Chapter 4

Optimization of Building Facade Voids Design, Facade Voids Position and Ratios - Wind Condition Relation

Enes Yasa

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.72697

Abstract

The air flow between building interior and the courtyard to form via natural convection in hot-dry climatic regions are achieved with the help of wind pressure in other warm-humid and hot-humid climatic areas. Therefore, it is necessary to take into consideration and to humid other openings of the building which might change the effectiveness of the air movement to form due to wind effect in courtyard buildings. Therefore, wind tunnel experimental ways were developed and examined first in this study for the purpose of gaining knowledge on the effect of the wind on the cooling load of the atrium and courtyard buildings, and information to allow pre-estimation of the air flow to take place at the surface openings of such structures. Since numerical methods would not be enough alone in particular with regard to the wind, the planned study on the models was realized via the experimental method in a wind tunnel; and also Computational Fluid Dynamics numerical analyses were realized. This is a wind tunnel experimental study for the investigation of various architectural solutions for better cooling and ventilation through examination of the air flow passing through the surface openings of courtyard structures and for revelation of the effects of those results on the cooling and ventilation load. In this context, a courtyard building model was made to experiment on. Example courtyard building models were acquired by modifying various parameters (courtyard and gap area rates) to assess the test data from the boundary layer wind tunnel of wind-supported natural ventilation event of the example model courtyard structure used in the study.

Keywords: air movement, building openings, building with courtyards, natural ventilation, passive cooling, wind effects, wind velocity, wind tunnel, building facade design, building facade voids position, numerical analysis, computational fluid dynamics

1. Introduction

Architects and city planners are in general held liable for production of the plan and for coordination of the project and some vital inputs are acquired from consultants of other disciplines [1]. Planners and designers have, for centuries, considered wind or air flow as innate data for construction of components at several levels which involve cities, regions and countries [2]. Miscellaneous passive or natural air-conditioning methods taking advantage of the wind are used by architects and city planners in order to reduce the costs of cooling in territories with high temperatures [3]. As a passive air-conditioning medium, the moving air may be precious for provision of ventilation within buildings, particularly when it comes to hot and humid climates. The traditional courtyard building form entailed by climates which are hot and dry ensures that air flow is due to wind pressure variations leading to some natural ventilation [4–7].

Therefore, other openings of buildings which may cause a change on the efficacy of air movements resulting from the wind effect in courtyard buildings should be a subject for thorough study. There have been several studies, either numerical or experimental on the angle of insulation for buildings with courtyards. Nevertheless, wind effects have served as subject to a limited number of studies only. For instance, the wind attitude is to either flow over or circle in the courtyard if buildings are adjacent forming an open courtyard in a settlement area. Area of and openings position in courtyards in view of the wind (as well as openings width or total width) constitute variables that influence qualitative and quantitative wind character in courtyards [8, 9]. Outdoor layout and outdoor position have their effects on discomfort parameters for pedestrian spaces. The discomfort parameter is at its highest degree in areas subject to wind and at a medium degree in areas that are fully closed or subject to wind from a single direction [10–12]. Wind directions influence ventilation performance of buildings with courtyards and weaken if those courtyards are located in perpendicular to the wind [13]. In case buildings contain openings, openings in wind direction will cause highest speed of air flows as a number of parallel experiments have confirmed [14]. Studies demonstrate in the courtyards that maximum outdoor temperature is observed at noon time in summer of hot climates and minimum outdoor temperature is experienced prior to sunrise.

Courtyard depth is an effective variable for control of those parameters in buildings without openings [15–17]. The openings of buildings with courtyards on perpendicular areas, nevertheless, gain high significance particularly in hot/humid and moderate temperature/humid climatic territories, a parameter that is not true in hot/dry climate areas. In this study we tried to expound the effects of openings in the architecture of buildings with courtyards on airflow velocity in those courtyards. The outcomes depend on not only scale tests in the wind tunnel but also CFD numerical analysis.

2. Limitations and assumptions of the case study

2.1. Experimental process of the research project

Experimental studies have been made on 17 separate opening configurations on the façade of a building not having (BSL-SUZ) openings on its mass that surrounds the courtyards preferred as reference building. The building has been evaluated as two stories as its original scale, whereby each storey has a height of 3.00 m, the external dimensions of the building are 14.00 × 14.00 × 6.00 m but courtyard dimensions are 6.00 × 6.00 × 6.00 m. 36 separate points of

http://dx.doi.org/10.5772/intechopen.72697

measurement have been determined on X and Y dimensions in the model courtyard; and measuring profiles with 36 measurement points have been found on Z dimension at each point of measurement.

The building model in relation to the courtyard is modular to allow observation of the ventilation effects caused by the openings on the courtyard building. A reference model was made of empty Plexiglas material with dimensions of 4.00 × 4.00 × 4.00 cm to allow 17 separate configurations for courtyards. The model dimensions are 28.00 × 28.00 × 12.00 cm and dimensions for the internal courtyard are 12.00 × 12.00 × 12.00 cm.

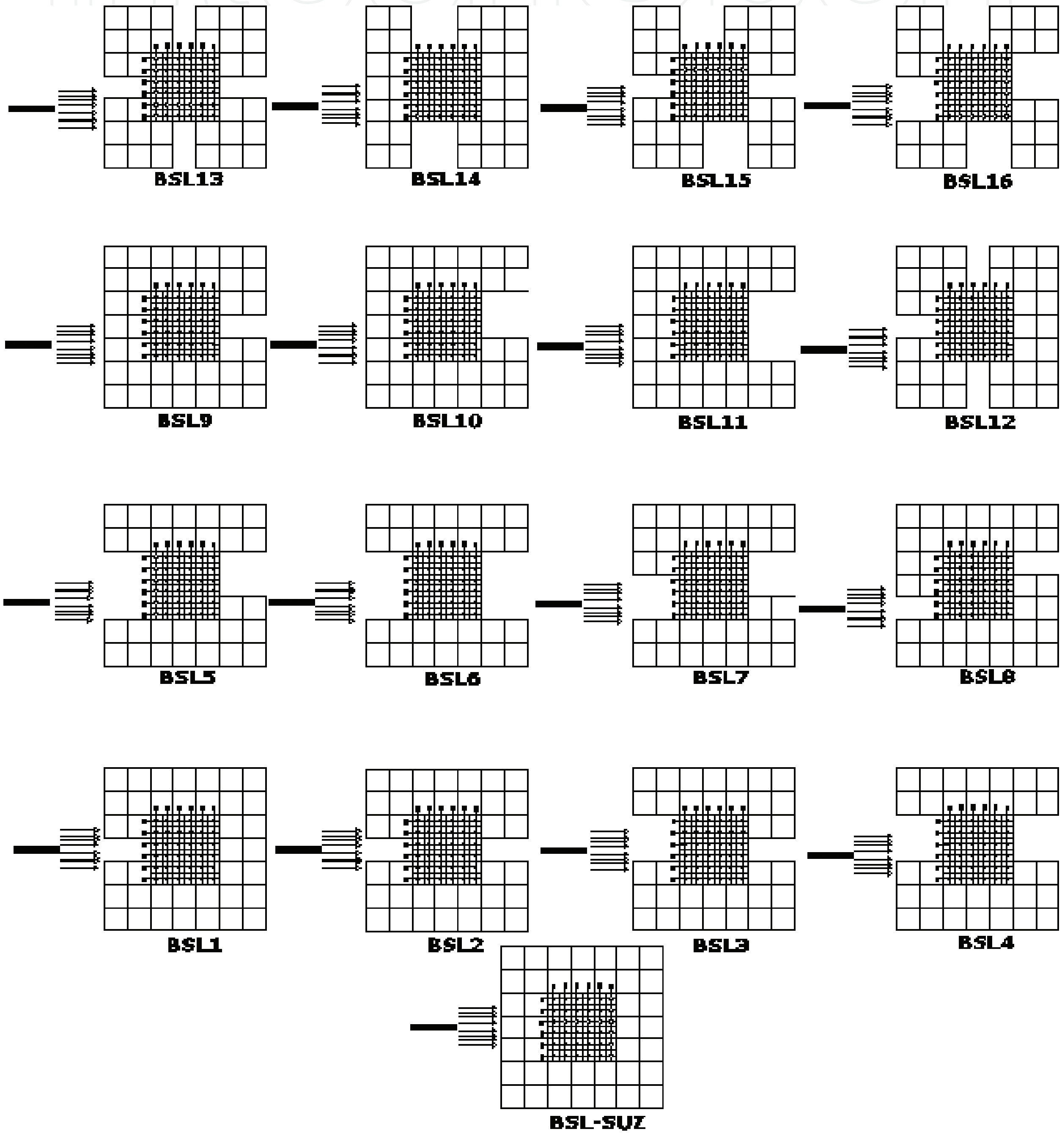

Figure 1. Appearance at ground floor plan level of the configuration for the courtyard with 17 different openings experimented [10].

The measuring axis perpendicular to the wind tunnel observation section "AB, B, C, D, E, F" lateral surface was in the wind direction. The points of measurement "1, 2, 3, 4, 5, 6" were placed on the axis perpendicular to the direction of the wind. At the courtyard, 36 points of measurement in total have been set with distances of 2.00 cm between directions of the X and Y axis. As to the points of measurement in dimension Z, profiles with 34 points of measurement have been placed at differing intervals in a way to be closer to the ground, to the roof and the opening edges that are to be organized on the model courtyard surfaces (**Figures 1–3**). At each measurement profile, nine points of measurement from 0 to 4 cm have been set at 0.5 cm intervals; 6 of them were placed at 1.00 cm intervals in the section as far as the following 10.00 cm; 14 have been placed at 0.5 cm intervals through the area between 10.00 and 17.00 cm; and another out-of-the-model 5 between 17.00 and 22.00 cm.

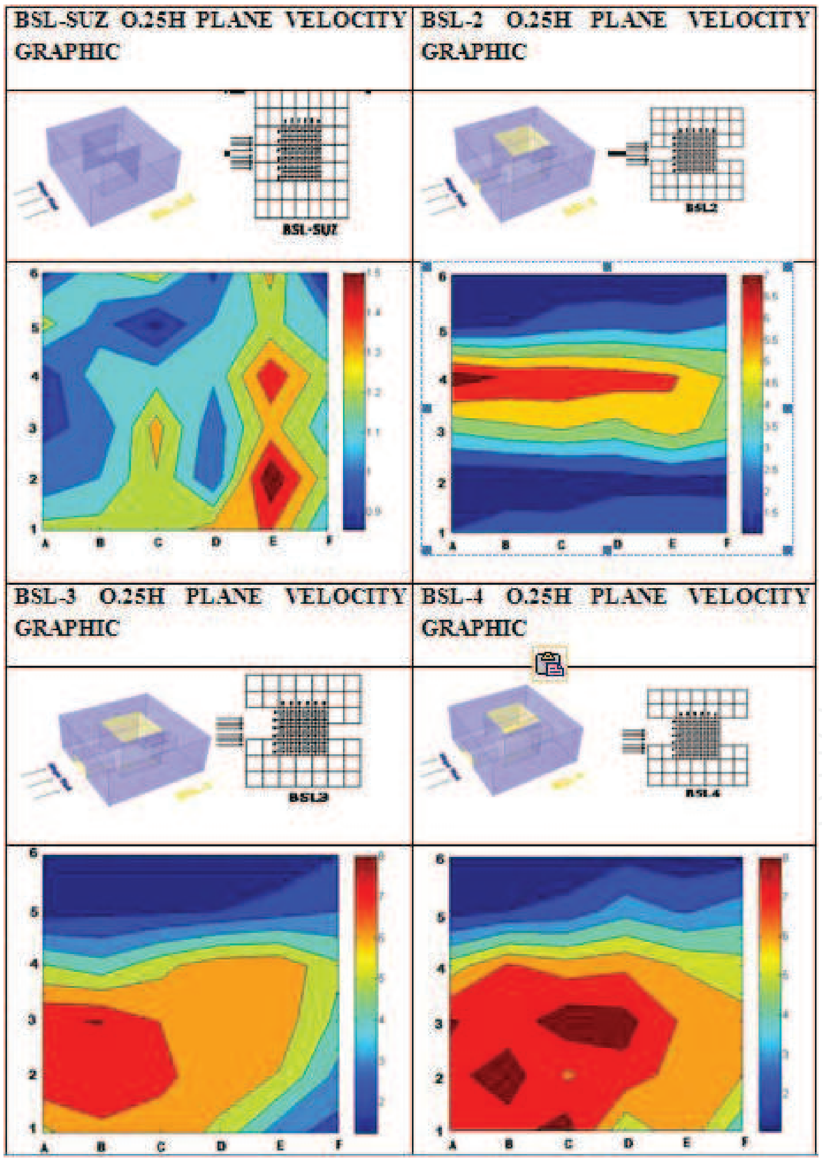

Figure 2. The wind velocity and air flow characteristics of courtyard options between BSL-SUZ-BSL-4 at 0.25H plane.

http://dx.doi.org/10.5772/intechopen.72697

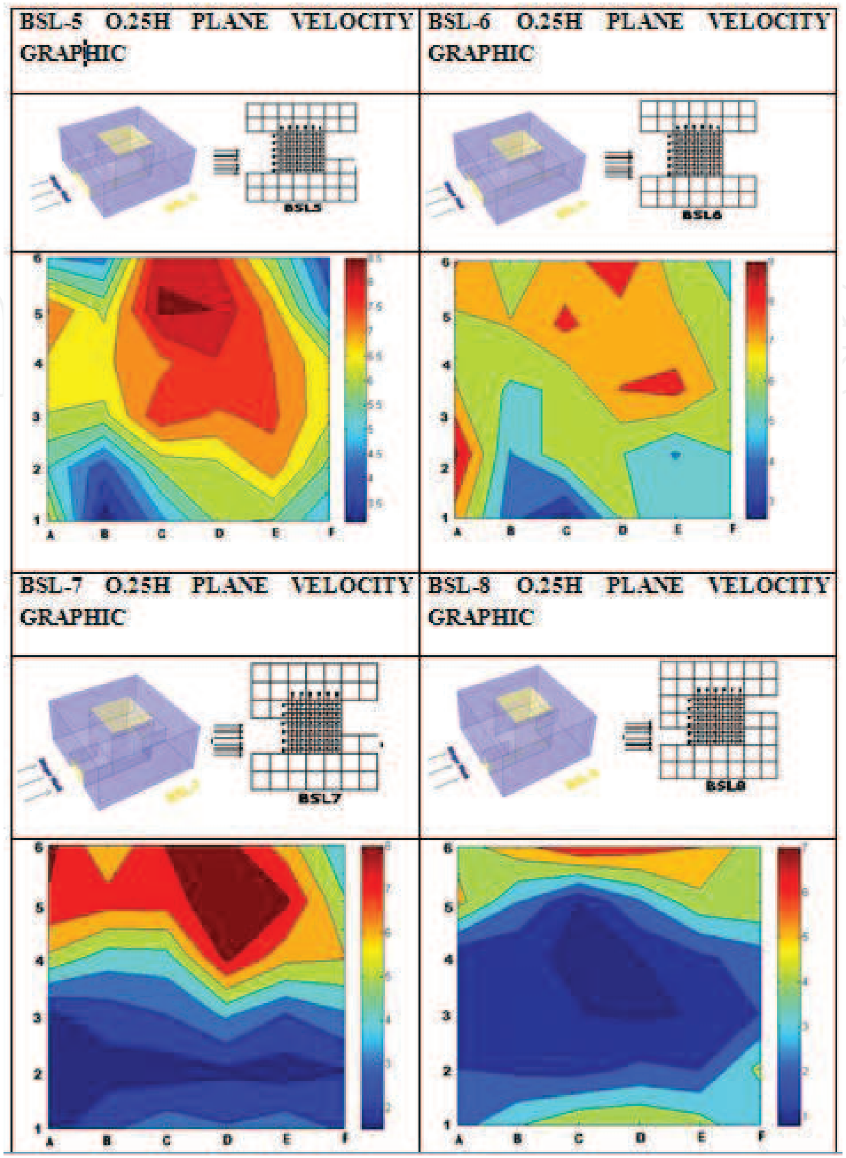

Figure 3. The wind velocity and air flow at 0.25H level for courtyard options between BSL-5-BSL-8.

2.2. Modeling and simulation in numerical analysis

Computational Fluid Dynamics have been utilized in prediction of the transfer of convective heat on the exterior of building surfaces [13–15]. The main advantages of CFD in this practice has been that: (1) it allows for analysis of a specific and complex building or building configuration; (2) it provides high data on spatial resolution; (3) it makes consideration of high Reynolds number flows for atmospheric conditions possible and (4) it makes information on the flow as well as the thermal areas available in detail.

Those former studies made possible the analysis in detail of: the Correlation over building surfaces of the distribution of the Heat Transfer Factor; the effect of turbulence in addition to the wind direction; correlation with various reference wind velocities; the thermal boundary layer, etc. Nevertheless, we need to highlight some important limitations of the numerical models applied, taking into consideration the building shell in assessment of thermal comfort and energy performance of buildings with a courtyard, as also studied in CFD. The wall section is made of several layers in various thicknesses and with miscellaneous physical properties. The external surface is subject to solar radiation (Is), convection heat transfer (qc,o) and an exchange of radiation from the sky (qr,o). The internal surface is affected by a combination of convection and radiation heat transfer (qi) in turn being relevant directly to the air-conditioning load necessary to preserve the inside design temperature (Tf,i). The following assumptions have been utilized in formulating the mathematical model:

i. Lack of heat generation.

ii. Fine contact of layers, resulting in interface resistance being negligible.

iii. Negligible variation of thermal properties.

iv. Relatively small thickness of composite roof in comparison to other dimensions. One-dimensional temperature variation has been thus assumed.

v. Constant convection factor based on the heat flow direction and daily average of wind velocity.

Taking as a basis the aforementioned assumptions,

Reynolds number:

Air intensity $\rho = 1225\ kg/m^3$

Wind speed (average) V = 30 m/s

Dynamic viscosity $\mu = 1.7894e\text{-}05\ kg/(m\cdot s)$

Building Length D = 14 m

Reynolds number has been found $28,75.10^6$ in view of the reference values. The flow has turbulence since the value is greater than 106.

Mach number:

$$M = \frac{V}{c} \tag{1}$$

Sound velocity $c \approx 340$ m/s

Wind velocity (average) V = 30 m/s

Mach number has been found as 0.09 in view of the reference values. Because the value is smaller than 0.3, the flow has been deemed incompressible.

Furthermore, because the properties at any point within the flow do not vary in time, the flow is defined as perpetual. According to those results, the flow is:

- incompressible,
- with turbulence

http://dx.doi.org/10.5772/intechopen.72697

- perpetual
- realized in 3 dimensions (x,y,z cartesian coordinate system).

Preservation equations

$$\frac{\partial \rho}{\partial t} + \nabla \cdot \left(\rho \vec{V}\right) = 0 \tag{2}$$

Perpetuity equation: (for perpetual flow)(for incompressible flow)

$$\nabla \cdot \left(\rho \vec{V}\right) = 0 \tag{3}$$

$$\nabla \cdot \vec{V} = 0 \tag{4}$$

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \tag{5}$$

Momentum Equation:

$$\rho \cdot g - \nabla P + \nabla \tau_{ij} = \rho \frac{dV}{dT} \tag{6}$$

in case of constant intensity and viscosity in Newtonian flow (because the air is Newton type fluid): the flow is perpetual and gravity acts in negative z direction turning the equation into:

$$\begin{aligned} -\frac{\partial P}{\partial x} + \mu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right) = 0 \\ -\frac{\partial P}{\partial y} + \mu\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial z^2}\right) = 0 \\ \rho \cdot g_z - \frac{\partial P}{\partial z} + \mu\left(\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2}\right) = 0 \end{aligned} \tag{7}$$

2.3. Boundary conditions

Entering right boundary conditions in CFD is highly important to solve equations correctly. Those conditions having being determined, necessary surfaces should be designated before the analysis process to read them for analysis and post-analysis. Fluids contacting to the solid surface adheres to the surface due to viscose effect, and velocity is zero on the surfaces. Consequently, those surfaces should, for correct solution, be determined in our model.

The ground on which the fluid moves and the surfaces of the courtyard buildings being set as Wall, non-slippery condition will be applied on those surfaces. Because the flow takes place outdoors, Symmetry boundary condition will be selected for upper and lateral boundaries.

2.4. Modeling of courtyard configurations

Separate geometries were formed for each of the 17 different courtyard configurations in Fluent Design Modeler. In choosing the control volume to be calculated, attention was paid to selection of a domain where all necessary geometric and flow properties can be captured. Sensitivity was paid at a few important points for mesh and analysis in forming those geometries.

The first one of those is to make independent from the control volume the analysis in the solution area to be formed around the building. Recommendations from some resources were used to this end. It is generally recommended that if the height of the building is H and width is W, then the control volume should be at least 5H in height and 10W in width, and 2H for upward flow and 10H for the downward flow of the building. [Tutorials: Fluent Introduction - Cell Zone and Boundary Conditions] Another recommendation suggests that the upward flow value should be at least 5H and the downward flow value at least 15H [18].

An average interval was elected among those recommended values and the height of the building which was designed in dimensions of 28.00 × 28.00 × 12.00 cm at the scale of 1/200 (H = 12 cm, W = 28 cm), was set 100 cm in height, 200 cm in width, 100 cm in upward flow and 200 cm in downward flow.

The second important point is that the geometry was divided into as many parts as possible to increase the number of structural meshes in the mesh procedure. Although a structural mesh is easier to approach a solution, they still are hard to shape in complex geometries. Therefore, the geometry may require elimination of unnecessary details and division into an adequate number of smooth parts. In our model, the geometry was divided into an adequate number of parts in view of the same. Furthermore, “form new part” option was used to define under a single form to allow mesh element nodes capturing each other among respective parts.

3. Evaluation of the experimental and numerical simulation data

Surroundings suitable for people’s comfort conditions may vary in view of the environmental conditions within and outside of the building as well as user’s age, gender, metabolism level and clothing. Human body not only can produce heat through the metabolism but also consumes the heat it has produced as a result of its actions. Creation of environments suitable for all kinds of climatic comfort conditions should considered as an objective in architectural designs in view of all these conditions. Openings at different ratios and locations on the building surface have been considered for comfortable ventilation and cooling in buildings with a courtyard, an indispensable architectural feature particularly for hot-dry climatic zones, if used in other climatic zones. And drawing from that central idea of this study, which was first to experimentally investigate to what extent such openings are effective in terms of climatic comfort and then to serve as a background for a more comfortable environment through comparison of achieved findings; the information from the measurements in the existing wind tunnel and the data from the analyses with CFD were examined and interpreted in detail.

With the experimental study; it was aimed to find out the effect on velocity profiles of the rates of opening placed on the building surface, the effects of the flow types on turbulence, and the comfort conditions that can be deducted from human-climate data. The results of the measurements were compared via charts to the average velocity and turbulence values gained from measurements at heights of 0.00H–0.25H–0.50H–0.75H–1.00H–1.25H–1.50H–1.75H at 36 different pre-set points within the courtyard in the pre-set courtyard building configuration with 17 different openings. All openings were opened at ground floor level and the BSL-SUZ configuration accepted as reference building consists of a total of 40 4.00*4.00*4.00 cm boxes on ground floor level.

The opening rates on the courtyard building models with experimented 17 different openings are as follows. Openings were formed at a rate of 1/20 of the total ground floor area for BSL1, at a rate of 1/10 of the total ground floor area for BSL2, at a rate of 3/20 of the total ground floor area for BSL3, at a rate of 1/5 of the total ground floor area for BSL4, at a rate of 1/4 of the total ground floor area for BSL5, at a rate of 3/20 of the total ground floor area for BSL6, at a rate of 1/5 of the total ground floor area for BSL7, at a rate of 1/10 of the total ground floor area for BSL8, at a rate of 1/20 of the total ground floor area for BSL9, at a rate of 1/10 of the total ground floor area for BSL10, at a rate of 3/20 of the total ground floor area for BSL11, at a rate of 3/20 of the total ground floor area for BSL12, at a rate of 1/5 of the total ground floor area for BSL13, at a rate of 1/5 of the total ground floor area for BSL14, at a rate of 3/10 of the total ground floor area for BSL15, at a rate of 2/5 of the total ground floor area for BSL16 (**Figure 1**).

Although the opening rates of some courtyard building configurations are of the same value, the air velocity and turbulence values within the courtyard were found at different levels. The reason why different values have been found is the position to the wind and opening dimensions rather than same opening rates.

In BSL-SUZ courtyard building configuration, the average wind speed in the courtyard is 1.50 m/s. While turbulence values were between approximately 50 and 60% as far as 1.25H level, they have showed a decrease after 1.25H level. Although turbulence values exhibit an unstable appearance going up and down at 0.25H level, high turbulence values have been reached at other levels.

The opening rate at BSL-1-BSL-9 courtyard building configurations is 1/20. It has been seen upon comparison of the velocity values in BSL1 configuration and the values in the configuration of BSL-SUZ, the reference building, that velocity values in the courtyard show an increase. The average velocity in reference building courtyard H height is 1.50 m/s compared to BS1, which rises to 2.50 m/s. As to the windward points with opening, that rate reaches values of 4.50–5.00 m/s. Laminar flow type has been observed considering the flow values at 0.00H- and 0.50H levels. Turbulence air flow type has been observed at other levels. BSL9 configuration shows similarity in terms of lack of windward opening, yet measurements in the courtyard came out differently. The average wind velocity in courtyard at the side of the windward area without opening is the same as between 1.50 and 2.00 m/s, in contrast to the average wind velocity at the side of the windward area with the opening, which has been between 3.50 and 4.00 m/s. Consequently, the average courtyard wind velocities at the side of openings for courtyard building models BSL-1-BSL-9 with openings are almost the same, as about 3.50–4.00 m/s. The average wind velocities at sides without opening in both configurations are 1.50–2.00 m/s, the same level as the reference building.

Other courtyard building models with equal opening rates are BSL-2-BSL-8-BSL-10. Opening rate is 1/10. A comparison of BSL2 with the previous building and BSL-1 buildings show us that the wind speed within the courtyard shows quite an increase. While the average velocity value in BSL1 was 2.50 m/s at H height, it rose to values of 4.50–5.00 m/s in BSL-2. The peripheral air flow to occur in gaps left oppositely will be quite high. The openings in BSL2-BSL-4-BSL-6 configurations were left oppositely at different rates. The reason why in the three configurations, wind velocities show an increase with the opening height within the courtyard at points with opening is due to the "Venturi Effect."

BSL-8 configuration essentially shows similar features to BSL-7 configuration. The only difference of BSL-8 configuration from BSL-7 configuration is the openings widths at windward and leeward regions. The openings widths at BSL8 are less. That has increased the wind velocity at windward and leeward areas with openings.

Average wind velocities as far as H height within the courtyard are about 3.50–4.00 m/s in BSL-2 and BSL-8 model. The wind velocities along the H height within courtyard are found close to wind velocities within the reference building except in general for the points with openings within BSL-8 model (**Figure 3**).

The BSL-10 building with courtyard configuration is highly similar with the BSL-9 building model with courtyard. The only difference of BSL10 configuration from BSL-9 configuration is the openings widths at windward and leeward regions. Openings width in BSL-10 configuration is 2H/3. Consequently, measured velocities and turbulence values are almost the same. Wind velocity as far as 1.25H level is average 3.00 m/s.

Courtyard building configurations BSL-12-BSL-13-BSL-14-BSL-15-BSL-16 are different compared to other configurations. While the openings of other model buildings were at windward and/or leeward area, openings were left in both windward and leeward area and in lateral areas in those models. The air flow within the courtyard is not from the windward and leeward area only but also from lateral areas. The openings at the lateral areas of the courtyard ensure a sudden change in direction after the air flow heads toward the courtyard, and limits toward the air outlet openings on the side wall. Thus, the high rate of air flow and velocity within the courtyard will have been prevented.

The openings rates at BSL-4-BSL-13-BSL-14 building configurations are 1/5. There are quite high values at BSL-4 openings points. The average wind velocity between 0.00H and 0.50H is 7.00–7.20 m/s. Between 0.50H and 1.25H, however, it showed a sudden decrease to fall to 2.00 m/s wind velocity values (**Figure 4**).

The wind velocity at average courtyard H height in BSL-13 is 3.50 m/s. The speed values at points with openings on 3-4 axis at windward region on ground level are quite high compared to other points without openings.

Since the openings left at BSL-14 configuration is only from lateral areas, the wind does not enter the building courtyard from the windward area, resulting in a fall in the courtyard wind velocity values. A comparison of the BSL-14 measurements to the measurements of the reference building, BSL-SUZ courtyard building model, showed that the air velocity values up to 1.25H and turbulence values in the courtyard were almost the same. Average wind velocity is 1.50 m/s. At that level, no speed over 2.00 m/s wind velocity value was encountered up to almost 1.25H level. A comparison of the turbulence values showed that BSL14 had higher turbulence values.

The openings rates at BSL-3-BSL-11-BSL-12 building configurations are 3/20. Although the speed values on 1-2-3-4 axes with openings in BSL3 are about 5.50–6.00 m/s, quite high up to 0.50H height, the wind speed at points on 5-6 axes without openings turned out to be about 1.50 m/s. The width at the windward area constituting the entry area with the openings is greater compared to the width at the leeward area, which constitutes the exit area. Consequently, thanks to the effect called "channel-funnel effect" at leeward area, the speed values particularly at leeward exit area are quite high (**Figures 4** and **5**).

The speed value is average 2.50–3.00 m/s at openings points within the courtyard in BSL-11 configuration. Openings were left only from the leeward area.

BSL-12 configuration differs from the other configurations examined until now. This is because openings were formed at windward and leeward areas only in the others in contrast to this one where openings were formed laterally in addition to those areas.

As a consequence, the air flow within the courtyard is not from the windward and leeward area only but also from lateral areas. The air entry openings placed in the middle of the courtyard and the openings in the middle of the lateral area ensure a sudden change in direction after the air flow heads toward the courtyard, and limits toward the air outlet openings on the side wall. Thus, a high rate of air flow and velocity within the courtyard will have been sent out before they may even occur. Average wind velocities up to 1.25H height at points within the courtyard are about 3.00–3.50 m/s. Turbulence values are high here particularly at points in the leeward area.

The openings rates at BSL-6-BSL-15 building configurations are 3/10. In BSL6, velocities of laminar flow type at very high levels between 0.00H and 0.50H such as 7.00–7.50 m/s have been achieved. Considering the flow values at 0.50H and 1.25H levels, wind velocity fell to values between 1.50 and 2.00, and velocities of turbulence flow type were achieved (**Figure 4**).

The BSL-15 building with courtyard configuration is similar to the BSL13 building model with courtyard. Consequently, courtyard and extra-courtyard measurements came out almost similar. While the openings widths at lateral areas were 2H/3, the openings widths of windward and leeward areas were at H/3 rate, and heights of the same at H/3 rate. The average wind velocity within the courtyard up to 1.25H height is about 2.50 m/s.

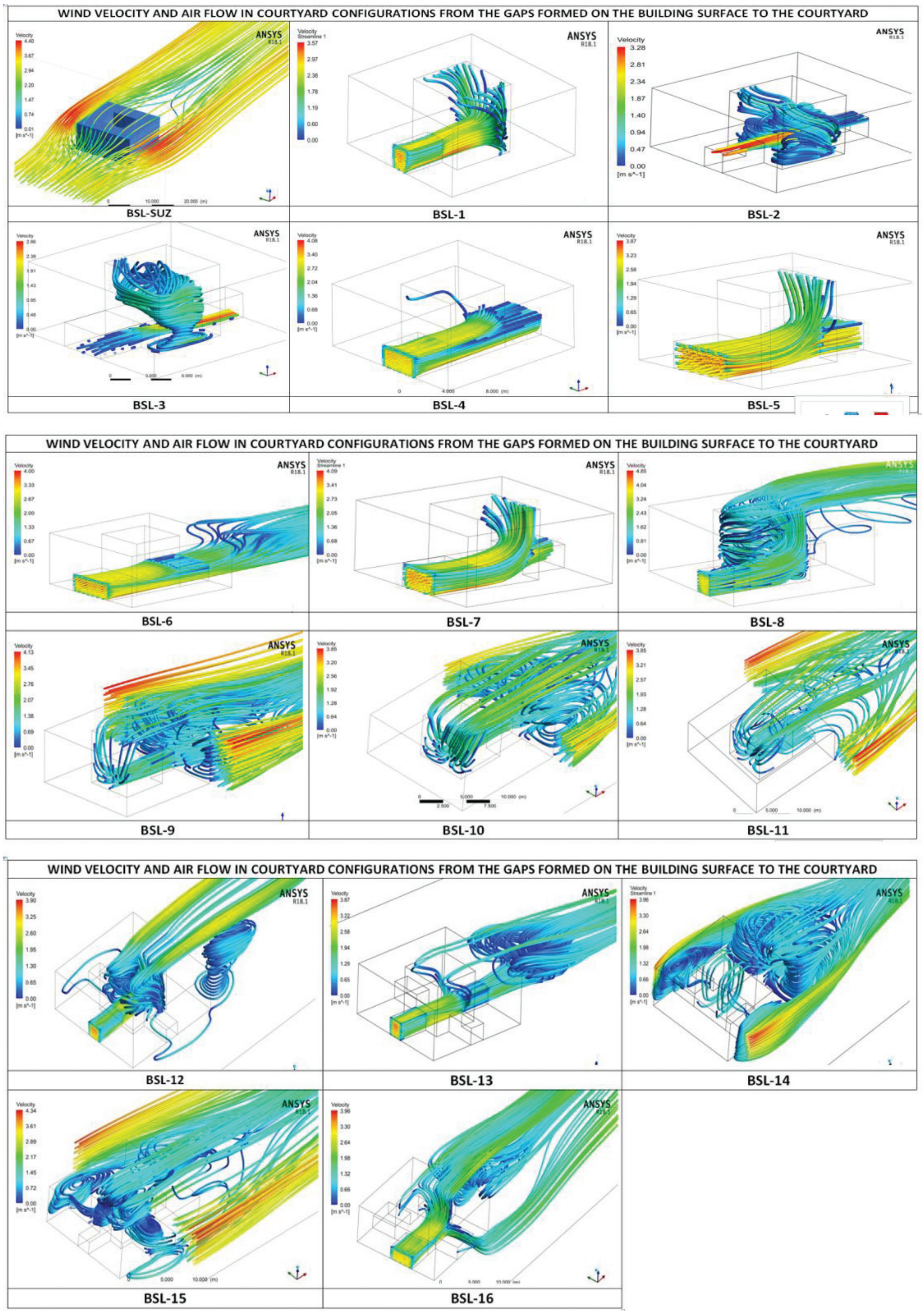

Figure 4. Wind velocity and air flow in courtyard configurations from the gaps formed on the building surface to the courtyard.

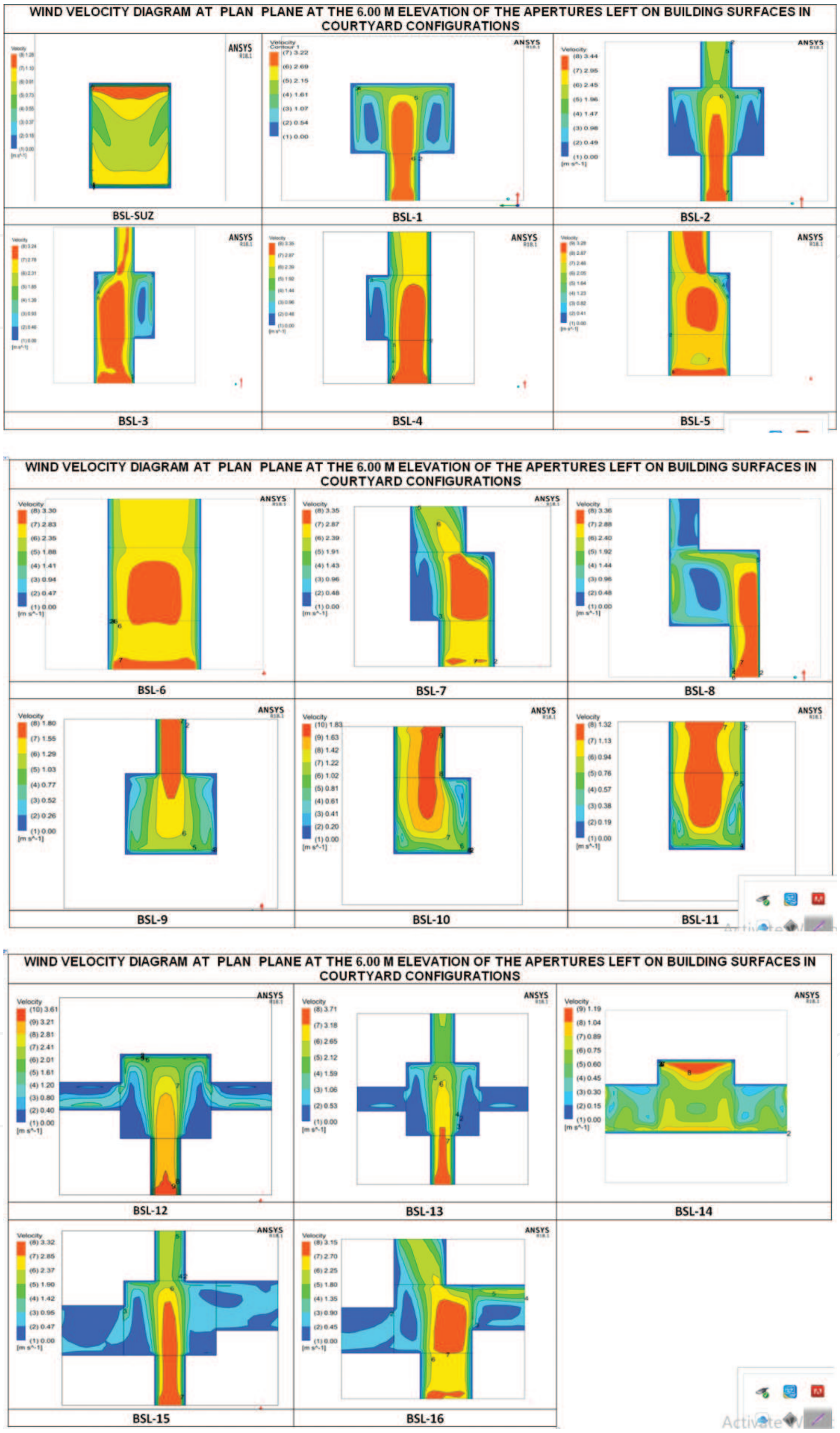

Figure 5. Wind velocity diagram at plan plane at the elevation of the openings left on building surfaces in courtyard configurations.

The BSL16 building with courtyard configuration is in fact a different version of BSL13-BSL15 models of building with courtyard. Consequently, courtyard and extra-courtyard measurements came out almost similar. The average wind velocity at points of 3-4-5-6 axes with openings is about 5.50–6.00 m/s. As to the points on windward 1-2 axes without openings, the increase of the wind velocity fell considerably to an average of 2.00 m/s. The wind velocity average between 0.50H and 1.50H is about 2.50–3.00 m/s (**Figures 4** and **5**).

As a result, the reference building model BSL-SUZ has a wind velocity of 1.50 m/s when assessed in view of average wind velocities in its region at H level area within the courtyard. There are two different velocity values within the courtyard in building configurations BSL1-BSL2-BSL3-BSL4-BSL5-BSL6. These are; while the average wind velocity is found out at high values up to 0.00H-0.50H level, the openings height at points with openings, a sudden fall occurs in locations without openings in the wind velocity values between 0.50H and 1.25H.

Wind velocities of 4.50–5.00 m/s were found for BSL1 up to openings level 0.00H-0.50H and of 2.00–2.50 m/s above openings level or at points between 0.50H and 1.25H without openings; of 5.50–6.00 m/s for BSL2 up to openings points level and of 3.50–4.00 m/s above openings level or at points without openings; of 5.50–6.00 m/s for BSL3 up to openings points level and of 1.50 m/s above openings level or at points without openings; of 7.00–7.20 m/s for BSL4 up to openings points level and of 2.00 m/s above openings level or at points without openings; of 6.50–7.00 m/s for BSL5 up to openings points level or of 2.50–3.00 m/s above openings level or at points without openings; of 7.00–7.50 m/s for BSL6 up to openings points level or of 1.50–2.00 m/s above openings level or at points without openings. There are average wind velocity values for other building configurations up to courtyard H height. Those are average velocity values of 2.00–3.00 m/s for BSL7, 3.50–4.00 m/s for BSL8, 1.50–2.00 m/s for BSL9, 3.00 m/s for BSL10, 2.50–3.00 m/s for BSL11, 3.00–3.50 m/s for BSL12; 3.50 m/s for BSL13, 1.50 m/s for BSL14, 2.50–3.00 m/s for BSL15, 2.50–3.00 m/s for BSL16.

4. Conclusions

As a result of the experimental study made; it is an experimental study aimed at presenting preliminary information for studies to be held thereafter and form a base for the designated data about exactly how much cooling and ventilation would occur within a courtyard building using numerical methods for the air flow values acquired within the courtyard. The results of this study can be summarized as follows. Courtyards of surrounded courtyard without openings (BSL-SUZ) type have minimal air velocity.

Although openings rates are same, the position of the openings becomes increasingly significant. Proportional velocity increases occur as the openings rate grows on windward and leeward opposite surfaces. In the event of different openings rates on windward and leeward opposite surfaces, velocity increases become considerable as the openings on the windward surface grows.

Very different wind velocity and ventilation characteristics are observed due to differentiation of the positions with openings in courtyard options with same openings rates. In the event of unilateral openings arrangement, the openings on the windward surface are effective at the highest level and those on the leeward surface at the lowest level. While there might be decreases in the average air movement velocity due to the relative positions and area rates of openings, points where it increases at spatial distribution may also be formed.

With this study, several experimental measurements and numerical studies will be held in relation with the building form and surface openings in courtyard buildings at different configurations and at different dimensions. As a result, it will constitute a very good reference to all studies to be held hereafter with regard to the reliability and availability of all measurements conducted and results found, and constitute a base to the design data in various conditions.

Author details

Enes Yasa

Address all correspondence to: enesyasa@yahoo.com

Faculty of Architecture, Department of Architecture, Ankara Yıldırım Beyazıt University, Turkey

References

[1] Erell E, Pearlmutter D, Williamson T. Urban climate: Designing Spaces Between Buildings. London: Earthscan/James & James Science Publishers; 2010. 266 p

[2] Ansley RM, Melbourne W, Vickery BJ. Architectural Aerodynamics. London: Applied Science Pub; 1977

[3] Awbi HB. Design consideration for naturally ventilated buildings. Renewable Energy. 1994;**5**(5):1081-1090

[4] Ratti C, Raydan D, Steemers K. Building form and environmental performance: archetypes, analysis and an arid climate. Energy and Buildings. January 2003;**35**(1):49-59

[5] Al-Mumin AA. Suitability of sunken courtyards in the desert climate of Kuwait. Energy and Buildings. January 2001;**33**(2):103-111

[6] Al-Hemiddi NA, Al-Saud KAM. The effect of a ventilated interior courtyard on the thermal performance of a house in a hot–dry region. Renewable Energy. November 2001; **24**(3–4):581-595

[7] Rajapaksha I, Nagai H, Okumiya M. A ventilated courtyard as a passive cooling strategy in the warm humid tropics. Renewable Energy. September 2003;**28**(11):1755-1778

[8] Lawson TV. Wind Effects on Buildings – Vol. 1, Design Applications. London: Applied Science Publishers; 1980

[9] Gandemer J, Guyot A. Integration du Phenomene Vent Dans La Conception du Millieu Bati. Paris, France: Premier Ministre Groupe Central deş Villes Nouvelles Secretariat General; 1976

[10] Yasa E. An experimental study on the effect of the surface openings on the air flows by the wind effect on natural ventilation and cooling [Master of Science thesis]. Institute of Science and Technology, Istanbul Technical University; February 2005

[11] Ok V et al. Yerleşme dokusu dizayn değişkenlerinin Açık mekanlardaki rüzgar hızına ve Akım tipine etkilerinin incelenmesi, TÜBİTAK Proje No. İNTAG-214, Istanbul: Istanbul Teknik Universitesi; 1996. pp. 3-4

[12] Ok V, Yasa E, Ozgunler M. An experimental study of the effects of surface openings on air flow caused by wind in courtyard buildings. Architectural Science Review. 2008;**51**(3): 263-268

[13] Sharples S, Bensalem R. Airflow in the courtyard and atrium buildings in the urban environment: A wind tunnel study. Solar Energy. 2001;**70**(3):237-244

[14] Ünal B. Bina Biçimlenmesinde Boşlukların Yakın Çevredeki Hava Hareketi Üzerine Etkilerinin İncelenmesi [Y.Lisans Tezi]. Istanbul, Turkiye: Istanbul Teknik Universitesi; 1995

[15] Grigs PF, Sexton DE. Experimental techniques for wind tunnel tests on model buildings. Energy and Buildings. 1974. CP 43/74, 11, Seiten, BRS, Garston, England

[16] Reynolds SJ. Courtyards, Aesthetic, Social and Thermal Delight. New York: John Wiley & Sons Inc.; 2001

[17] Harrouni K. Thermal Comfort in Courtyard Housing Model in Morocco. A Case Study of a Traditional House Model in the Medina of Rabat. Architecture, Energy & Environment. HDM, Lund University, Sweden; 2002

[18] Daeung Kim. The Application of CFD to Building Analysis and Design: A Combined Approach of an Immersive Case Study and Wind Tunnel Testing. Architecture and Design Research. Blacksburg, Virginia; December 11, 2013