.0	7.2	0.7	0.0	5.8
Nov.	11.6	13.5	21.9	35.2	12.1	4.0	0.3	0.1	5.3
Dec.	9.4	13.6	22.1	35.2	12.7	4.9	0.4	0.0	5.5
Annual mean	8.4	10.8	19.0	31.3	17.0	10.1	1.7	0.1	6.4

Table 1. Percentage frequency of wind speeds in m/s at a height of 10 m for Hurghada, [34].

Month	**Temperature (°C),** [35]			**Relative Humidity (%),** [35]			**Mean wind speed (m/s)** [34]
	Max.	**Min.**	**Avg.**	**Max.**	**Min.**	**Avg.**	
Jan.	26.0	10.0	17.1	82	24	49	5.8
Feb.	26.1	8.1	17.7	88	23	45	6.3
Mar.	35.1	10.0	20.6	87	23	44	6.5
Apr.	37.0	15.0	24.4	91	11	40	6.4
May.	38.0	20.0	28.6	89	13	36	6.9
Jun.	40.8	22.4	31.0	68	17	35	7.4
Jul.	39.4	26.0	32.0	74	14	36	6.6
Aug.	39.0	20.7	32.0	95	19	39	6.6
Sep.	38.6	17.7	30.9	79	15	39	7.0
Oct.	36.0	19.0	26.6	94	16	50	5.8
Nov.	31.0	13.0	22.8	100	20	51	5.3
Dec.	31.0	3.0	18.4	100	17	50	5.5

Table 2.Weather data for Hurghada.

2.2 Room selection

A touristic village, shown in**Error! Reference source not found.**, in the city of Hurghada is selected to perform this study.**Error! Reference source not found.**shows the position of the chosen single room that is between two collect walls.Theroom is selected based on the following two criteria (i) the roomposition is perpendicular to the wind direction in order to achieve a regular movement of air flow patterns inside the space, and (ii) the room has a short length and long width to maximize the stagnation and the venturieffects.The room is5 m long and 3.5 m wide and 3 m high. The windwardfaçade is 5 m long and has a sliding door, inlet opening. The leeward façade has two windows, outlet openings. The position and width of the inlet opening are changed, while the two windows on the back are fixed in position and width.

In this study, the relationships among the inlet opening, the outlet openings and the facing walls are used to achieve the stagnation and the venturi conditions. The intermediate wall that is between the two outlet openings, on the leeward façade, is required to obtain the stagnation effect.The variable narrow widths of the inlet opening with respect to the total width of the space are to obtain the venturi effect. The variable positions of the inlet opening with respect to the outlet openings are to obtain the stagnation and the venturieffects.The two facing external wallsagainst wind directionareto achievea two sided-cross ventilation. One of these walls is windward side and the other wall is leeward side to make cross-ventilation more effective.

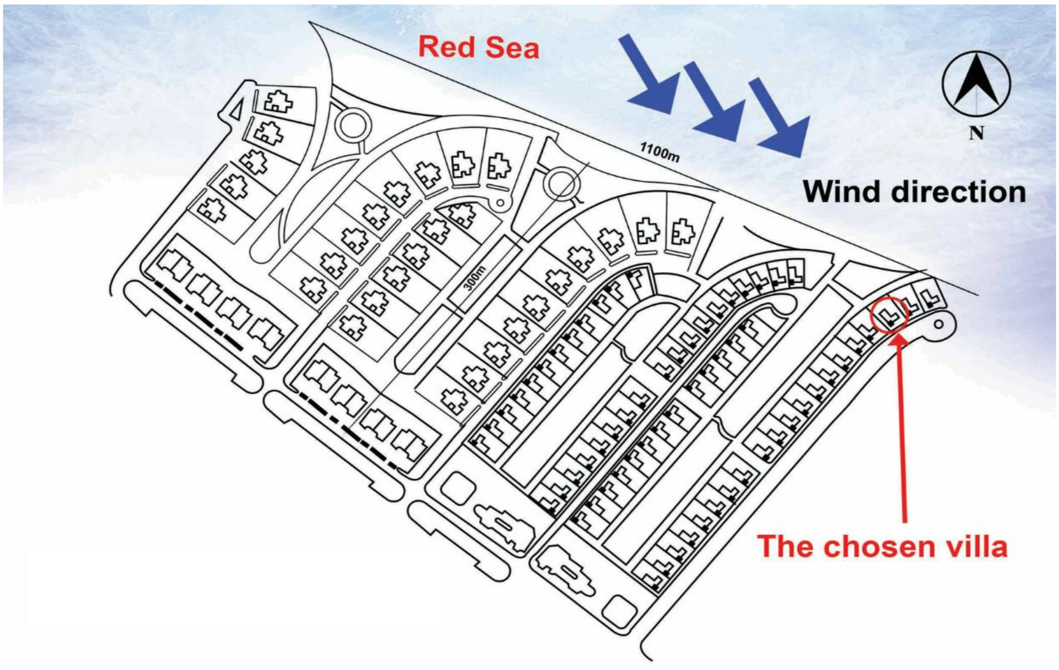


Figure 7.Chosen touristic village in Hurghada region in Egypt.

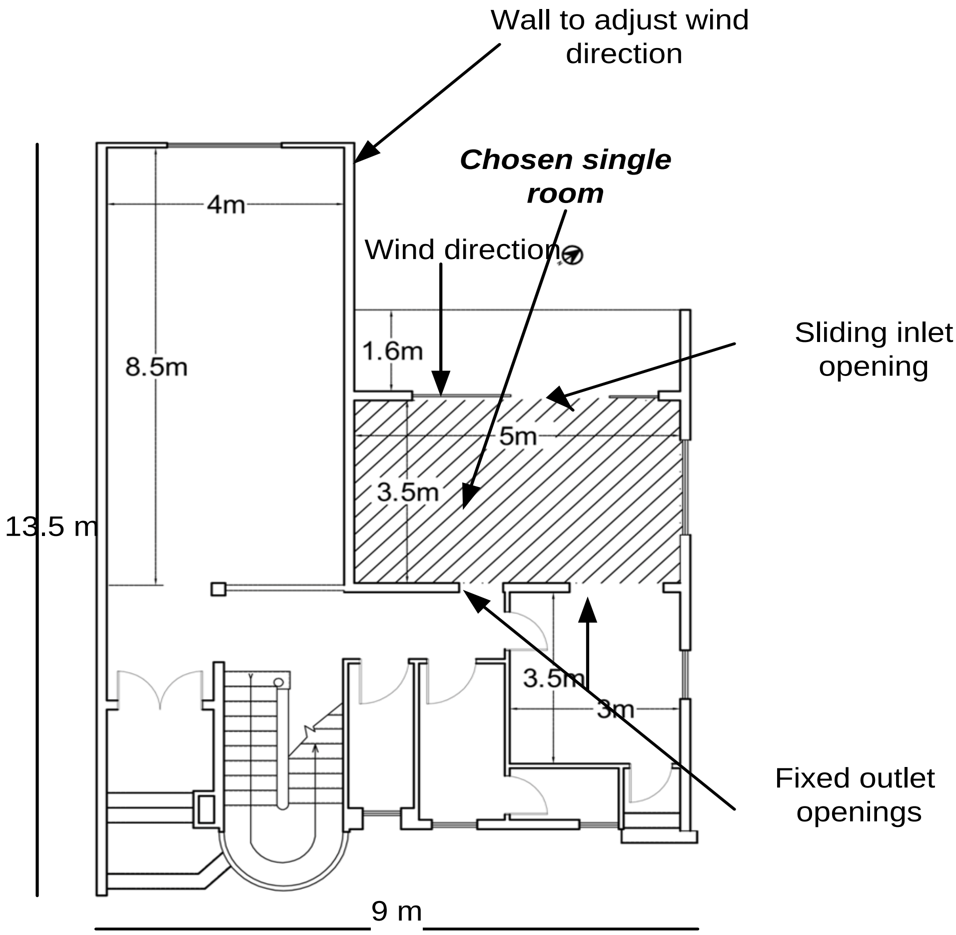


Figure 8. Chosen single room selection from the villa unit in Hurghada region.

2.3 Measuring technique

The effectiveness of a natural ventilation strategy in an interior space can be evaluated by measuring indoor airflow rates, air changes per hour, and indoor air velocities. A portable handheld instrument is used to make indoor measurements. The instrument is equipped with a van anemometer that can measure indoor air velocity from 0 m/s to 20 m/s, with a resolution of 0.1 m/s and an accuracy of about ±0.2m/s. The NTC thermistor in the device measures the indoor temperature with a resolution of 0.1°C and an accuracy of ±0.5°C. For outdoor measurements a portable ambient weather instrument is used. The van anemometer of the instrument can measure air velocities from 0.4 m/s to 40 m/s, with an accuracy of about ±3%. The outdoor temperature is measured with an accuracy of ±1°C. Indoor measurements are averaged over 5 minutes intervals while outdoor ones are averaged over 60 minutes intervals.

To evaluate the effectiveness of the three different configurations, indoor measurements are performed on a grid shown in Figures **Error! Reference source not found.–Error! Reference source not found.**atan elevation of 1.1 m over the ground level. For each point a 10 minute average for the wind speed are obtained. Since measurements are obtained using a hand held probe, the probe is rotated until the speed is maximized to ensure that the measurements are aligned with the air flow velocity vector. In addition to the grid measurements, five extra points are measured, as shown in **Error! Reference source not found.**. These extra points are points of interest representing the inlet and outlets openings, points 1, 2 and 3, respectively, and the centre of the space, point 5.

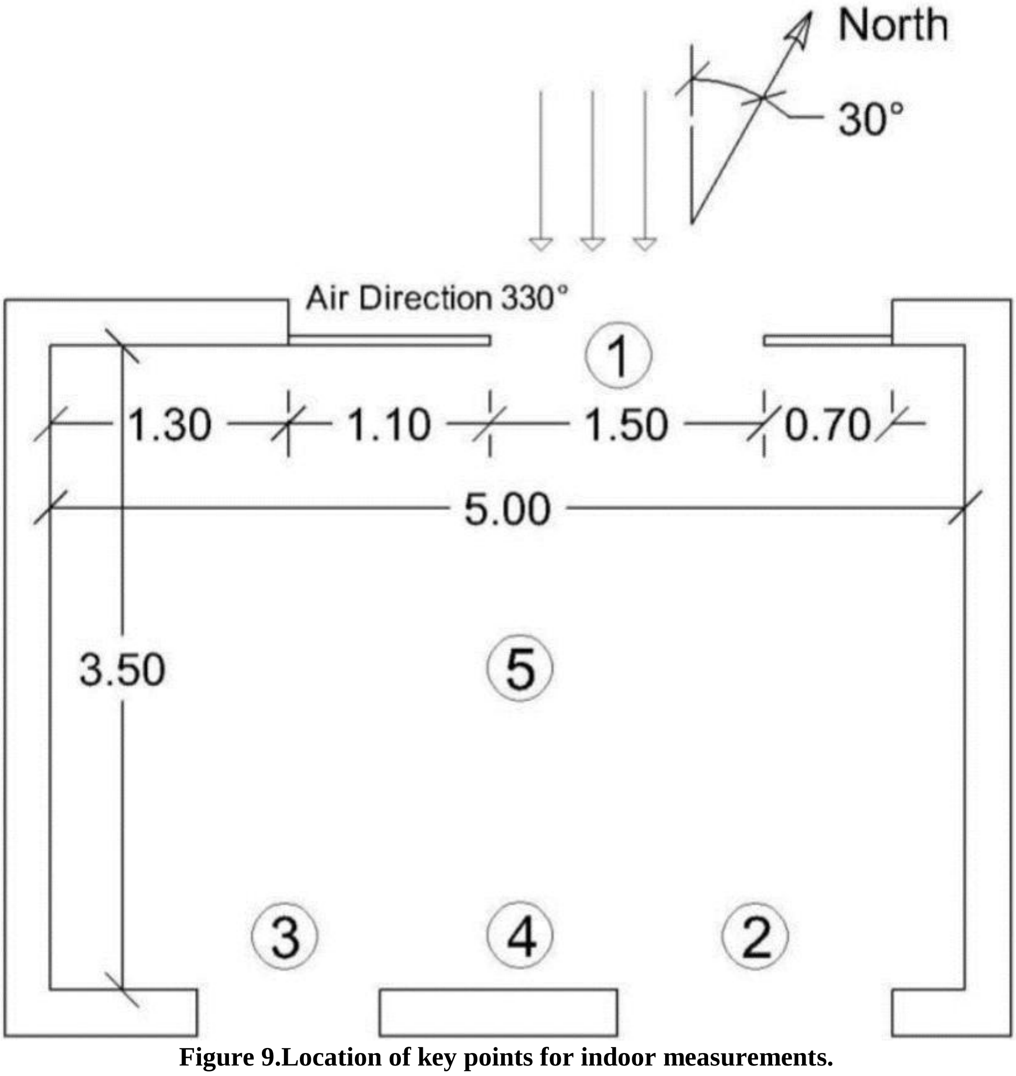


Figure 9.Location of key points for indoor measurements.

III. Results and Discussions

Experiments are performed to evaluate two studies. In the first study, therelativepositionsof the inlet and outlet openings are modified, configurations A, and B. The inlet opening can be aligned with the outlet opening or face a wall to stagnate and further force circulation within the space. In the first case the orientation of the openings suggests that the flow within the space will represent the venturi ventilation. In the second case the orientation of the openings will cause the flow to stagnate on the opposing wall and hence will represent the stagnation ventilation. In the second study, the effect of outdoor air speed will be examined for the optimum opening placement as suggested from the first study. For both studies, field measurements inside the space are obtained and contours for flow speed are presented. The ventilation performance, comfort and cooling effects can be estimated based on these measurements.

3.1 Effect of inlet location and outlets

To achieve the venturi effects in a room, the openings must be aligned to one another as shown in**Error! Reference source not found.**. In this case, configuration A, the airflow will flow from the inlet to the outlet and penetration of the fresh air into the room will depend on the inlet air speed. For very high air speeds little or no fresh air can full fillthe room and the space will be short circuited. For lower air speeds diffusion of the air within the space can occur and ventilation effectiveness can be high. A measure for the ventilation effectiveness is the air speed and circulation within the room. To achieve the stagnation effect the inlet opening should facewalls. In this case,configurationB,the air stagnates at the wall and the fresh air is circulated within the room to exit from the outlets. This configuration is suitable for high outdoor air speeds to avoid short circuiting effects. A third configuration, configuration C,is the mixed venturi-stagnant flow which can be achieved by staggering the inlet and outlet openings.

Figures **Error! Reference source not found.**–**Error! Reference source not found.**presentthe velocity magnitude contours, as a percentage of wind speed, for the three tested configurations. The tests are taken for an outdoor air speed of 5 m/s. The average outdoor temperature and relative humidity are25.5°C and 55%, respectively. Comparing the contour lines, it is possible to deduct the following. For configuration A, the air short circuits the space and exits from the outlets. This is typical in venturi type ventilation, since the openings and otlets are aligned with one another. Even though the air change rate inside the room can be very large, the room is poorly ventilated. For configuration B, the flow mixes mostly inside the room, because the incoming flow stagnates at the opposing wall forcing the air to circulate until it exits the room through the outlets. This configuration is excellent particularly for high outdoor air flow since the stagnation effect reduces the indoor air speeds which is needed for comfort conditions. Configuration C is an intermediate solution between the venturi and stagnation effects. The inlets are staggered such that the incoming flow is distributed between the wall and the outlet, enforcing good circulation inside the room, reduction of flow velocity for increased comfort and higher speed flows short circuit the space and exit from the outlet.

For configuration A, the air speed at the inlet opening is 8 m/s (location 1 shown in **Error! Reference source not found.**). Also, the air speed is 4 m/s at the primary exit (location 2 shown in **Error! Reference source not found.**)and 2.45 m/s at the secondary exit (location 3 shown in **Error! Reference source not found.**), as summarized in **Error! Reference source not found.**. The exit velocities arethe highest reported values in all studied configurations.This is due to the façade effect and the relative position of the inlet and outlet openings that creates a tunnel effect or venturi effect. The observed average indoor velocity is 1.80±0.04 m/s. In this configuration, 52% of the floor area is within the acceptable indoor velocities of 0.5-2 m/s, while the indoor velocities in 30% of the floor area is higher than 2 m/s.

For configuration B, the shapes of indoor air velocity contour lines are curve shapes indicating stagnation condition, as shown in**Error! Reference source not found.**.Although the air velocity at the inlet opening is 160% of the outdoor wind velocity, indoor air velocity at the outlet openings is55% and 15% of outdoor wind velocity because the inlet opening faces the wall. As a result, the observed average indoor velocity is 1.89±0.04 m/s.In this configuration, 60% of the floor area is within the acceptable indoor velocities of 0.5-2 m/s, while the indoor velocities in 30% of the floor area is higher than 2 m/s.

Finally, configuration C is a balanced case between configurations A and B, where the observed average indoor velocity is 1.78±0.04 m/s. In this configuration,25% of the floor area is within the acceptable indoor velocities of 0.5-2 m/s, while the indoor velocities in 39% of the floor area are higher than 2 m/s.

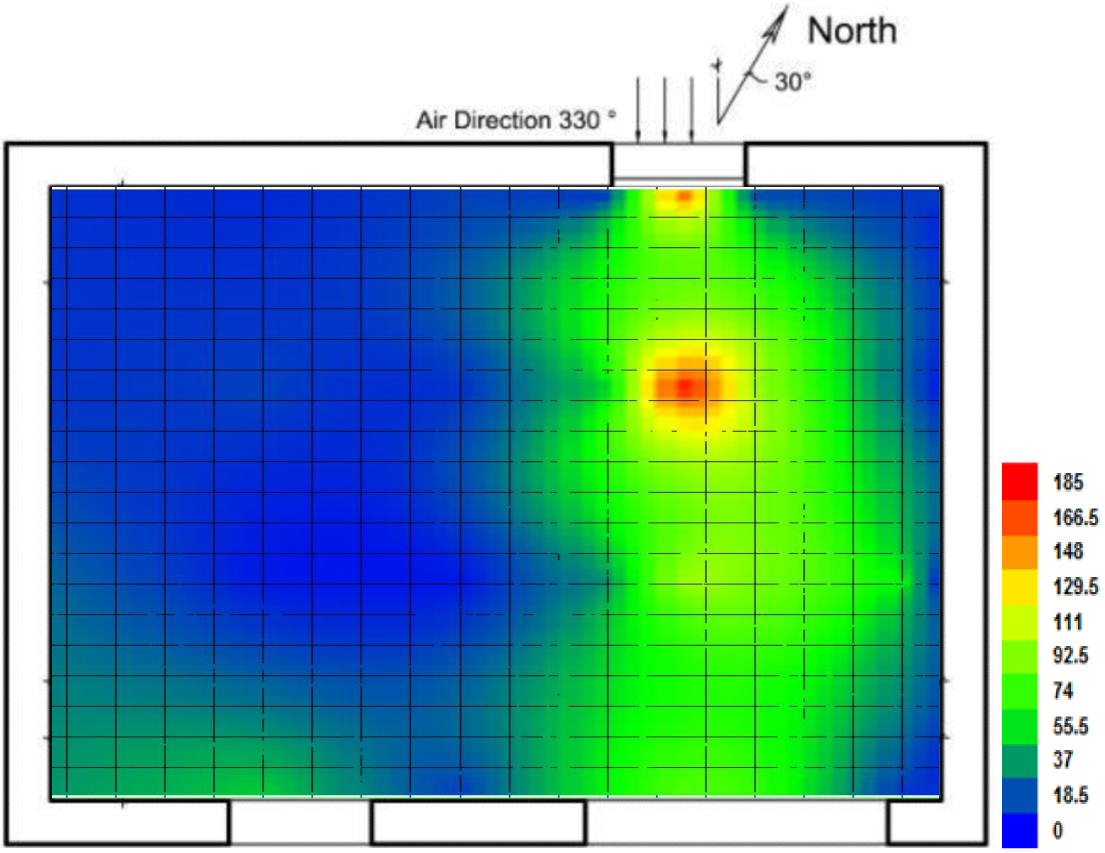


Figure 10.Contours for velocity magnitude as a percentage of wind speed, configuration A. Outside humidity (55%), temperature 25.5°C and wind speed of 5 m/s.

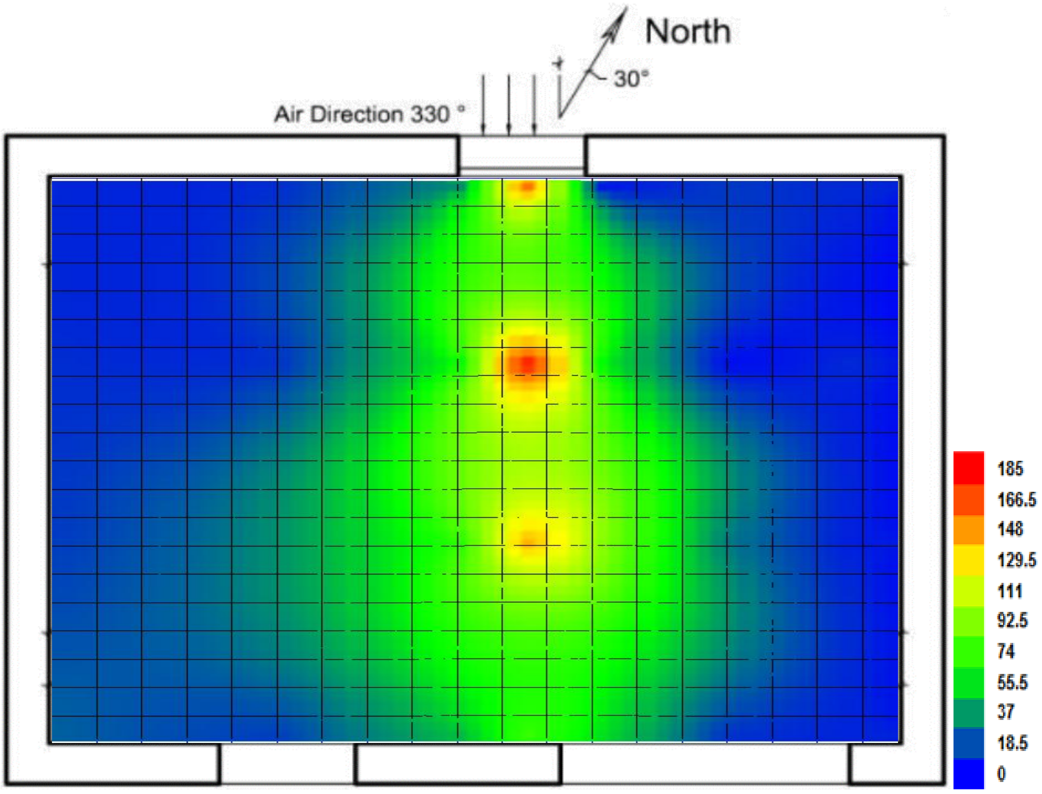


Figure 11.Contours for velocity magnitude as a percentage of wind speed, configuration B. Outside humidity (55%), temperature 25.5°C and wind speed of 5 m/s.

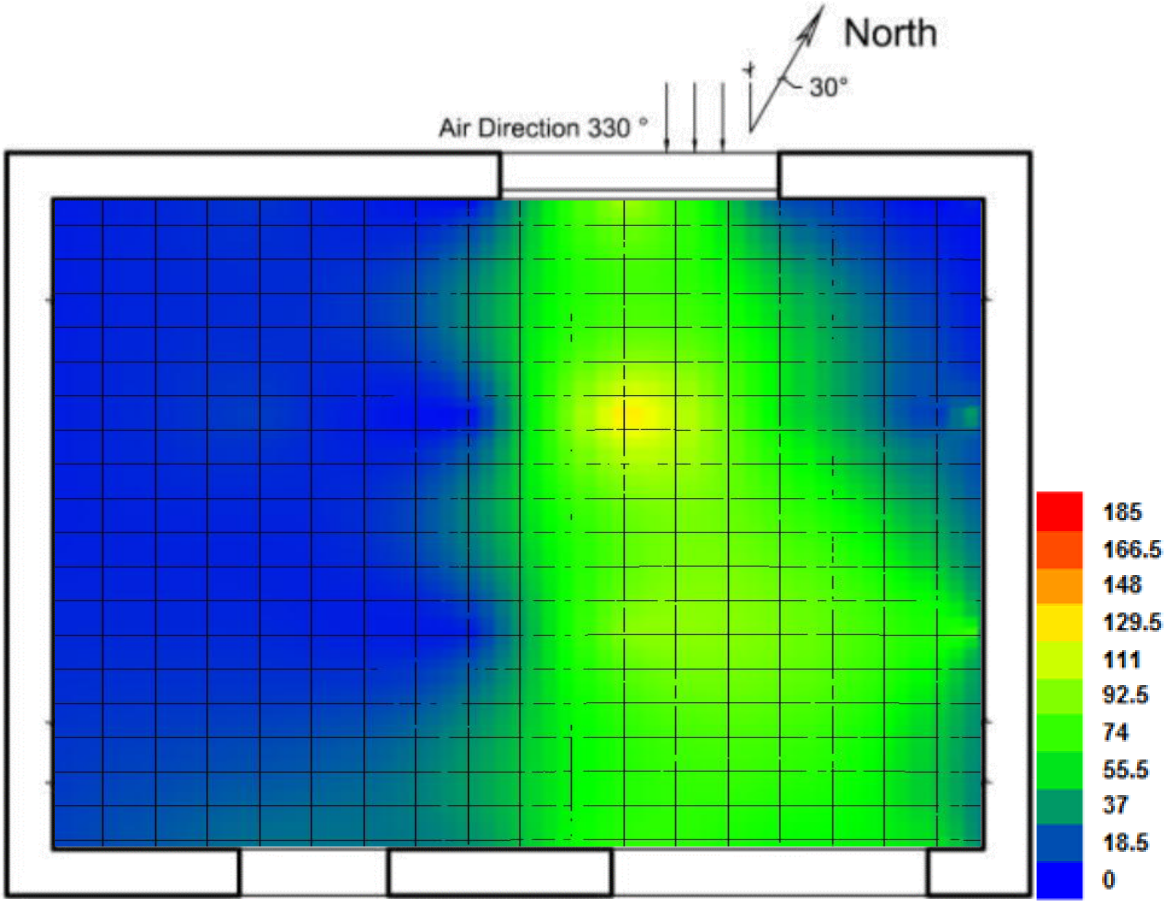


Figure 12.Contours for velocity magnitude as a percentage of wind speed, configuration C. Outside humidity (55%), temperature 25.5°C and wind speed of 5 m/s.

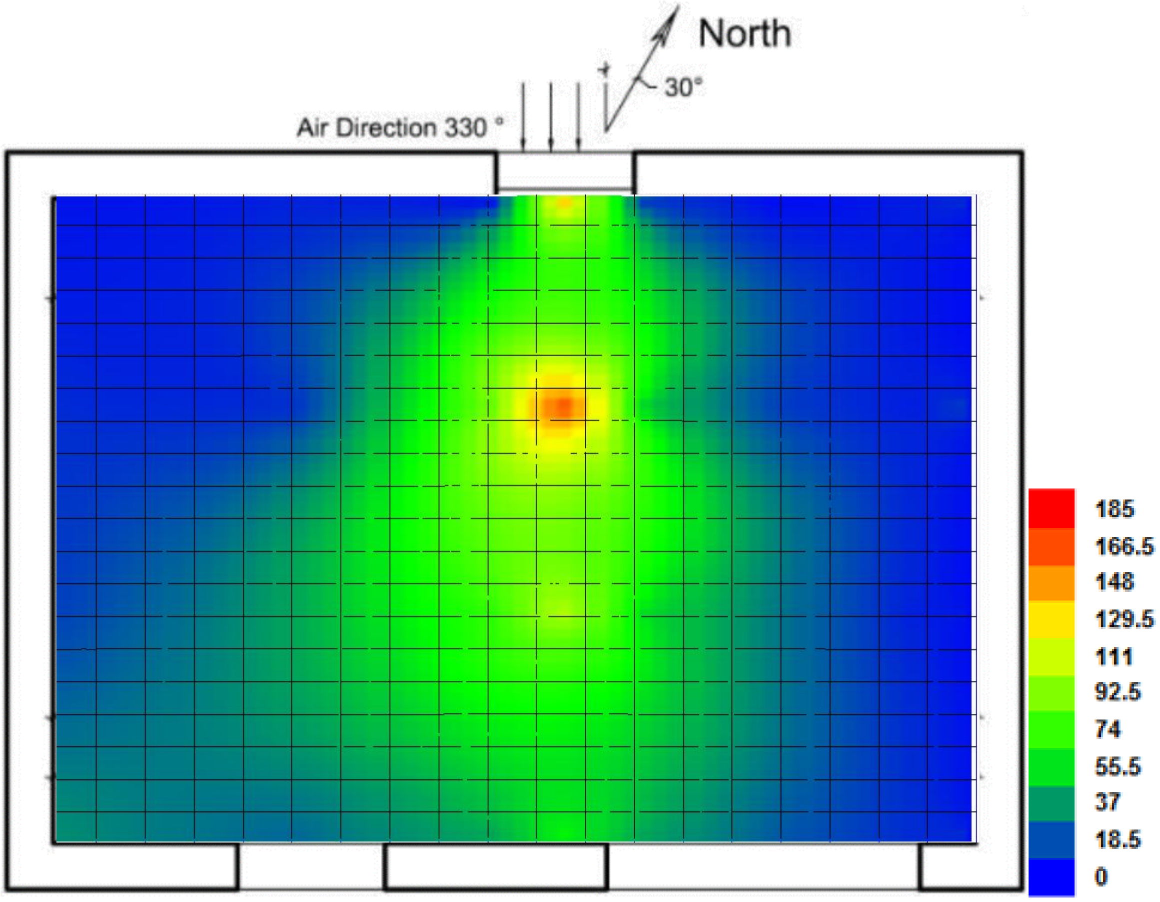
	Configuration A	Configuration B	Configuration C
Inlet	8	8	5.125
Primary exit	4	2.750	2.830
Secondary exit	2.450	0.750	1.500

Table 3.Midpoint indoor velocities in m/s at inlet and outlets, for studied configurations.

3.2 Effect of outdoor air speed

The results of section 3.1 suggest that configuration B presents the best ventilation condition. To examine the effect of outdoor air speed best opening placement, field measurements are performed for an outdoor air speed 3.5 m/s. The outdoor temperature and relative humidity are 25.5°C and 55%, respectively.

Figure 13presents the velocity magnitude contours for the examined configuration. The observed average indoor velocity is 1.19±0.04 m/s.In this configuration, 41% of the floor area is within the acceptable indoor velocities of 0.5-2 m/s, while the indoor velocities in 17% of the floor area are higher than 2 m/s.



'Figure 13.Contours for velocity magnitude as a percentage of wind speed, configuration B. Outside humidity (55%), temperature 25.5°C and wind speed of 3.5 m/s.

IV. Conclusions

The current study investigates the effect of changing the openings in two facing opposite walls, in a single room, on the room ventilation under wind-driven cross-ventilation. Measurements are performed inside a selected room in a building located in the coastal city of Hurghada, Egypt. Three geometric configurations of the façade door are examined, (i) configuration A, where the width of the inlet opening is 1/3 the width of the outlet opening and the inlet opening faces one of the outlet openings, (ii) configuration B,where the width of the inlet opening is 1/3 the width of the outlet opening and the inlet opening faces the intermediate wall between the two outlets, and (iii) configuration C,where the width of the inlet opening is 2/3 the width of the outlet opening and the inlet opening partly faces one of the outlet openings. The results show that, among the three configurations, configuration B presents the best ventilation conditions. The air velocity in more than 50% of the ventilated space area is within the acceptable limit of 0.5 m/s to 2 m/s.

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