ENHANCING NATURAL VENTILATION THROUGH MASSING: NEW POSSIBILITIES FOR TURKISH MASS HOUSING

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Abstract

Urban growth and economic policies in Turkey have produced structural alterations in the housing dynamics. Currently, the Turkish Mass Housing Administration (TOKI) solves the residential deficit through large-scale high-rise proposals. Although reaching more, these developments are characterized by a low users' satisfaction: overheated units during the hot period of the year challenge thermal comfort of people. The TOKI projects are indistinctive to climates where they are built. In hot and dry regions, the "residential tower" relies on a low window-to-wall ratio (WWR) to minimize heat gains in summer.

The repetition of this model makes residential projects lacking functional diversity, while limits the possibility of different unit size and usage of local natural forces. As a traditional strategy, passive cooling has been used to balance indoor and outdoor environments. Historically, communal courtyard buildings known as "karavanserais" have displayed the relationship between openings and the building mass to make wind the main climatic regulator.

This paper investigates the typical flow regimes through a case study: a TOKI project in Gaziantep. Located in the southeastern part of the Anatolian peninsula, hot and dry conditions of this city and its influence on a 12-story residential project are simulated in IES-VE. By using the MicroFlo analysis tool, this modeling is compared to a proposed typology that takes advantage of convection from the prevailing winds via external simulations. Besides using envelope design parameters and massing configuration to improve indoor conditions of units, this typology also brings new spatial alternatives for the limited conditions that represent living in a public high-rise housing in Turkey.

It is observed that building orientation according to prevailing wind direction increases the potential of natural ventilation. Channeling and diverting effects were seen in different building patterns. Behavior of wind in different width-height aspect ratios were compared with the literature.

Introduction

Since the 1940s, rural migration has increased the demand on mass housing in Turkey (Bolen, 2004). According to the Turkish Statistical Institute (TUIK, 2017), every year 200,000 people immigrated to the urban areas between 1950 and 2008. However, these cities could not answer the housing problem of people because the unprecedented immigration surpassed the capacity and resources to provide a formal dwelling production; hence, municipalities not providing enough infrastructure and slum areas extended quickly (Senyapili, 1998).

As a solution to control informal settlements, "gecekondu" in Turkish, in cities' peripheries (Karpat, 1976), governmental initiatives have developed housing solutions by establishing the Mass Housing Authority called TOKI.

In 1984, with law number 2985, TOKI was created with the purpose of providing financial support for new projects, including the clearance and transformation of slum areas (Dulgereoglu-Yuksel et al., 2009). TOKI has looked for mass housing alternatives for low- and middle-income groups, gathering public funds for urbanization. Since that moment, this agency has developed more than 600,000 units in renewal projects around the country (TOKI, n.d.). Its models include social housing, disaster housing, and slum transformation projects (Devrim, 2016).

During the period between 2003 and 2008, many regulations passed in favor of TOKI. With these financial benefits and power, "65,808,839 m² of land were transferred to TOKI" allowing the institute to build projects on state-owned land (Akcan, 2015).

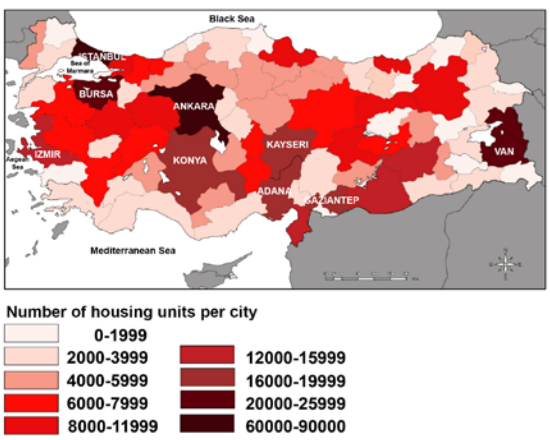

Figure 1: Housing production by TOKI agency in Turkey between 2003-2017.

Concentrated on the main cities, large-scale real estate projects have emerged by investments of private construction companies and subsidies of local governments. Under the scenario of an earthquake destruction, TOKI agency has gained power as a main actor in the housing sector (Bozdogan et al., 2012).

Therefore, public-owned lands started to be used for mass housing projects. However, the repetition of this model makes residential projects lacking functional diversity, while limits the possibility of different unit size and usage of local natural forces.

In this sense, its projects have been criticized for having living areas that overheat in summer and underheat in winter. Their fenestration and wall assemblies are built under budget restrictions and without clarity about their compliance with thermal standards.

In this paper, one of the TOKI projects which was built for low income groups whose houses were demolished during gecekondu clearance of three districts (Turktepe, Etiler and Ozdemirbey) in the city of Gaziantep is selected ("Sahinbey' de Toplu Konut Sevinci," 2011) (Table 1 and Figure 2).

Features	
Number of towers	6
Total number of units	288
Number of units in a tower	48
Unit area (m²)	86
Number of floors	12
Building height (m)	39.95
Building volume (m³)	14.163
Number of units per floor	4
Floor to floor height (m)	2.91
Window-to-wall ratio (WWR)	8.4
Balcony	1 per unit
Heating/hot water	Natural Gas
Construction material	Concrete

Table 1: Features of TOKI Etiler project.

Figure 2: TOKI Etiler project during construction, surrounded by low-rise buildings. Gaziantep, Turkey, 2011. (Source: www.haber3.com.)

Climate

Gaziantep is defined as a hot and dry climate region in Turkey. According to the measurements from two stations between 1935 and 1990, urban heat island density in the city was detected as maximum 7°C. The effect of urban warming increases slightly in autumn months (Santamouris et al., 2016) (Figure 3).

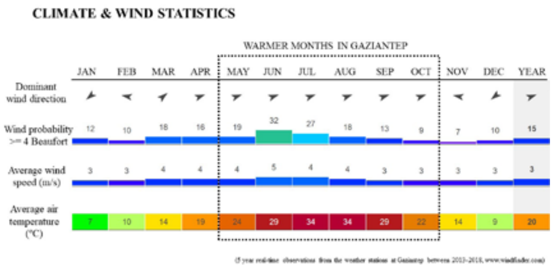

Figure 3: Average annual temperature and wind statistics Gaziantep, Turkey. (Source: Windfinder.)

The wind conditions in Gaziantep are characterized by a prevailing southwest wind although it has a wind regime with almost diametrically opposed seasonal wind directions: cool southwest wind during the period between May and October and a cold winter wind in the four-month period November–February (Figure 4).

Figure 4: Wind regime in Gaziantep. (Source: Windfinder.)

Methodology

For air quality and cooling, the presence of wind is the most affordable requirement. Since wind is directly connected to the quality of life in the city, airflow corridors in open spaces is essential for urban ventilation. These corridors let cool air to flow close to ground into the city center where wind mitigates the heat island effects significantly and control over the heated atmosphere.

Since the behavior of urban wind flow can be significantly influenced by the arrangement of buildings and porosity, aerodynamic flow effects are various depending on the width-height aspect ratio (Figure 5).

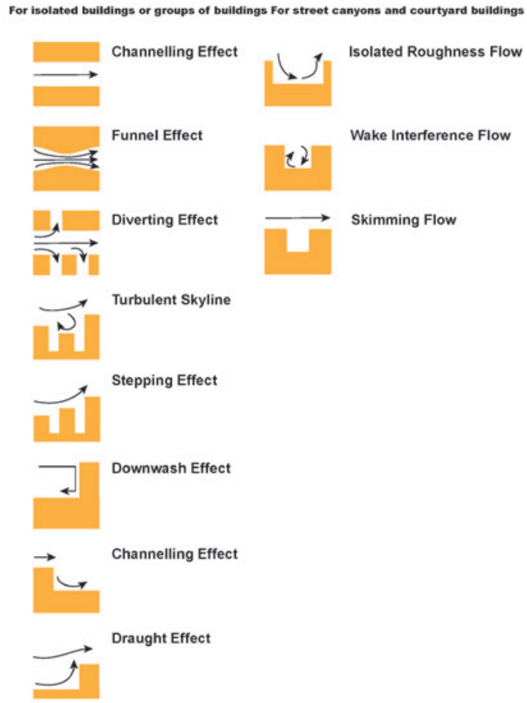

Figure 5: Aerodynamic flow effects. (Source: Krautheim, 2014.)

Wind moves through the alignment of building mass. Its speed increases through narrowing building structures. Street canyons cause diverting effect into side streets. Irregular height of buildings creates turbulences and increase velocity between buildings. Continuously rising heights of structures move wind to the top. When wind meets the facade, it creates turbulence on the ground through a downwash effect. Buildings facing the upward and leeward sides are subject to back pressure and draught effect, which are related to air pressure, respectively. In addition, width/height aspect ratios of greater than 2.4 results in 'full flushing of courtyards,' while those of 1.4–2.4 generates two connected flows. On the other hand, a ratio smaller than 1.4 decreases the air exchange in courtyards (Hussain et al., 1980; Oke, 1983; Krautheim et al., 2014).

Because urban wind flow is also related to urban density, the arrangement of buildings, their geometrical configurations and dimensions, the project in Gaziantep was evaluated through urban density which can be described with floor space index (FSI) and ground space index (GSI). The FSI or floor area ratio (FAR) is the result of the total floor surface area divided by the plot area of a residential projects. The GSI is the result of the 'building footprint' divided by the plot area (Uytenhaak, 2013). And the number of floor (H) is also used (Figure 6).

For the project with 12-story towers, FSI value is 1.78. Since the values between 1 and 2, which are considered urban by Uytenhaak (2013), this number is acceptable. However, for a different proposal, various heights and GSI values were tried by achieving the same index of FSI which is 1.78.

Urban wind flow can be evaluated by full-scale measurements, wind-tunnel experiments or numerical simulation with Computational Fluid Dynamics (CFD) (Chen, 2009). Since CFD simulations can be conducted at full scale and allow parametric studies to evaluate various design configurations, the software IES is used to test the enclosure possibilities that can enhance ventilation performance in this project.

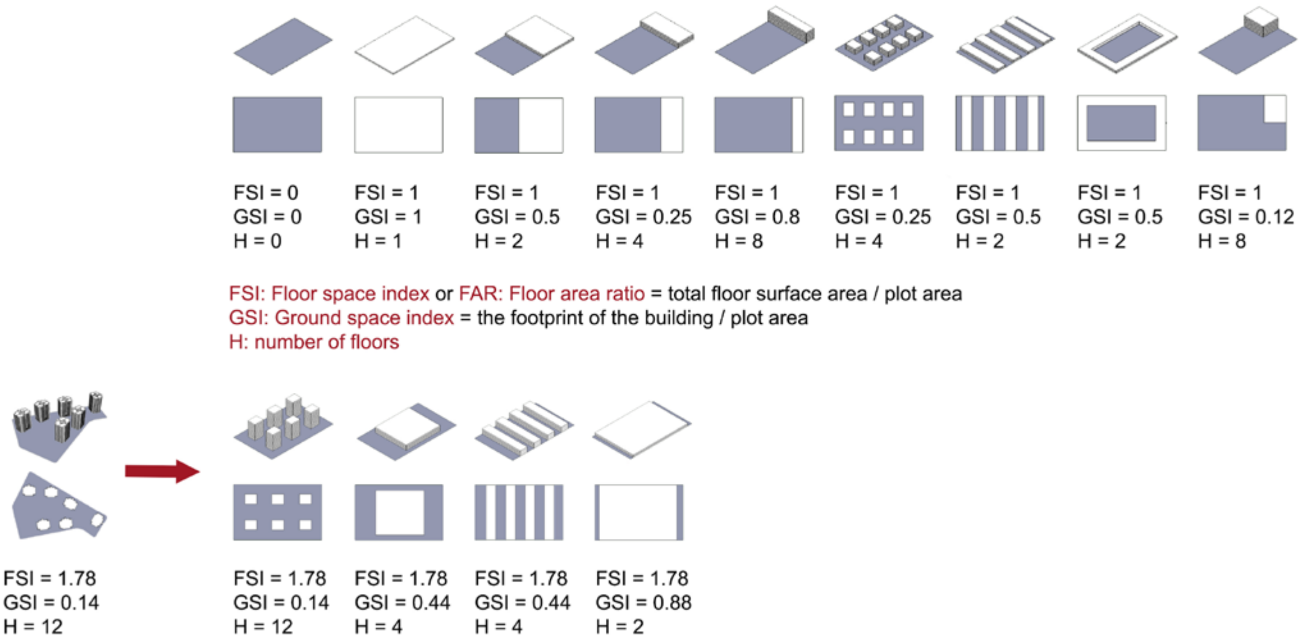

Figure 6: FSI and GSI comparison of the TOKI Etiler project with different building patterns.

Although the accuracy of this method depends on grid resolution, they are seen as an alternative method to expensive empirical studies in wind tunnel (Krautheim et al., 2014). Its graphical output will be used to conclude that how porosity affect the outdoor urban ventilation.

External CFD simulations were done to analyze airflow over the buildings. Since this type of simulations do not allow modelling for heat transfer and do not read any weather data, these are useful to observe the wind effects on the around buildings (IES VE Microflo User Guide, 2015). Therefore, wind direction, wind speed and the size of its domain were used as user inputs.

The domain is divided into small blocks on which the computational equations are applied (Figure 7). This domain should be large enough to be able to create flow information around the buildings. Also, k-e turbulence model which is widely used and calculates turbulent viscosity for every grid cell is used. In this sense, 174m, 522m, 139m, and 208m are used for upwind, downwind, sides, and above, respectively. Since the height of the tallest building is accepted as 34.8m (12th floor in TOKI Etiler towers), the maximum cell aspect ratio is 7:1.

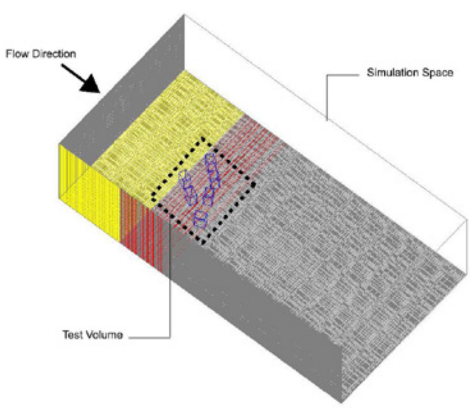

Figure 7: Diagram showing CFD external simulation domain in IES.

Real-Scenario Model

In the first series of tests, the case study, a 6-tower residential projects in Gaziantep was modeled in IES and examined in MicroFlo for a six-month period (the warmer months from May to October) and the two months when wind velocity is more intense (May and July when cooling is required). When the average wind speed of these six months is 4.5 meters per second (mps), those are 4 mps and 5 mps for May and July, respectively (Figure 8).

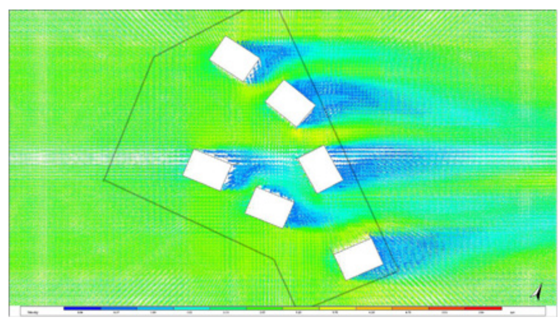

Figure 8: TOKI Etiler project in MicroFlo (tested from May to October).

In the MicroFlo interface, the modeled geometries are reoriented to be perpendicular to the prevailing wind direction. In the case of the TOKI model in Gaziantep, it is observed how the prevailing comes from the left side of the interface and makes visible the wind forces on the six TOKI towers that composes this residential complex.

In order to gain accuracy for the model, a specific number of cells were used along each one of the 3-dimensional axes of the coordinate system. Overall, 3.7 million CFD grid cells were used, and this allowed to give resolution to the flow regimes such as canyons. The 'grid spacing' of the default IES mesh was modified from 1m to 2m.

Each one of the six towers has a volume of 249m^3 for 48 apartment units. Each has an average of 63.8m^2 enclosure area facing outdoors, with 8.4% used for windows. Since

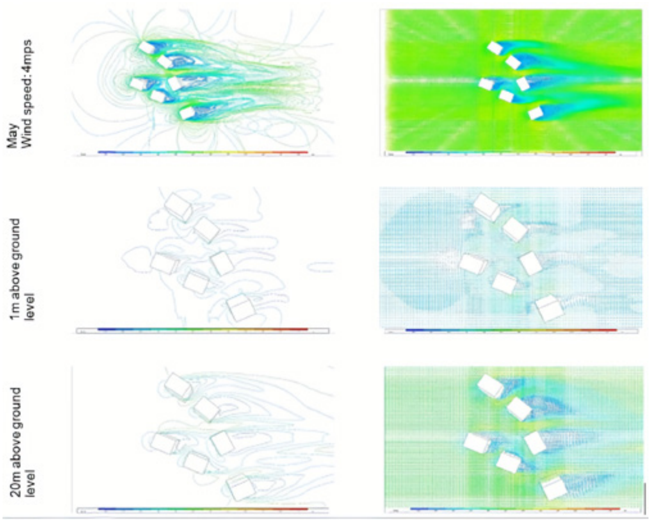

Figure 9: CFD analysis at different heights (1m and 20m) of the project during May.

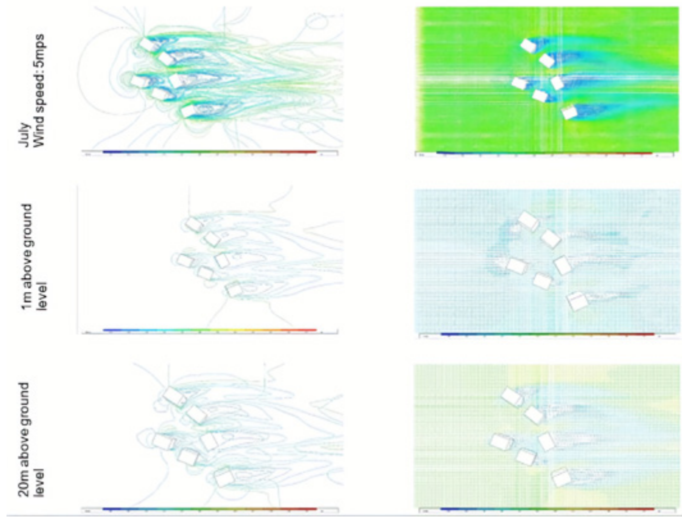

Figure 10: CFD analysis of the project for July.

balconies in this project are small and tend to be adapted into solariums were not considered for the natural ventilation effects. Most of them are used for storage and are not usually dwelled.

Since the ratio of buildings to open space determines the character of urban airflow, this case study addresses the original arrangement of towers to capture when the wind is led into aisles by the alignment of the towers (channels) or when the narrower space between volumes causes an acceleration in the speed of the flow. By iterations at different heights (1m, 20m), these effects are modeled to perceive the effects of wind further from the ground (Figures 9 and 10).Within the irregular arrangement of towers in the TOKI Etiler project, it was observed that distance between towers affects its performance either making them 'isolated volumes' or part of 'street canyons.' Since all volumes are separated nearly 20m from each other (except the southwest tower), it seems that their alignment causes that some units which face northeast, east, and southeast have weak windspeed for cross-ventilation. From both images, wind velocity around these units changes between 0.02 mps and 1.2 mps, as it is shown with blue colors (Figures 9 and 10).

The second and third rows in both figures show the difference behavior and speed of wind on the 1-meter above ground level and 20-meter level. On the street level, the velocity is between 0.02 and 2.15 mps while these values are increasing with height and reaching 3.9 mps at the seventh-floor level.

The first series of tests display that units located on upwind facades have higher value of velocity at 20m level. On the other hand, the higher level of a unit does not accelerate the speed of wind at downwind sides. Through the observation of this building pattern, it is evident that under this urban configuration, natural ventilation will be a challenge for residential units that are not adjacent to areas under 'channeling effects.'

With the purpose of researching flow regimes that can benefit natural ventilation in this location new spatial parameters and orientations could be tested. The current configuration of TOKI Etiler project seems to be inappropriate for a region where in the hot periods, prevailing wind flows could be essential to reduce cooling loads.

The tower configuration of TOKI Etiler project with isolated rectangular floor plans shows that this form does not enhance positive or negative pressures to enhance effects such as "Venturi" or "Mesh" effects. The volumes could not be integrated to take advantage of the prevailing stream. Besides this, inside the tower each space (room) is ventilated only through one facade which could reduce the possibilities of cross ventilation.

GENERIC COURTYARD MODELS

As an alternative through residential towers, a new urban configuration is developed. This new model balances a similar urban density and explores the orientation of different size openings of the building mass to the prevailing wind. It tests how surrounding building volumes of an open space make possible particular range of speed (mps) across a new set of volumes.

As a first step to investigate passive cooling in this location, the outdoor environment is observed. Traditionally, communal courtyard buildings, known as "karavanserais" in Turkey, have displayed the relationship between openings and the building mass to make wind the main climatic regulator in the city. Therefore, in these second series the generic courtyard is modeled.

In IES, several features are gradually added to a courtyard basic form (changes in the floor plan and in the number/size of openings). Three generic courtyard buildings illustrated different patterns respective to the TOKI Etiler projects. In MicroFlo, three preliminary models are set to 8 mps, keeping the same orientation to mainstream such as the TOKI Etiler project.

With this angle, it is less unlikely to see typical effects in courtyards (such as channeling, funnel, and diverting effects) having an important effects on this prototype that is thought as a multifamily buildings that enclosed an open space. Modeled courtyards have width to height proportions (W/H) of 1.25, 2.5, and 3.75, making constant a height of 12 m and modifying the courtyard depth (Figure 11).

As it is expected, on a new approach with a geometry parallel to the prevailing forces, perpendicular external forces penetrate the courtyards. Wind is led into aisles by the alignment of courtyards between two openings on windward and leeward walls. Also, narrowing buildings structures provide accelerated velocity (funnel effect) when the width of the openings on windward walls that have positive pressures was increased.

In this further step, the orientation setting of the courtyard building (247º) allows to see with more clarity the magnitude of the outdoor prevailing southwest wind direction in the depth of the courtyard (Figure 12). Openings on the upwind facades have a stronger influence in the test volume with courtyards of W/H of 1.25 (left column).

On narrower courtyards (W/H of 3.75) (right column), a funnel effect is more evident with a more constant acceleration of the prevailing streams. Finally, in courtyards with a W/H of 2.5 (central column) with diverting forces generated by lateral canyons some trend to central turbulences in the open space are observed.

In the last test series, the proposal examples were modelled as 4-story courtyard buildings. Communal courtyards were aligned at 247º prevailing southwest wind direction. For mesh, 2m grid spacing was used. Values of 60m, 180m, 48m, 72m were used for the domain.

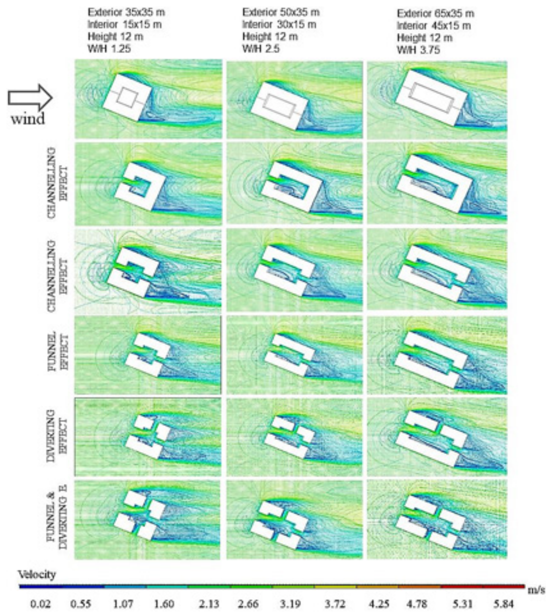

Figure 11: Courtyards of W/H proportions of 1.25, 2.5, and 3.75 under different aerodynamic changes parallel to prevailing wind.

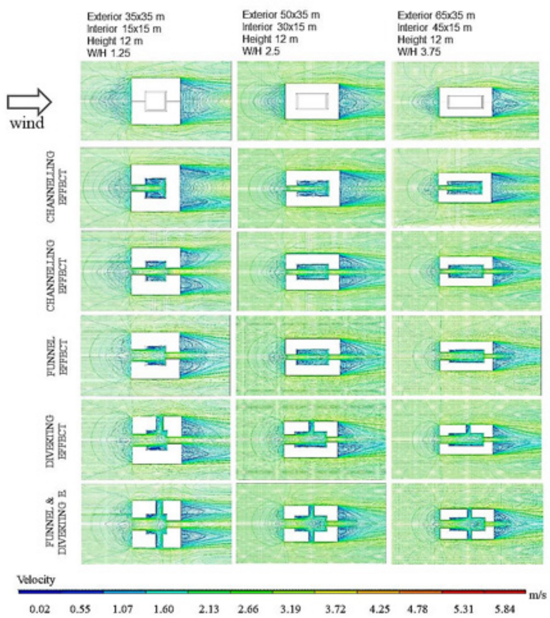

Figure 12: Courtyards parallel to prevailing wind.

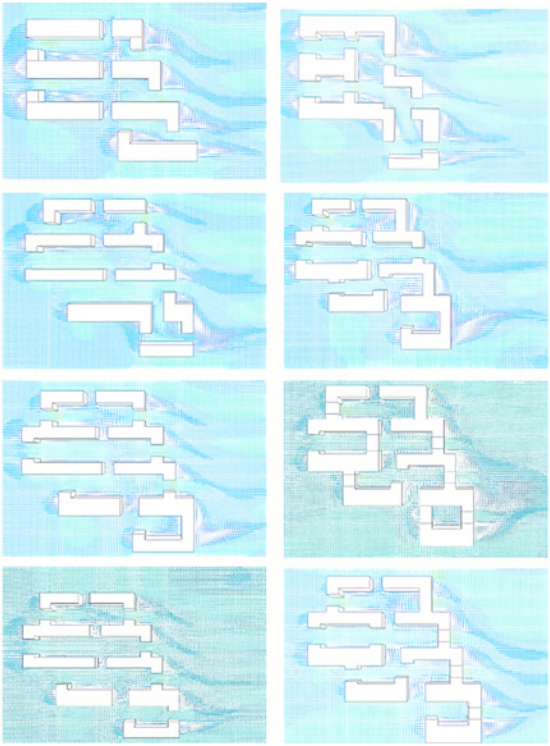

Figure 13: Courtyard development parallel to prevailing wind–vectors on 1-meter level.

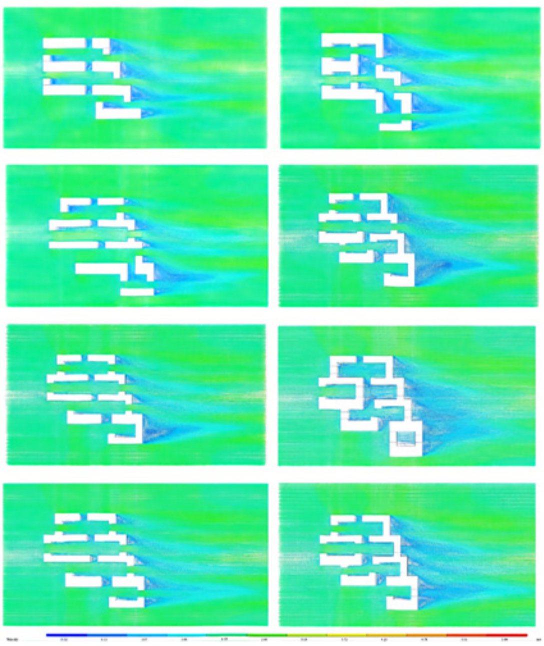

Figure 14: Courtyard development parallel to prevailing wind.

DEVELOPMENT OF A COURTYARD PATTERN

The last simulation series were repeated with different sizes of courtyards. The number of 1,152 residents in 288 apartments of TOKI Etiler project was provided by using a courtyard pattern with different W/H ratios to keep the density. While TOKI Etiler project has identical four 2-bedroom apartments per floor, for proposed series 50 m² 1-bedroom apartments, 75 m² 2-bedroom apartments, and 100 m² 3-bedroom apartments were used for different sizes of families. Instead of using 12 stories, the exact density was used with four stories.

Funnel effect, channeling effect and diverting effect were tested for the series located at 247° prevailing southwest wind direction in Gaziantep (www.windfinder.com/windstatistics/gaziantep). It is considered that this angle also allows units to have south orientation for desired daylight.

Stagnation on windward walls, recirculation in leeward walls and corners of buildings were observed on the street level through velocity vectors. At this level (1 meter above ground level), wind speed is changing between 0.02 and 2.20 mps (Figure 13).

Results

This study tested orientation and porosity as the two most important parameters through the three series of external simulations. Based on the test results from previous phases, general assumptions were made about wind effects. It is observed that building orientation to prevailing wind direction increases the potential effect of natural ventilation through channeling effect in courtyards or street canyons compared to free standing / isolated buildings.

Wind is diverted into the voids of building mass in courtyards. This effect is getting stronger when ratios of width/height are bigger than 1.25 (W/H=15/12m). This result was validated through research on wake interference value on typical flow regimes. According to Hussain and Lee (1980) and Oke (1988) ratios between 1.4 and 2.4 create wake interference flow and connects vortices.

For both isolated and courtyard buildings, turbulence on corners of buildings' leeward façade creates recirculation. A ratio of width/height = 5.4 (65m/12m), 3.75 (45m/12m), 3.3 (40m/12m), 2.5 (30m/12m) were tested and isolated roughness flow was observed. These simulations showed that a ratio of W/H > 2.4, wind flows towards these courtyards and no interaction occurs between vortices on upwind and downwind sides (Figures 13 and 14).

Conclusion

Since the behavior of wind flow around buildings has a significant effect on the quality of life in urban areas, even small-scale modifications of building geometry and typology can influence the performance of wind. These strategic arrangements of building mass that have a great potential to reduce cooling loads can easily alter velocity and surface conditions.

The integration of passive cooling through natural ventilation, passive solar heating through correct orientation and daylighting is the priority for the design process of low-maintenance and high-quality mass housing. These ecological goals allow residents to live more satisfied by decreasing their possible energy consumption to reach the minimum comfort level.

Architecture can definitely provide tangible ways of integrating sustainability into our daily lives. It helps to solve ecological problems with design and provides solutions to living in balance within our local environments more respectfully.

For further steps, internal analysis will be conducted to see indoor temperatures of units by considering surface heat transfer, openings, boundary conditions and building components such as construction materials, infiltration rate and internal loads.

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