[Computational and Experimental Investigation on Natural Ventilation through Wind Catchers and Window Openings all provided With Wing Walls]

"Natural Ventilation Process"

-Mechanical Engineering-

(Engineering Scientific Paper)

انطلاقا من قول رسول الله نبينا محمد صلى الله عليه وسلم:

"إذا مات ابن آدم انقطع عمله إلا من ثلاث: صدقة جارية،أو علم ينتفع به، أو ولد صالح يدعو له"

ولأن زكاة العلم نشره، فإن هذا البحث هو علم ينتفع به وصدقة جارية على روح المتوفية المهندسة/ سيدة نصر الجابري السيد زهو" رحمها الله وأسكنها أعلى فسيح جناته وجازاها بالحسنات إحسانا وبشدة مرضها عفوا وغفرانا وانطلاقا من قول الله تعالى:"وقفوهم إنهم مسؤولون" وتحقيقا لمسؤولية الوصية الملقاة على عاتق ابن المهندسة المذكورة أعلاه، قام ابنها السيد المهندس: عبدالله صالح محمود صالح"

بإهداء هذا البحث لروحها الطاهرة سائلا العلي القدير أن يجعله في ميزان حسناتها ، كما أن هذا البحث هو إهداء لمعالي السيد الدكتور المهندس/ فاروق الحكيم" الأمين العام لجمعية المهندسين المصرية،

وفيما يلي نبذة مختصرة عن المهندسة سيدة نصر الجابري السيد زهو رحمها الله

أولا: حاصلة على بكالوريوس الهندسة تخصص "ميكانيكا قوى" عام ١٩٨٣م من كلية الهندسة بشبرا التابعة حينئذ لجامعة الزقازيق، وتم قيد المهندسة المتوفية رحمها الله منذ هذا العام بنقابة المهندسين المصرية بشعبة الهندسة الميكانيكية .

ثانيا: عضوة بجمعية الهندسين المصرية وكذلك جمعية المهندسين الميكانيكيين المصرية.

ثالثا: حاصلة على درجة الماجيستير في العلوم الهندسية بهندسة القوى الميكانيكية من كلية الهندسة بجامعة عين شمس عام ٢٠١٤.

رابعا: أشرفت - رحمها الله - على العديد من األقسام أثناء عملها كمهندسة ميكانيكا بشركة النصر لصناعة المحولات والمنتجات الكهربائية منذ عام ١٩٨٣ حتى عام ١٩٩٦ .

خامسا:قامت بتأليف كتاب هندسي علمي في نفس موضوع هذا البحث، وتم إيداعه بدار الكتب المصرية برقم إيداع محلي (8200/2023) ، وبرقم إيداع دولي (978-977-94-5291-3) Isbn Mobile Number: (+201030276987)

[Computational and Experimental Investigation on Natural Ventilation through Wind Catchers and Window Openings all provided With Wing Walls]

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Abstract

In Natural Ventilation, Air passes through Wind Catchers, window's openings provided with wings walls. The Performance of the window openings and wind catchers provided with wingwalls is based on the driving force of wind. The numerical model is based on Navier-Stokes equations coupled with Realizable (k- ε) turbulence model represented on momentum equations. The commercial code used for these equations is FLUENT code which performs (CFD). The study showed the velocity distribution of air, volume flow rate and (ACH) are increased while providing the wind catcher room with wing walls. Windows Openings and Wind Catchers in building provided with Wings Walls are factors including aerodynamic characteristics of flow conditions and building geometry. Nejat previous Wind tunnel experimental work is re-investigated for Wind catcher model at FLUENT software and also atwind Tunnel measurement, good agreement is found between CFD & Wind tunnel experimental new work. To validate the results, FLUENT meshing and FLUENT software were used under the same reported conditions. The previous results are compared with the newly calculated values in order to confirm the correctness of the software application and good agreement is found.

Nomenclature

A	Area	[m^2]
C	Constant of integration	[-]
H	Height of the building	[m]
K	Kinetic energy per unit mass	[m^2/s^2]
L	Length of the window	[m]
Q	Volume flow rate	[m3/s]
Re	Reynolds number	[-]
u	Wind Speed	[m/s]
v	Air velocity	[m/s]
V	Volume of the building	[m^3]
W	Width of the window	[m]
ΔP	Pressure difference between inflow and outflow	[Pa]
ε	Dissipation Rate per unit mass	[m^2/s^3]
μ	dynamic viscosity	[Pa.s]
ρ	Density of air	[kg/m^3]

Abbreviations

ACH	Air change per hour	[1/h]
BC	Boundary conditions	
CFD	Computational Fluid Dynamics	
LES	Large eddy simulation	
NVCP	Natural Ventilation Cooling Potential	
RANS	Reynolds average Navier-Stokes equation	
RTM	Realizable K- ε turbulent model	
RNG	Renormalization Group	
SBOS	Sick Building Opening syndrome	

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1- Introduction: Providing solutions for effective natural ventilation in buildings is a topic that receives increasing attention from building designers and researches. On an one hand, the fresh air supply from natural ventilation forms a sustainable alternative for more energy-intensive typesof mechanical Ventilation. On another hand, it can serve as a strategy for improving Inhabitants comfort conditions by harnessing the cooling potential of air in the ambient environment.

Wind Catchers are building structures that support Air flow through the utilization of pressuredifference throughout the structure and the openings it has along with the variable wind. Flowfield that surrounds the building, a wind catcher can act as either air supply or extract system addition, the wind induced pressure differences can result in significant flow velocity, which enables the potential for energy harvesting, Previous studies have identified wind catchers as ahigh potential technology for enabling natural ventilation in buildings. In this study we have provided an overview of previous steps taken for the development of wind catchers. The wind catchers concept is ground for lots of renewable ideas to utilize its environment fact to improveair flow systems to be able to satisfy modern Wind-Driven Ventilation assessment of ancient and commercial modern wind-catchers Renewable Energy (H. Montazeri).

Natural ventilation is the process of supplying and removing air by Natural wind forces, i.e. drive natural ventilation of buildings. There are a large number of Wind driven and stack drivenventilation, Ref. or Source: Web: www. gilberts blackpool

governing factors in natural ventilation, such as wind speed and its turbulence, the shape and dimensions of ventilation building opening such as wind catcher and windows openings. Hot summer conditions havinghigh temperatures above the internal level lead to the cut off of all external air resources until the temperature drops to more acceptable levels. A Wind catcher is a top–down, roof mounted, omni-directional used for naturally ventilating buildings. Wind Catchers work usually by tunneling the air in a series of air openings to the room utilizing the air pressure gradient and out of the room by lowering the pressure of wind inside it. The Wind catcher concept has beenaround for centuries and is common in the Middle East.

Nejat-Fatimah (2016) Passive cooling systems can be a promising alternative to reduce energyconsumption. Wind Catchers are considered to be one of the very known methods for air cooling by utilizing the wind pressure gradient to create a uniform profile of air ventilation distribution in buildings. Since most of the previous wind catcher studies assessed the design characteristics, 2nd Part

Indoor air quality and thermal comfort assessment Computational analysis of wind driven natural ventilation in buildings Evaluation of a two-sided wind catcher integrated with wing wall (as a new design) and comparison with a conventional wind catcherconsumption d-y.

Fatimah-Jomeh-Zadeh (2017) Integration of “wing wall” with wind catchers was explored forlow wind speed-- Experimental scaled wind tunnel testing and CFD simulation were used for analysis -- Performance of wind catchers with various wing wall angles (5º to 70º) were compared – The optimum angle range for the wing wall in terms of inflow was between 15º-30º - compared with a conventional wind catcher. They declared that coherence between windcatchers and wing walls can expectedly improve the air flow.

Hossein-Dehghani (2018) has done an analyzed a four-sided wind tower structure at the intersection of a room and a courtyard at different angles and he used ANSYS Fluent to to simulate the flow field through the generated grid. He carried out a wind tunnel experiment onthe same model mentioned before and used trial and error for optimizing the air flow rate at each wind angle. The results they had were satisfying as they had for 61.5% of all the angles the wind tower was working as a wind catcher getting air outside from it.

Montazeri (2017) has performed a CFD simulation of cross-ventilation between structures through wind catchers embedded in rooftops and he came to the conclusion that the effect of outlet openings is very difficult to determine because of interrelated outside factors such as theaerodynamics of wind catchers themselves and building geometry. Prior to this study, researchers investigated the effect of wind opening positions and building geometry on the airflow but they didn’t see how they affect cross ventilation. The paper therefore represents an evaluation of the opening positions on the air flow based on three metrics: induced airflow rate,age of air and air change efficiency. The results indicate that using the openings close to the wind catcher won’t improve the induced airflow.

Givoni (2009) was the first one to analyze the effect of wing wall on natural ventilation of theroom having only 2 openings. Later 6-(Haw et al (2012), studied wind-induced natural ventilation tower under hot and humid conditions Results showed a higher extraction airflow rate comparing to other wind ventilators in the market. The analysis showed that the tower of the experiment could produce high air changes per hour (ACH) for indoor building environment in hot weathers. The flow rate recorded was 10,000 m^3/h at a external air velocityof 0.1m/s and an average of 57 ACH.

Davoud Jafaria (2017) Experimental and numerical study of natural ventilation in (four-sidedwind tower) traps in the past, wind towers were applied as the main architectural part of building construction in the desert areas of Iran. The aforementioned tall buildings were used as cooling blocks in the residential districts. In the present study, the effect of symmetric four-sided wind tower in flow induction to the bottom space has been analyzed by using a wind tunnel and numerical simulations. The flow was assumed to be three dimensional, unsteady, compressible and turbulent and they were therefore modeled by placing them at a laboratory wind tunnel.

(Lo et al (2013) the steady state result showed that it is possible for combined wind tunnel- CFD to predict the averaged cross ventilation through small openings adequately. Similarly, the transient result showed that the fluctuation of the flow at the openings could be predicted at a frequency as high as 0.1 Hz. The experiment utilized the wind tunnel pressure data as an assessment for a building cross ventilation as part of structural analysis.

MaK et al (2007) The paper presented a numerical study of the ventilation performance of wingwalls using computational fluid dynamics (CFD). Two-dimensional and three-dimensional simulations are compared with the published experimental results. The results indicated wing wall can improve natural ventilation through doubling of the mean inside air speed relative to wind speed at various wind speeds and wind angles and air change per hour. The best recordedangle was 45^{o} for wing wall improvement. Even if there are some discrepancies between them,the study also shows that 3D CFD simulation has same similar results.

In the current article, two ways of investigation will be taken: 1) experimental work,

2- Numerical simulation (CFD).

2 - Experimental and numerical domain

The aim of the present work is to investigate the effects of number of windows and wing wallson Volume Flow rate and ACH which affecting the velocity distribution inside tested zone. Total cases are discussed numerically. Of course it is difficult to perform the experiment for allof these models , so the experiment has been performed for Two cases. The experimental andnumerical geometry are shown in Figs. 1, and 2.

Figure 1: building model with wind catcher only, Case-1

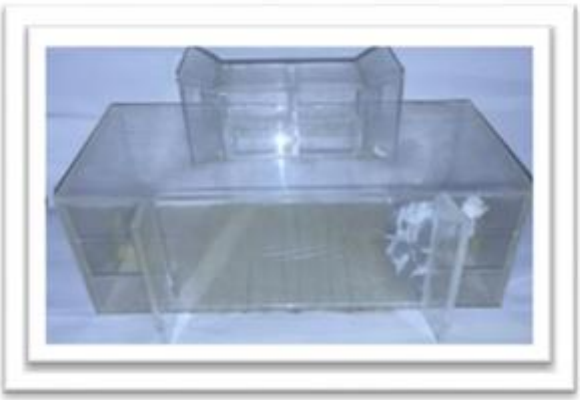

Figure 2: Building model with wind catcher and two windows and two wing walls, Case-9

3 - Experimental setups

During the test, the air velocity was measured in four points (I1−I4) in the inlet diffuser and four points (E1−E4) in the outlet diffuser. In order to place the sensor inside the channel, two holes were drilled on the supply channel as well as the exhaust channel of the wind catcher (same level with roof of the room). The test consisted of 2 steps of data recording for model asshown in Fig. points (I1−I4) and (E1−E4) are positioned in a horizontal plane (parallel to roof) in the supply and exhaust channels. For each point, the measurement was done in Z vertical direction (parallel to channel) with duration of 1 minute which was repeated 3 times to have more reliable data Figure The positions of I and E points in inlet and outlet diffuser of model (all the dimensions are in m wire probe repair consists of a micromanipulator (55A13), a welding Power Generator (55Al2) and stereomicroscope . The Micromanipulator is equipped with holders for most DISA probes, a coil holder, wire guides, a wire manipulator and a welding electrode. The Welding Power Generator furnishes the current pulses required for spotwelding. Welding current is produced by discharging a number of capacitors through a thyristor, which is triggered either with the button marked WELDING or with an external switch connected to the remote-control terminal. The welding energy stored in the capacitors

is adjustable between 0 and 300 mill joules with a control knob, and is indicated by a built-in meter. The meter also indicates the completion of the charging operation. Pushbuttons providea choice of three welding times (100, 200 and 400 μs). For optimum use of the Probe Repair equipment a stereomicroscope should be fitted to the 55A13 Micromanipulator with magnification factor up to 100X [184 illustrate the 5μ hotwire welding process under the stereomicroscope follow (hot wire Anemometry)]

The method used for air velocity measurement was a hot wire anemometer y (hot wire Anemometry of the air velocity data logger utilized in this investigation was an OMEGA® HHF-SD1 combination standard thermistor anemometer and a hot wire which both had lots offeatures we needed to accomplish this study. In fact, The OMEGA® HHF-SD1 had an accuracyof 5% of reading and resolution of 0.01 m/s. The hot wire sensor had 4 μm diameter, 1.27 mmlong and can measure mean velocity

3 – 1 - Hot wire Anemometry(experimental study)

Hot wire Anemometer Calibration Constant-temperature hotwire anemometer will be used to investigate the flow velocity at the hoe wind-catcher. The specifications of CTA: a. 4 μm diameter, 1.27 mm long b. 5% accuracy of reading and c. resolution of 0.01 m/s. The hot wiresensor can measure mean and fluctuating velocities in one-dimensional flows. The transduceris a small resistance element that is heated and controlled at an elevated temperature. The electrical energy dissipated in the sensor is a measure of the cooling effect of the fluid flowingaround the heated sensor. This cooling effect is balanced by the electrical current to the wire and the change in current, due to a change in flow velocity, shows up as a voltage at the anemometer output. The sensor is a thin platinum cylindrical wire that is only 5μm in diameter.The hot wire is connected to the anemometer at the end of standard coaxial cable and mountedon a probe. As the change in flow velocity is shown up as a voltage at the anemometer output,calibration is very important for the hot wire to determine the DLR calibration chamber is usedfor calibration (Emara A., 2011). Case-1 velocity using hot wire anemometer will be used to investigate the flow velocity at wind-catcher and windows of the room. The specifications of CTA:

a - 4 μm diameter, 1.27 mm long

b - 5 % accuracy of reading and

c - resolution of 0.01 m/s

d - The hot wire sensor can measure mean and fluctuating velocities in one-dimensional flows.

The transducer is a small resistance element that is heated and controlled at an elevated temperature. The electrical energy dissipated in the sensor is a measure of the cooling effect of the fluid flowing around the heated sensor. This cooling effect is balanced by the electrical current to the wire and the change in current, due to a change in flow velocity, shows up as a voltage at the anemometer output. The sensor is a thin platinum cylindrical wire that is 5μm indiameter. The hot wire is connected to the anemometer at the end of standard coaxial cable andmounted on a probe.

As the change in flow velocity is shown up as a voltage at the anemometer output, calibrationis very important for the hot wire to determine the flow velocity. A DLR calibration chamberis used for calibration

velocity U (m/s) is calculated. γ is the heat capacity ratio (1.4) for dry air at the room temperature R_{air} is the gas constant (287.058J/kg.K) velocities .

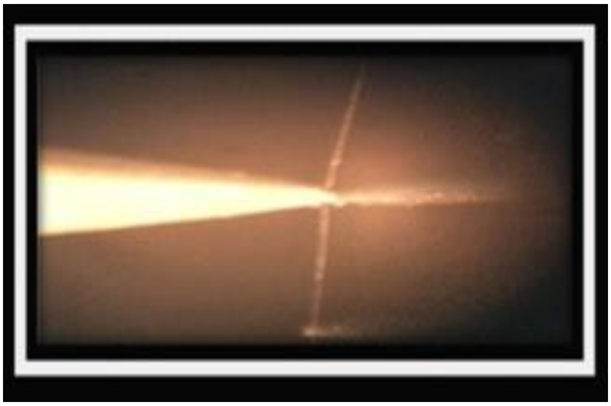

Figure 3: Hot Wire Anemometer Calibration used in experimental measurements Flow

Table 1: Summary of the experimental procedure

material of models	**0.3cm plexiglass, cut with laser**
numbers of models	**2 modelscase-1, case-9**
scale of the models	**1:30**
speed of wind	**6 m/s**
date	**5-8-2018,11-2018,4-2019**
measurement factor	**air velocity**
type of anemometeromega® hhf-	**measures mean and fluctuating velocities.-had 4µm diameter, 1.27 mm long sd1**
accuracy, resolution	**5%reading, 0.01 m/s**
wind tunnel test pat specification	**low speed, its dimensions0.5*0.5*1.5m**

4 – Numerical and Mathematical Approaches

The Ansys Fluent software has been used in this work to perform the CFDs. Where the realizable k- ε turbulent model has been employed. In this section, the govenering equations will be reviewed. Then the mesh geometry and computational domain which are used in theCFD will be presented. The mesh independent study is discussed after that.

4 – 1 - Governing Equations

In this section the governing equation in integral and differential for are presented. Integral mass balance, Integral momentum balanced,

$$\frac{d}{dt}\int_v \rho dV = -\oint_A \rho v dA \qquad (1)$$

$$\frac{u}{d}\int_v \rho dV + \oint_A \rho v v.dA = -\oint_A p dA = \int_A p dA - F_s + F_g. \qquad (2)$$

The equations of the kinetic energy and its dissipation rate are read as follows,

$$\frac{\delta u\varepsilon}{\delta x}+\frac{\delta v\varepsilon}{\delta y}+\frac{\delta w\varepsilon}{\delta z}=\frac{\delta}{\delta x}\left(\frac{\upsilon}{\sigma\varepsilon}\cdot\frac{\delta\varepsilon}{\delta x}\right)+\frac{\delta}{\delta y}\left(\frac{\upsilon}{\sigma k}\cdot\frac{\delta\varepsilon}{\delta y}\right)+\frac{\delta}{\delta z}\left(\frac{\upsilon}{\sigma\varepsilon}\cdot\frac{\delta\varepsilon}{\delta z}\right)+C\varepsilon\frac{\varepsilon}{k}Pk, \qquad (3)$$

$$Pk - C\varepsilon\frac{\varepsilon}{k}\upsilon = C\mu\frac{k^2}{\varepsilon} \qquad (4)$$

$$Pk=\upsilon\,\left[2\left(\frac{\delta u}{\delta x}\right)2+\left(\frac{\delta v}{\delta y}\right)2+\left(\frac{\delta w}{\delta z}\right)2+\left(\frac{\delta u}{\delta z}+\frac{\delta v}{\delta z}+\frac{\delta w}{\delta z}\right)2\right] \qquad (5)$$

Where, F_S is the surface force which affects the control surface, for example because the drag and body forces F_g affect the fluid, for gravitational force. Both F_S and F_g are taken equal to zero in the current research. k-ε. In most of the commercial software, the most common representation for the continuity and momentum is the partial differential form as follows, continuity equation,

and momentum Equations,

$$\frac{\partial\rho}{\partial t}+\frac{\partial}{\partial x}(\rho u)+\frac{\partial}{\partial y}(\rho v)+\frac{\partial}{\partial z}(\rho w)=0 \qquad (6)$$

$$\rho\frac{Du}{Dt} = -\frac{\partial p}{\partial x} + \frac{\partial}{\partial x}\left[2\mu\frac{\partial u}{\partial x} - \frac{2}{3}\mu\nabla.v\right] + \frac{\partial}{\partial y}\left[\mu\left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right)\right] + \frac{\partial}{\partial z}\left[\mu\left(\frac{\partial w}{\partial x} + \frac{\partial u}{\partial x}\right)\right] + \rho g_x \quad (7)$$

$$\rho\frac{Dv}{Dt} = -\frac{\partial p}{\partial y} + \frac{\partial}{\partial y}\left[2\mu\frac{\partial v}{\partial y} - \frac{2}{3}\mu\nabla.v\right] + \frac{\partial}{\partial x}\left[\mu\left(\frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}\right)\right] + \frac{\partial}{\partial z}\left[\mu\left(\frac{\partial w}{\partial y} + \frac{\partial v}{\partial z}\right)\right] + \rho g_y \quad (8)$$

$$\rho\frac{Dw}{Dt} = -\frac{\partial p}{\partial z} + \frac{\partial}{\partial z}\left[2\mu\frac{\partial w}{\partial z} - \frac{2}{3}\mu\nabla.v\right] + \frac{\partial}{\partial x}\left[\mu\left(\frac{\partial w}{\partial x} + \frac{\partial u}{\partial z}\right)\right] + \frac{\partial}{\partial y}\left[\mu\left(\frac{\partial w}{\partial y} + \frac{\partial v}{\partial z}\right)\right] + \rho g_z \quad (9)$$

$$\frac{D\phi}{Dt} = \frac{\partial\phi}{\partial t} + v\nabla\phi \quad (10)$$

4 –2– Mesh independence study adaption

In order to ensure that the numerical model was independent of the grid size, different sizes of grid evaluated that the computational mesh used was based on a Mesh sensitivity analysis whichwas performed by conducting additional simulation of the same domain and boundary conditions, but by using various mesh sizes the area -weighted average value of the inflow velocity was taken as the error indicator as shown in fig. 5 below, as the grid was refined from 4,789.021 to10254.352elements.the discretization error was found to reduce to before 1% whenthe cells were increased to8,138,056 and hence the size was used in this investigation. The repetition of the numerical model with finer mesh had no considerable effects on the Results. Therefore, it could be concluded using the men sinned mesh size was accurate and no need for the finer me Natural Ventilation is a way of ventilating an indoor space without utilizing mechanical systems. It usually happens as a result of pressure gradient that allows air to flow into the space.It usually has two types based on their methodology: Buoyancy-driven ventilation and wind driven one. While wind is the main mechanism of wind driven ventilation the pressure difference between any two points on the building envelop will determine the potential for ventilation, buoyancy-driven ventilation occurs as a result of temperature differences betweenthe inside and outside of the space that lead to a buoyancy force between them. In warm climates they use natural ventilation to improve the inside thermal comfort by reducing the effects of humidity more than 50%. Air movement inside place removes foul air and moisturethen causes healthy building. Natural ventilation Saves energy consumed in mechanicalventilation and also saves operating costs (no invoice for maintenance).

The main required parameters creating natural ventilation:

-Air Volume Flow Rate

-Air velocity distribution inside the room

Factors affecting natural ventilation to predict the above two parameters in this numerical study (inputs) Will be:

1-Different WIND velocity values as shown at 1-st stage results.2-Effect of one window, as shown at

2-nd stage results.

3 – Different Wings walls numbers as shown at 2-nd stage results

4 – Different wing walls positions from windows (Space between wing and window) as shownat 2-nd stage results.

5 – Different numbers of windows, as shown at 2-nd stage results. The results of the CFD simulation are as follows:

Cells numbers = 2,035,087Domain Extents

x-coordinate: min (m) = -1.288826e+00, max (m) = 7.111736e-01y-coordinate: min (m) = -2.549651e-01, max (m) = 2.450349e-01 z-coordinate: min (m) = 3.059378e-01, max (m) = 8.059378e-01

Volume statistics

Minimum volume (m^3): 1.795712e-14

Maximum volume (m^3): 9.979016e-05

Total volume (m^3): 4.998411e-01

Face area statistics

Minimum face area (m^2): 1.648478e-10 maximum face area (m2): 3.182227e-03Cells Faces Nodes 2,035,087 10,616,704 7,491,338NO Time Step (Steady Solution)and windows of the room industrial applications. Accurate CFD analysis on a variety of fluids problems was allowed by the physical models. FLUENT software for fluid dynamics is best inincompressible and half compressible flows. FLUENT has these advantages due to its ability to create multiple physical models on unstructured meshes that allow for greater accuracy usingadaptation of the mesh.

FLUENT software is used to build virtual prototypes and simulate the performance of proposedand existing design problems, allowing improvement of design quality while reducing cost. FLUENT software package is a popular commercial CFD package that is used to simulate theproblem under consideration of Realizable (k- ε) turbulence model.

As a software that enables creating mesh geometry, FLUENT also solve the flow problem. Thedesired grid spacing is specified by the mesh of the edge. The proposed mesh was checked to ensure the mesh suitability for a solution and to verify that the mesh gives accurate solution.

5 - Discussion and Simulation Results

This Thesis consists of 3-stages,the first stage at 2.5m/s and full dimensions wind catcher is The first stage, Five cases at 2.5m/s velocity value, dimensions are as follows: room300*400*600mm,wind catcher 90 *150 *180 mm.

The second stage, Nine cases conditions: at 0.08m/s velocity value and Models at 1:30 scale Wind capture =30*45*57mm,room dim =90*120*180.mm. The Third stage)More accurate Results at wind speed=0.08m/sand Models at 1:30scale) as a Results of second stage Results**:**

The existence of wing increases the value of volume flow rates CFD Calculations AND velocity distribution First stage Results over the wind catcher Building no window
The first stage, Five cases at 2.5m/s velocity value, dimensions are as follows: room300*400*600mm,wind catcher90*150*1 80mm.

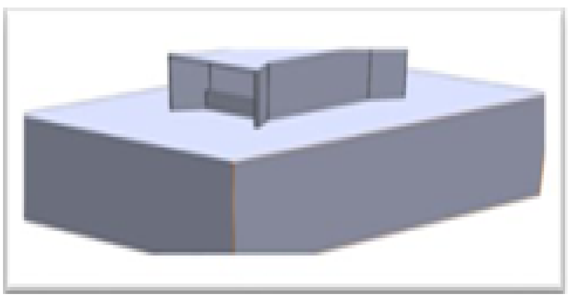

Figure 4: Isometric Shape for First Stage Case 1#

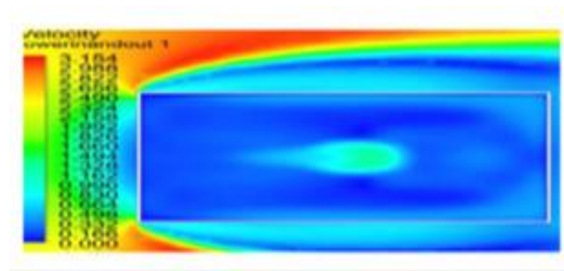

Figure 5: Contour Velocity for First Stage Results Case #1 in horizontal positionFirst stage results building with wind capture and with- windows openings

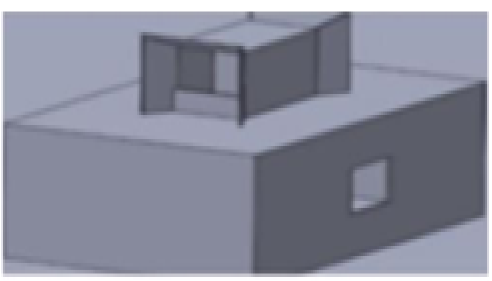

Figure 6: Isometric Shape for First stage Results Case-2

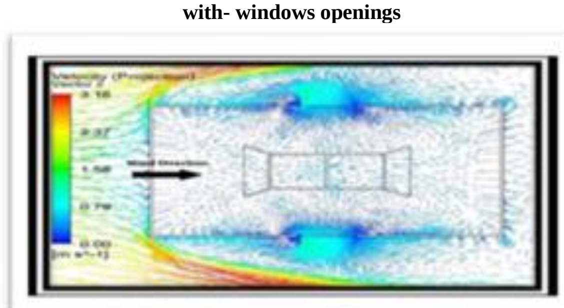

Figure 7: Velocity Vectors for First stage Results Case-2

First stage Results building with 2- windows openings and 2-wings one each side

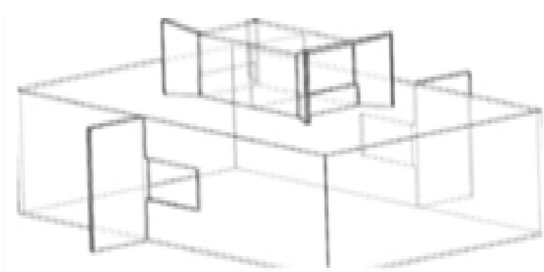

Figure 8: First stage Results Case -3 (building with wind catcher and window and wingwall from the left of the window)

Table 2: The effect of wind speed values on flow rates

volume flow rate	Wind speed
0.230	0.5
0.458	1.0
0.678	1.5
0.895	2.0
volume flowrate m 3/s Case -3a	2.5

Case 4: first stage results wind capture building with 4-windows openings two at each side

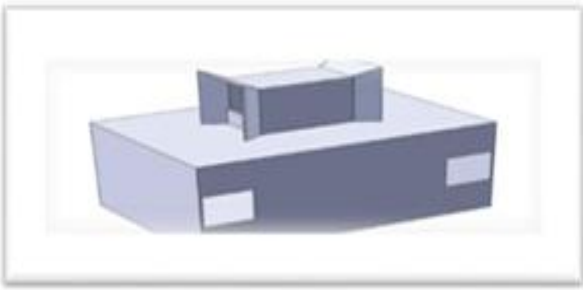

Figure 9 : Isometric Shape for First stage Case 4 (Building with wind catcher and twowindows opening)

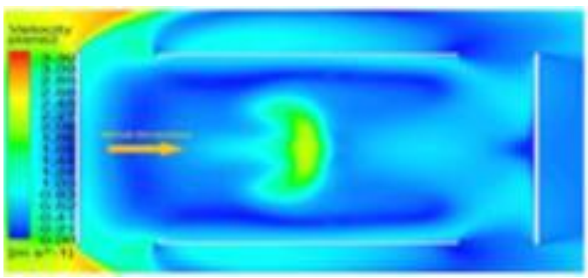

Figure 10: Contour Velocity for First stage Results Case 4

First, Case -5 Stage Results wind capture building with 4-windows openings two at each side&2wings walls

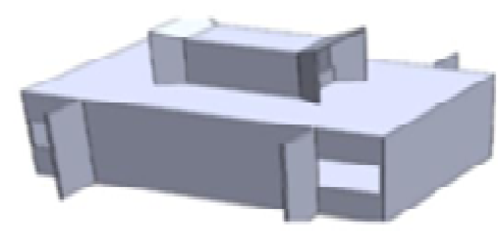

Figure 11: Isometric Shape for First stage Results Case -5

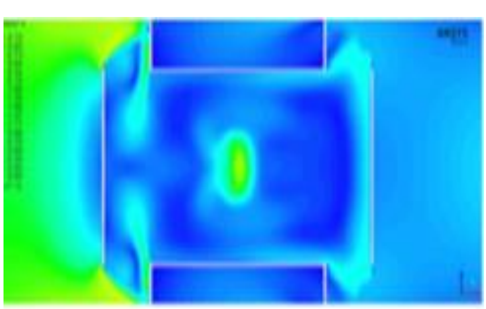

Figure 12: Contour velocity for First stage Results Case -5

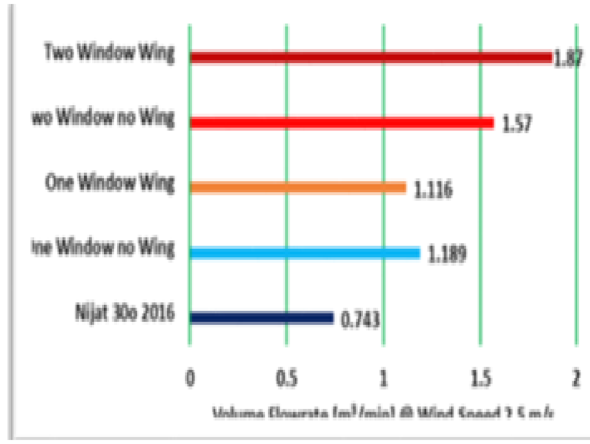

Figure 13: First stage Results comparison of 5 cases regarding flow rate

First five Cases for first Stage Results showed that air volume flow rates &air change per hour were very big values compared to the required values and realized air draught diseasesfor occupants which let me do other designs which will realize the required values of ACPHwhich caused thermal comfort Relation between velocity of Air and Mass Flow Rate for Case-3b

Velocity (m/s)	mass flow rate (Kg/s)
0.5	0.501
1	0.98
1.5	1.57
2	2.15
2.5	2.6

Figure 14: First Stage Results comparison between the 5-results volume rates for 5 models

First five Cases for first Stage Results showed that air volume flow rates &air change per hourwere very big values compared to the Required values and realized air draught diseases for occupants which let me do other designs which will realize the required values of ACPH whichcaused thermal comfort.

Second stage Results

Nine cases conditions: at 0.08m/s velocity value and Models at 1:30 scale Wind capture =30*45*57mm, room dim =90*120*180.mm

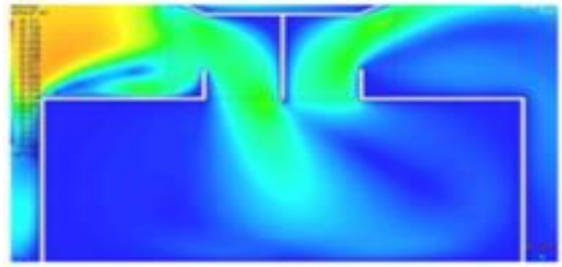

Figure 15: 49.14ACPH Second stage Results Case#1 contour velocity for building withwind catcher only in vertical projection

Table3:CFD Results at case#1 at second stage at 6m/s velocity

CFDWind catcher in or outCase-1x-cm,at 6m/s	CFD Velocity m/sWind catcher in Case-1at 6m/s	CFDVelocity m/sWind catcher outCase-1at 6m/s
0.0	0.000	-0.009
0.5	2.928	-1.462
1.0	3.548	-2.513
1.5	3.838	-3.133
2.0	4.196	-3.697
2.5	4.953	-3.563
2.7	5.323	-3.167

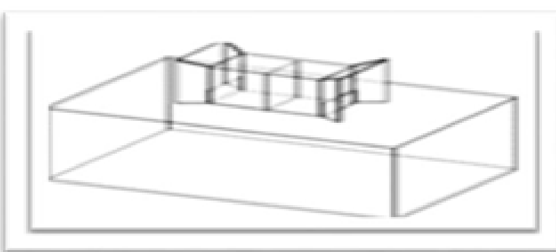

Figure 16: Isometric Shape for Second stage Results Case#1 (Building with wind catcheronly)

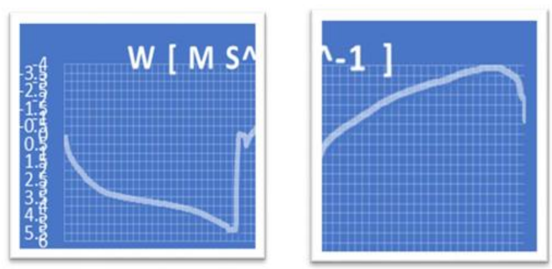

Figure 17: Case-1 WC air in velocity WC air out Velocity Case#1 CFD at 6m/s Seco

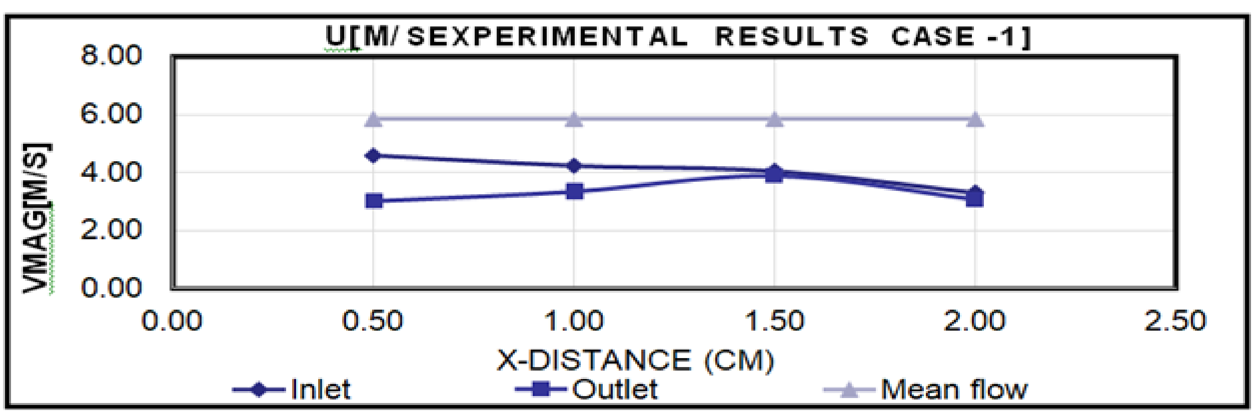

Figure 18: Experimentally Case#1at 6m/s Second stage Results: The Relation between velocity & distance

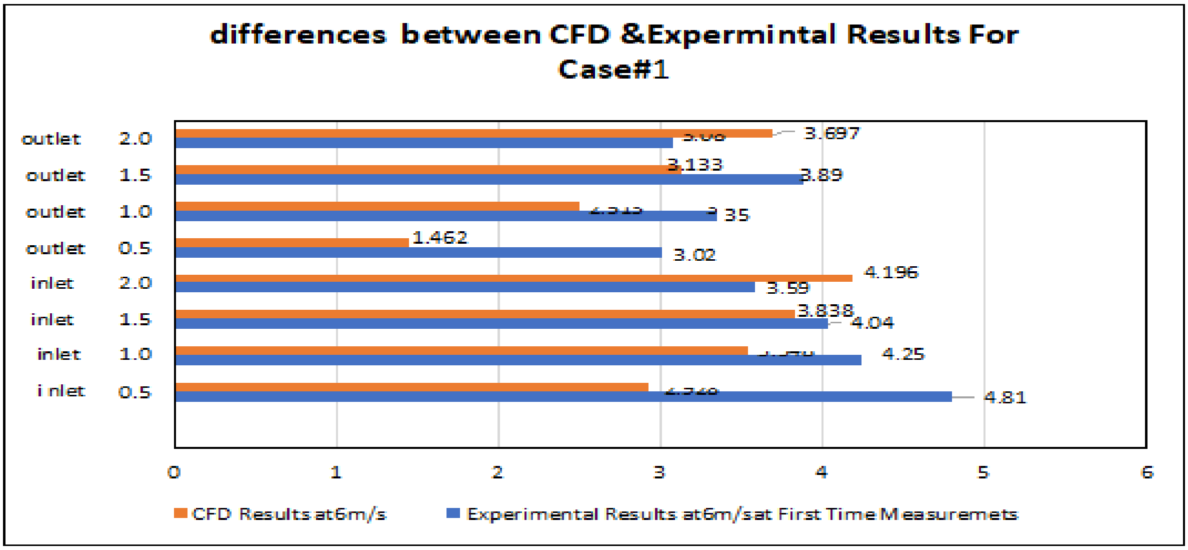

Figure 19: Differences between Experimental and CFD Results for case-1at6m/s no-Window No-Wing.

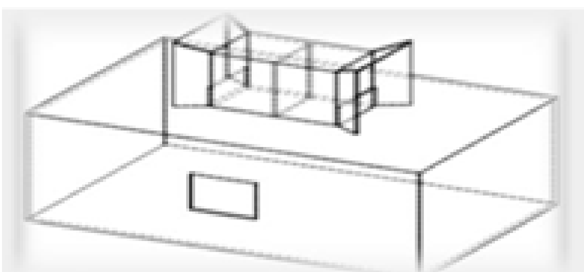

Figure 20: Isometric Shape for Case##2 72.81 h-1 ase2 Second Stage Results building has wind catcher with 72.81ACPH

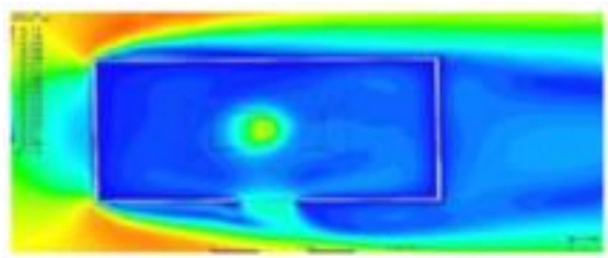

Figure 21: Contour Velocity for Second stage Results Case##2 72.81 h-1

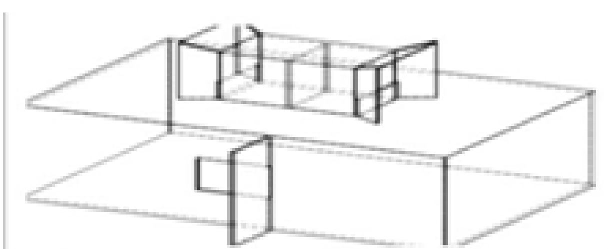

Figure 22: Case##3 Second Stage Results building has wind capture with 70.14 h-1ACPH

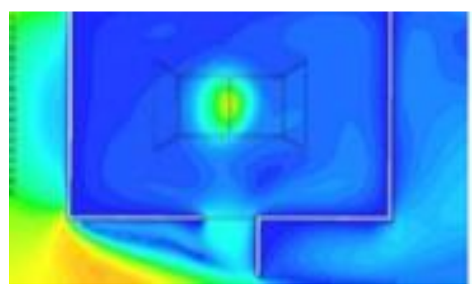

Figure 23: Velocity Contour for Second stage Results Case##3 70.14 h-1

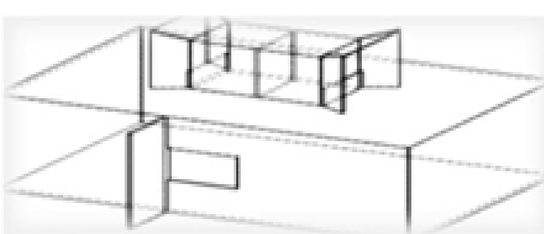

Figure 24: Case -4 (70h-1) second Stage Results building has wind capture with 2-windows

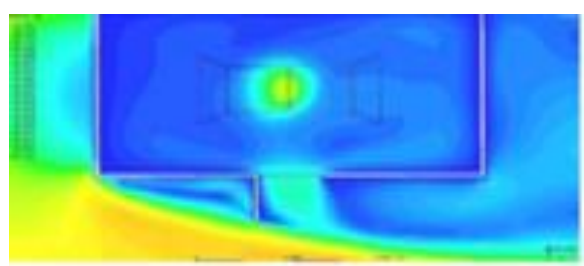

Figure 25: Contour Velocity Case -4 (70h-1) second Stage Results building has wind capture with 2-windows

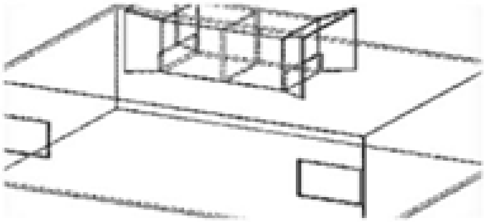

Figure 26: Isometric Shape for Case # 5 Second Stage Results building has wind capture with 2-windows(78h-1) ach

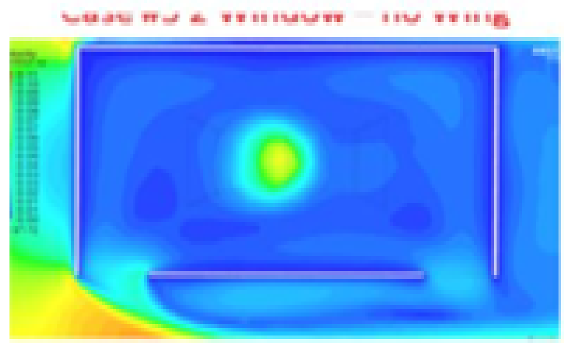

Figure 27: Contour Velocity for Case # 5 Second Stage Results building has wind capture with 2-windows(78h-1)ach

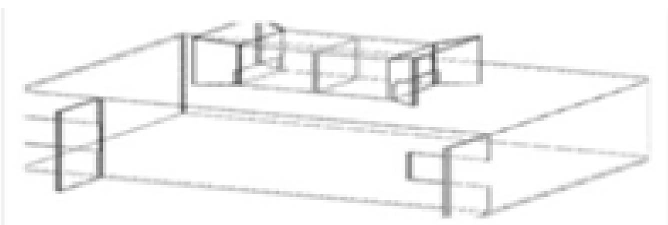

Figure 28: Isometric Shape Case # 6 with 2 windows openings , 2-wings before the windows(85h-1)ACH

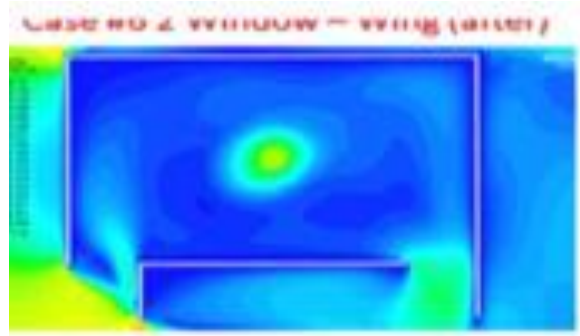

Figure 29: Contour Velocity Case # 6 with 2 windows openings , 2-wings before the windows(85h-1)ACH

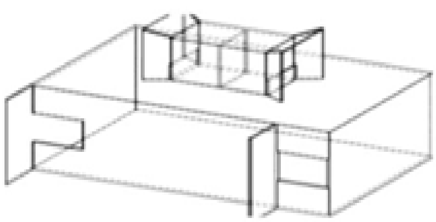

Figure 30: Isometric Shape Case # 7 Second stage (Building with wind catcher and two windows with wing wall at the left and the right from the window) where v = 0.08 m/s with 80ACPH

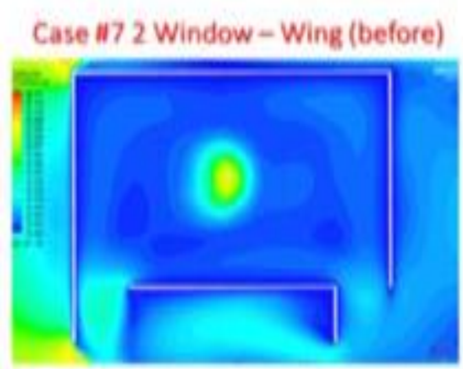

Figure 31: Contour Velocity Case # 7 Second stage (Building with wind catcher and two windows with wing wall at the left and the right from the window) where v = 0.08 m/s with 80ACPH

Figure 32: Isometric Shape Case # 8 Second stage (Building with wind catcher and two windows with wing wall at the right and the left from the window) where v = 0.08 m/s with 81ACPH

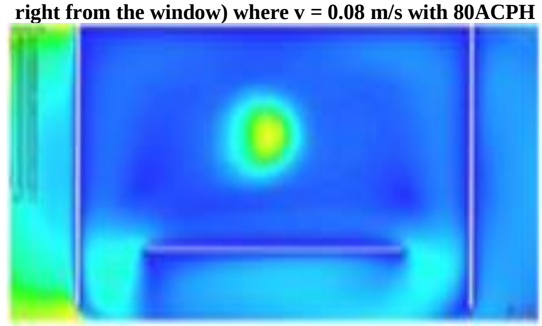

Figure 33: Velocity Contour Case # 8 Second stage (Building with wind catcher and twowindows with wing wall at the right and the left from the window) where v = 0.08 m/s with 81ACPH

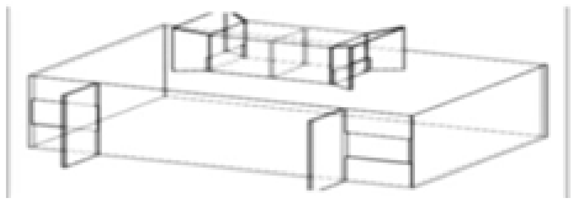

Figure 34: Isometric Shape for Case # 9 Second stage (Building with wind catcher and two windows with two wing wall at the inside of window) where v = 0.08 m/s with 89.1ACPH h-1

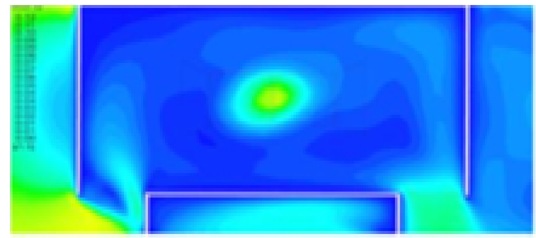

Figure 35: Velocity Contour for Case # 9 Second stage (Building with wind catcher andtwo windows with two wing wall at the inside of window) where v = 0.08 m/s with 89.1ACPH h-1

Table 4: CFD at 6m/s Case-9 Second stage Result

Case-9 X[mm]	Case-9 WC air in Velocity x [m s^-1]	Case-9 WC air out velocity w [m s^-1]
00	0.00	-000
05	2.82	-1.37
10.	4.88	-1.88
15	5.59	-2.16
20	6.00	2.32
25	6.35	-2.03
27	6.59	-1.52

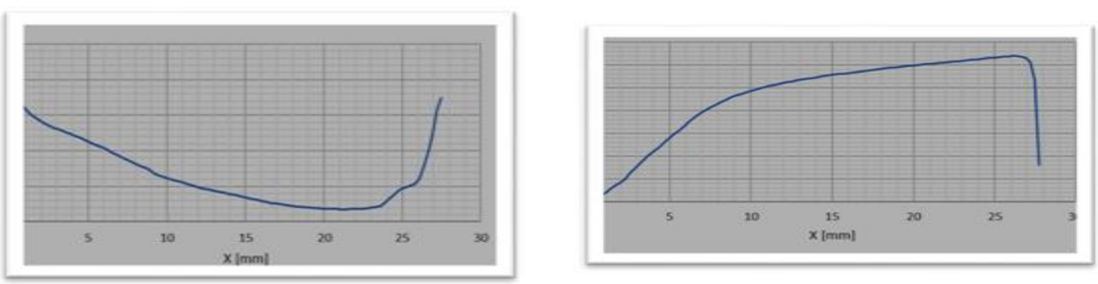

Figure 36: Case-9 WC air in velocity WC air out Velocity w [ms^-1]at 6m/s TheRelation between velocity & distance

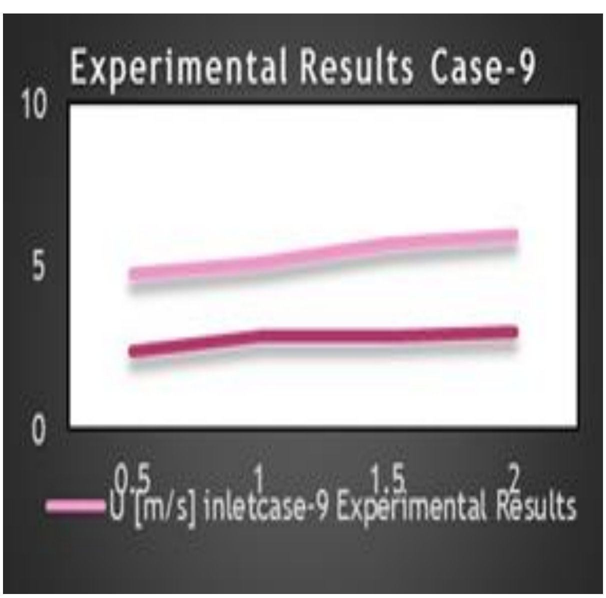

Figure 37: Differences between Inlet and Outlet Results Case

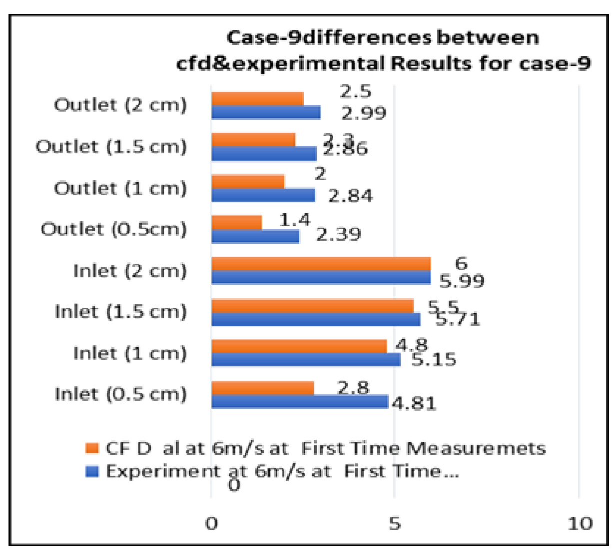

Figure 38: Differences between Experimental & CFD Results case-9

Second stage Results at 0.08m/s scale 1;30 in both dimensions and applied wind speed Consist of 9-cases including the effect of wing positions with respect to window positions.

Case-1(model)building with wind catcher no-window no-wing obtained 49 air change per hour This value49h-1 is correct for the model and approximately equal Nejat value46h-2-Case-2(model)building with wind catcher 1-window from one side only, 73 air change per hour.

Which mean that one window increased air change per hour, one and half time1.5 or 150% 3,and4-Case-3,4(model)building with wind catcher 1-window provlded by 1 wing wall, gave 70 or 72 air change per hour means no need to provide wing wall when making only one window because it decreased the air change per hour

Case-5(model)building with wind catcher 2-windows from one side only means need to provide the) building with2-windows because it increased air change per hour with 5 air changeper hour ,78ACH Case-6(model)building with wind catcher 2-windows window provided with wing, means needto provide the) building with2-windows and 2-wings walls one at each window because it increased air change per hour with big values80 air change per hour

Case-7(model) building with wind catcher 2-windows window provided with wing, means need to provide the) building with2-windows and 2-wings walls one at each window because it increased air change per hour with big values81 air change per hour

Case-8(model)building with wind catcher 2-windows window provided with wing, means need to provide the) building with2-windows and 2-wings walls one at each window because it increased air change per hour with big values79 air change per hour- building with wind catcher 2-windows window provided with wing,outer. neglected ,low natural ventilation.

Case-9(model)building with wind catcher 2-windows window provided with wing, means need to provide the) building with2-windows and 2-wings walls one at each window because it increased air change per hour with big values79 air change per hour- building with windcatcher 2-windows window provided with wing,inner. The best case gave more natural ventilation and 89 air change per hour. Which is the biggest value, this design

The Third stage gives more accurate results at wind speed=0.08m/s for the effect of wing positions of one Window&2-windows

Third stage Results (9-cases Results) showed ACPH for each Case and showed the best case is case Number -9. 89 ACPH improvement percentage 181% More accurate Relations for different effects of different numbers of windows, numbers of wings, wings positions, full comparison, ACPH. Effect on Improvement Percentage [%], and other Relations as a result of second stage results

6- Conclusions

1- Building design–type has a strong effect for natural ventilation for example building has wind catcher creates more ventilation

2- Effect of 1-window Opening represent the main factor to be considered in building design, when provided to design-type of aeration. Maximum air change per hour and maximum air distribution in zone are obtained when window opening provided to building has wind catcher

3-Effect of 1-Wing wall when providing to window is very effective in improving velocity distribution and realizing more ACH inside the building

4- Increasing the number of windows will increase the value of volume flow rate

5- Maximum values of air volume flow rate are obtained when the inlet opening of the wind catcher is facing the wind direction as studied before in previous studied.

6- The position of wings with respect to window play an important role for describing more ventilation inside place.

7- The current studies have shown that the CFD approach I air flow and velocity distribution tocreate natural ventilation.

8- In experimental work the physical simulation studies using wind tunnel have shown high potential to understand air movement systems (natural ventilation) inside wind catcher

9- Numerical simulation of the three-dimensional models, under the effect of different variables, showed significant correlations with experimentally data using one thirty scale model in a wind tunnel.

10- Wind captures at the top of the building and window openings in the walls of a building certainly provide better natural ventilation. However, it also increases the quantity of air movement into indoor

11- The use of wings walls is considered a feature the green buildings, as it creates effective natural ventilation reducing the energy consumed in active ventilation. Some experimental studies of the performance of wing walls were conducted in a wind tunnel. From the above- mentioned Results, it could be concluded that Wind speed is considered very important for natural ventilation.

12- The present work studies predicted the effect of wind velocity in two types of natural ventilation; wind catcher, wind catcher with windows openings provided with wing walls, thefront wall’s wind capture and windows provided with wing walls serve as inlet and the outlet of wind capture, it serves as outlet at steady state condition in natural ventilation. The volumeflow through the wind capture and windows increases linearly with the increment of wind speed.

13- The most important result is that when providing the building which has wind capture withwinnows openings and wings walls it creates more ventilation which is the main objective in present work

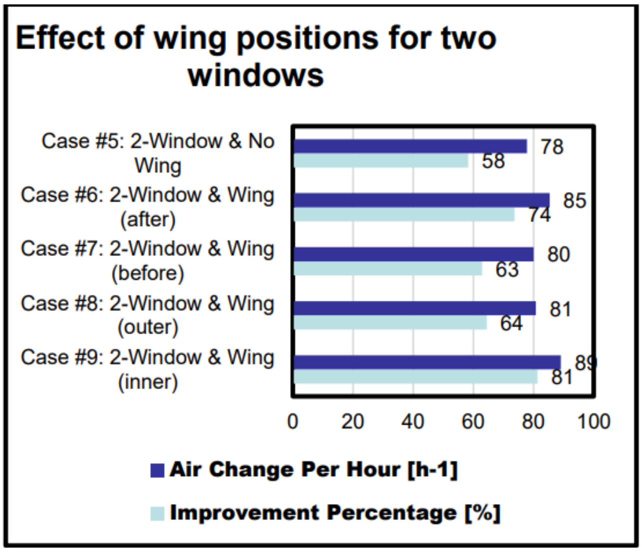

Figure 39: Third stage results: Effect of wing positions for two windows

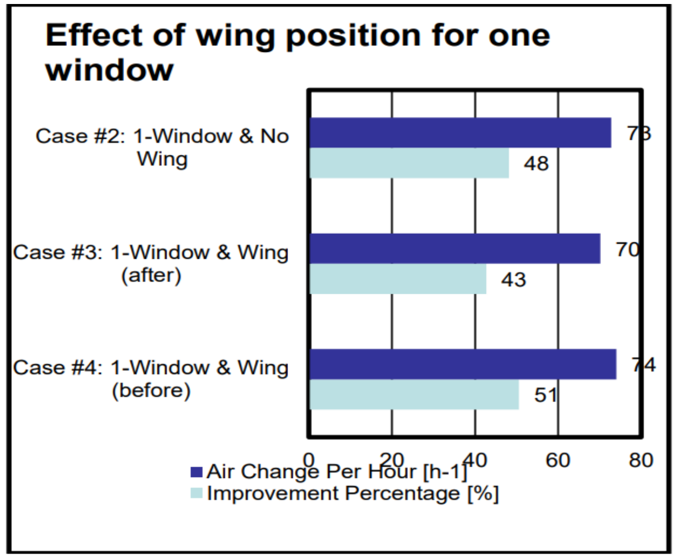

Figure 40: Third stage results: Effect of wing positions for one window

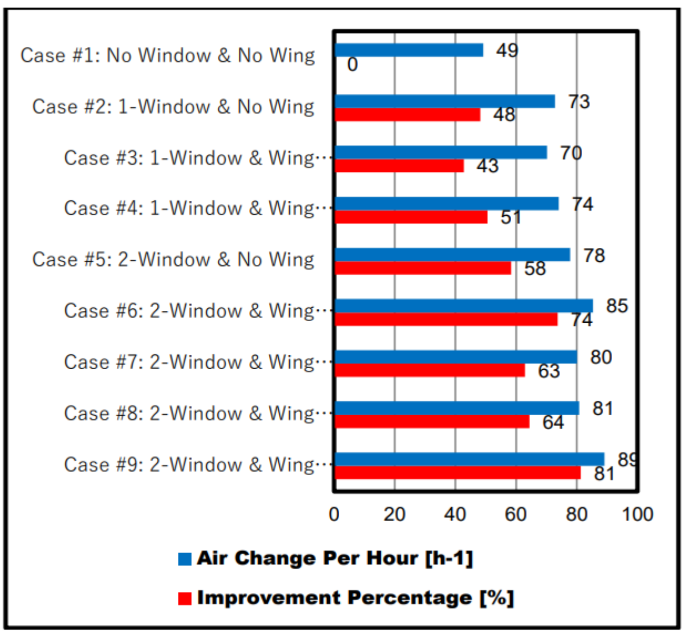

Figure 41: Third stage results: ACPH and Improvement Percentage for the 9 cases

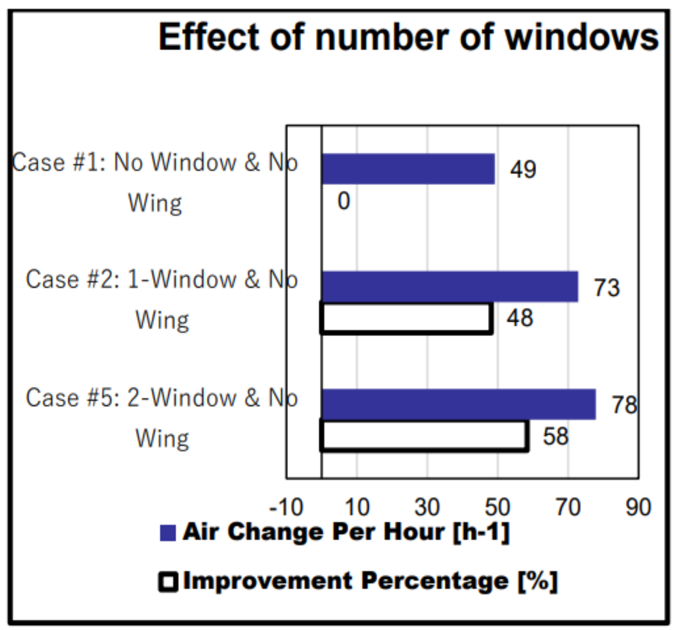

Figure 42: Effect of number of windows on the ACPH and Improvement Percentage

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