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A Study on the Evaluation of Wind Energy to Reduce Energy Loads in Settlements

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Abstract- Rapid construction, intensive urbanization, developing technology, and the desire to live in comfortable and high-quality environments have increased the use of energy and caused environmental problems. As buildings and urban areas account for a significant proportion of overall energy consumption, priority should be assigned to energy efficient solutions in buildings and urban area design. One of the most effective ways to ensure energy efficiency in buildings is to use wind, which is one of the resources that comes to mind when it comes to renewable energy sources and that has not been widely used in buildings before. In this article, the use of wind as a roof-mounted wind turbine was examined and the results of the parametric computational fluid dynamics (CFD) study conducted in a city to analyze the effects of texture form, building height, building height/street width (H/W) ratio, and texture orientation of wind speed on the roofs were reported. The study was carried out for the city of Istanbul, Turkey, where urban transformation is very fast. The results of this study showed that among the developed urban texture alternatives, compact structure alternatives (row houses and 4-courtyards), provide higher wind speed than the alternatives with single blocks. When analyzing the urban texture orientation, it was observed that the wind speed on the roofs of the textures at an angle of 45° with the wind direction (0°, 90° alternatives) was higher than a wind speed on the roofs of the textures parallel to the wind direction (45°, 135° alternatives).

Keywords Wind energy on buildigs, Energy efficient cities, Urban texture form, H/W ratio, Roof mounted wind turbine, ENVI- met.

1. Introduction

As a result of urbanization and industrialization, an energy efficient approach has been adopted as people need more energy to heat, cool, and light their buildings in order to achieve climatic and visual comfort conditions. Despite the increasing energy need, scarce and consumable energy resources make it obligatory to use alternative energy sources in buildings.

In a world where approximately 40% of total global energy consumption is spent by buildings [1], it is an inevitable requirement that buildings become self-sufficient buildings and produce their own electricity with renewable, clean, and natural resources. Turkey also has a very important share of the energy costs used in buildings when compared to other expenses; therefore, it is essential for the country to benefit from clean and inexhaustible energy sources. Although wind energy has the highest and fastest growth rate renewable energy source [2], it is not being used sufficiently in buildings in Turkey. One of the most efficient and applicable natural energy resources in the world is wind energy [3].Wind energy is not actually a new energy source, it is an energy source that has existed since the world emerged [4].This clean and inexhaustible energy is definitely candidate as an important energy sources of the coming years in buildings in Turkey. The widespread use of renewable energy and energy efficiency is very important in terms of reducing climate change and economically [5]. In contrast to large wind turbines installed in rural areas, small-scale wind turbines, especially those mounted on buildings, are less frequently used in urban areas. This is because wind is very difficult to control in urban areas, and wind reaches urban areas at lower speeds [6]. Although wind turbines in urban areas have difficulties, such as turbulence, noise, size, space, and the visual impact created in a city, it is a great advantage for small-scale wind turbines that the energy they produce does not have the storage and transportation costs that large-scale turbines have [7]. In urban areas, roof-mounted wind turbines have been getting more attention, as they reduce energy transmission costs and use the building's height as a turbine tower, as well as using the accelerator effect of the building when placed properly [8]. In addition, the connection of renewable energy systems to the grid has many positive aspects in terms of environmental, social and economic aspects [9].

Wind flow in urban areas is seen as a clean, safe, and potentially available energy source for buildings [7]. Since the energy generated from the wind is theoretically proportional to the cube of the wind speed (V^3), a small increase in wind speed creates large differences in wind energy [10]. Therefore, when placing a wind turbine in urban areas, the wind source in the region should be well utilized, the turbine should be placed where the wind is most efficient, and the aerodynamics of the building should also be designed so that the wind flows towards the roof.

In urban areas, it is usually possible to estimate the micro-scale and building-scale wind source in 3 ways, or a combination of these ways, which comprise 1) field measurements, 2) full scale or reduced-scale wind-tunnel measurements, and 3) numerical solutions. Numerical solutions on a meteorological microscale are made, especially with computational fluid dynamics (CFD) [11, 12]. However, in wind tunnel experiments, which are thought to be effective from approaches to measure wind speed, the most common problems that arise are those with dynamic similarity and high blockage rates [6].

The biggest advantage of numerical simulations when compared to others is the opportunity to make a comparative analysis based on different scenarios and analyze them according to all of the variables in the whole calculation area. While only data from specified points in limited areas can be obtained in wind tunnels, it is much easier to access many data of each desired point in a numerical analysis [13]. Another advantage of numerical simulations is that they require less time and less cost, and many different data can be obtained from a simulation [14]. CFD is a useful method in the application of small wind turbines, which is much less costly and faster in the measurement of wind speed than on-site measurement and visually evaluate wind flow [15]. In recent years, CFD has begun to attract great attention in the fields of wind engineering, such as the natural ventilation of buildings and wind-driven and pedestrian-level wind conditions, and has been implemented in many projects [6]. Limited studies on the wind flow around buildings, wind speed in urban areas, and the use of wind turbines in buildings have increased over the last decade as CFD began to become widespread.

Blocken et al. [16], comparing CFD results with wind tunnel measurements, studied the effect of the passage between the two parallel buildings in different widths on wind flow and wind speed. In the study of Mithraratne [17], the appropriateness of the use of rooftop wind turbines on urban houses in New Zealand was examined, and the net energy and carbon emissions of these residences were evaluated with a life cycle assessment. Although it was determined that the energy produced was very low when compared to large turbines in terms of energy production, it was found that the roof top wind turbines had the potential to decrease the energy and carbon density that the houses used by 81% and 26%, respectively. In the study of Lu and Ip [18], building group alternatives using three different states with different building ranges, building heights, and roof shapes were simulated with the CFD program. The improvement methods of different situations were examined and the effects on wind speed and wind flow on the roofs of the buildings where the turbines will be placed were examined. In the study of Ledo et al. [19], wind flow characteristics, such as turbulence density, and wind speed, on the roofs of residential groups in suburban areas with different roof profiles, such as gable, hipped, and terrace roofs, were simulated with CFD. Abohela et al. [20], conducted a CFD study to determine the energy efficiency of rooftop wind turbines on buildings with different roof shapes, different wind directions, and different building heights, and where the wind turbine will be located on the roofs. The results of their research showed that the vaulted roof was more suitable than other roofs and in this case, 56.1% more electricity was produced.

Razak et al. [21], studied the wind speed and airflows at the pedestrian level. In their study, the wind speed was investigated as a result of simulations performed on idealized urban building arrays under the conditions of the plan area ratio, building aspect ratio, and height variability. In the study of Tabrizi et al. [15], a model was created by combining wind atlas software with a CFD program used as a wind energy assessment tool while placing a small-scale wind turbine on the roof of the buildings, and this model was tested for a building in Australia. This model was found to be sensitive to the building height and shape, roof shape, wind direction, and turbine installation height and location. In the study of Nishimura and Kolhe [22], as a result of simulations of two buildings in Tsu, Japan, the buildings were oriented according to the wind in order to find the most suitable place for the wind turbine. In order to increase the power value obtained from the turbine in the study, the buildings were placed like nozzles, thus increasing the wind flow towards the buildings. Lu and Sun [23], investigated the wind speed and wind flow on the roof of a high-rise building in a busy urban area in Hong Kong with the CFD program and tried to determine the most suitable point for the wind turbine. They reported that there was an increase of 1.3–5.4 times in the wind power density taken from 4 m above the roof. Wang et al. [24], evaluated different building lengths, widths, heights, corner separation distances, angles of inlets, and altitudes of assessment and wind speeds from different heights above the roofs of the two symmetrical buildings taken as reference in the CFD study conducted in Ansys Fluent Fluid Simulation Software (ANSYS). In their study, the most suitable building groups were also determined. Simoes and Estanqueiro [25], analyzed the urban wind source for different urban areas and enabled the determination of suitable areas for small wind turbines. The methodology of the study was determined as the use of the data in this model as an input in the Meteodyn CFD program, based on the creation of an urban digital terrain model (U-DTM) that includes the land and existing buildings as a whole.

In the study of Toja-Silva et al. [26], wind flows of a single building were modeled in the Open Foam program, and these results were compared with the wind tunnel results. According to the wind flow results, the points and height at which the turbines should be placed on the roof were determined. For each point, the most suitable turbine model was chosen for wind energy generation. In the study of Yang et al. [14], the most suitable areas for turbine installation were determined depending on the wind speed, wind direction, and wind density taken at five different heights on a building in a dense urban area with high turbulence. The results obtained with the CFD program were verified by ultrasonic anemometers at 10 different points on the roof. According to the results obtained, replacing the typical rectangular roof with rounded roof increased the wind power density and decreased the turbulence density. In the study by Wang [27], the wind concentration capacity on a roof was examined in order to mount a wind turbine on the canopy roof located on the roof of a building, and the wind potential was evaluated for different heights, different roofing situations, and canopies at different angles. The wind tunnel experiment was also performed to verify the results in the CFD program, the best results were obtained on double-pitched roofs with a 20% pitch angle. Wang et al. [28], performed CFD simulations with ANSYS Fluent to work out the most suitable height and optimal location for a roof-mounted wind turbine on a building in an urban setting. Wind lidar measurements were made to confirm the results obtained in the study. Liu et al. [29], calculated the wind speed on the roof of a building in four different situations by expanding the detail and area of the surrounding buildings with the CFD program. Since the presence of buildings surrounding the building whose wind speed is being measured affects the wind flow around the target building, it was concluded that the buildings should be handled with large environments in order to obtain correct results.

Finally, in the study of Arteaga-Lopez et al. [30], the wind speed and wind flow of a building where a wind turbine would be installed was simulated. Then, gradually, scenarios related to the location, height, and number of wind turbines were created and the most suitable turbine location and number of turbines were found on the building using CFD simulations. It was found that the electricity consumption of the building could be met using 5 turbines of 10 kilowatt (kW) placed on the roof of the building.

After the above-mentioned studies were examined, it was seen that studies in which the data of the building (building height, roof shape, roof canopy distance) were evaluated; however, there were no studies evaluating the texture orientation, building height/street width (H/W) ratio, texture form, and building height together. Previous studies had generally been limited to a few building scales. Other authors have focused on existing buildings and settlements. Simoes and Estanqueiro [25] studied two existing settlement textures with in situ measurement and U-DTm methodology and examined whether these textures are suitable for small-scale wind turbines. Differently, the present work aimed to create a guide to benefit from wind energy in energy production while designing new settlement patterns and avoiding unwanted wind speed at the pedestrian level.

The purpose of this study was to investigate the use of wind turbines with different urban texture alternatives depending on the forms, building heights, H/W ratios, and orientations, and determine the most suitable texture alternatives in terms of wind speed. In other words, the framework and method proposed herein can be used to evaluate how design parameters affect wind speed, so as to use wind energy efficiently. This study sought to identify key parameters for the development of an optimal planning strategy in the early design stage by evaluating the arrangement and planning of urban texture design parameters.

This study is different from other studies as it sheds light on the evaluation of the settlements in terms of wind speed as well as the evaluation of wind potential as a renewable energy source in urban areas. This study proposes a viable solution for the creation of new settlement textures by using the wind energy potential in Turkey.

In the study, it was aimed to determine the wind speed on the roof of a reference building selected in the urban texture alternatives created, determine the urban texture alternative that enabled the most suitable wind speed among the different alternatives, and form the basis for the use of wind energy as a renewable energy source. For this purpose, the urban texture alternatives created in the study were simulated in a CFD program and the wind speed was evaluated. Four main factors (urban texture form, building height, H/W ratio, urban texture orientation) were handled and the textures were modeled in a CFD program in order to determine the texture in which the wind speed on the roof was optimal. The results of the wind velocity at the roof level where the wind turbine would be installed were presented in graphs. Wind speeds on the roofs of the reference buildings were calculated for 128 urban texture alternatives created in the study, where four main factors were examined, and the alternatives with the highest wind speed were selected. According to these results, among all of the alternatives, urban texture alternatives with optimum wind speed was determined to utilize the wind energy at the roof level.

Simulation results for each chosen alternative are given in Figures 15–18, including the wind speed distribution values at z = 38 m at 6:00, 12.00, 18.00, and 24.00 h, as well as the sections, plan view, a table containing information about the alternatives, and an hourly wind speed graph for July 21st.

2. Methodology

In the study, the wind speed values on the roofs of the buildings in different urban texture alternatives, created by changing the urban texture form, building height, H/W ratio, and texture orientation, in the city of İstanbul, Turkey were evaluated. The urban texture alternatives created were based on very common traditional houses and settlements in Turkey. The urban texture forms of 6 different traditional housing types were created. The simulations were carried out for İstanbul, which is located in the temperate humid climate zone and is the city with the highest population density in Turkey. In this study, where the wind speed values on the roofs of the buildings were evaluated, all of the simulations were created using the ENVI-met program.

ENVI-met is a complete three dimensional modelling (3D) CFD model designed for micro-scale studies with a horizontal grid resolution of 0.5 to 5 m, with a time interval of 1 to 5 s in a 24 to 48-h period. This resolution dimension serves to analyze small-scale interactions between buildings, surfaces, and plants. ENVI-met uses CFD to analyze and solve problems related to wind flows in complex artificial environments, and this dynamic is constantly updated according to changing thermal conditions. Changing wind flows and wind speeds depending on building density and street canyon dimensions are modeled and simulated in the ENVI-met program for specific areas, and the program provides many tools for this analysis [27].

According to Oke, the geometry of urban canyons has an important role in determining the heat island effect and influencing the thermal comfort in the streets [32, 33].

In the alternatives created in this study, the effect of the width of the urban canyon on the wind speed of the roofs was observed. The steps of the study developed with the aim of evaluating the wind speed of the alternatives, created depending on different parameters in residential buildings, are given in Fig.1.

2.1 Determination of Urban Texture Forms

One of the most important factors affecting the microclimate of a city is urban geometry. In this context, in the study 6 different widely used urban texture types were developed based on very common traditional housing plan types in Turkey. The developed urban textures were assumed to be located in İstanbul, a temperate humid climate zone, and the effect of the texture form on wind speed was evaluated.

The features of the named tissues as seen in Figure 2 are as follows;

S1 is a texture form containing square buildings with the dimensions of 12*12 meters, S2 is a texture form containing square buildings with the dimensions of 24*24 meters, R1 is a texture form containing rectangular buildings with the dimensions of 8*16 meters, R2 is a texture form containing rectangular buildings with the dimensions of 8*96 meters, C1 is a texture form containing courtyard buildings with the dimensions of 16*16 meters, C2 is a texture form containing 4-courtyard buildings with the dimensions of 48*48 meters.

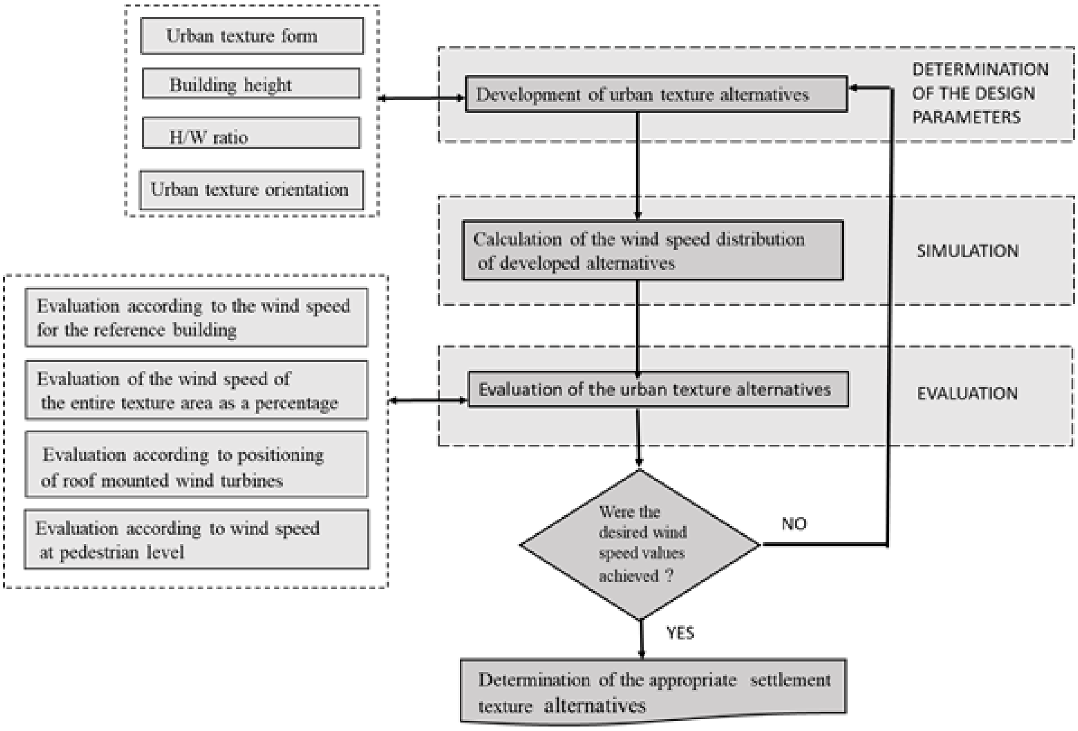


Fig. 1. Flowchart representation of the steps used in the study.

2.2 Determination of Building Height

The wind speed increases as the ground clearance increases. Therefore, as the height of the building where the wind energy will be used increases, the wind speed affecting the building will also increase [34]. In this study, the wind speed on the roofs was evaluated. In order to examine the effect of building height on wind speed, texture alternatives with 3 different building heights, which are frequently found in the city texture, were created. In the study, as seen in Fig.3, three different storey heights were used, comprising 3-storey, 5-storey, and 10-storey, which were defined as low-rise, mid-rise, and high-rise, respectively in Turkey.

Since the alternatives used in the study had a grid resolution of 4 × 4 × 4 m, the building heights were determined as 8, 16, and 32 m in multiples of 4.

2.3 Determination of H/W (Building height/ Street width) Ratio

It was described by Oke that "H the average height of the canyon walls and W is the canyon width" [32, 33]. According to Bakarman and Chang [35], urbanization and the microclimate of cities are defined by the ratio of the height of the building to the width of the street (H/W ratio) and the orientation of the canyons formed between the buildings. These two parameters affect the emission of thermal radiation and the absorption of sunlight, causing urban areas to be more exposed to the heat island effect than rural areas. For urban textures with 3 (8 m) and 5 (16 m) - storey buildings, the H/W ratios were accepted as 0.5, 1, and 2, respectively, while for urban textures with 10-storey (32 m) buildings, the H/W ratios were accepted as 1, 2, and 4, respectively.

2.4 Determination of Urban Configurations Orientation

According to Hang et al. [33], in the studies conducted while creating ideal city models, it was seen in both wind tunnel experiments and CFD studies that the general form of the city, the location and orientation of the streets, and the direction of the dominant wind direction are important urban morphological parameters that will affect the wind conditions.

The positioning of the buildings according to the wind direction is quite effective on the wind speeds above the buildings and at the pedestrian level. When the buildings are aligned in the direction of the wind direction, if the streets are wide, the effect of the building geometries on the wind flow will be lower, and the wind speed on the roofs will be less. In urban textures, the angle of the textures with the prevailing wind due to the canyon effect affects the wind speed on the roof. Since the ENVI-met program works with the grid system, there are restrictions on rotating the model. For the created urban texture alternatives herein, the orientation changes were implemented in 45° increments for the reference building model in each urban form and for intersecting streets at that location. The wind direction was the northeast for each alternative. The urban texture orientations of the alternatives selected in the study are given in Fig 5.

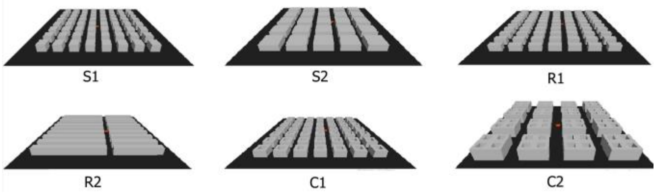


Fig. 2. Urban texture forms used in the study (3-layered, textures H/W = 1 ratio).

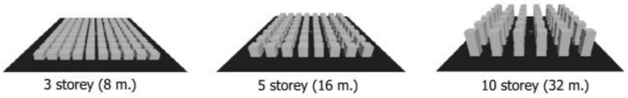


Fig. 3. Building heights used in the study: 3-storey = 8 m, 5-storey = 16 m, 10-storey = 32 m (texture alternatives with a H/W ratio of 1 for the S1 texture form).

For the square and courtyard planned texture alternatives (S1 and S2, and C1 and C2, respectively), since the width between the streets of each texture was also equal, it was foreseen that the simulation results of alternatives with 90° and 135° orientations would be the same as those with 0° and 45° orientations. Since there was no change in the wind speeds on the roof, only the 0° and 45° orientations were evaluated for texture alternatives S1 and S2, and C1 and C2.

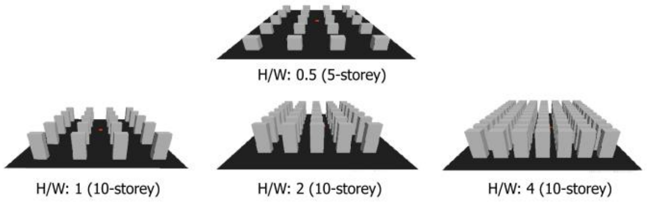


Fig. 4. H/W ratios used in the study.

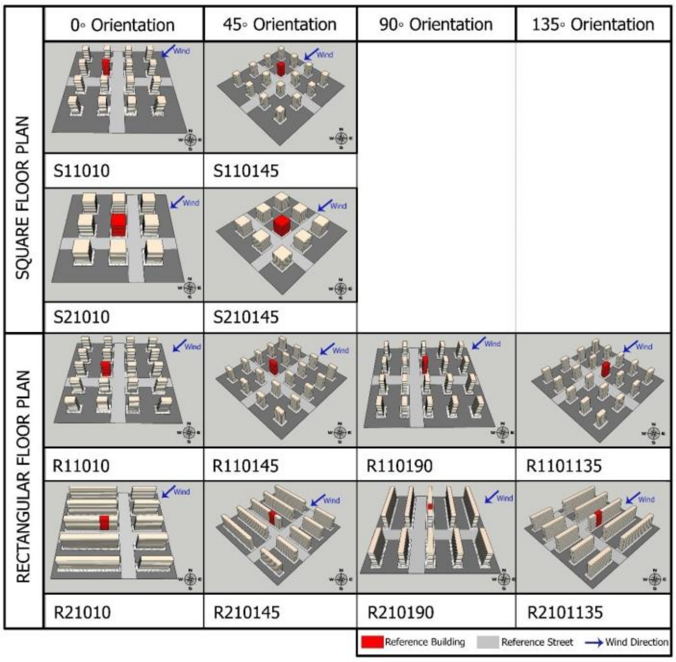


Fig. 5. Orientation degrees of the created alternatives with reference buildings (0°, 45°, 90°, and 135°).

2.5 Development of the Urban Texture Alternatives

All of the blocks in the defined hypothetical site had the same properties as the building model described in the previous sections. Each urban texture alternative was based on minimum based on a minimum of 9 blocks in a 3 × 3 matrix, in line with the uniform configuration. In each case, the overall number of buildings varied according to the H/W ratios of the alternatives. The development process generated 128 alternative urban textures, which differed with regard to the plan type (square, rectangular, courtyard), number of stories (3, 5, or 10), H/W ratio (0.50, 1.00, 2.00, or 4.00), and orientation (0°, 45°, 90°, or 135°). In Fig. 6 the coding system is explained for the alternatives.

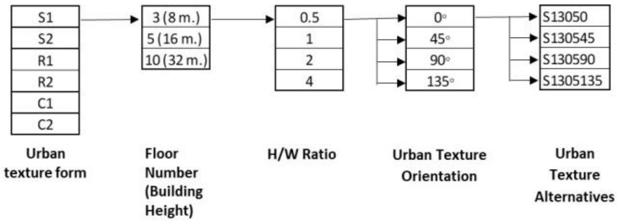


Fig. 6. Coding of the urban texture alternatives.

2.6 Model Properties

Table 1 summarizes the inputs for the configuration of simulation model. The simulation was performed for the location of the city of İstanbul, at latitude N41.01 and longitude E28.95. The simulation was run for the summer design day of July 21st, starting at 06:00 h, with a total simulation time of 24 h. The lowest air temperature for June 21 was 18 °C, the highest was 25 °C, and the relative humidity was 72% [37]. Wind speeds of 50 m in height were given for each region in the Turkish wind atlas. Depending on the wind speed of 50 m, which was determined for the selected area in İstanbul, a wind speed of 10 m was determined as 4.63 m/s [38]. In the study, the dominant wind direction of İstanbul was chosen as northeast, and the wind direction was entered as 45° to north in the angle tab in the program.

As shown in Fig. 8, the building at the midpoint of the texture for each texture alternative was identified as the reference building describing that texture. The simulation results of the wind speed were determined to be 6 m higher than the roof of the reference building. To avoid turbulence on the roof of the building, the tower height of the turbine was assumed to be 6 m.

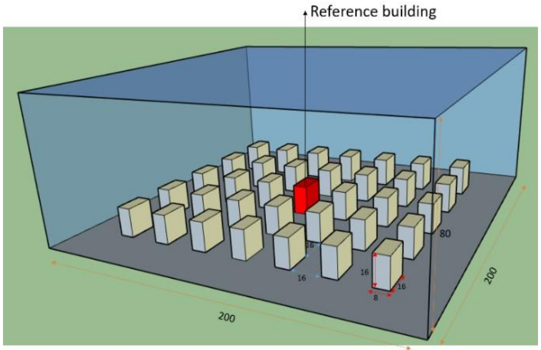


Fig. 7. Domain boundary (R1510 alternative).

2.6.1 Domain Area

In the geometric model used in the program, the grid resolution was determined as 4 × 4 × 4 m (x × y × z), and as shown in Fig. 7, a 200 × 200 × 80 m model grid was created. For each alternative, the wind speed data of the reference building was determined and graphics were created with these data. The buildings were not modeled very close to the walls of the domain area in order to make the correct calculation and avoid the turbulence effect in the created grid.

3. Results and Discussions

In the study, the calculated wind speed distributions for all of the urban texture alternatives evaluated in terms of wind turbines. For all of the urban texture alternatives, the maximum wind speeds were measured on the roof, so roof-mounted wind turbines were preferred. Facade-mounted wind turbines were not deemed suitable for this study.

In this study, suitable alternatives for roof-mounted wind turbines were determined at the urban texture alternative scale. The alternatives were evaluated in terms of the wind speed according to the graphs created based on the wind speed results of the summer design day of July 21st on the roof of the reference building for each alternative. Figures 9–12 show the 128 urban texture alternatives grouped according to the H/W ratios and wind speed results.

Table 1. Simulation inputs.

Input data for case study	
Model area	
Main Model Area	200*200 m.
Grid size in metre	dx=4; dy=4; dz=4
Grids number	50*50*20
Construction Material	
Wall Material	0.03 m cement rendering + 0.05 m extruded polystyrene + 0.2 m aerated concrete block + 0.02 m gypsum plaster
Roof Material	Gravel + roofing felt + 0.05 m expanded polystyrene + 0.04 m concrete + 0.14 m reinforced concrete + 0.02 m gypsum plaster
Soil	Sandy soil, Road: asphalt,
Position	
Longtitude (◦**)**	41.01
Latitude (◦**)**	28.95
Start and Duration of the Model	
Date of Simulation	21.06.2018
Start Time	06:00
Total Simulation Time	24 h.
Wind speed measured at 50 m. height (m/s)	6.8 m/s
Wind speed measured at 10 m. height (m/s)	4.63 m/s
Roughness lenght at measurement site	0.1
Wind Direction (0◦= from N, 180◦= from S)	45◦

Fig. 8. Wind speed values calculated at z = 14 m (for 3 stories), z = 22 m (for 5 stories) for June 21st for a H/W ratio of 0.5.

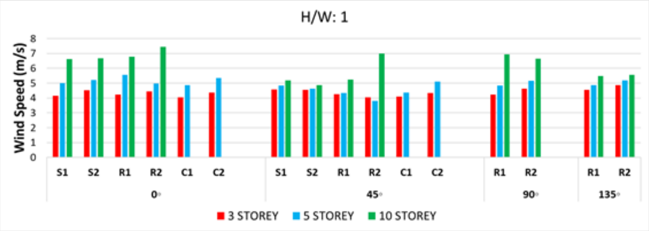


Fig. 9. Wind speed values calculated at z = 14 m (for 3 stories), z = 22 m (for 5 stories), z = 38 m (for 10 stories), for June 21st for a H/W ratio of 1.

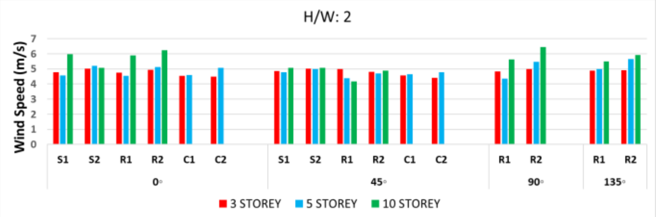


Fig. 10. Wind speed values calculated at z = 14 m (for 3 stories), z = 22 m (for 5 stories), z = 38 m (for 10 stories), for June 21st for a H/W ratio of 2.

Fig. 11. Wind speed values calculated at z = 14 m (for 3 stories), z = 22 m (for 5 stories), z = 38 m (for 10 stories), for June 21st for a H/W ratio of 4.

Fig. 12. Wind speed values calculated at z = 38 m, for June 21st for the 10-storey building.

According to Figures 8–11, the average wind speeds for the 10-storey buildings were higher than the others, and the height of the building played an important role in the values related to the wind speed on the roof. While creating the result graphs, for the texture alternatives for 10 stories (32 m.), since the results obtained at z = 34 m were not suitable for wind energy use because they showed low wind speed and high turbulence, the results of the wind speed at z = 38 m were discussed herein. While analyzing the results in all of the other alternatives, wind speed values for 6 m above the roof of the building were discussed (z = 14 m for 3 stories, z = 22 m for 5 stories).

The graph of the average wind speed for the urban texture alternatives with 10 stories are given in Fig.13, which showed that the urban texture alternatives with H/W ratio of 1 enabled the highest wind speed among urban texture alternatives with 10 stories. For this reason, 12 urban texture alternatives with a H/W ratio of 1 among the 10-storey texture alternatives were examined in detail. A comprehensive methodology to evaluate the proper urban texture alternatives was developed. This methodology provided the opportunity to create the most appropriate combination of urban texture forms and urban texture orientations in terms of wind turbine use on roofs. Four different urban texture forms and four urban texture orientation degrees were examined to determine the most suitable urban texture alternative.

The wind speed simulation results of 12 different alternatives for June 21st are summarized in Fig.13, in which the average wind speeds of the urban texture alternatives with 10-storey buildings and a H/W ratio of 1. In Table 2, the values of the parameters used while creating the urban texture alternatives evaluated in the study are given.

As seen in Fig.13, the most efficient alternatives in terms of wind energy were attempted to be determined by considering the following criteria for each of the 12 selected alternatives.

Table 2. Values related to parameters of urban texture alternatives

Urban Texture Alternative	Urban Texture Form	Floor Number	H/W Ratio	Urban Texture Orientation
S11010	S1	10	1	0
S110145	S1	10	1	45
S21010	S2	10	1	0
S210145	S2	10	1	45
R11010	R1	10	1	0
R110145	R1	10	1	45
R110190	R1	10	1	90
R1101135	R1	10	1	135
R21010	R2	10	1	0
R210145	R2	10	1	45
R210190	R2	10	1	90
R2101135	R2	10	1	135

- Average wind speed of the reference building.
- Percentage of areas exceeding 5 m/s across the entire texture.
- Number of turbines in texture.

- Exceeding comfort thresholds at pedestrian level wind speed in the street.

In the result graphics created herein, the images and information of each alternative are given in detail in Figures 14–17, in which the following information about each alternative is given.

- XY plane simulation results at 06:00, 12:00, 18:00, 00:00 h (at z = 38 m).
- The sections.
- A site plan showing the position of the alternative relative to the north.
- Simulation result at plan plane in pedestrian level (at 2 m).
- Information containing the results of the alternatives.
- Hourly wind speed for each alternative for June 21st.

3.1 Evaluation of the alternatives according to the wind speed for the reference building

To investigate the impact of the urban texture forms, 2 square (S1, S2) and 2 rectangular (R1, R2) urban texture forms with different dimensions were studied, as demonstrated in Figures 14–17. Wind speeds on the roofs of the reference buildings of the 10-storey texture alternatives with a H/W ratio of 1 are shown in Table 3. The highest wind speed (7.44 m/s) was calculated for alternative R21010, while the lowest wind speed (4.88 m/s) was calculated for alternative S210145. The 12 alternatives shown in Table 2 are alternatives created by changing the urban texture form and urban texture orientation.

3.1.1 Urban Texture Form

When the alternatives with rectangular planned R1 and R2 urban texture forms were compared with the square planned S1 and S2 texture forms, it was seen that the wind speed on the roofs of the rectangular planned textures was higher than the wind speed on the square planned textures.

In the alternatives with 0° orientation, the wind speeds for texture forms S1, S2, and R1 were very close to each other (6.62, 6.68, and 6.77 m/s respectively). In the alternatives with 0° orientation, the wind speed of the R2 texture form was higher than the wind speed measured in texture forms S1, S2, and R1. The wind speed for the R21010 alternative was 7.44 m/s. The wind speeds for the S110145 and R110145 alternatives were very close to each other. In the case of the compact S2 texture form with a 45° orientation, the wind speed was measured as 4.88 m/s. This value alone could not provide the wind speed value required for the roof-mounted wind turbine installation. The wind speed for the R2 texture form was also higher in case of 45° orientation when compared to the other texture forms (6.99 m/s). The wind speed for the R1 and R2 texture form was obtained at very close values with 90° and 135° orientation. In the alternatives with 90° orientation, the R1 texture wind speed was 6.95 m/s, while the wind speed of the R2 texture was 6.66 m/s. For the 135° orientation, the R1 texture wind speed was 5.49 m/s, while the wind speed of the R2 texture was 5.56 m/s. The wind speed for the R2 texture form created with 0° orientation was 7.44 m/s (R21010 alternative), while the wind speed of the alternative (R2101135) created with 135° orientation was 5.56 m/s. For the 0°, 45°, and 135° orientation, the wind speed of the R2 texture form was higher than the wind speed of the other texture forms (S1, S2, and R1).

3.1.2 Urban Texture Orientation

Four different orientation angles were applied for the urban texture forms. These angles were 0°, 45°, 90° and 135°. Orientations of 0° and 45° were applied for all of the urban texture forms, while orientations of 90° and 135° were applied only for the R1 and R2 urban texture form alternatives. The wind speed of the 0° and 90° oriented alternatives, making an angle of 45° with the prevailing wind direction, was determined to be higher than the wind speed of the 45° and 135° oriented alternatives, located perpendicular to the prevailing wind direction.

When the 0° orientation alternatives were compared to the alternatives with other orientations (45°, 90°, 135°), it was seen that the wind speed on the roof of the reference buildings that had alternatives with 0° orientation were higher than that of the other orientations (45°, 90°, and 135°). The highest wind speed was calculated for alternative R21010. For the 45° orientation alternatives the urban texture orientation was parallel to the prevailing wind direction. According to the results obtained, the S210145 alternative (4.88 m/s) had the lowest wind speed among all of the alternatives. The S110145 and R110145 alternatives were the alternatives with the lowest wind speed, at 5.2 m/s and 5.24 m/s, respectively. For the 90° orientation alternatives, the wind speed of the R110190 alternative was 6.95 m/s and that for R210190 was measured as 6.66 m/s. In the case of only the 90° orientation, the R2 texture form had a lower wind speed than the R1 texture form. For the 135° urban texture orientation alternatives evaluation between the textures with 135° orientation, the wind speed of the R1 and R2 texture forms were very close to each other, at 5.49 and 5.56 m/s.

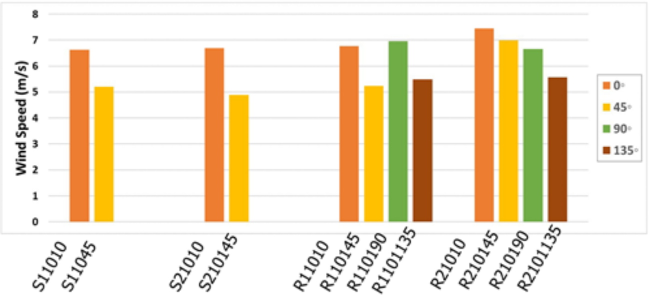


Fig. 13. Average wind speed values calculated at z = 38 m, for June 21st for the 10-storey buildings for H/W = 1

Table 3. Average wind speeds of the alternatives for June 21st

Orientation Form	0◦	45◦	90◦	135◦
S1	6.62 m/s.	5.2 m/s.		

S2	6.68 m/s.	4.88 m/s.		
R1	6.77 m/s.	5.24 m/s.	6.95 m/s.	5.49 m/s.
R2	7.44 m/s.	6.99 m/s.	6.66 m/s.	5.56 m/s.

According to the obtained results for the urban texture orientations, it can be concluded that the best orientation alternative for the S1 urban texture form was 0° (S11010 alternative), for the S2 urban texture form was 0° (S21010 alternative), for the R1 urban texture form was 90° (R110190 alternative), and for the R2 urban texture form was 0° (R21010 alternative). These alternatives were where the wind velocity reached its maximum value, which was greater than the other orientations at the same locations.

3.2 Evaluation of the Wind Speed of the Entire Texture Area as a Percentage

In order to benefit from wind energy efficiently, wind turbines are required to be higher than 5 m/s. In other words, wind turbines can be installed in the area in which wind speed exceeds 5 m/s. In this context, the percentage of areas exceeding 5 m/s at z = 38 m in the entire texture area in each alternative were calculated. In Table 4, the wind speed on the roof of the reference building for each alternative and the percentage of areas whose wind speed exceeded 5 m/s in the entire texture area in each alternative are given.

According to the results obtained at the wind turbine height (38 m) in the whole texture for the S11010, S21010, R11010, R1110135, and R2101135 alternatives, the wind speed exceeded 5 m/s. In these urban texture alternatives, it was seen that the wind turbine application would be effective in the whole texture. The wind speed of the R21010, R210145, and R210190 alternatives was also obtained at high values on the reference building roof. For the S110145 and R210190 alternatives, the wind speed decreased below 5 m/s in approximately 20% of the urban texture area. The places where the wind turbine would be placed in these two alternatives should be determined by considering the simulation results.

3.3 Evaluation of the Efficiency of Alternatives According to Positioning of Roof Mounted Wind Turbines

In order to evaluate the efficiency of urban texture alternatives according to the positioning of roof-mounted wind turbines, the wind turbine type, number of turbines, positioning of the wind turbines, and the distance between the turbines should be determined for each alternative. A XZERES Skystream 3.7, 2.4-kW turbine was chosen to be used in the study [39]. The minimum distance between the turbines of this turbine is 8 m or 2.16 D (rotor diameter of wind turbines) in the study of Arteaga-Lopez and Angeles-Camacho [40]. In this report, the distance between the turbines was determined as 16 m, since the turbines should be placed in such a way that they do not affect the turbulence of each other. This criterion was taken into account in the placement of the turbines and the positioning of the turbines are given in Table 5. As seen in Table 5, for the square planned S1 alternatives, a total of 16 turbines, comprising 1 in each building and for the S2 alternatives a total of 18 turbines, comprising 2 in each building, were placed by positioning them so that they did not overtake each other in the direction of the prevailing wind. For the rectangular planned R1 alternatives, a total of 20 turbines, comprising 1 in each building and for the in each building and for the R2 alternatives (with row buildings), a total of 40 turbines were placed at 16-m intervals.

Considering the distance between the turbines determined in the study, the R2 textured forms were quite efficient when compared to all of the other alternatives. It was seen that the R21010, R210145, and R210190 alternatives with 40 turbines were more efficient in terms of wind energy production when compared to the other alternatives. The number of turbines to be placed in the R2 form alternatives was almost twice as much as the number of turbines to be placed in the S1, S2, and R1 formed alternatives.

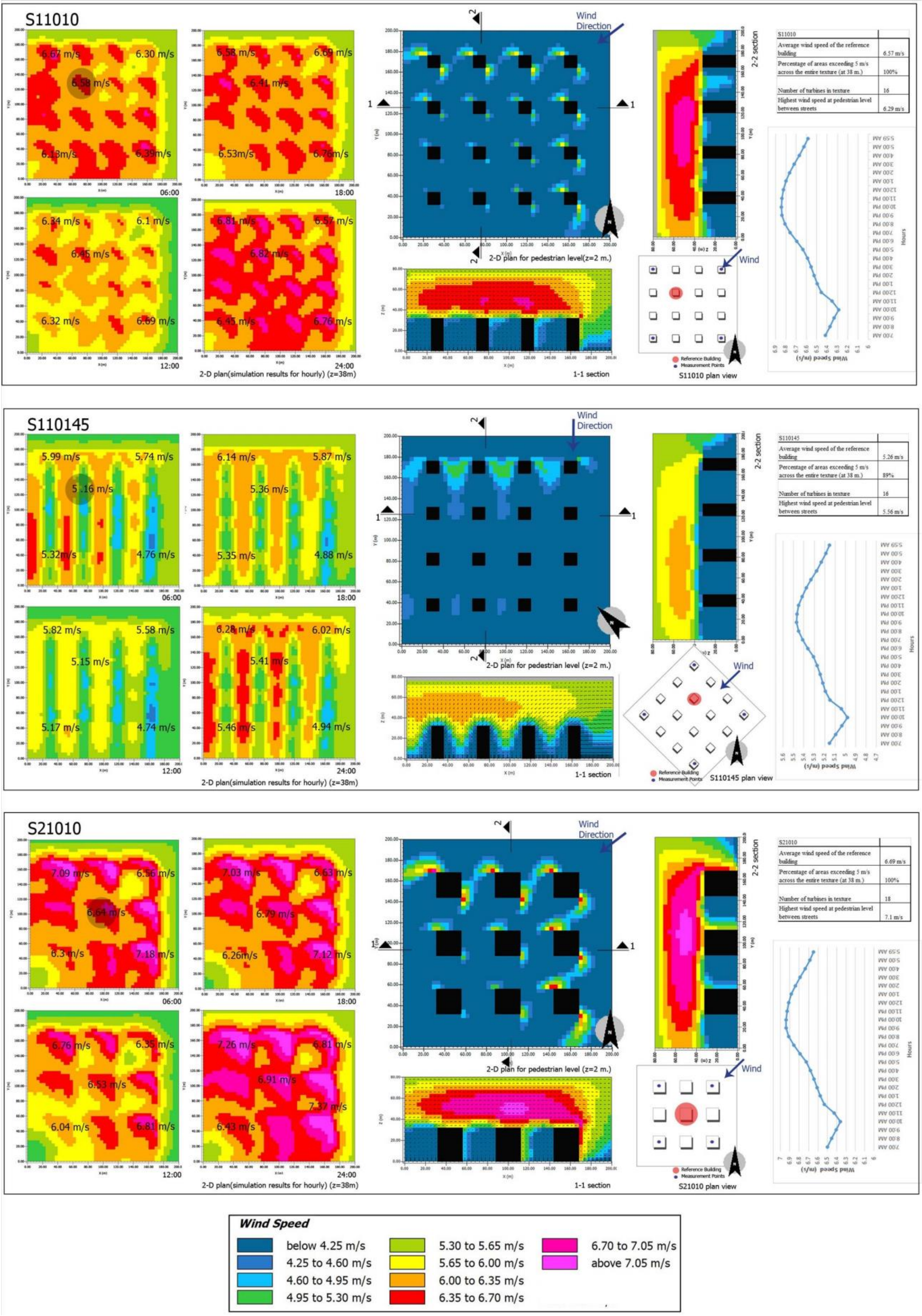
3.4 Evaluation of Alternatives According to Wind Speed at Pedestrian Level

In the study of Penwarden, wind speeds above 5 m/s were determined as the beginning of uncomfortable situations, wind speeds above 10 m/s were undesirable, and wind speeds above 20 m/s were dangerous [41,42].

In the alternatives with 45° and 135° orientations, the wind speed between the street was higher when compared to

Table 4. Wind speed of alternatives (on reference building z = 38 m) and the percentage of areas exceeding 5 m/s across the entire texture for each alternative (%).

Orientation Form	0°	45°	90°	135°
S1	% 100	% 89		
S2	% 100	% 95		
R1	% 100	% 91	% 99	% 100
R2	% 97	% 92	% 83	% 100

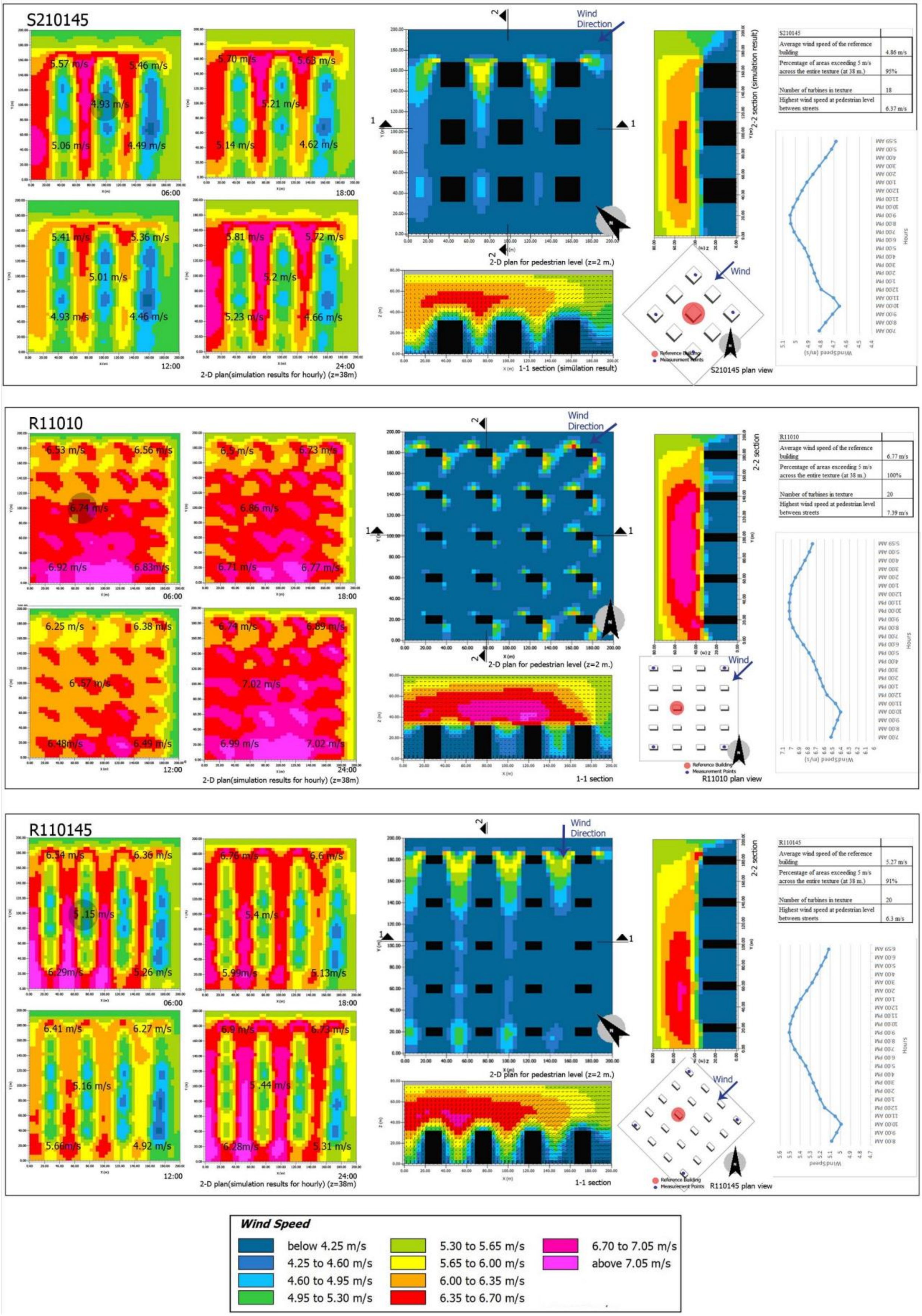


S11010	
Average wind speed of the reference building	6.57 m/s
Percentage of areas exceeding 5 m/s across the entire texture (at 38 m.)	100%
Number of turbines in texture	16
Highest wind speed at pedestrian level between streets	6.29 m/s

S110145	
Average wind speed of the reference building	5.26 m/s
Percentage of areas exceeding 5 m/s across the entire texture (at 38 m.)	89%
Number of turbines in texture	16
Highest wind speed at pedestrian level between streets	5.56 m/s

S21010	
Average wind speed of the reference building	6.69 m/s
Percentage of areas exceeding 5 m/s across the entire texture (at 38 m.)	100%
Number of turbines in texture	18
Highest wind speed at pedestrian level between streets	7.1 m/s

Fig. 14. Wind speed distribution values of the S11010, S11045, and S21010 alternatives (wind speed graphs of 6:00, 12:00, 18:00, and 24:00 h, at z = 38 m, as well as the sections, plan view, a table containing information about the alternatives, and wind speed-hour graph for June 21st).

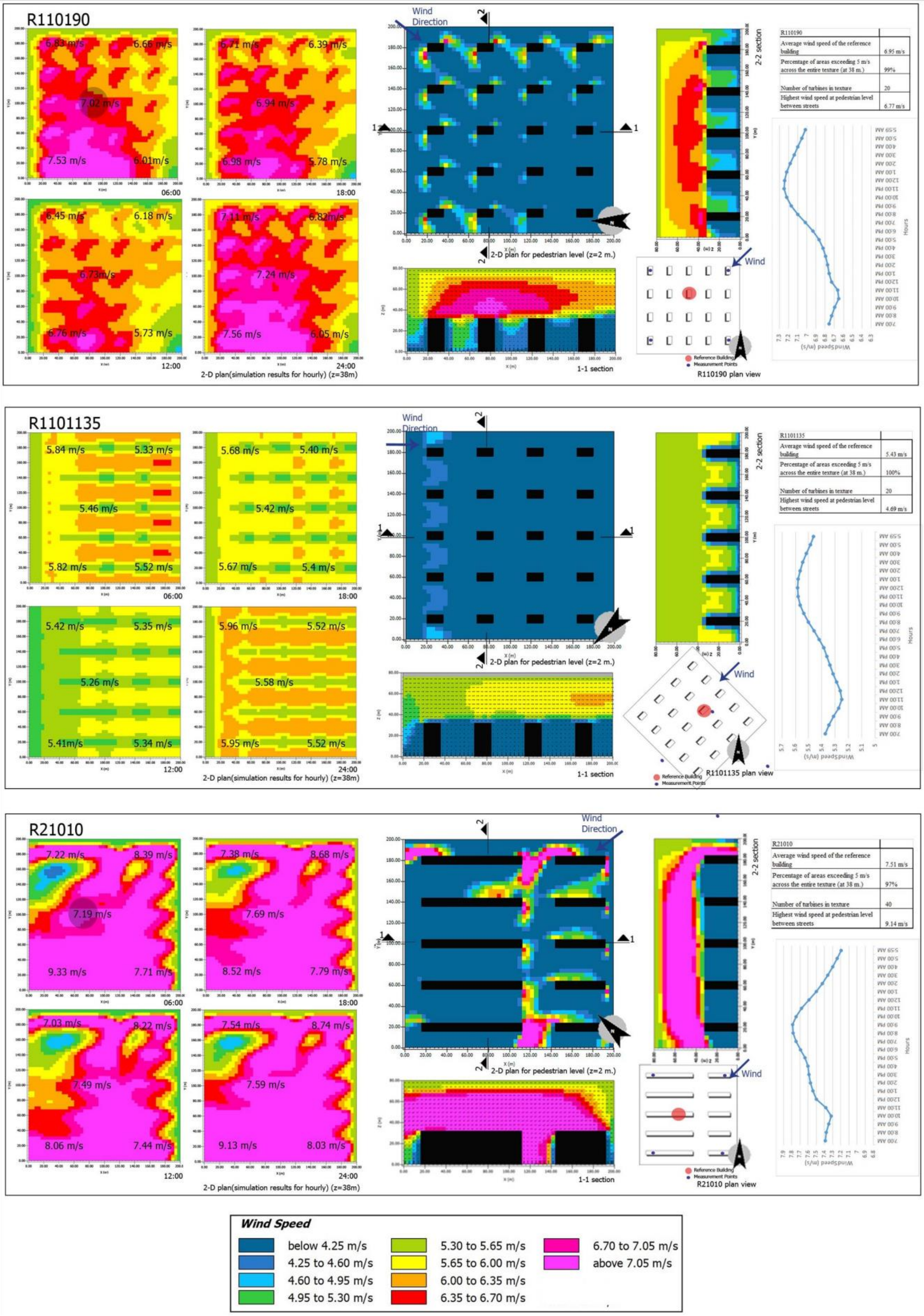


S210145	
Average wind speed of the reference building	4.86 m/s
Percentage of areas exceeding 5 m/s across the entire texture (at 38 m.)	95%
Number of turbines in texture	18
Highest wind speed at pedestrian level between streets	6.37 m/s

R11010	
Average wind speed of the reference building	6.77 m/s
Percentage of areas exceeding 5 m/s across the entire texture (at 38 m.)	100%
Number of turbines in texture	20
Highest wind speed at pedestrian level between streets	7.39 m/s

R110145	
Average wind speed of the reference building	5.27 m/s
Percentage of areas exceeding 5 m/s across the entire texture (at 38 m.)	91%
Number of turbines in texture	20
Highest wind speed at pedestrian level between streets	6.3 m/s

Fig. 15. Wind speed distribution values of the S210145, R11010, and R110145 alternatives (wind speed graphs of 6:00, 12:00, 18:00, and 24:00 h, at z = 38 m, as well as the sections, plan view, a table containing information about the alternatives, and wind speed-hour graph for June 21st).

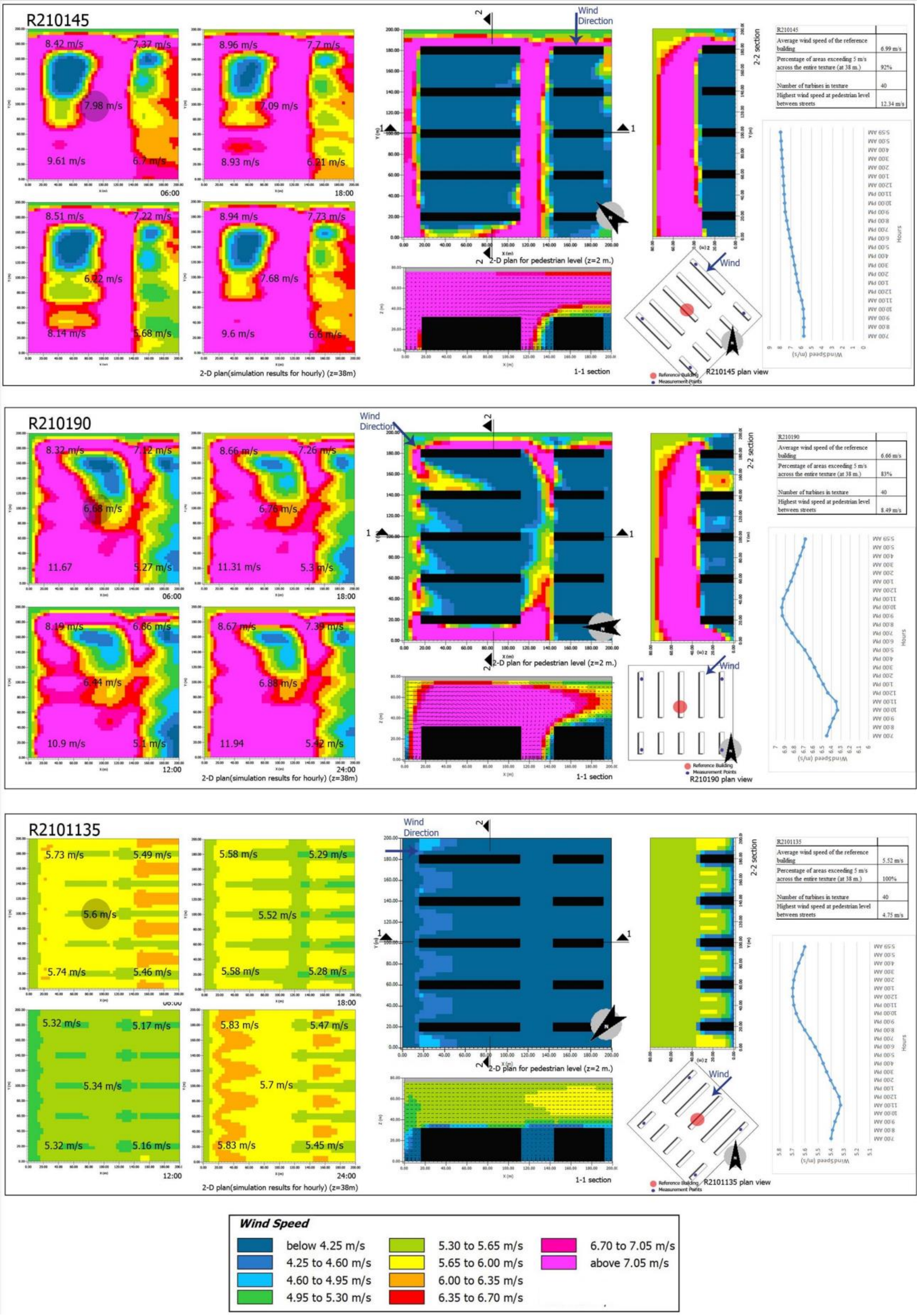


R110190	
Average wind speed of the reference building	6.95 m/s
Percentage of areas exceeding 5 m/s across the entire texture (at 38 m.)	99%
Number of turbines in texture	20
Highest wind speed at pedestrian level between streets	6.77 m/s

R1101135	
Average wind speed of the reference building	5.43 m/s
Percentage of areas exceeding 5 m/s across the entire texture (at 38 m.)	100%
Number of turbines in texture	20
Highest wind speed at pedestrian level between streets	4.69 m/s

R21010	
Average wind speed of the reference building	7.51 m/s
Percentage of areas exceeding 5 m/s across the entire texture (at 38 m.)	97%
Number of turbines in texture	40
Highest wind speed at pedestrian level between streets	9.14 m/s

Fig. 16. Wind speed distribution values of the R110190, R1101135, and R21010 alternatives (wind speed graphs of 6:00, 12:00, 18:00, and 24:00 h, at z = 38 m, as well as the sections, plan view, a table containing information about the alternatives, and wind speed-hour graph for June 21st).



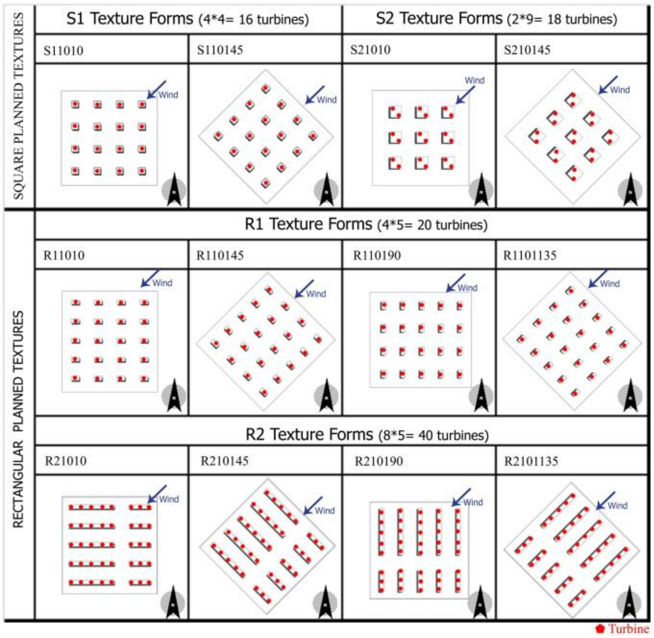
R210145	
Average wind speed of the reference building	6.99 m/s
Percentage of areas exceeding 5 m/s across the entire texture (at 38 m.)	92%
Number of turbines in texture	40
Highest wind speed at pedestrian level between streets	12.34 m/s

R210190	
Average wind speed of the reference building	6.66 m/s
Percentage of areas exceeding 5 m/s across the entire texture (at 38 m.)	83%
Number of turbines in texture	40
Highest wind speed at pedestrian level between streets	8.49 m/s

R2101135	
Average wind speed of the reference building	5.52 m/s
Percentage of areas exceeding 5 m/s across the entire texture (at 38 m.)	100%
Number of turbines in texture	40
Highest wind speed at pedestrian level between streets	4.75 m/s

Fig. 17. Wind speed distribution values of the R210145, R210190, and R2101135 alternatives (wind speed graphs of 6:00, 12:00, 18:00, and 24:00 h, at z = 38 m, as well as the sections, plan view, a table containing information about the alternatives, and wind speed-hour graph for June 21st).

Table 5. Positioning of the turbines.



other situations since the wind direction was parallel to the street. The alternatives with 0° and 90° orientations were not parallel to the wind, and the wind hit the corner of the texture form in these alternatives. Therefore, the wind speed between the street in alternatives with 0° and 90° orientations was lower than those with 45° and 135° orientations. The wind, which could not enter between the streets, hit the buildings and rose directly towards the roof, alternatives with 0° and 90° orientations. In these alternatives, the wind speed measured high on the roofs was measured at lower speeds in the streets. . In the alternatives with the square planned S1 and S2 urban texture forms, the alley wind speed of the alternatives with 0° orientations was higher than those with 45° orientations.

The highest wind speeds between the streets of the square planned alternatives were measured between 5.56 and 7.1 m/s. These values were measured not in the urban texture, but in small areas where the wind created turbulence with the building. For this reason, since high values were effective in very small areas, there was no negative situation affecting the pedestrians, and an uncomfortable texture was not formed. In the alternatives of the rectangular planned R1 and R2 urban texture form, the alternatives with 0° and 90° orientations were determined to be higher than those with 45° and 135° orientations. Among these alternatives, only the R210145 alternative created an exceptional situation and the wind speed at the pedestrian level was measured as the highest, at 12.34 m/s, in this alternative. While the high wind speeds measured in the other alternatives were usually measured at the corners of the buildings, wind speeds higher than 10 m/s were obtained in almost the entire urban texture in this alternative. Since the R2 urban texture form with the row building form and the wind and buildings were parallel to each other in the case of 45° orientation, when the wind blew between the buildings, a tunnel effect was formed. With the tunnel effect, the pedestrian level wind speed of the R210145 alternative was included in the category of undesirable wind speeds, and alternatives should not be created without adding windbreak elements around the building in these alternatives. Wind speeds at the pedestrian level for other rectangular planned alternatives varied between 4.75 m/s and 9.14 m/s.

The results obtained in the study were summarized as follows:

- ➢ When the evaluation was made according to the average wind speeds taken from the reference building; It had been determined that R2 was the texture form with the highest wind speed compared to the other forms, and 0◦ and 90◦ were the texture orientation with the highest wind speed.
- ➢ Considering the percentage of areas where the wind speed was exceeded 5 m/s in the whole texture area, the most efficient textures were obtained as S11010, S21010, R11010, R1101135, R210135.
- ➢ When evaluated according to the number of turbines of the alternative, the R2 texture form was found to be the texture that would produce the most energy with the highest number of turbines.
- ➢ When the wind speed at pedestrian level is evaluated, the texture alternative with undesirable wind speed was found to be only R210145.

4. Conclusion

Considering urban redevelopment processes continue to occur quickly, especially in developing countries, such as Turkey, and the rapid increase energy consumption in urban areas, using clean and renewable energy recourses, such as wind, have become important. In this context, this study was aimed to evaluate the performance of roof-mounted wind turbines in urban textures considering urban texture design parameters, such as the urban texture form, building height, H/W ratio, and urban texture orientation.

According to the simulation results obtained, the texture alternatives enabling the highest wind speed were determined as 10-storey textures with a H/W ratio of 1, and a detailed examination was made among these alternatives. The wind speed simulations for buildings with different urban texture forms and orientations were performed. As a result, among the textures used, the R2 texture was determined as the texture form with the highest wind speed for 3 different texture orientations. Among the texture orientations, alternatives with 0° and 90° orientations (textures making a 45° angle with the prevailing wind direction) were the urban texture alternatives with the highest wind speed. The results showed that the urban texture form and urban texture orientation had a great impact on the energy generated by the wind from the rooftop wind turbine and wind speed between the streets. In future studies, different results will be obtained in cases where different types of buildings are added next to the textures, afforestation and obstacles are designed around the texture, the buildings belonging to the texture are of different heights and forms, and different turbines are used.

Through proposed methodology, this study obtained findings that provide the guidance needed for future studies on improving pedestrian comfort levels and energy and economic performance of new settlements, which will be developed within the scope of worldwide urban redevelopment projects, and especially those in Turkey.

These findings will help to prevent mistakes in the construction of settlement textures that affect many occupants.

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