The Impact of Different Morphological Characteristics of Residential Areas on Wind Movement: Case Study of Karşıyaka (Izmir)

Nurdan Çağla Çamaş[1*], Mediha Burcu Sılaydın Aydın[2*]

[1] Dokuz Eylül University, The Graduate School of Natural and Applied Science, Orcid ID 0000-0001-8015-1199, nurdancagla.camas@ogr.deu.edu.tr
[2] Dokuz Eylül University, Department of City and Regional Planning, Orcid ID 0000-0001-9843-3370, burcu.silaydin@deu.edu.tr
[*] Correspondence: nurdancagla.camas@ogr.deu.edu.tr

Abstract

Cities are warmer than their surrounding rural areas due to the urban heat island effect. The heat island effect occurs in urbanized areas in which structures such as buildings and roads are highly concentrated and green cover is limited. Extreme heat waves resulting from climate change also cause temperature increases in the urban environment. In addition, the urban heat island effect negatively affects the comfort of individuals living in cities and increases the amount of energy required for cooling, especially in warm climate regions. To reduce both the urban heat island effect and the need for cooling, it is necessary to consider wind movement during the urban planning process. Within this context, it is vital that spatial development decisions allow planned building groups to benefit from natural ventilation opportunities. The morphological features of buildings directly affect the available opportunities to use wind energy for passive cooling in urban areas. Therefore, it is necessary to determine which morphological parameters affect the building-wind relationship. This study presents an analysis of wind simulations made by modeling selected examples of actual residential areas to determine the effects of different morphological features on wind movement. Twelve residential areas located in the Karşıyaka District of İzmir Province were determined for analysis due to their distinct morphological characteristics. The results of the study revealed that the parameters that affect wind movement in urban areas are the array of the buildings, their density, the distances between them, their floor area ratio, and their height. With regard to the provision of wind movement, it was found that the detached housing type is the most

advantageous for hot climate zones. In addition, increasing the distances between structures was found to have a positive effect on natural ventilation. However, when viewed at the scale of residential areas, building heights on wind movements in the residential areas depends on the other two parameters. The simulations created for this study show that all morphological features of the building group under analysis affect wind movement, both separately and in combination.

Keywords: Residential Areas, Urban Morphology, Wind Movement

1.   Introduction

Surface and air temperatures are higher in urban areas than in rural areas due to factors such as higher population and building densities, concrete and asphalt surface materials, and the lack of green spaces. This situation has given rise to a phenomenon termed the urban heat island (UHI) effect. The enhanced warming associated with UHIs has direct implications for a range of environmental, economic, and health-related outcomes in cities [1,2]. UHIs can negatively affect the health of city inhabitants and urban ecosystems and increase the amount of energy consumption used for cooling during summer. Additionally, it has been verified by many studies that climate change and UHIs can affect each other, and that in combination they have resulted in increased mortality rates due to the extremely high air temperatures they can produce [3]. Therefore, efforts aimed at reducing the UHI effect have gained importance.

One of the basic factors which both cause UHIs and increase their magnitude is poor urban ventilation. High building density in cities prevents the movement of wind, which leads to higher temperatures. For this reason, promoting natural ventilation is considered to be an important measure to mitigate the UHI effect [e.g. 4,5,6,7]. The urbanization character of a city directly affects its ventilation performance [8]. Urban ventilation depends on the characteristics of parameters such as urban length, frontal area ratio, and plane area ratio [9]. At the microscale, the movement of wind between buildings and street ventilation are factors that can directly affect conditions within housing units and influence the demand for domestic energy used for cooling. The morphological characteristics of building areas play an important role on whether natural ventilation can be provided or not. These include parameters such as building height [7,10,11,12,13], building density [7,11,12,14,15], floor area ratio [7,11,12,13,14,16], the distance between buildings [10,11,16], orientation [10], building layout [10,15], building forms [10,13,15], block forms [14], building coverage ratio [7], block size [11,14], the open space ratio [11], and site coverage [16]. Given this context, it is necessary to consider wind movement in urban planning processes by taking these morphological parameters. The effect of these morphological parameters on wind movements has been an important

issue that needs to be examined in different purposes (urban heat island, energy consumption, urban energy saving, etc.).

This study presents an analysis of wind simulations made by modeling selected samples from actual residential areas to determine the effects of different morphological features on wind movement. Twelve residential areas located in the Karşıyaka District of İzmir Province were determined for analysis due to their distinct morphological characteristics. The aim of this study is to determine the impact of different morphological characteristics of residential areas on wind movement by investigating the relationship between natural ventilation possibilities with the morphology formed by urban planning decisions.

2.   Materials and Methods

The method followed in this study consists of three stages: 1) Selecting the sample residential areas by considering different morphological characteristics; 2) Drawing three-dimensional sketches of the building arrays within the sample residential areas; and 3) Creating wind movement simulations.

2.1.   Case Area

To determine the urban morphology features that will provide the optimum benefit from wind movement, the Karşıyaka District of İzmir Province was chosen as the case area due to its having dense residential areas with differing morphological characteristics (Fig. 1). Karşıyaka is located on the north shore of İzmir Bay and is surrounded by Bayraklı to the east, Bornova to the northeast, Menemen to the north, and Çiğli to the west. İzmir is located in the Aegean climate zone and has summers that are dry and hot and winters that are warm and rainy [17]. The prevailing wind direction is between the south and southeast, and the average wind speed is 3 m/s [18].

Figure 1 The Built-up Area of Karşıyaka District (Resource: Google Earth)

2.2. Selection of the Residential Areas used for the Simulation

Twelve Karşıyaka residential areas with different morphological characteristics were determined for use in the simulation (Fig. 2). These morphological characteristics include parameters such as building density, housing types (attached, detached, block, etc.), building height (number of floors), and floor area ratio. The selected residential areas can be classified according to 3 groups: 1) 5 mass housing patterns (high-rise, villa type, and mixed) (Fig. 2 no: 1, 2, 3, 4, 5); 2) 6 apartment types (Fig. 2 no: 6, 7, 8, 9, 10, 11); and 3) 1 slum type (Fig. 2 no: 12). The morphological characteristics of the selected residential areas are given in Table 1.

Figure 2 Selected Residential Areas in Karşıyaka (Resource: Google Earth)

Table 1 The Morphological Characteristics of the Selected Residential Areas*

Area no	Housing type	Number of floors	Density	Floor area ratio
1	Detached	21, 22	1.90	0.09
2	Attached, Blocked	2, 18, 19	2.85	0.18
3	Attached, Blocked	2, 3	1.02	0.37
4	Attached	2	0.66	0.31 - 0.35
5	Attached	5, 9	1.47	0.21 - 0.27
6	Detached	5	2.62	0.32 - 0.62
7	Detached	2, 5, 6, 7	2.51	0.25 - 0.56
8	Attached	5, 6	4.84	0.71 - 1.20
9	Attached	3, 4, 5, 6	4.32	0.62 - 1.20
10	Attached	2, 4, 5, 6, 7	4.49	0.68 - 1.50
11	Attached	5, 6, 7, 8, 9	5.00	0.58 – 1.25

| 12 | Attached, Detached | 1, 2, 3, 4 | 1.32 | 0.18 – 1.23 |

* Table 1 was produced by the authors using Google Earth and the Parcel Inquiry App of the TC General Directorate of Registry and Cadastre.

2.3.   Modeling

Following the selection process, three-dimensional sketches of the building arrays of the twelve residential areas were drawn by using the Sketchup programme (Fig. 3). Only the form of the building groups was used in the modeling; in other words, the façade features of the buildings (windows, doors, roofs etc.) were ignored. In addition, the external areas surrounding the building groups were not included in the modeling. A floor height of 3 m was accepted as a means to estimate the building heights for the modeling process.
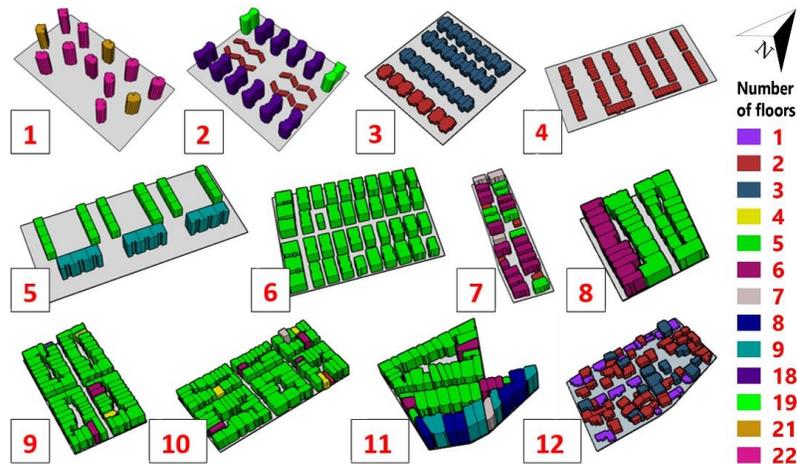

Figure 3 Three Dimensional Sketches of the Selected Residential Areas

2.4.   Simulations

The wind simulations were carried out using the Autodesk CFD (2021) program. Since this program works with computational fluid dynamics (CFD) logic and has good accessibility, it is commonly preferred for use in studies examining wind movement [e.g., 15,19,20,21]. When running wind simulations, two main data are important: wind direction and wind speed. In İzmir, the prevailing wind direction is from the southeast, with an average wind speed of 3 m/s. However, wind direction data can be entered in the simulation program only in the main directions (north, south, east, and west). For this reason, the three-dimensional drawings of the study areas were transferred to the simulation program after they had been rotated by -45 degrees in Sketchup (Fig. 3). By

entering the wind direction as south in Autodesk CFD, it was possible to apply a southeast wind direction to the models.

Due to the working logic of the simulation program, it was necessary to assign computational boundary domain sizes around the three-dimensional drawings (Fig. 4-a). The resolution factor value of the models was entered at the lowest value (500) to minimize errors from the program or the faster simulations (Fig. 4-b). Following this, the material types of the models and their computational boundary domains were selected. Concrete was chosen for the models (Fig. 4-c) and air was chosen for their computational boundary domains (Fig. 4-d). The boundary conditions data was input to establish a wind direction from south to north (Fig. 4–e and f). The magnitude of the wind inlet-velocity magnitude was set at 3 m/s (Fig. 4 - e), and the pressure was applied at zero Pascal (Pa) at the outlet of the computational boundary domain (Fig. 4 - f). Finally, "iterations to run data" was set in the solve section to start the simulation (Fig. 4 - g). During this step, each simulation was repeated 100 times to ensure the reliability of the results. The running time of the wind simulations differed in each model, depending on the surface area sizes of the models, and ranged from 40 minutes to 170 minutes. The settings for the models were made in the same way and used the same data. The data used in the simulation are given in Table 2, and the simulation process of the Autodesk CFD program is given in Fig. 4.

Table 2 Data Used in the Simulation Program

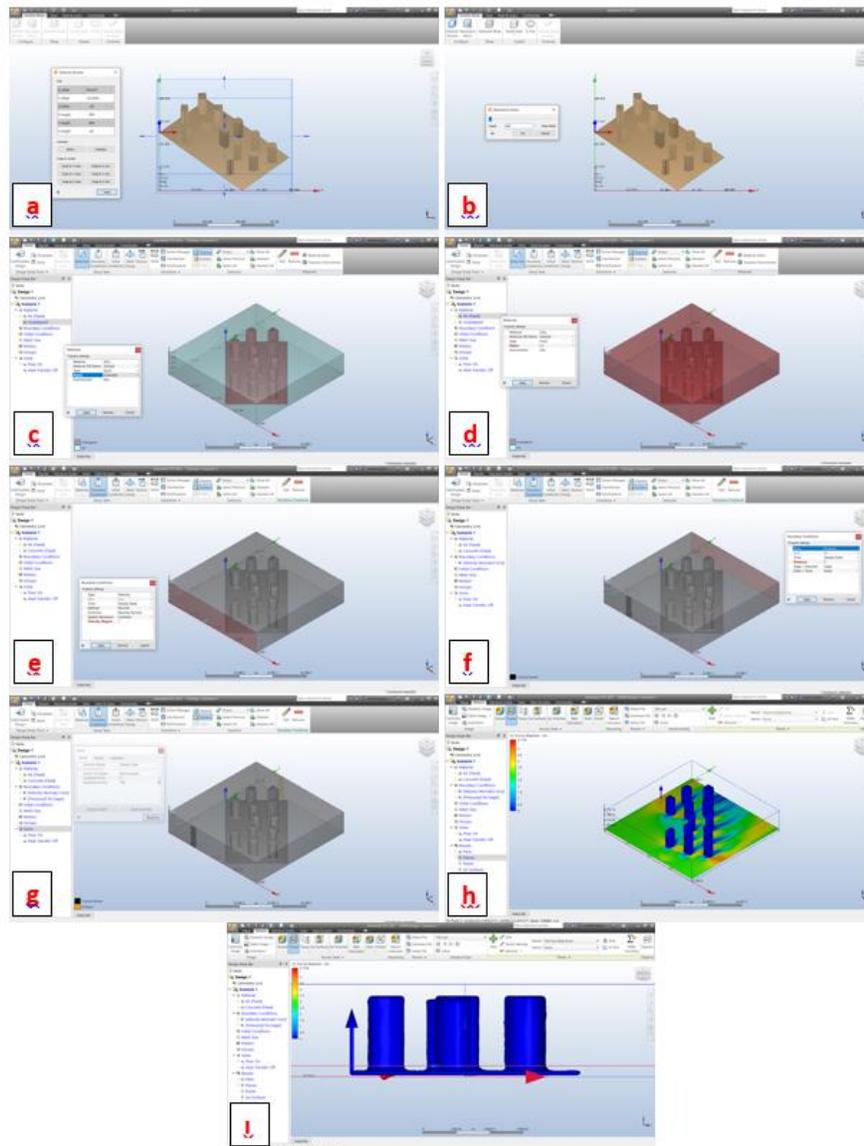| Data name	Value / Explanations
Resolution factor	500
Computational boundary domain material	Air
Model material	Concrete
Boundary conditions	From south to north
Wind speed	3 m/s
Iterations to run	100

Figure 4 Processes of Simulation

3.   Results

The simulation outputs were taken from 1 m above the ground (Fig. 4 – h, ı, and Fig. 5). In the results of the wind simulations of the modeled building groups, the maximum wind speed magnitudes in the area are different for each model and vary from 0 to 13.37 meters per hour. These changes are represented using a color scale from blue to red for the values of the velocity magnitudes (Fig. 5).
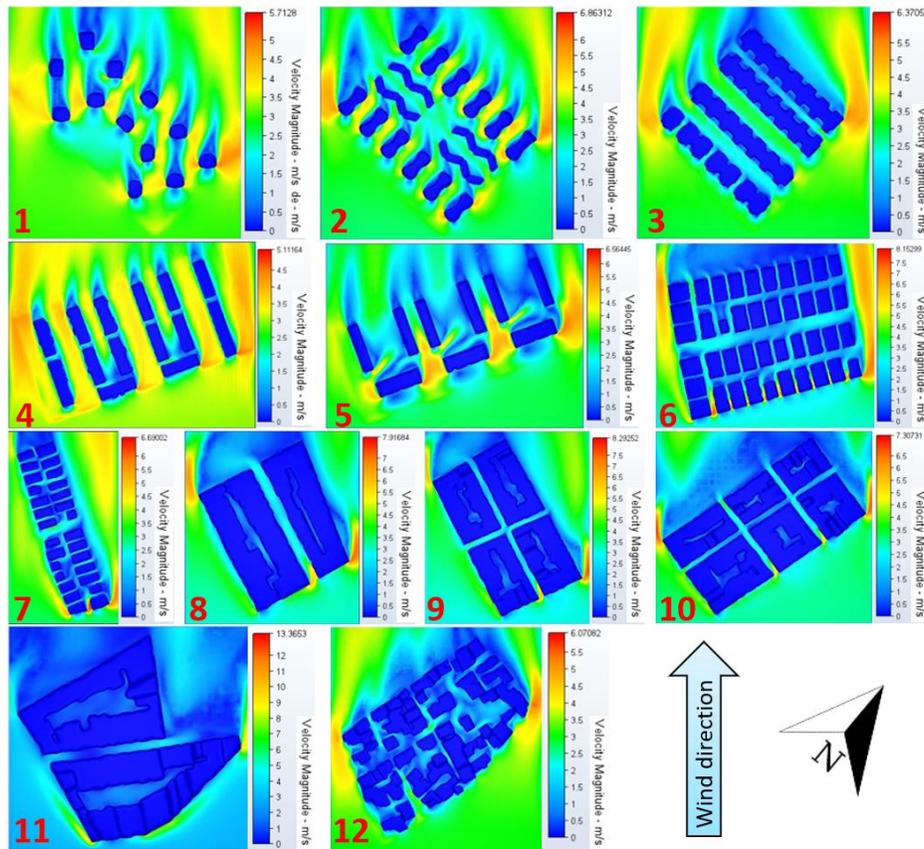
Figure 5 Wind simulation results

According to simulation results, the detached housing type (Fig. 5 no: 1, 6, 7) is more advantageous than the attached housing type (Fig. 5 no: 8, 9, 10, 11) in terms of providing natural ventilation. The results show that the distance between buildings is also a significant parameter for the behavior of the wind flow around the detached house type. As the distance between buildings increases, the flow of wind into the building groups increases. In other words, increasing the distance between buildings strengthens natural ventilation.

These two criteria (the detached housing type and the distance between buildings) are both related to the floor area ratio parameter. The detached housing type and/or increased distance between buildings means a decrease in the floor area ratio. In this case, it has been proven that a lower floor area ratio creates a building that is more suitable for creating natural ventilation. As can be seen from the residential patterns given in this study, a low floor area ratio (0.09-0.35) increases wind flow and speed (Fig. 5 no: 1, 2, 3, 4, 5). Conversely, raising the floor area ratio by 2 times (0.25-0.62) (Fig. 5 no: 6, 7) or more (0.58-1.20) (Fig 5 no: 8, 9, 10, 11) reduces the wind flow. However, when the simulation results of models no: 4 and no: 5 (Fig. 5) are examined, although the floor area ratio of model no: 4 (0.31-0.35) is higher than that of model no: 5 (0.21-0.27), it can be observed

that model no: 4 provides better natural ventilation due to the building layout. Because the multi-storey and attached residential buildings of model no: 5 are perpendicular to the direction of the prevailing wind, this positioning prevents wind movement and eliminates the advantage of the floor area ratio parameter.

The attached house type creates a barrier effect against the wind (Fig. 5: no: 8, 9, 10, 11) and this negatively affects the potential for natural ventilation of building groups by preventing the wind movement. On the other hand, the results of this study show that natural ventilation is also related to building layout. For example, although building groups model no: 3, 5 and 8 all have attached housing types, enclosed block forms (Fig. 5 no: 8, 9, 10, 11) more severely limit wind movement. When comparing enclosed type blocks, the results show that the size of the block's yard is a factor that impacts wind behavior, but not to an important degree. In enclosed blocks, the height of each of the buildings around the inner yard affect the level of ventilation, and the height of the buildings which meet the wind movement is the determining factor. For example, when comparing model no: 8 and model no: 11, although both have the same characteristics in terms of building height, model no: 8 benefits from the orientation of its buildings within its block array.

The simulation results also show that the effect of the building height parameter on wind movement is closely related to the building layout and orientation of the buildings. When the residential areas with high-rise (18-22 floors) buildings (Fig. 3 no: 1, 2) are examined, both can be claimed to have good natural ventilation opportunities. However, the simulation results show that model no: 1 allows more wind flow compared to model no: 2 due to its having larger distances between buildings that result in a smaller floor area ratio and a lower building density.

When the building groups with villa type buildings (1-3 floors) (Fig. 3 no: 3, 12) are compared, the simulation results show that the natural ventilation opportunities are better in model no: 3 than in model no: 12 (Fig. 5). In slum-type residential areas (Fig. 5 no: 12), the wind can move within the building groups to a certain extent, but it is largely interrupted since the buildings are mostly attached and the layout is therefore similar to the enclosed type. For this reason, there are ventilation problems in such areas.

The evaluation of the simulation results according to the building density parameter revealed that the most suitable model for natural ventilation is the building group with the lowest building density (0.66) (model no: 4). In the building groups with the highest building densities (4.32 – 5.00) (model no: 8, 9, 10, 11), natural ventilation was found to be poor.

Street layout is another factor that determines the layout of buildings and is also an important parameter in terms of ventilation. When streets are oriented in the same direction as the prevailing wind and the widths of the streets are increased, the ventilation of the building groups built along them is also improved.

These evaluations show that all the morphological parameters of a given building group can affect wind movement, reinforcing the importance of the relationships between them, as given in the literature. In addition, this study shows that different results can be obtained from differing combinations of these parameters, and that the prevailing wind direction is an external element that should be considered in the formation of the morphology of a city.

4.   Discussion and Conclusion

In this study, wind movement in residential areas was examined according to the natural ventilation possibilities of building groups with different characteristics formed by urban planning decisions. By comparing the simulation results, it was possible to analyse the effects of morphological parameters on wind movement and ventilation, and to determine which parameters are advantageous and disadvantageous for optimum utilization of natural ventilation.

In summary, the results of this study show that the best choice for promoting better levels of natural ventilation is the detached housing type, due to the greater distances between buildings, a lower floor area ratio, and lower overall building density. Conversely, the enclosed block form is shown to be the most disadvantageous building array for ventilation from wind movement. In particular, the height and location of the buildings (especially those facing the prevailing wind direction) surrounding the inner yard have negative effect on ventilation. Furthermore, the results show that building height affects wind movement, but that this parameter is primarily related to building layout and orientation, then floor area ratio, distance between buildings, and building density. In all cases, the orientation of buildings and building layout are important parameters for ventilation. The simulation results show that when buildings are not oriented according to the prevailing wind direction, this directly prevents ventilation. Finally, morphological parameters were shown to affect wind speed, which in turn affects the effectiveness of wind movement with regard to the level of natural ventilation it can provide.

As a result, it can be clearly stated that all of the morphological parameters examined in this study affect wind movement. However, it is also the case that not only the individual parameters, but also their combination is important with regard to the provision of ventilation. Therefore, different combinations that encourage natural ventilation should be applied during urban planning processes. In addition, the prevailing wind direction of a given city is dependent on the local climatic characteristics and also plays a major role in ventilation. The morphological parameters of an urban development should be designed by considering both their likely effect on wind movement and their suitability for the prevailing wind direction. In this way, urban planning processes can be used to achieve energy savings and mitigate the UHI effect.

5. Acknowledge

References

[1] Jr, B. S., Vargo, J., Liu, P., Hu, Y., & Russell, A. (2013). Climate change adaptation through urban heat management in Atlanta, Georgia. Environmental Science & Technology, 47(14), 7780-7786. https://doi.org/10.1021/es304352e

[2] Heaviside, C., Macintyre, H., & Vardoulakis, S. (2017). The urban heat island: Implications for health in a changing environment. Current Environmental Health Reports, 4, 296–305.

[3] Kim, S. E. & Brown, R. D. (2021). Urban heat island (UHI) intensity and magnitude estimations: A systematic literature review. Science of the Total Environment, 779, 1-17. https://doi.org/10.1016/j.scitotenv.2021.146389

[4] Rajagopalan, P., Lim, K. C., & Jamie, E. (2014). Urban heat island and wind flow characteristics of a tropical city. Solar Energy, 107, 159-170. https://doi.org/10.1016/j.solener.2014.05.042

[5] Hsieh, C. M., & Huang, H. C. (2016). Mitigating urban heat islands: A method to identify potential wind corridor for cooling and ventilation. Computers, Environment and Urban Systems, 57, 130–143. https://doi.org/10.1016/j.compenvurbsys.2016.02.005

[6] He, B. J., Ding, L., & Prasad, D. (2020). Urban ventilation and its potential for local warming mitigation: A field experiment in an open low-rise gridiron precinct. Sustainable Cities and Society, 55, 1-17. https://doi.org/10.1016/j.scs.2020.102028

[7] Ku, C. A., & Tsai, H. K. (2020). Evaluating the influence of urban morphology on urban wind environment based on computational fluid dynamics simulation. ISPRS International Journal of Geo-Information, 9(6), 399. https://doi.org/10.3390/ijgi9060399

[8] Gülten, A. (2019). Natural ventilation performance of residential urban areas at pedestrian level: Comparison of old and new settlements. International Journal of Innovative Engineering Applications. 3(2), 61-66.

[9] Chen, G., Rong, L., & Zhang, G. (2021). Impacts of urban geometry on outdoor ventilation within idealized building arrays under unsteady diurnal cycles in summer. 206, 1-17.

[10] Huang, Y., Musy, M., Hegron, G., & Chen, H. (2008). 663: Towards urban design guidelines from urban morphology description and climate adaptability. P. Kenny, V. Brophy, J. O. Lewis

(Edi.), PLEA 2008 – 25th Conference on Passive and Low Energy Architecture, October 22-24, 2008. Dublin.

[11] Srifuengfung, S., & Peerapun, W. (2013). Investigation of the ventilation rate around different urban morphological property types: High rise -vs- low rise in Bangkok's high density areas. ABAC Journal, 33(3), 65–81.

[12] Jin, H., Liu, Z., Jin, Y., Kang, J., & Liu, J. (2017). The effects of residential area building layout on outdoor wind environment at the pedestrian level in severe cold regions of China. Sustainability, 9(12), 1-18. https://doi.org/10.3390/su9122310

[13] Wang, B., Geoffroy, S., & Bonhomme, M. (2021). Urban form study for wind potential development. Environment and Planning B: Urban Analytics and City Science, 0(0), 1-16. doi:10.1177/2399808321994449

[14] Çetintahra, G. E. (2013). Yapı adası tasarımının yaşam kalitesine etkileri: İzmir Güzelyalı mahallesinde bir araştırma (in Turkish) (Effects of building island design on quality of life: A study in İzmir Güzelyalı neighborhood) E. Böke (Edi.), 25. Uluslararası Yapı ve Yaşam Fuar ve Kongresi, March 28-30, 2013 (pp. 53-62). Bursa: TMMOB Mimarlar Odası Bursa Şubesi.

[15] Javanroodi, K., Mahdavinejad, M., & Nik, V. M. (2018). Impacts of urban morphology on reducing cooling load and increasing ventilation potential in hot-arid climate. Applied Energy, 231, 714-746. https://doi.org/10.1016/j.apenergy.2018.09.116

[16] Adelia, A. S., Yuan, C., Liu, L., & Shan, R. Q. (2019). Effects of urban morphology on anthropogenic heat dispersion in tropical high-density residential areas. Energy and Buildings, 186, 368-383. https://doi.org/10.1016/j.enbuild.2019.01.026

[17] IBŞB. (2022). Green Re-vision: A Framework for resilient cities. İzmir Büyükşehir Belediyesi. https://direnclikent2019.izmir.bel.tr/en/LocalInformation/26/20

[18] MGM. (2022.). İzmir ilinin iklim durumu (in Turkish). (Climate situation of Izmir province). Meteoroloji Genel Müdürlüğü. https://izmir.mgm.gov.tr/files/iklim/izmir_iklim.pdf

[19] Şabanoğlu, Ö. (2018). Toplu konut yerleşimlerindeki açık alanlarda rüzgarın kullanıcı konforuna etkisinin analizi ve değerlendirilmesi (in Turkish). (Analysis and evaluation of the wind effect on user comfort in mass housing open areas). Master's thesis, İstanbul: İstanbul Teknik University.

[20] Johansson, E., & Yahia, M. W. (2020). Wind comfort and solar access in a coastal development in Malmö, Sweden. Urban Climate, 33, 1-14. https://doi:10.1016/j.uclim.2020.100645

[21] Gao, M., Zhang, L., Ni, P., Zhang, Y., & Wang, W. (2021). Research on the Influence of Building Layout Forms on Wind Environment in Urumqi City Based on CFD Simulation. 2021 4th International Symposium on Traffic Transportation and Civil Architecture (ISTTCA), November 12-14, 2021 (pp. 776-782). Suzhou: Institute of Electrical and Electronics Engineers (IEEE).