The role of traditional Lattice window "Mashrabiya" in delivering single-sided ventilation-A CFD Study

Elwan, Mustafa M [1]

[1] Assistant Professor, Architecture Engineering Department, Tanta University, Gharbia, Egypt

[1] mustafa.elwan@f-eng.tanta.edu.eg

***Abstract* — *Single-sided ventilated spaces are a common type of spaces, which have openings in only a single side, which is responsible for delivering natural ventilation, unfortunately in many buildings, these openings do not deliver the required ventilation into building spaces, despite the Availability of desired prevailing wind, this paper concerns the role of traditional wooden lattice windows "Mashrabiya", in delivering natural ventilation in single-sided ventilated spaces, a computational fluid dynamics CFD simulations program ANSYS was used to investigate air movement behavior, through several unique types of 3D lattice models, to figure out the impact of lattice windows in delivering natural ventilation, results show that some types of Lattice windows with multiple rounded surfaces, create a pressure difference, because of some surfaces of lattice window located upward wind, and some others located leeward, which creates a pressure difference that leads air to move between high-pressure zones to low-pressure zones, and delivers a natural ventilation in single-sided spaces, which could be considered in building design, in order to deliver natural ventilation in single-sided ventilated spaces.*

Keywords — *Natural Ventilation; Lattice window; single-sided ventilation; CFD Simulation.*

I. INTRODUCTION

The Mashrabiya is a kind of opening covered with wooden lattice[1], and it is one of the most prevalent attributes of the Arab-Islamic architecture, it can be observed in many cities like Baghdad, Damascus, Cairo, Jeddah, Tunis[2], and it was known by several names, like Shanasheel, Mushabak, Takhrima, Jaali, and Roshan in many regions, such Iraq, Iran, Yemen, India, Saudi Arabia [1], initially the openings screened by a flat or rounded carved wood, literally The Mashrabiya meant the place reserved for small jars needed to stay cool, and composed of small wooden elements assembled to create a grid[3].

Natural ventilation renowned as an ancient effective technique to cool indoor environments and manage thermal comfort in buildings[4], different ventilation strategies were used in traditional architecture like the "Mashrabiya" traditional Arab oriel window[5], which is one kind of windows with carved wooden latticework that controls light, airflow, humidity, temperature and visual privacy in Arabic Islamic architecture[6], the name Mashrabiya was given also to the space which is enclosed with wooden lattice openings where jars of drinking water were put to cool[7], which ensures a cool air circulation inside the space according to the stack effect theory, due to cooling air bypassing the inlet air on a wet surface, through lower interstices of the Mashrabiya, and expel the un desired air out from the large interstices at the upper part, Mashrabiya were used in interior design as a partition between spaces to increase ventilation.

Some researchers studied many kinds of shutters as a heat storage tool [8], other researchers investigated "Mashrabiya" and it is impact in delivering natural lighting and visual comfort environment[9], "Mashrabiya" represents an opportunity to deliver natural ventilation and protection from solar radiation[10], some researchers studied some kind of windows "Jaranas" as a ventilation tool to reduce the indoor temperature of about 1-2°C[11], However, traditional techniques could be more investigated to figure out its influence on delivering natural ventilation into buildings, Fathy's experimentation led him to discover that different sizes of the interstices (spaces between adjacent balusters) and the diameter of the balusters would affect different functions[5], Kazerooni demonstrate the use of traditional Mashrabiya allow a nice breezy airflow to enter the space and cool it in a passive manner[12], Almerbati.N explained that The functionality of traditional Mashrabiya focused mostly on privacy and ventilation[13], and Baarimah, Aseel mentioned that by understanding and improving Mashrabiaya's limitations, a high-performance Mashrabiya could be achieved and applied in today's contemporary architecture[14], Mashrabiya also can efficiently regulate physical environmental factors, such as wind, heat and light, and improve the occupant's thermal comfort[15].

Egypt has an ancient reputation for lathing wood since the Mameluke era from 1250 to1517 AD, and Cairo marked a breathtaking flowering of Islamic art and became one of the wealthiest cities in the Near East and the center of artistic and intellectual activity[16], in which lathing craft flourished and developed The Mashrabiya and the wooden barriers were two main types of lathing wood, The first was the wide turning such as the wooden fence at the Mardani Mosque, and the second is the lathe known as the Mashrabiya, and it has many forms, and sizes[17], the Mashrabiya is covered by fine pieces of turned wood in a lattice pattern, assembled in complex geometrical patterns, and designed to fit within a frame surrounded these patterns[15], The basic principle of Mashrabiya is a lattice constructed of turned shapes joined and composed together by short turned and ribbed links[18].

Figure. 1. House of Zaynab Khatun Cairo, Egypt[19]

Climatic seasons effect due to the difference in weather temperature leads to contraction and expansion of wood, so the thin thread of wooden cones is assembled by making a delicate cylindrical tongue into the perforated beads, according to the shape to be assembled in many shapes without the use of nails or glue, such as Al-Maimouni, Al-Salibi, and Abu-Sherwan and Al-Mangour lattice shapes, which were used as a wooden partitions and Mashrabiya[4] as shown in figure 1,2.

Givoni [20] found that, in some windows arrangements, higher average indoor air velocities could be obtained at oblique wind angles between 30 and 120 degrees[21], this is particularly true for rooms with two windows located in two facing walls[22], but unfortunately, design requirement does not always allow architects to locate openings in opposite walls to create airflow and deliver cross-ventilation, which requires making sure that air flows from the inlet opening and get out from the outlet opening in the facing wall, or passing through several building spaces to find the outlet openings.

On the contrary, single-sided ventilated rooms are more common because it has openings in only a single side, but it is more complicated to create an airflow in single-sided ventilated spaces because this requires a special handling with openings, to control pressure difference to create the air movement, and deliver single-sided ventilation, various types of openings were designed to enhance the airflow into buildings, However, excessive openings may allow excessive heat into buildings[23], which causes indoor overheating, also unsuitable openings fail to achieve comfort ventilation, This demand a proper design solution to improve air movement to balance the design requirements, Place appropriate windows, could provide natural ventilation, and reduce the demand for mechanical air conditioning[24].

Some window elements like fly screens and lattice windows, reduce airflow rate, so to decrease this interference with delivering ventilation, it is recommended to increase the area of these screens much greater than the area of the opening itself, like placing screens over a porch in front of the openings to reduce airflow interference[25], therefor putting lattice windows in front of balconies and enlarging it is area reduces the interference of the screens with the airflow.

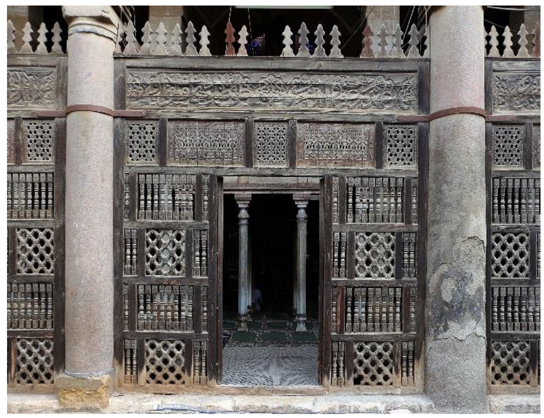
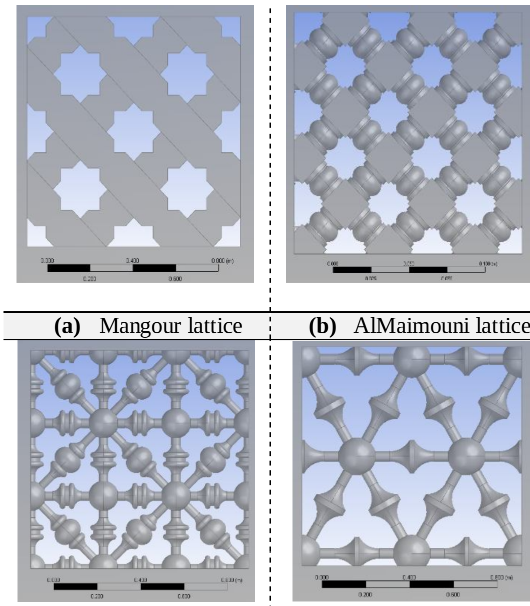


Figure 2. Mosque of Amir al-Maridani Cairo, Egypt[26]

In both cases of natural air movement, stack effect, and pressure difference the Mashrabiya as the primary inlet, acts a critical role in how the air flows through the space, also improves a cycle of moving air masses, from the zone of high pressure to that of low pressure[27], the inlet air flow rate is affected by the parameters of size and porosity of the Mashrabiya, the inlet air flow rate increases by increasing the size of openings of the Mashrabiya which named porosity factor PF[28], The size for a Mashrabiya depending on the desired flow rate, indicated by the porosity of the screen and the airflow driver[10], according to the predicted prevailing wind[29].

This paper study the natural ventilation through a common wooden lattice window types, to improve nature ventilation, the research tries to investigate the effect of lattice wooden window on delivering natural ventilation in terms of single-sided spaces, by using a three-dimensional Computational Fluid Dynamics analysis CFD, applied to a single-sided ventilated room to get detailed information about airflow, for different configurations, and how these wooden lattice types improve delivering ventilation to the depth of the room and spread the air movement along the width of the room, by studying the air pressure difference at the upwind window, created by some common lattice window types, such as Al-Maimouni, Al-Salibi, and Abu-Sherwan and Al-Mangour as shown in figure 3.



(a) Mangour lattice | **(b)** AlMaimouni lattice | **(c)** Al-Salibi lattice | **(d)** AbuSherwan lattice

Figure 3. wooden lattice window types

II. MATERIALS AND METHODS

Accurate Computational Fluid Dynamics CFD simulation is essential for evaluation of natural ventilation for buildings, CFD simulations can be very sensitive to a lot of computational parameters set by the user[30], natural ventilation is difficult to precisely predict, CFD allows full control over the boundary conditions, and easily and efficiently allows parametric studies to be performed[31] so that CFD models suited for studying and optimizing the natural ventilation, construction of the mesh geometry was done by ANSYS ICEM CFD in ANSYS 14.5 Workbench platform (ANSYS Inc), ANSYS FLUENT simulations were used to investigate airflow patterns in steady-state condition[32].

To study Lattice window performance in terms of natural ventilation, a square single-sided model room with smooth surfaces were used, with changing the typology of the lattice window, five configurations were studied as shown in Fig. 3, In the first one a standard opening, 1.0m long and 1.0m high, is installed in the windward façade in the other four hypotheses, four common wooden lattice window types Al-Mangour, Al-Maimouni, Al-Salibi, and AbuSherwan, fixed to the window opening[33].

The openings considered always open in the models, the natural ventilation analysis simulation was carried out through ANSYS FLUENT software to solve the governing equations at each grid of the computational domain, the study model is a single-sided ventilated space, it has been considered to investigate the flow phenomena inside a full-scale building of 3m length×3m width×3m height, the thickness of the walls and ceiling is 0.10 m, the floor of the room has been considered as surface wall free of thickness, The square-shaped window has a dimension of 1.0m high ×1.0m width, the center of the window is located at 1.5m high from the ground, at the middle of the outside wall of the room, the outside air velocity is 3 m/s, blowing by angle 45 degrees, the ground of the surroundings and the outer surface of the building are smooth walls, as shown in figure 4.

The internal flow was modeled by using the standard k– ε turbulence model, the effective viscosity is the sum of the molecular viscosity and a turbulent viscosity, which is derived from the turbulence kinetic energy (k), Evola and Popov [34] explained that it is not a major concerned in natural ventilation slight disagreement between the result of LES and RNG k–ε which was observed in the outside of the box, Chen [35], investigated eight different turbulence models to study indoor airflows and concluded that RNGk–ε model [36] might be the best, the numerical solution is carried out by using ANSYS FLUENT software, the flow is steady case, RNG k–ε model is considered for simulating the turbulence for accuracy results with the robustness of the solution [37], AutoCAD 2016 was used for generating 3D model, ANSYS ICEM CFD 14.5 has been used for the entire grid generation, solutions were considered converged when the residuals of continuity, momentum, and turbulence were small than 1x10-4 and when there was no remarkable change in results .

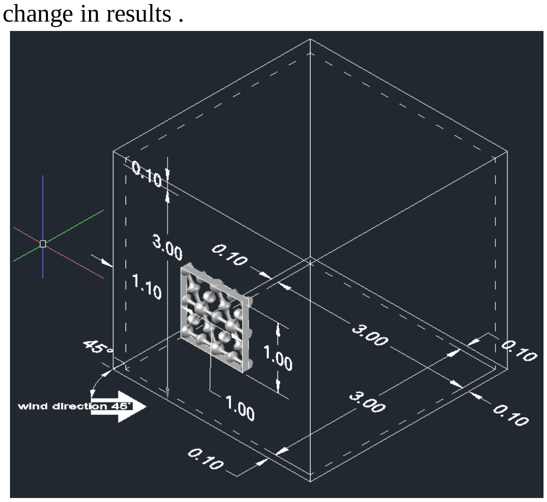


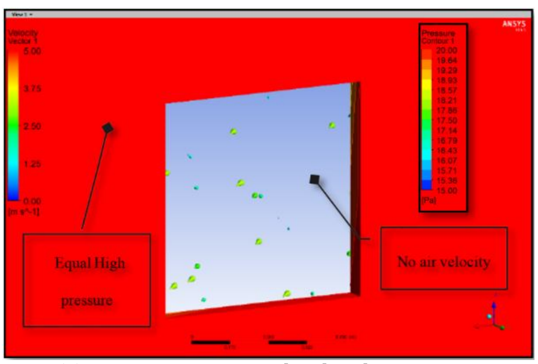
Figure 4. The model room with a single opening in the windward wall

III. RESULTS AND DISCUSSION

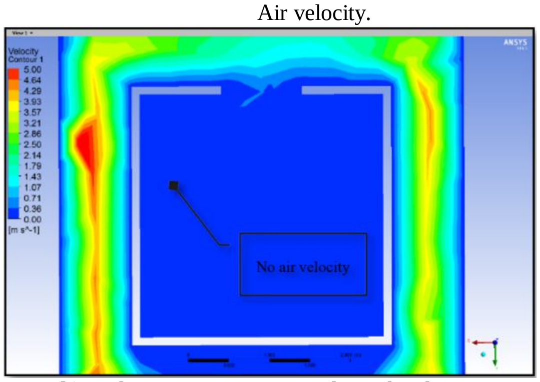
Airflow is one of the beneficial functions of the traditional Mashrabiya[14], Five experiments were made, to investigate air movement behavior, through an ordinary window, square-shaped, with an area of 1m2, at windward air velocity 3m/s, oblique to window with by 45 degrees, the other four experiments, investigate the impact of common lattice window types Al-Mangour, Al-Maimouni, Al-Salibi, and AbuSherwan as shown in figures 5-9.

1) first experiment a standard opening, 1.0m width, and 1.0m high, installed at the windward façade without a lattice window, and results shows:

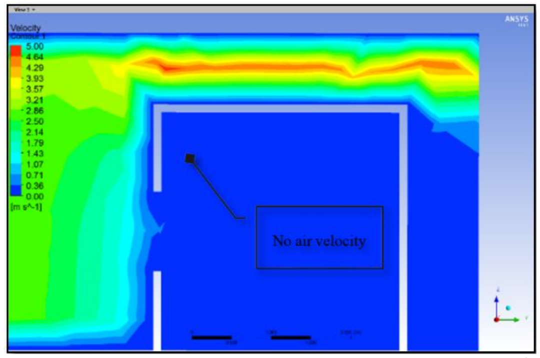
- an equal pressure contour 20pa, at the inner side of the Winward wall, and the colored arrows show that there is no air movement through opening and inlet airspeed is 0.00 m/s, as shown in figure 5 (a).
- there is no air movement at level 1.5-meter-High, in the model room without a lattice window, as shown by the velocity contour in figure 5 (b).
- there is no air movement in the middle of the single-sided ventilated room, with square-shaped windows 1.00 m2, without a lattice window as shown in figure 5 (c).



(a) pressure contour and Colored arrows represent Air velocity.



(b) velocity contour section plan at level 1.5-meter-High In the model room

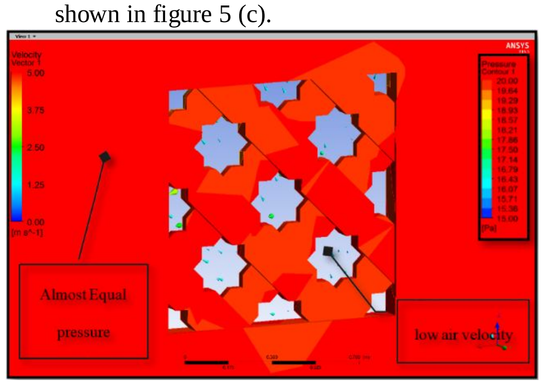


(c) Velocity contour cross-section in the middle of the model room.

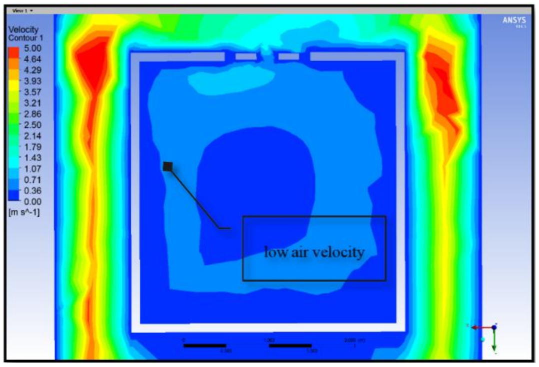
Figure. 5. The first experiment a standard opening 1.0 m^2, installed in the windward façade without a lattice window

2) Second experiment a standard opening, 1.0m width, and 1.0m high, installed at the windward façade with Al-Mangour lattice window shape.

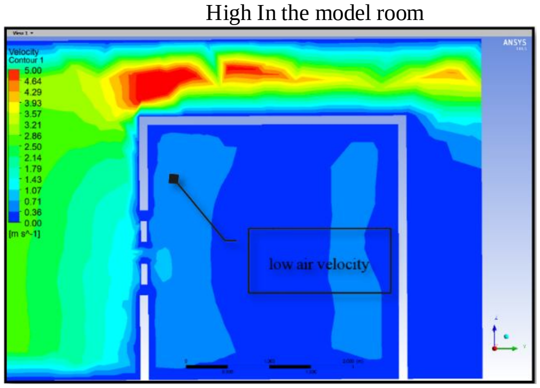
- A pressure contour shows a small range of gradual pressure range, from 19.29 to 20.00 pa, at the internal side of the Windward wall, due to Oblique wind with 3 m/s velocity, as shown in figure 6 (a).
- Colored arrows show there is a weak airflow coming through Al-Mangour lattice window opening, and inlet airspeed is 0.7 m/s, as shown in figure 6 (a).
- A velocity contour plan shows that there is a barely air movement near the opening with velocity up to 1.07 m/s at level 1.5-meter-High, as shown in figure 6 (b).
- A velocity contour section shows, a barely air movement near the opening, with velocity up to 1.07 m/s in the middle of the model room, as shown in figure 5 (c).



(a) pressure contour and Colored arrows represent Air velocity through Al-Mangour lattice window shape.



(b) velocity contour section plan at level 1.5-meter-High In the model room

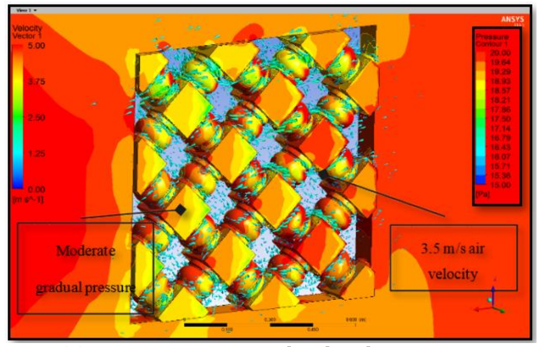


(c) Velocity contour cross-section in the middle of the model room.

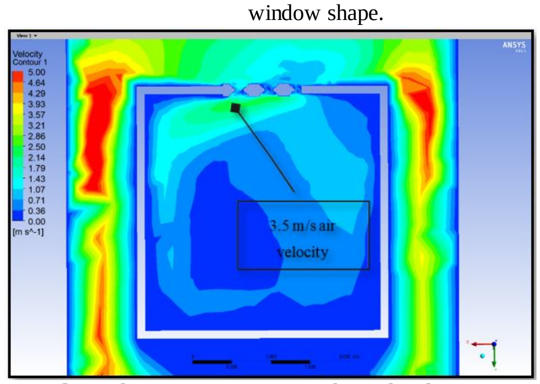
Figure. 6. Second experiment a standard opening 1.0 m^2, installed in the windward façade with Al-Mangour lattice window shape.

3) Third experiment a standard opening, 1.0m width, and 1.0m high, installed in the windward façade with Al-Maimouni lattice window shape.

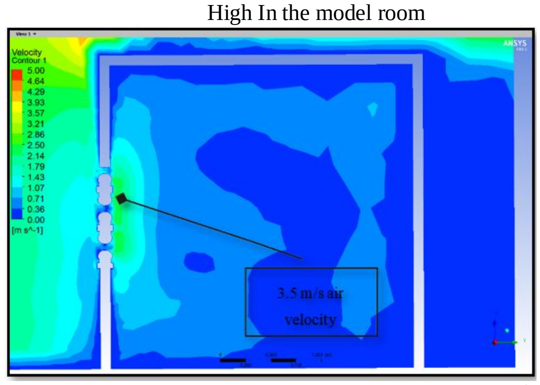
- A pressure contour shows a moderate range of gradual pressure, from 17.14 to 20.00 pa, at the internal side of the Windward wall, as shown in figure 7 (a).
- Colored arrows show there is an airflow coming through Al-Mangour lattice window opening, and inlet airspeed is up to 3.5 m/s, due to external Oblique wind with 3 m/s velocity, as shown in figure 7 (a).
- A velocity contour plan shows an air movement, with a velocity range from 0.36 up to 3.5 m/s, at level 1.5-meter-High, as shown in figure 7 (b).
- A velocity contour section shows an air movement, with a velocity range, from 0.36 up to 3.5 m/s, in the middle of a model room, as shown in figure 7 (c).



(a) pressure contour and Colored arrows represent Air velocity through Al-Maimouni lattice window shape.



(b) velocity contour section plan at level 1.5-meter-High In the model room



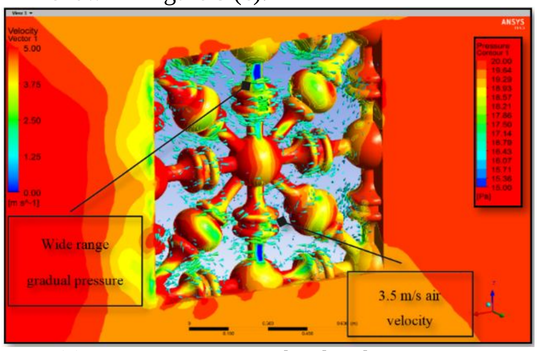
(c) Velocity contour cross-section in the middle of the model room

Figure. 7 Third experiment a standard opening 1.0 m^2, installed in the windward façade with Al-Maimouni lattice window shape.

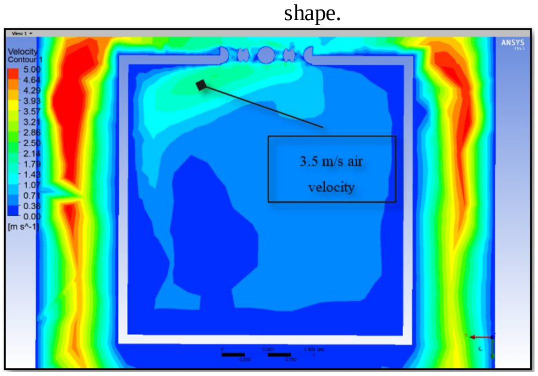
4) Fourth experiment a standard opening, 1.0m width, and 1.0m high, installed at the windward façade with Al-Salibi lattice window shape.

- A pressure contour shows a wide range of gradual pressure range, from 15.00 to 20.00 pa at the internal side of the Windward wall, due to Oblique wind with 3 m/s velocity, as shown in figure 8 (a).
- Colored arrows show an airflow coming through Al-Salibi lattice window opening, and inlet airspeed is up to 3.5 m/s, as shown in figure 8 (a).

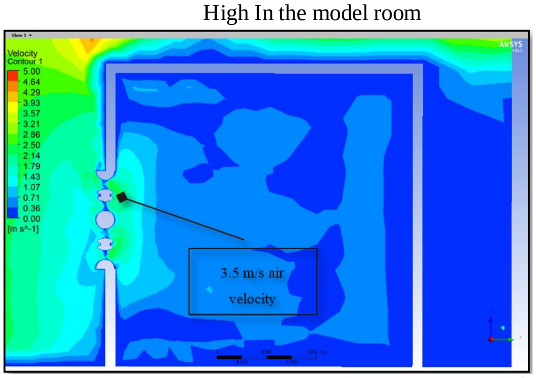
- A velocity contour plan shows an air movement with a velocity range from 0.36 up to 3.5 m/s at level 1.5-meter-High, as shown in figure 8 (b).
- A velocity contour section shows an air movement with a velocity range from 0.36 up to 3.5 m/s, in the middle of the model room, as shown in figure 8 (c).



(a) pressure contour and Colored arrows represent Air velocity through Al-Salibi lattice window shape.



(b) velocity contour section plan at level 1.5-meter-High In the model room

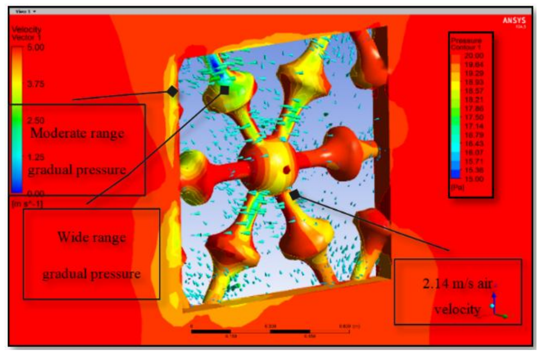


(c) Velocity contour cross-section in the middle of the model room.

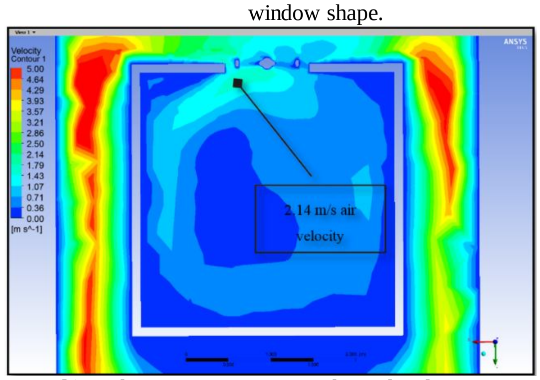
Figure. 8 Fourth experiment with a standard opening, 1.0 m^2 width, and 1.0m high, installed in the windward façade with Al-Salibi lattice window shape.

5) Fifth experiment, a standard opening 1.0m width, and 1.0m high, installed at the windward façade, with AbuSherwan lattice window shape.

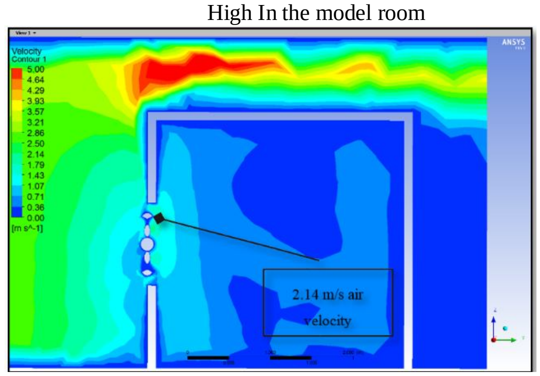
- A pressure contour shows a wide range of gradual pressure range, from 15.00 to 20.00 pa, at AbuSherwan lattice window, and a gradual pressure range from 18.93 to 20.00 pa at the internal side of the Windward wall due to Oblique wind with 3 m/s velocity, as shown in figure 9 (a).
- Colored arrows show an airflow coming through AbuSherwan lattice window opening, and inlet airspeed is up to 3.5 m/s, as shown in figure 9 (a).
- A velocity contour plan shows an air movement with a velocity range from 0.36 up to 2.14 m/s, at level 1.5-meter-High in the model room, as shown in figure 9 (b).
- A velocity contour section shows an air movement, with a velocity range from 0.36 up to 2.14 m/s in the middle of model room, as shown in figure 9 (c).



(a) pressure contour and Colored arrows represent Air velocity through AbuSherwan lattice window shape.



(b) velocity contour section plan at level 1.5-meter-High In the model room



(c) Velocity contour cross-section in the middle of the model room.

Figure. 9 Fifth experiment, a standard opening 1.0 m^2 width, and 1.0m high, installed in the windward façade, with AbuSherwan lattice window shape.

Results demonstrated that the squared window without latticework, did not deliver single-sided ventilation, to the model room, due to oblique wind with velocity 3m/s, on the contrary, the lattice window delivered a single-sided ventilation to the model room, as shown in the experiment 3,4, and 5, with velocity up to 3.5 m/s, with all-around characterized proliferation course inside the room space, as shown in Figures from 5 to 9, these figures illustrate the airspeed distribution upon the lattice window type.

It is critical to take note of internal airspeed distribution contingent upon the rounded cross-section, which has multiple surfaces creates a pressure difference, like the Al-Salibi lattice window type which distinguished by multi rounded surfaces, in contrary the Al-Mangour lattice-type which distinguished by plain surfaces that creates a little pressure difference, providing a weak airflow inside the single-sided ventilated spaces.

So, there is a clear positive relationship, between the multiple rounded cross-section of lattice windows Mashrabiya, and creating a pressure difference, that causes air movement, and delivering single-sided ventilation, as shown as in figures 10,11.

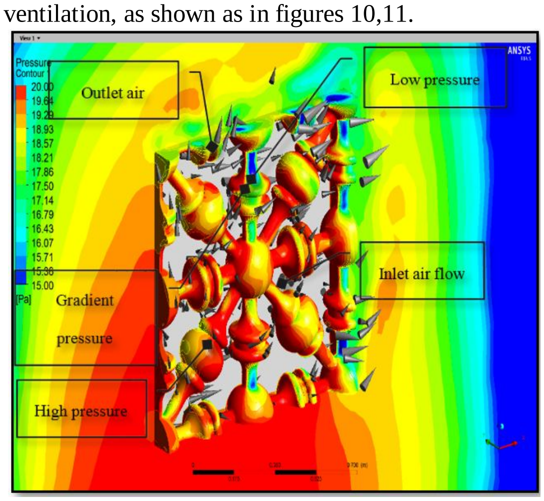


Figure. 11. The square-shaped opening 1.00 m2 with Al-Salibi lattice window shape at the Winward side of oblique wind with velocity 3m/s

A pressure contour shows a wide range of gradual pressure, from 15.00 to 20.00 pa, at Al-Salibi lattice window shape, and due to special rounded cross-section elements of the lattice window, which acting as wing walls, a pressure difference occurs due to several surfaces angle facing airflow, so some openings located in high-pressure zones, pressure difference allow air to move between high-pressure zone to low-pressure zone creating a single-sided ventilation.

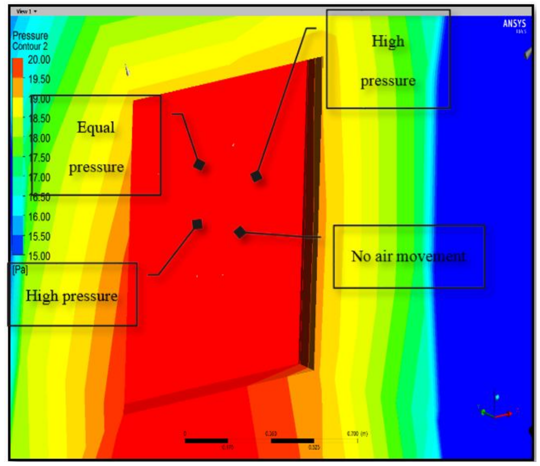


Figure. 10. The square-shaped opening 1.00 m^2 without lattice window at the Winward side of oblique wind with velocity 3m/s

A pressure contour shows an equal pressure 20 pa, all over the square model window without a lattice window, this equal pressure does not allow air to move between the high-pressure zone to the low-pressure zone and does not deliver single-sided ventilation.

IV. CONCLUSION

. This paper discussed the role of traditional lattice windows Mashrabiya, in delivering natural ventilation, in single-sided ventilated spaces, a square single-sided ventilated model room, with five different types of lattice windows Al-Mangour, Al-Maimouni, Al-Salibi, and Abu-Sherwan were investigated by using a computational fluid dynamics program Ansys Fluent, to find out the impact of Mashrabiya on delivering single-sided ventilation.

The results revealed how Mashrabiya could be adjusted to deliver internal airflow, Porosity, geometry shape, and overall size are primary factors that influence the performance of the traditional Mashrabiya, the shape of the baluster and curves diameter, which affects the pressure deference of the screen, was the variable which was most frequently changed to deliver single-sided ventilation, with velocity up to 3.5 m/s due to oblique windward with velocity 3 m/s, special cross rounded elements of Mashrabiya, create a pressure difference zones because of its multiple rounded surfaces facing upwind airflow, some openings of Mashrabiya are located in high-pressure zones acting as inlet openings, and other openings located in the suction zone acting as an outlet opening, this which leads air to move from high-pressure zones to low-pressure zones, and creates single-sided ventilation.

So, this paper demonstrates a direct relationship, between the multiple rounded cross-sections of lattice windows, and creating a pressure difference, that causes air movement and delivers a single-sided ventilation, which could be considered in designing single-sided ventilated spaces.

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