Wind [CFD] & Outdoor Comfort Levels

Sustainability Global Sector

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Humans need a certain set of thermal conditions in order to feel satisfied with the environment around them. A building envelope is developed not only to protect humans from the extreme weather conditions but also to make them thermally comfortable by combining the use of environmental design strategies and the mechanical systems. While it is very common to find indoor environment fine-tuned to offer optimal thermal comfort to the occupants, the same cannot be said for the outdoors.

In the case of indoors, with the help of a carefully designed envelope and mechanical systems, desired thermal conditions are created and maintained. The same cannot happen outdoors and therefore, planning for outdoor thermal comfort has traditionally been challenging for the designers. In response to that, a metric named **Universal Thermal Climate Index (UTCI)** was devised. This document reports on UTCI for the area of urban art park plaza in the business bay peninsula master plan.

This report begins by reviewing the local annual weather data. The weather data used in this study is recorded at the Dubai international airport which is located at a distance of about **10.7 km** from the site. Calculation of outdoor thermal comfort requires hourly values of climatic variables such as; outside air dry-bulb temperature, relative humidity, and radiation. In order to obtain such extensive data for a site, data metering needs to happen for at least a year. In the absence of such data set for the site of interest, the data recorded at the **weather station at the Dubai international airport** is used.

The weather data review will be followed by measurement of pedestrian comfort and outdoor thermal comfort at the **urban art park plaza** in the proposed master plan for the business bay peninsula, Dubai and a discussion of the analysis results.

Site — Dubai International Airport

Urban Art Park Plaza

Introduction

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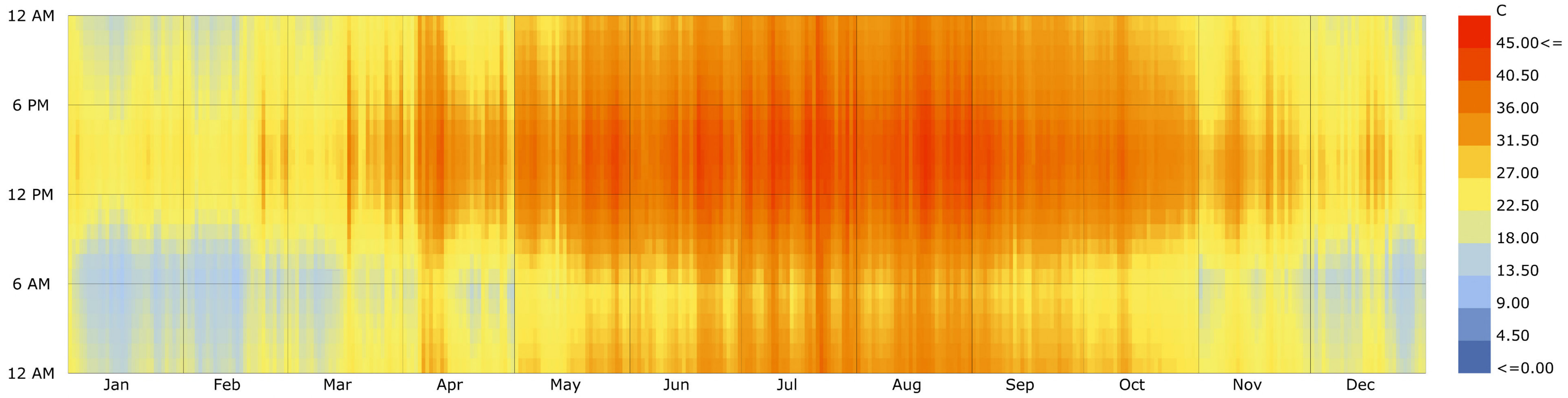
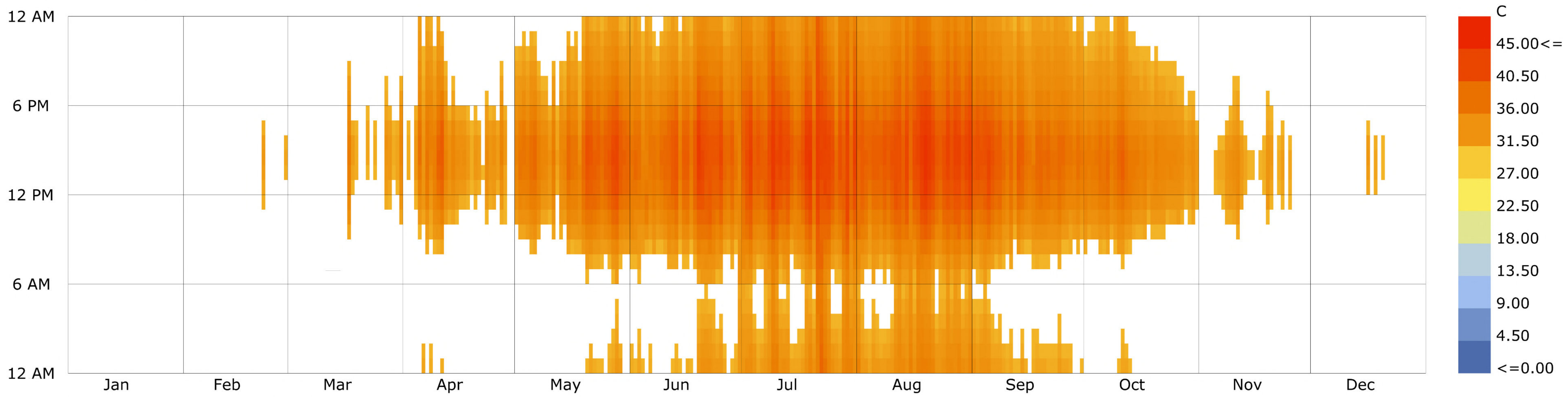


Dry Bulb Temperature (C) - Hourly
EPW Dubai Intl Airp._ARE
1 JAN 1:00 - 31 DEC 24:00

The charts on the left shows the outdoor air dry bulb temperature for all the hours of the year. The chart below shows only the hours of the year when outdoor dry bulb temperature is above **28C**.



Dry Bulb Temperature (C) - Hourly
EPW Dubai Intl Airp._ARE
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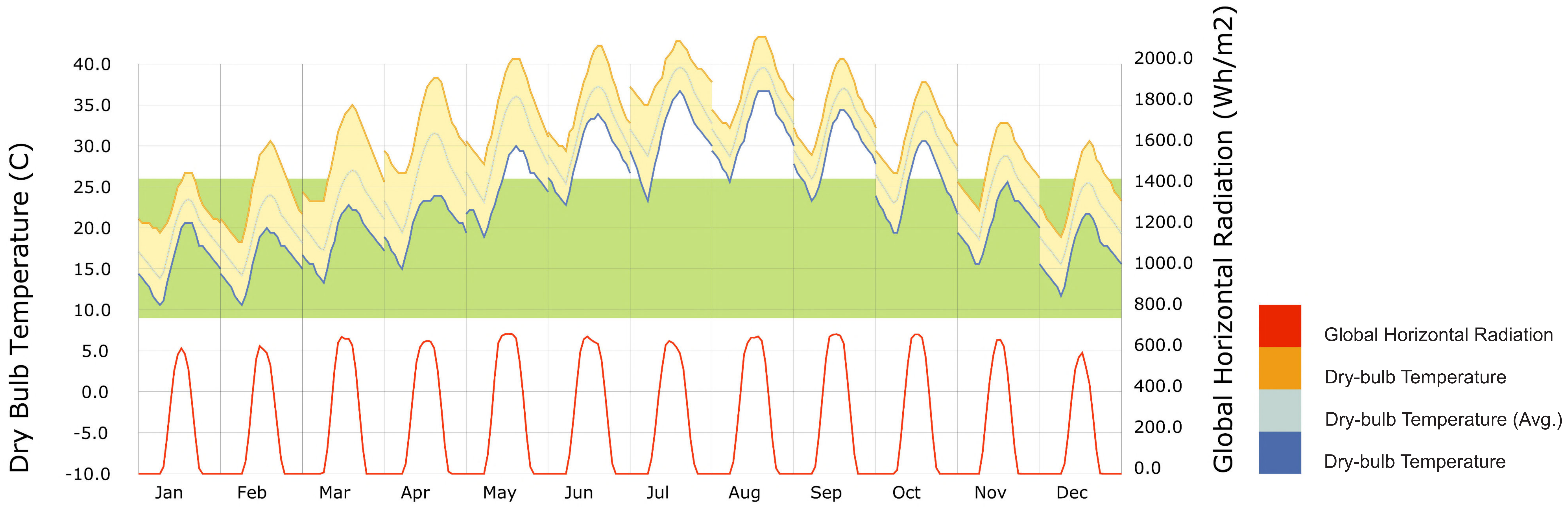
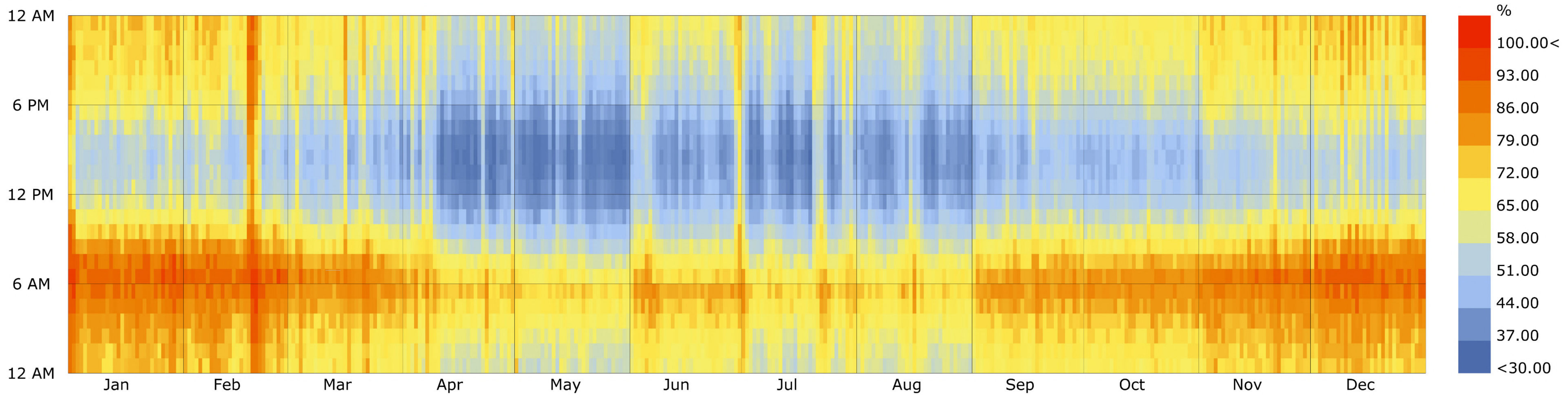
For the climate of Dubai, at least **44%** of the time of the year the outdoor dry bulb temperature remains above 28C. It is clear from the chart that such high outdoor air temperatures will be a matter of concern for outdoor thermal comfort.



As per UTCI scale, humans tend to feel comfortable in the temperature range of **9C to 26C**. It is evident from the chart above that during at least seven months of the year, the average monthly temperature goes **out of the comfort range** of the UTCI. This clearly demonstrates that achieving outdoor comfort can be a concern for seven months of the year.



Relative Humidity (%) - Hourly
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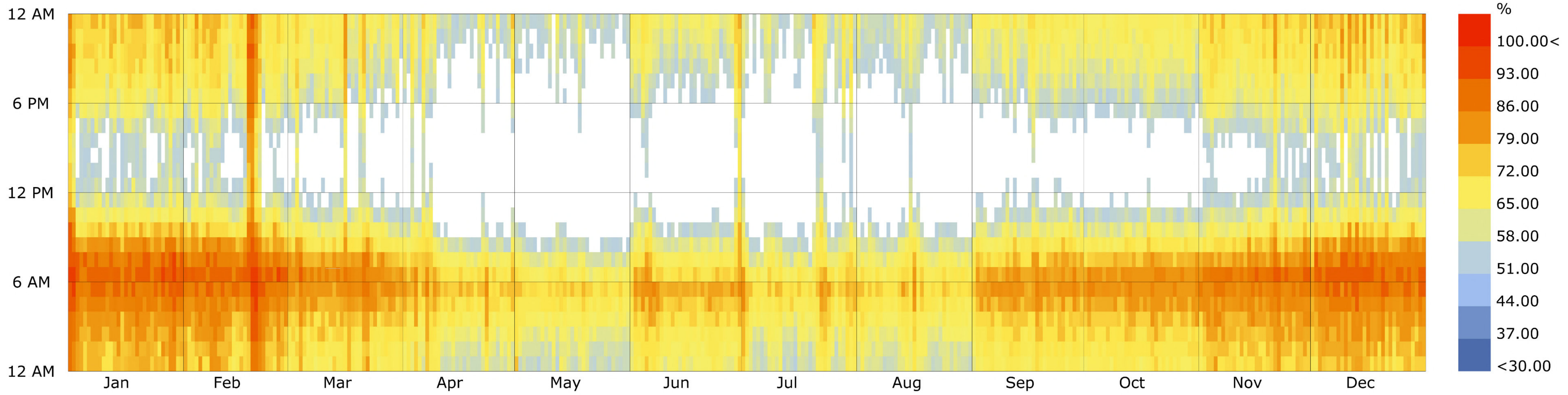
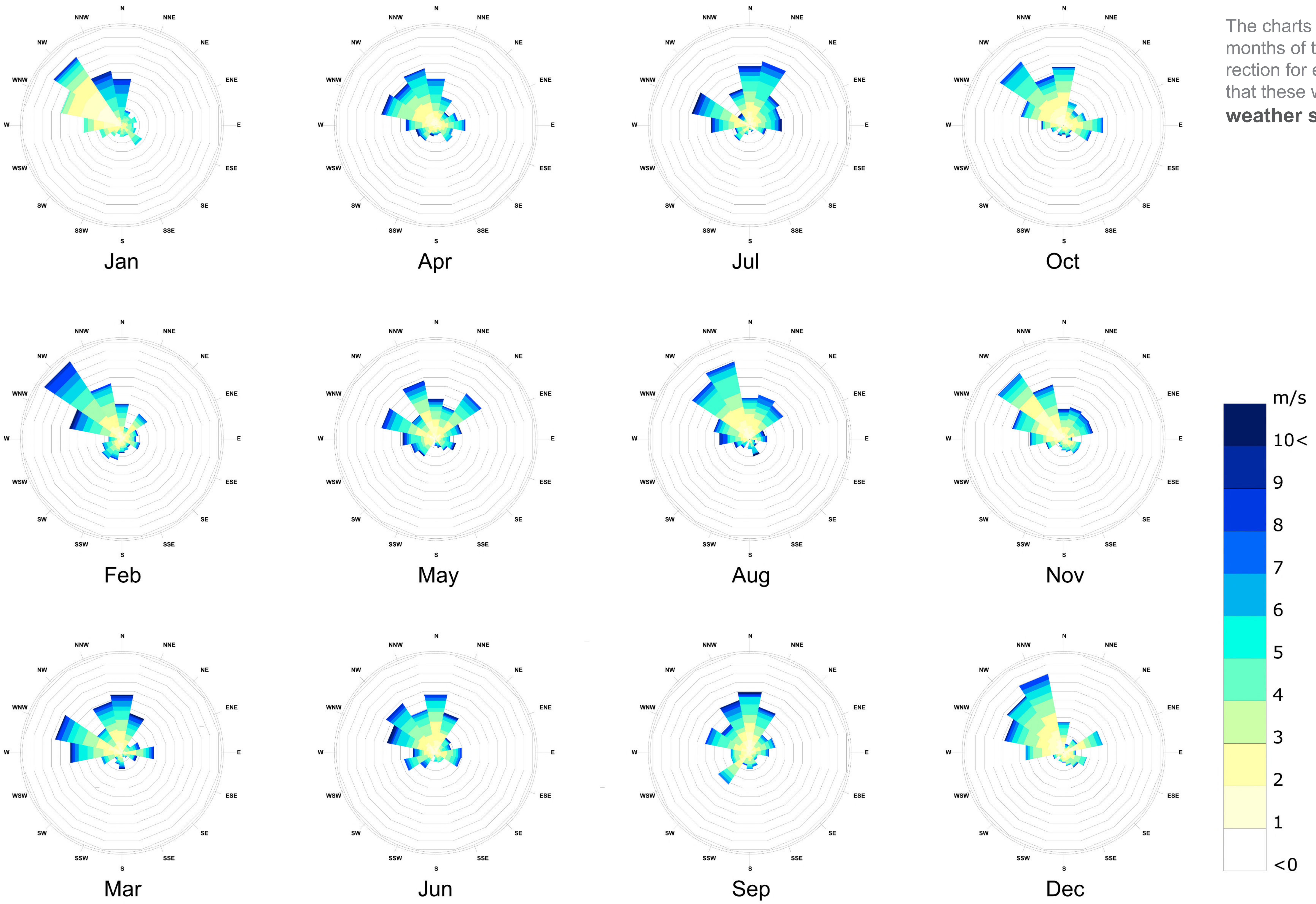
1 JAN 1:00 - 31 DEC 24:00

The charts on the left shows the relative humidity (percentage of moisture in a unit volume of air). One of the ways humans release the heat generated from the metabolic activity is by **perspiration**. The amount of heat one can loose to the environment depends on the amount of moisture present in the air. As the amount of moisture in the air increases, it becomes difficult for humans to loose heat by perspiration.

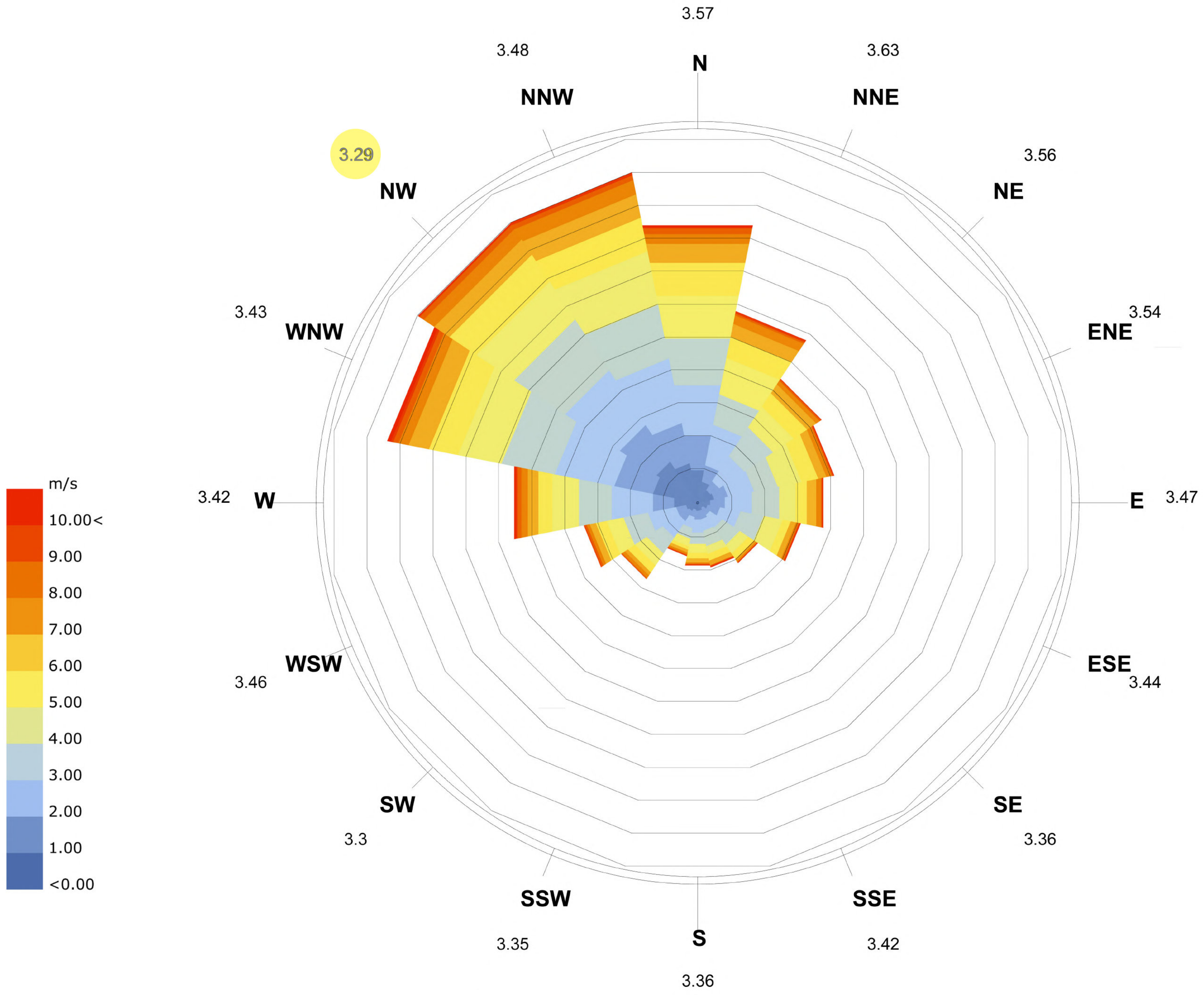


Relative Humidity (%) - Hourly
EPW Dubai Intl Airp._ARE
1 JAN 1:00 - 31 DEC 24:00

As seen from the chart on the bottom left, at least **75%** of the time of the year relative humidity remains above **50%**. Less humidity ratios are preferred for outdoor thermal comfort. With such high moisture content in the air throughout the year, it is going to be challenging for humans to release heat by perspiration to the outdoor environment.

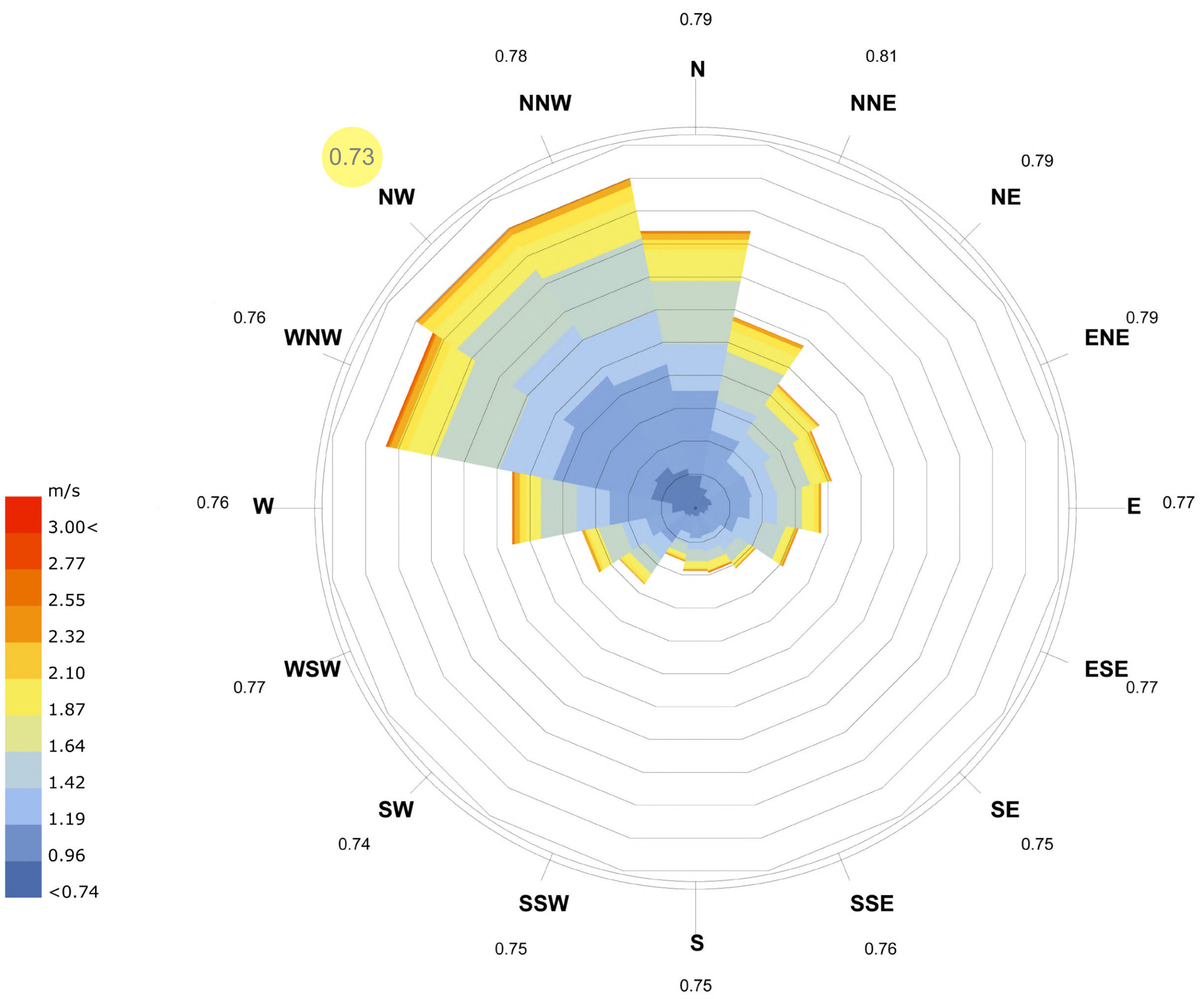


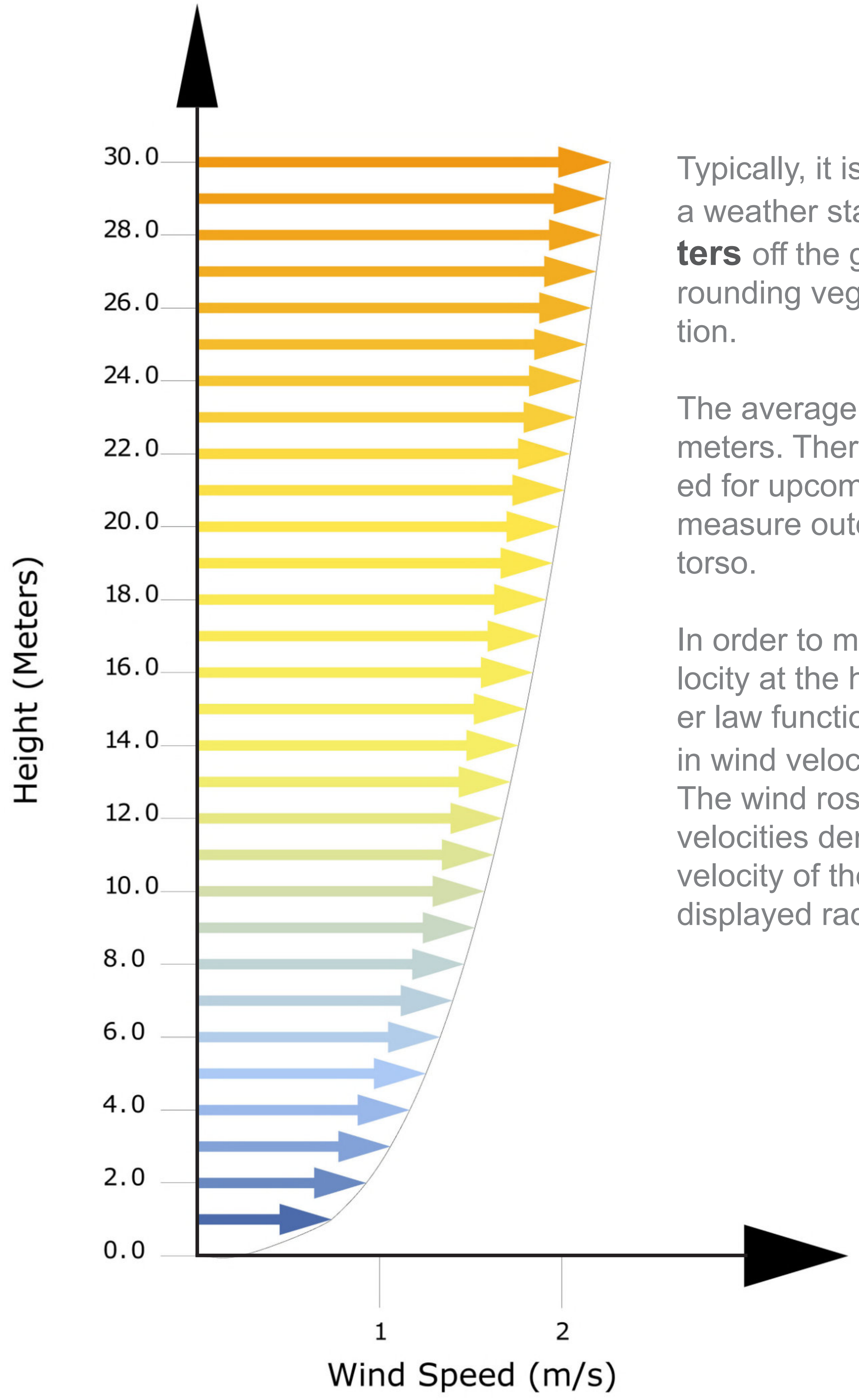
The charts on the left show wind rose for all the months of the year. It displays the primary wind direction for each month of the year. It is to be noted that these wind roses are for the data recorded at the **weather station**.



The chart on the left shows the annual wind rose for data recorded at the **weather station**.

It is evident from the chart that the **northwest** is the **prevailing wind direction**. The wind rose also radially displays the average velocity of the wind coming from sixteen directions in black.



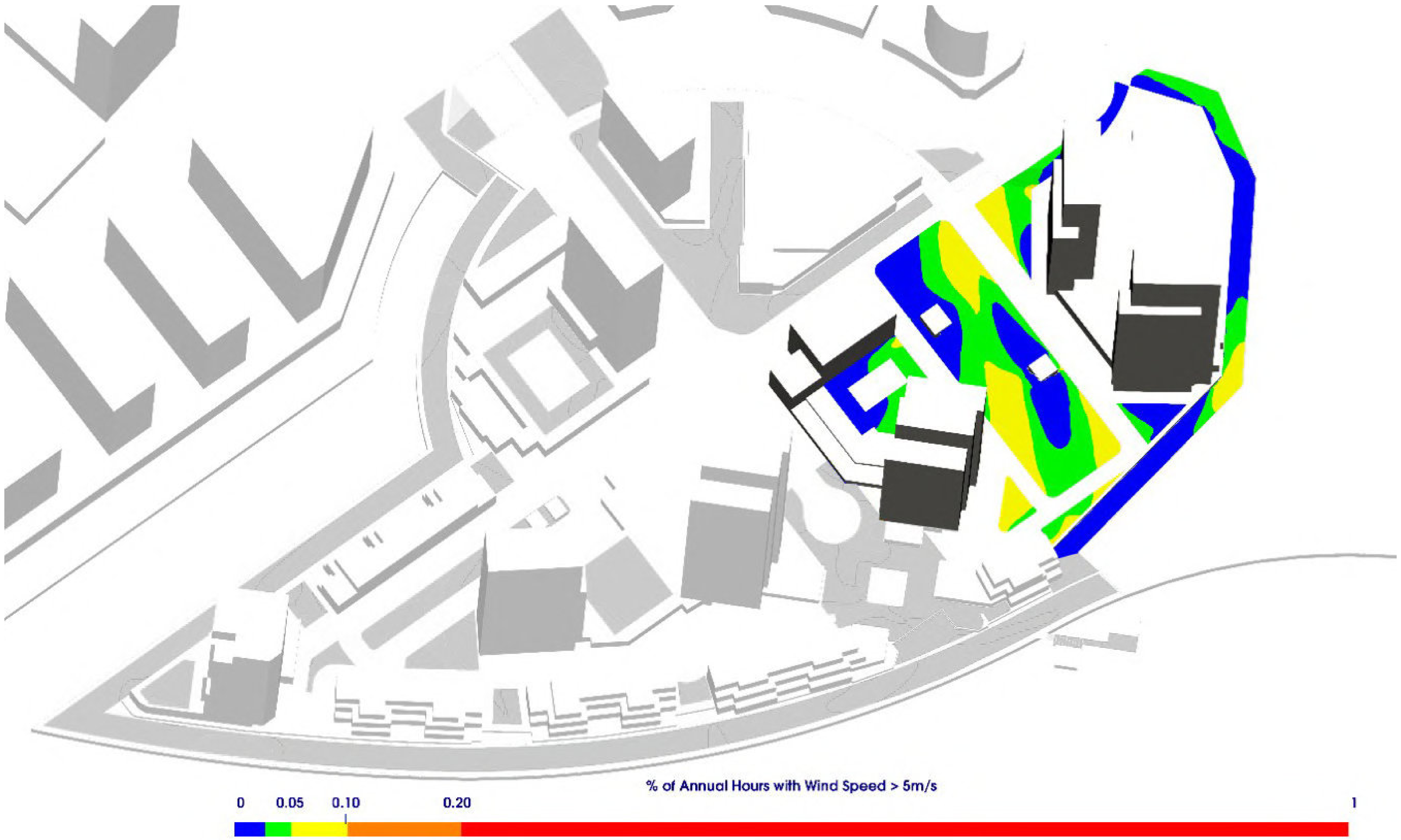


Typically, it is observed that the wind data recorded at a weather station is recorded at the height of **10 meters** off the ground in order to make sure that the surrounding vegetation does not influence the data collection.

The average human height for the UAE region is 1.6 meters. Therefore, the height of 1.2 meters is selected for upcoming analysis in the report with an idea to measure outdoor comfort at the average height of the torso.

In order to measure pedestrian comfort, the wind velocity at the height of 1.2 meters is derived based power law function. The graph on the left show the change in wind velocity based on the **power law** function. The wind rose on the left is drawn based on the wind velocities derived for the height of 1.2 meters. Average velocity of the wind coming from all the directions are displayed radially on the wind rose in black color.

Simulation Parameter



On the left, annual pedestrian comfort for the urban art park plaza is highlighted from the analysis performed during the stage 3.1.

In the following slides, local wind velocity in the urban art park plaza is checked for two directions at a more refined level. The plots in the following slides show the local wind velocity that will be experienced at the height of 1.2 meters when wind is coming from a particular direction.

Based on this wind velocity, pedestrian comfort is evaluated using the Lawson's pedestrian comfort criteria and the Beaufort scale.

Review - Annual Pedestrian Comfort - Stage 3.1

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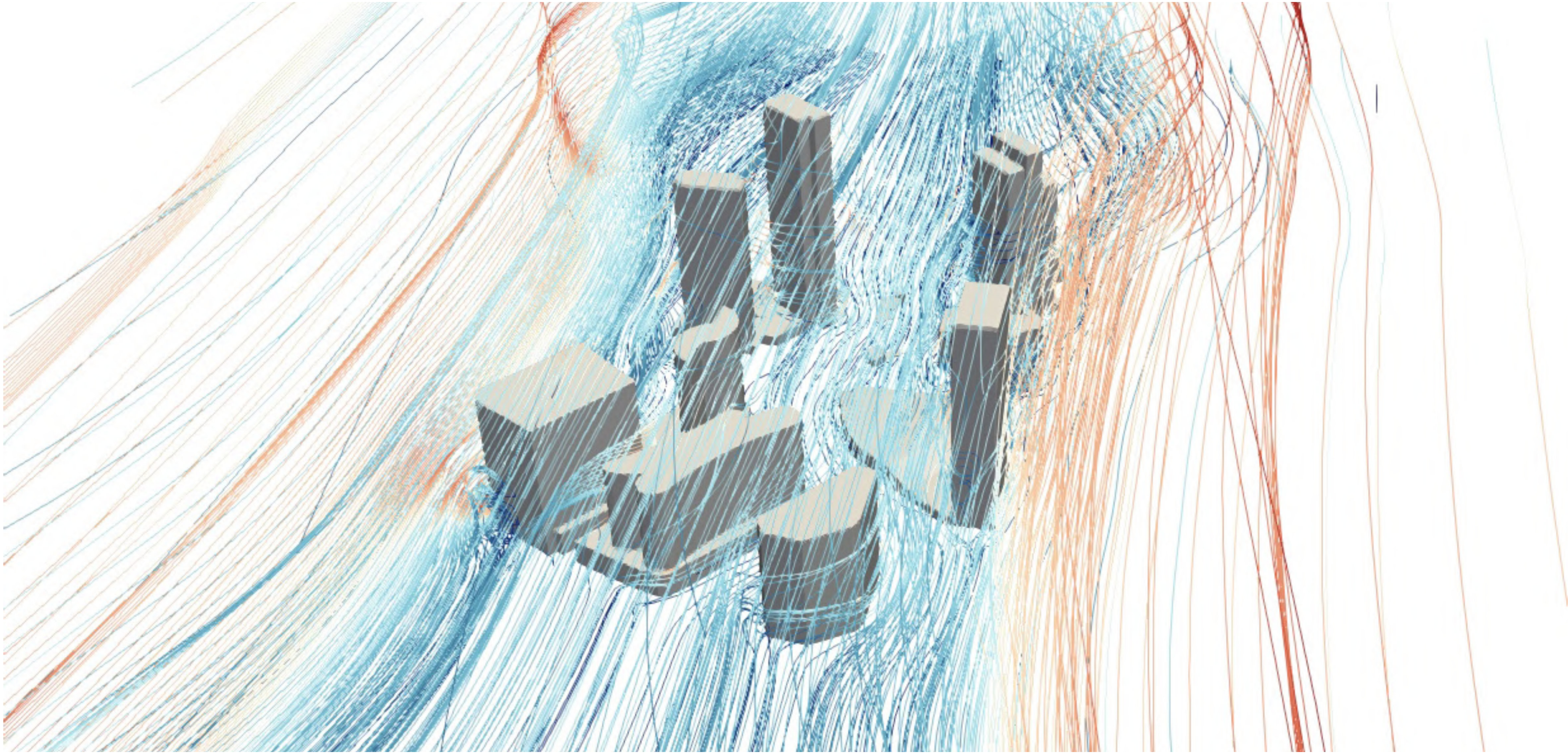

Wind Studies [CFD]

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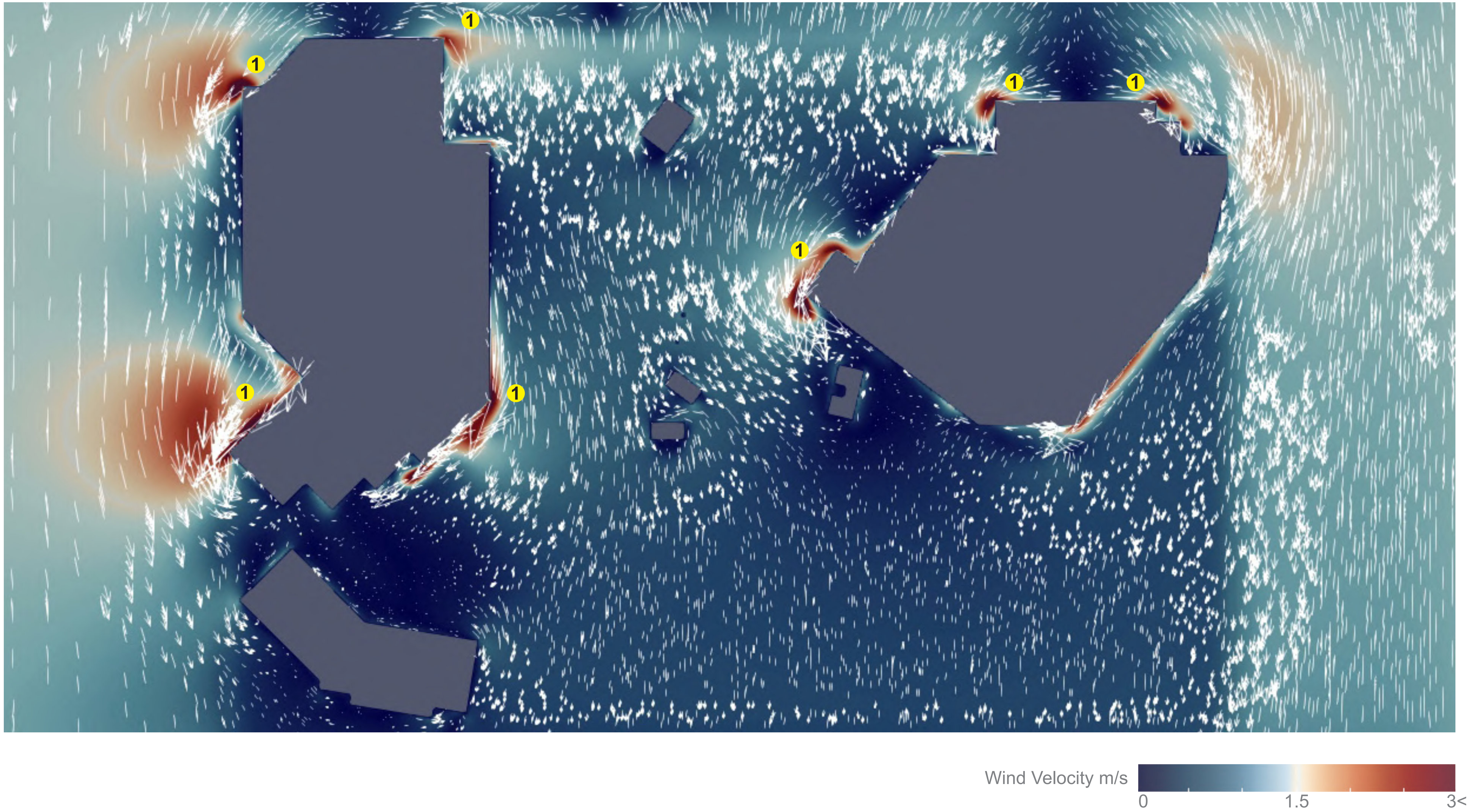
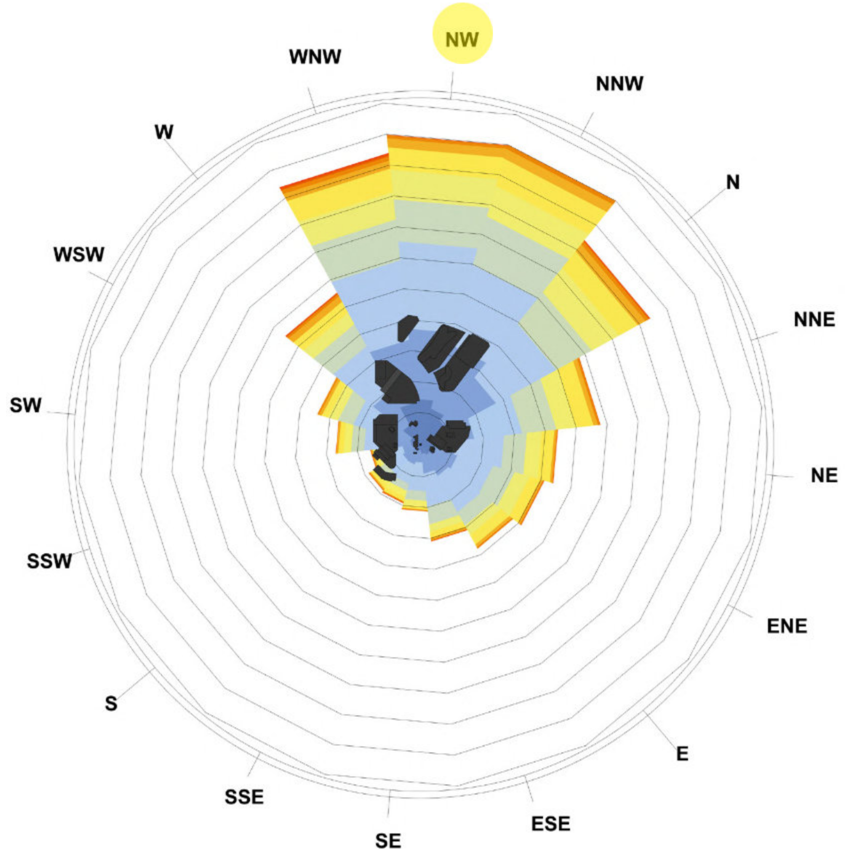
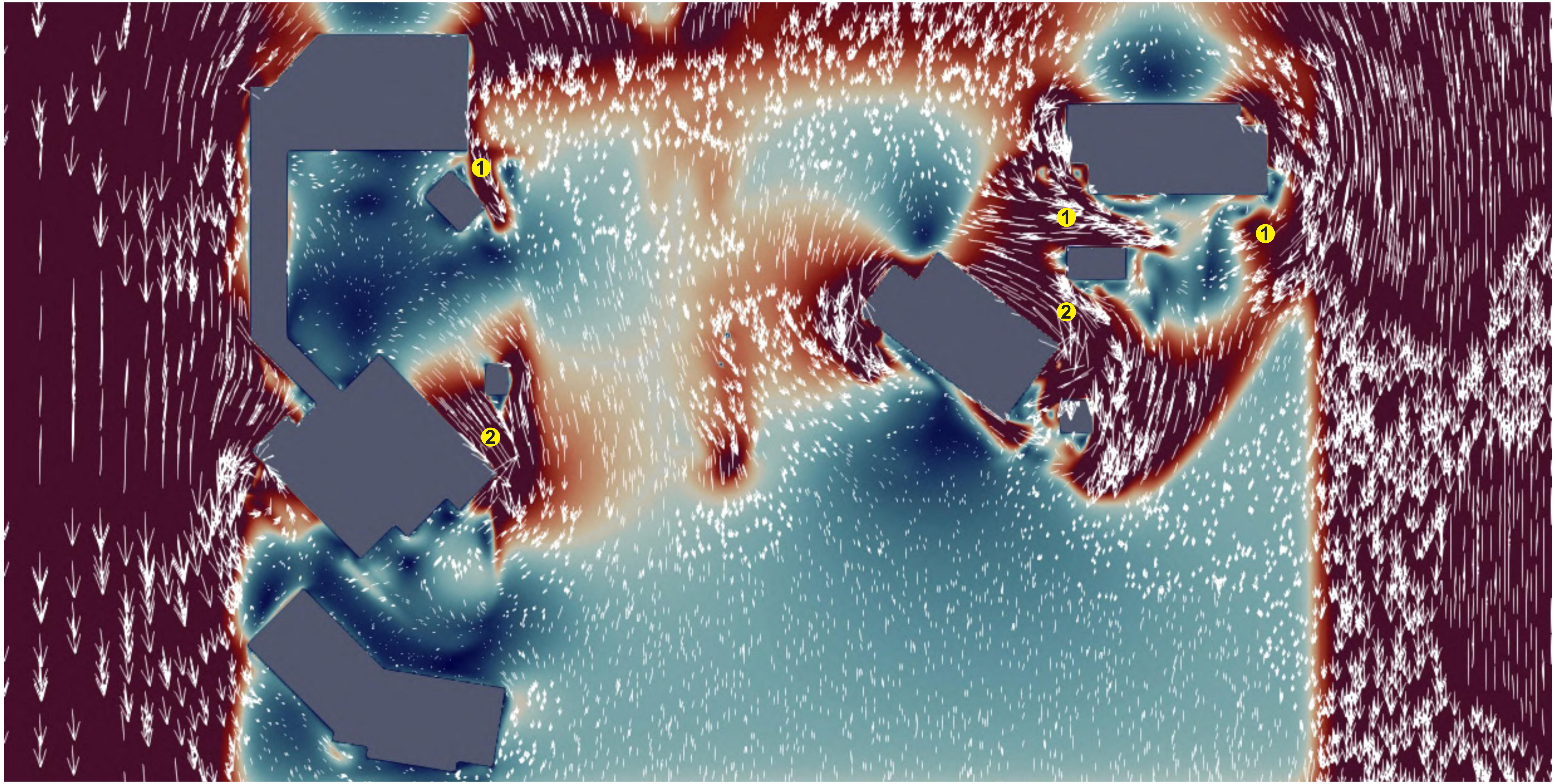


As identified from the wind rose that the prevailing wind direction is the **north-west**. Using the derived wind velocity at the height of 1.2 meters from the direction of the north west, wind velocity in the urban art park plaza area is plotted.

At [1], acceleration of wind is observed at corners. Entraces to a building shall be avoided at such locations.

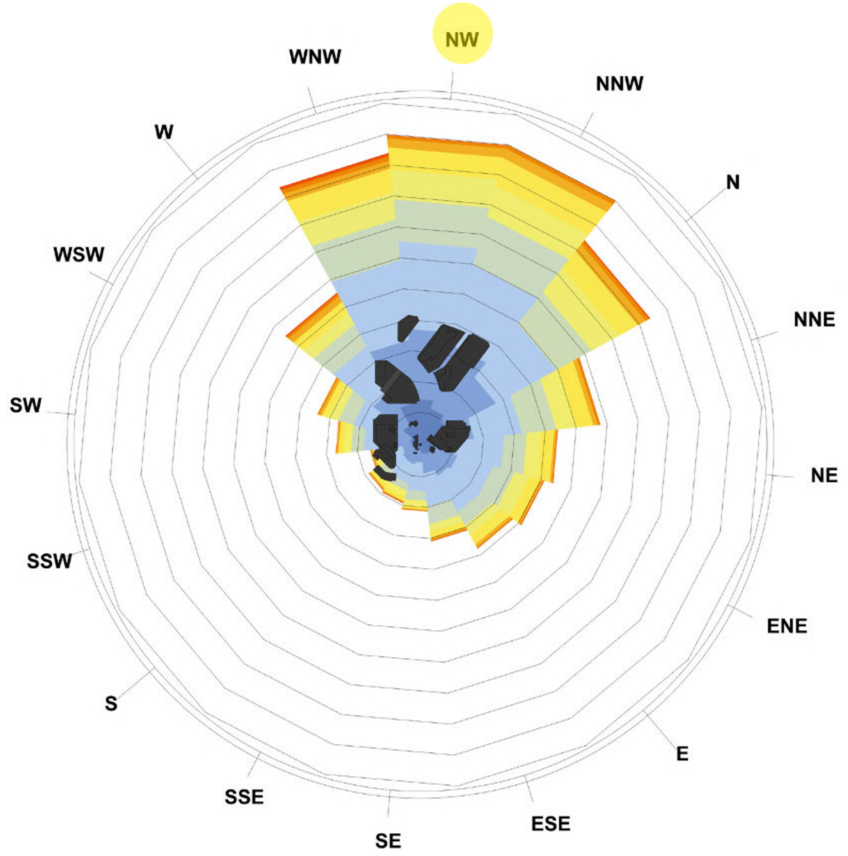


Analysis - 1.2M off Ground - Wind Velocity - from the **North-West** direction
OCTOBER 2018



On the left, wind velocity 1.2 meters off the terrace is plotted. At [1], wind acceleration is observed due to pressure short circuiting [Explained later] at [02].

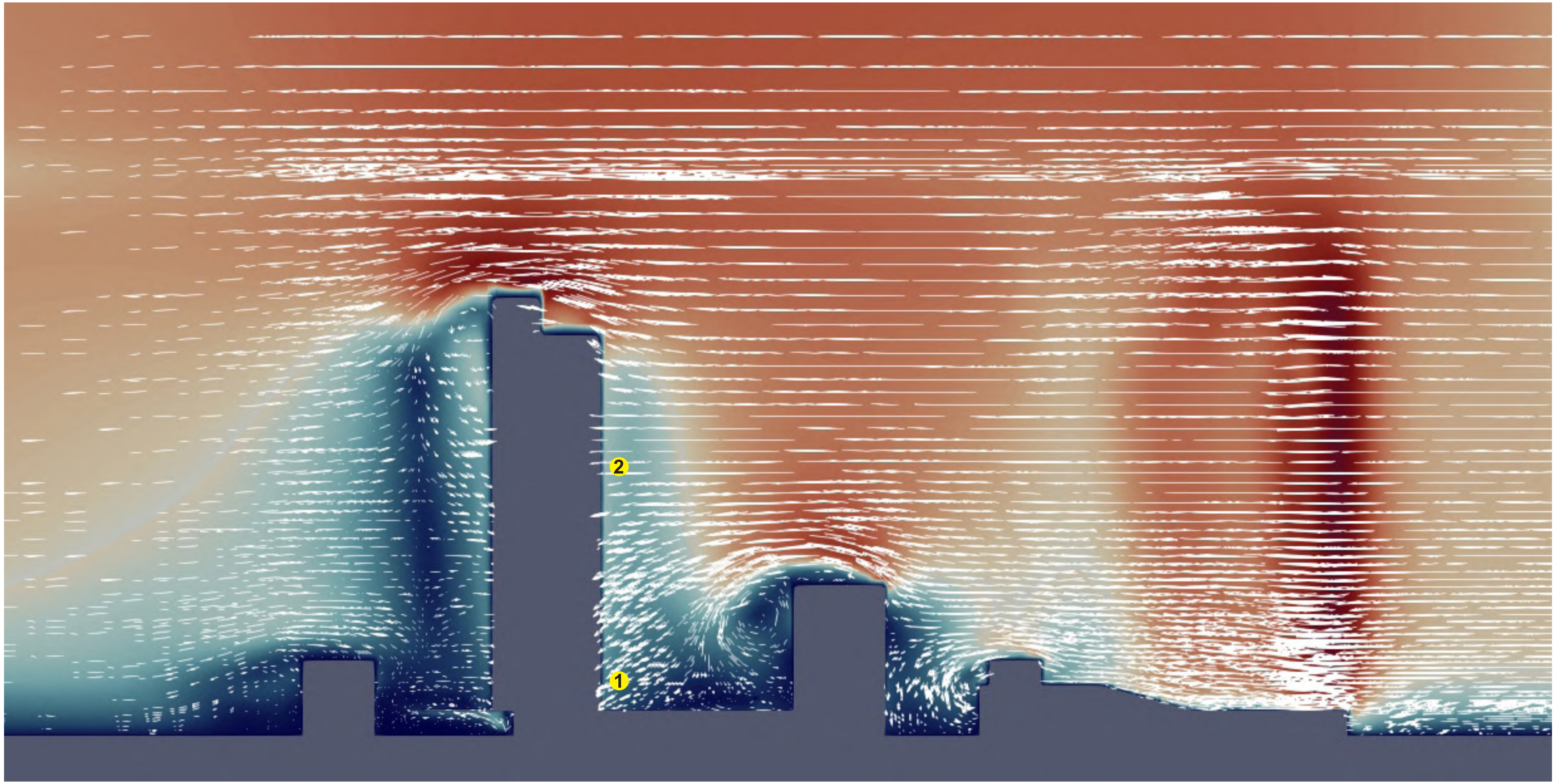
The area at [1] receives wind speeds greater than 3m/s. From the wind comfort standpoint, this area shall be avoided for outdoor seating. The area is good for outdoor standing.



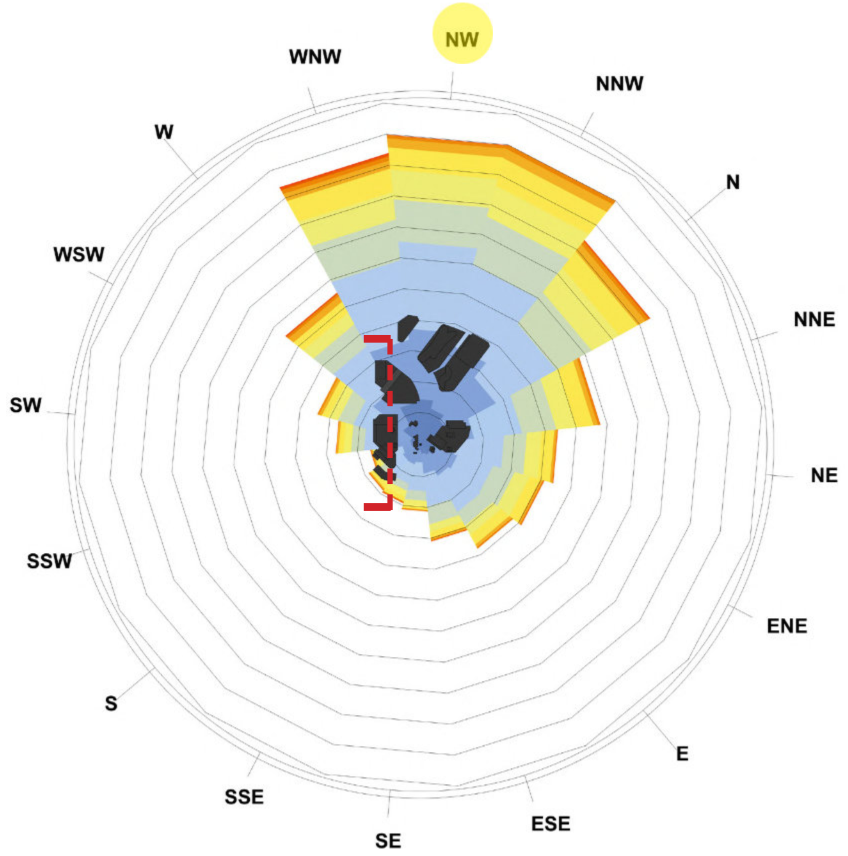
Wind Velocity m/s
0 1.5 3<

Analysis - 1.2M off Terrace - Wind Velocity - from the **North-West** direction

OCTOBER 2018



At [2] stagnation point [Explained later] can be observed. Standing vortex are observed at [1]. It is advisable to have canopies attached to building similar to a porch. The canopy can greatly help in addressing the vortex.



Wind Velocity m/s 0 4 8<

Analysis - Site Level Wind Velocity - from the **North-West** direction

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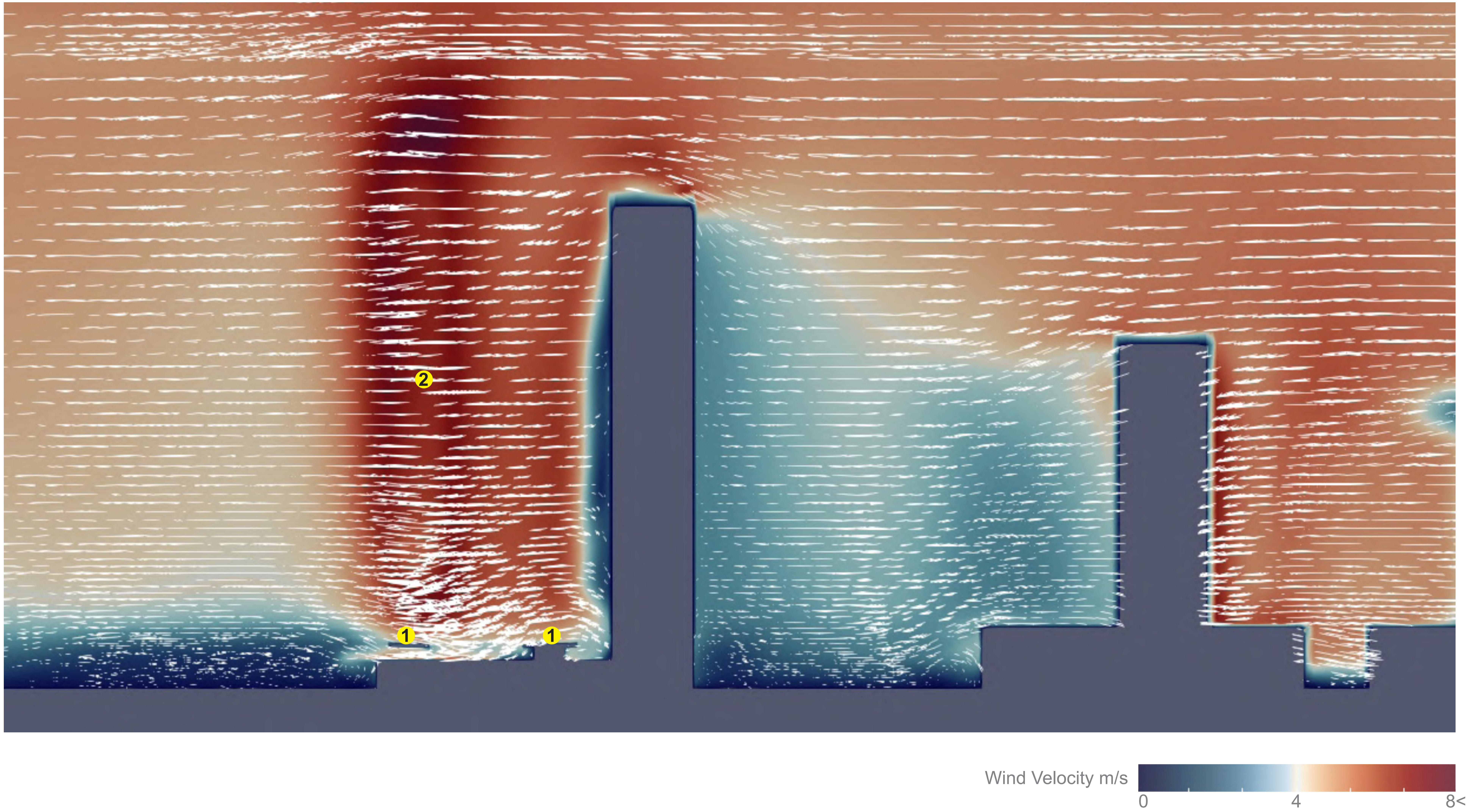
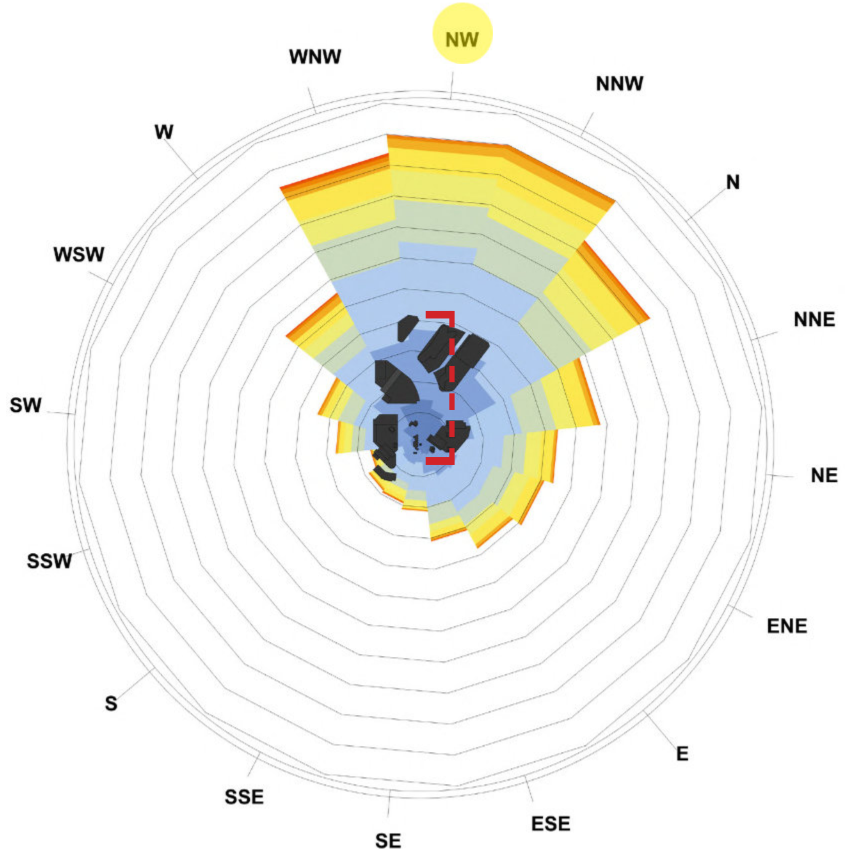
At [1], canopies will help if outdoor seating is planned. This acceleration at [2] is observed due to the building behind this section. The same can be observed clearly on the plan.





Analysis - Site Level Wind Velocity - from the **North-West** direction

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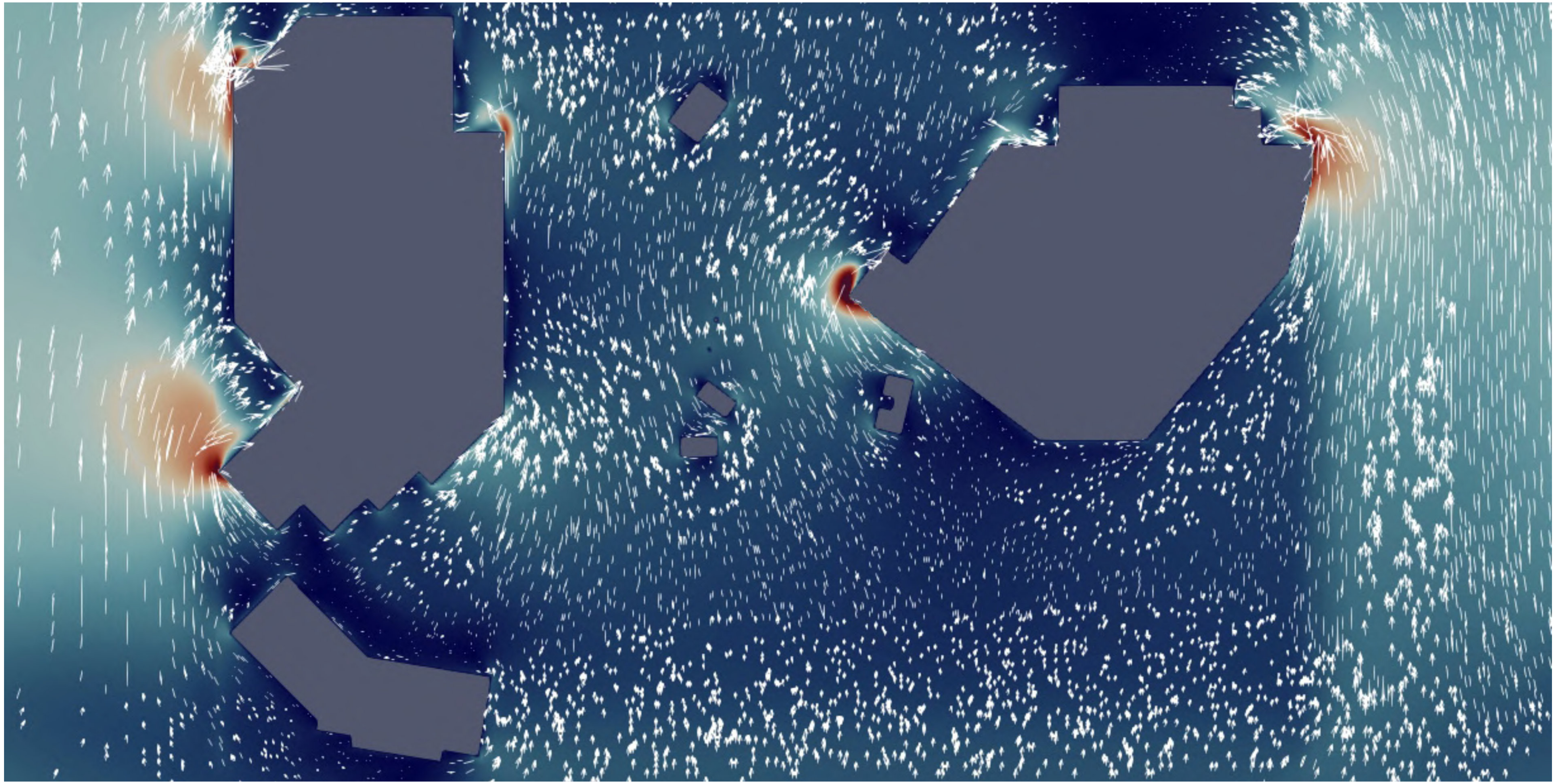
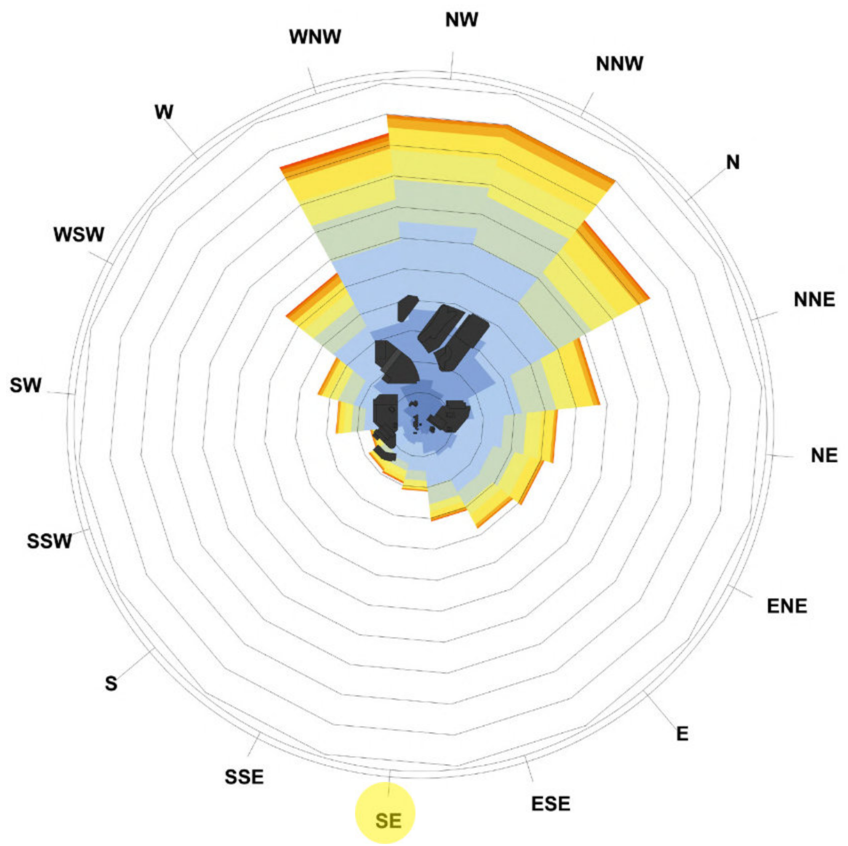


The map on the left shows the local wind velocity for the wind coming from the **south-east** direction. Although, acceleration at the corners can be clearly observed, the velocity remains within 3 m/s in most of the area. Entrances should be avoided at the corners where high velocities are observed.



Wind Velocity m/s

Analysis - 1.2M off Ground - Wind Velocity - from the **South-East** direction

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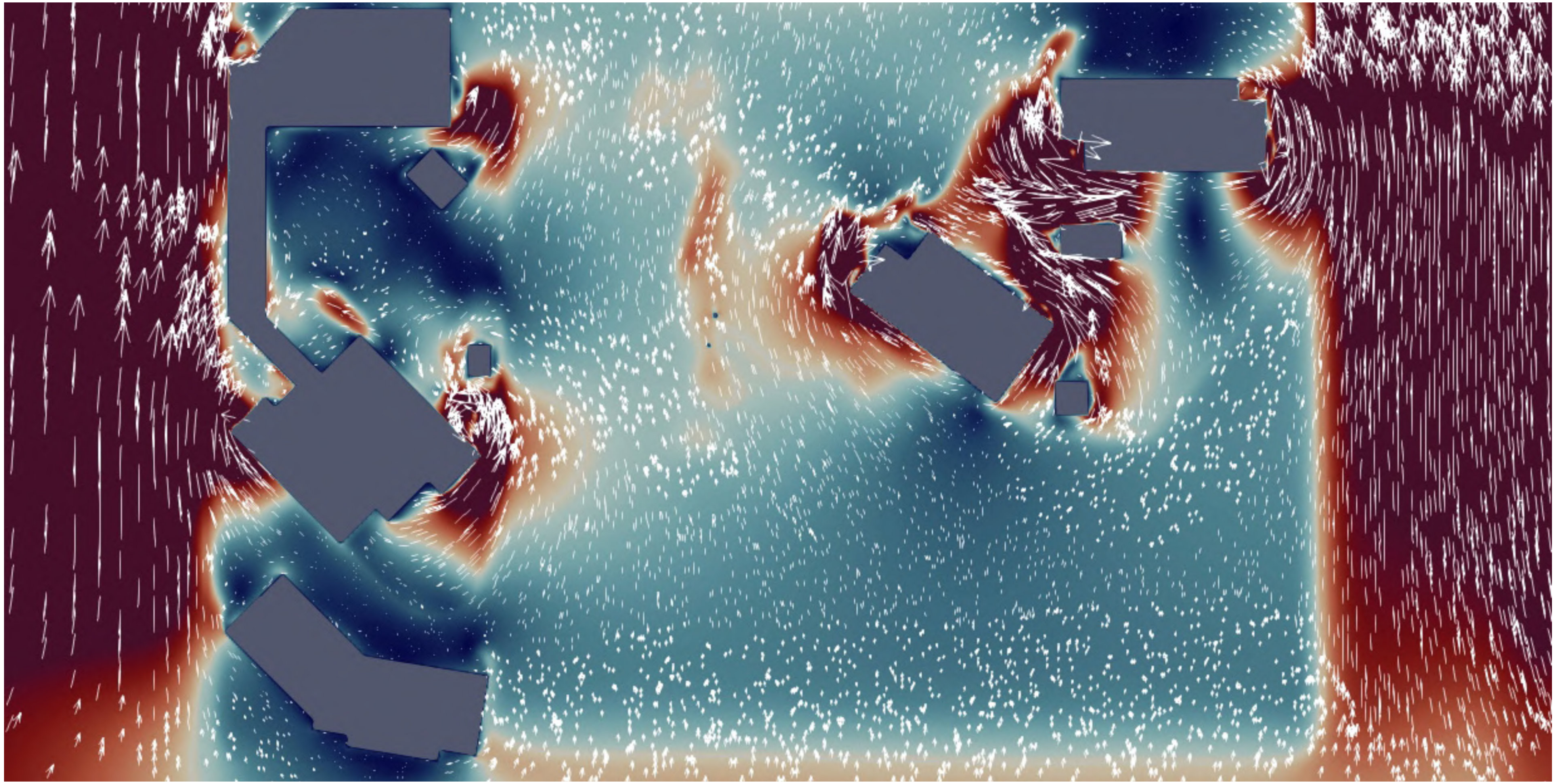
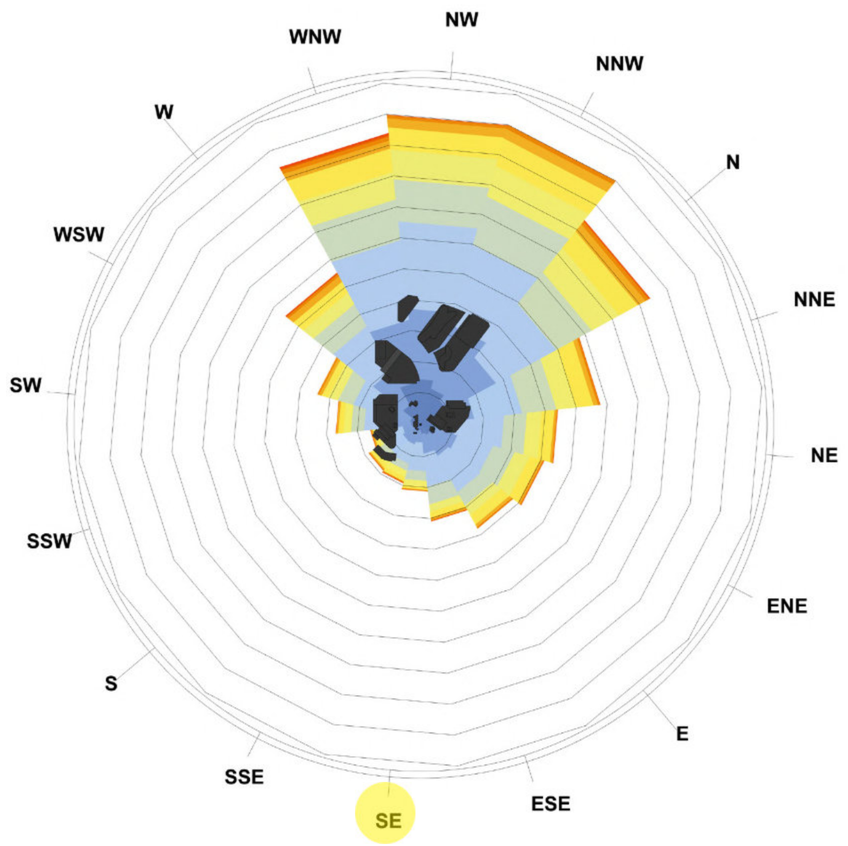


The map on the left shows the local wind velocity for the wind coming from the **south-east** direction. Again, wind speed more than 3m/s are observed at the terrace area. These areas will be observed agains the established metrics for the pedestrian comfort such as Beaufort scale of Lawson's criteria in the upcoming slides.

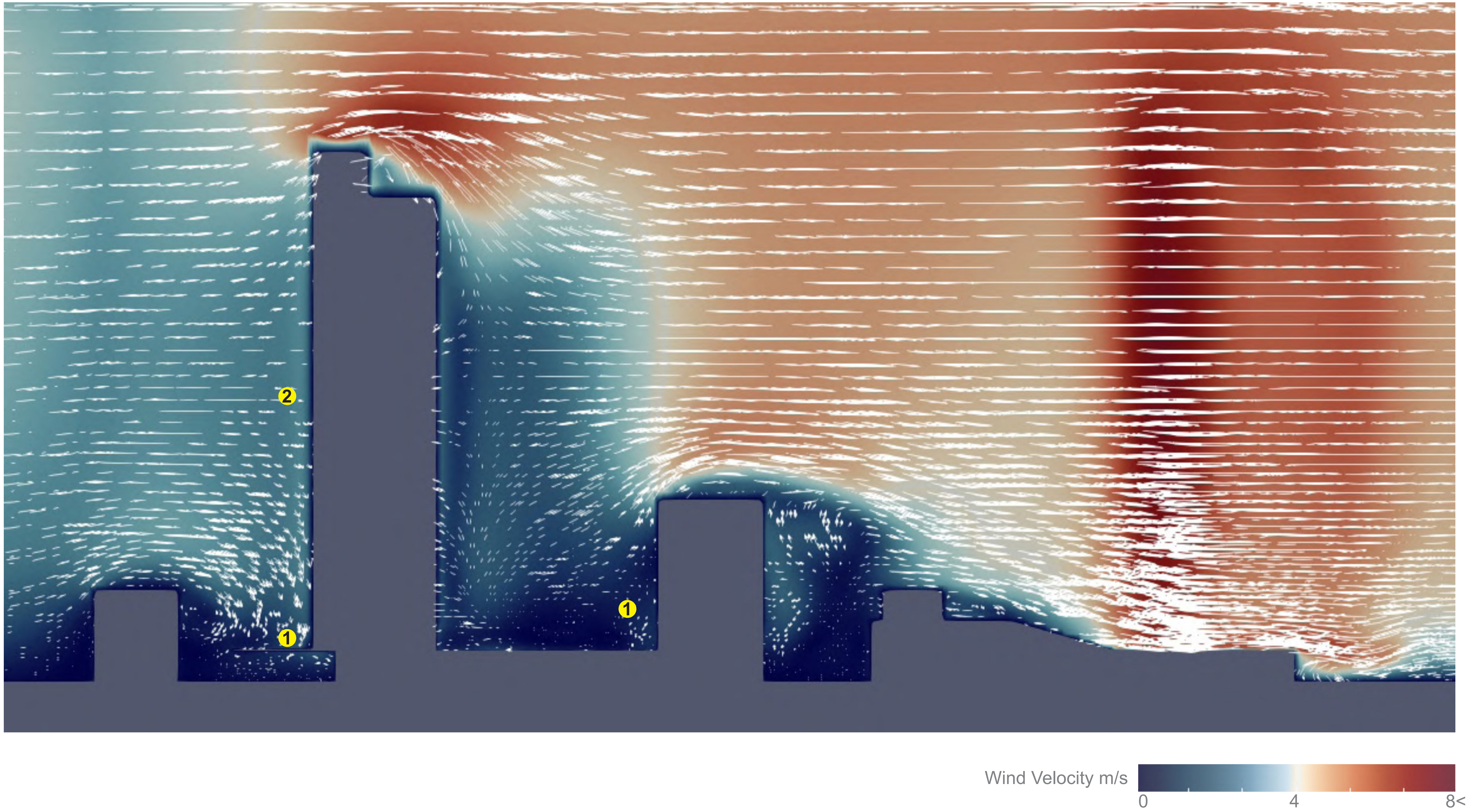


Wind Velocity m/s

0 1.5 3<

Analysis - 1.2M off Terrace - Wind Velocity - from the **South-East** direction

OCTOBER 2018



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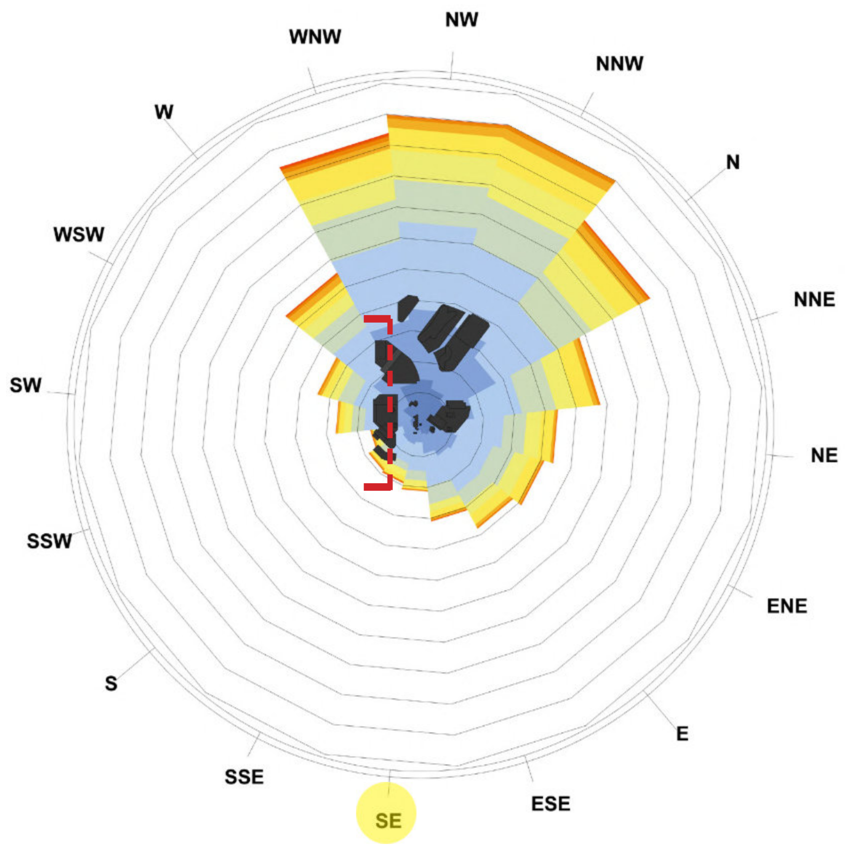
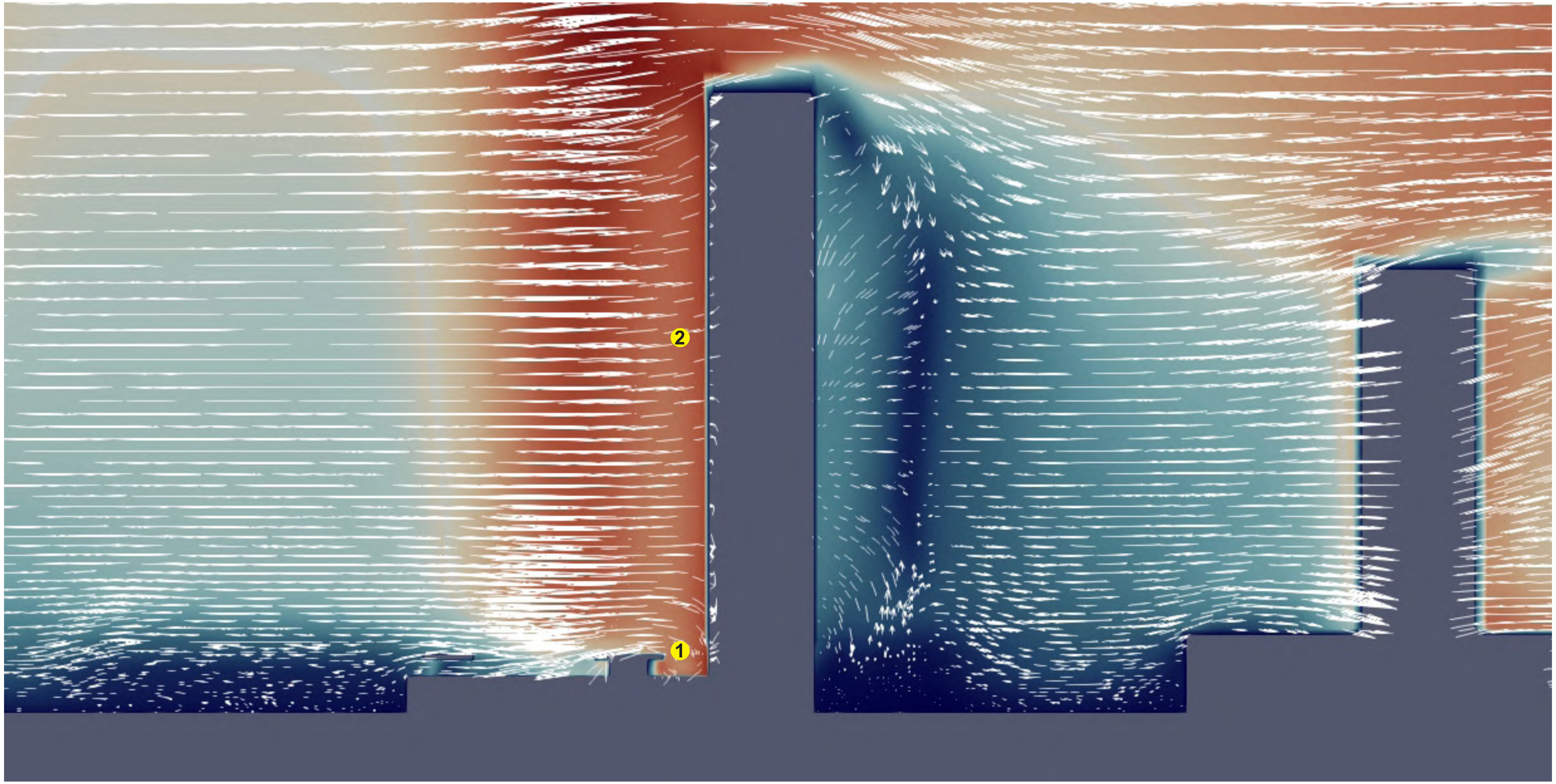


Analysis - Site Level Wind Velocity - from the **South-East** direction

OCTOBER 2018



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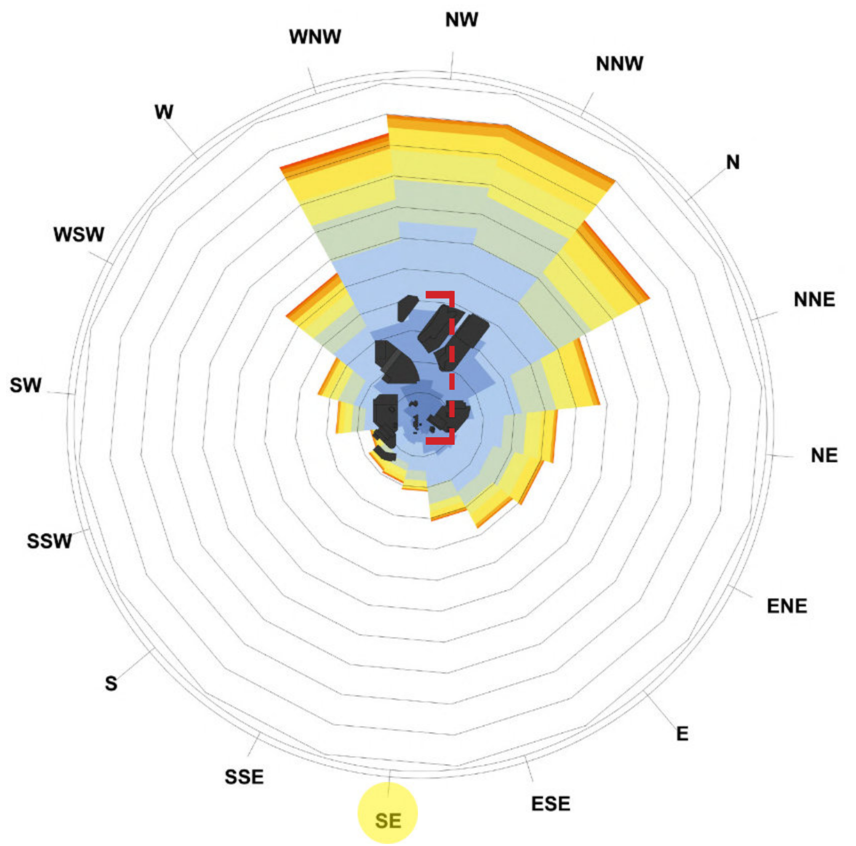
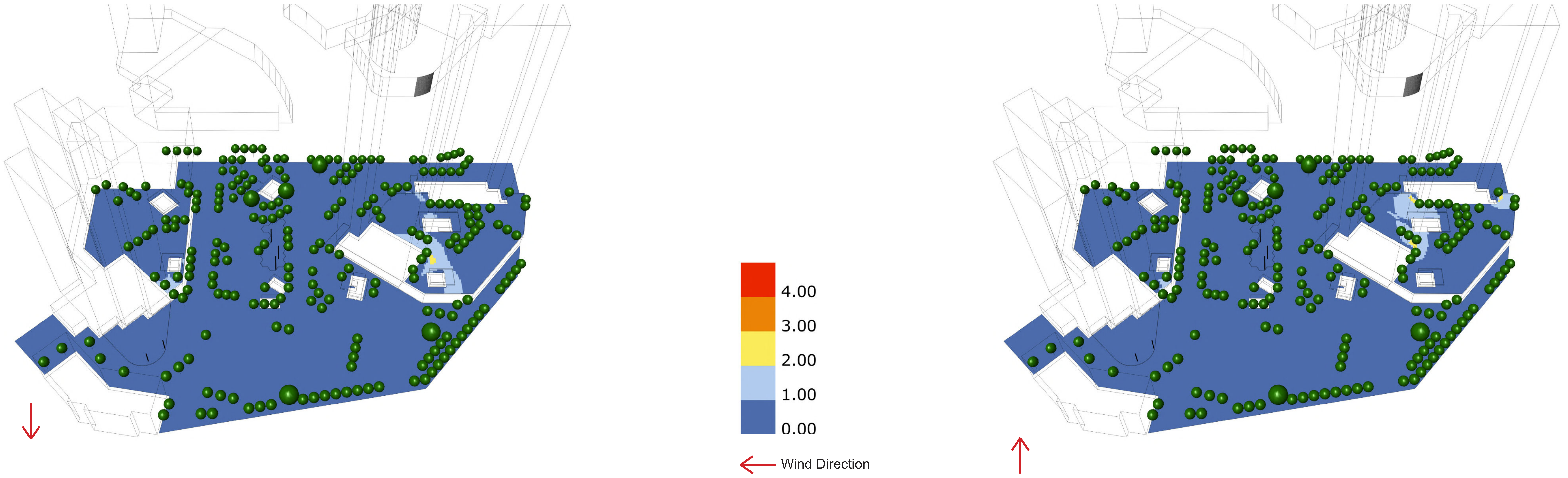


Analysis - Site Level Wind Velocity - from the **South-East** direction

OCTOBER 2018



Site level wind velocity was checked for two wind directions. It can be observed from the site level wind studies that wind velocity in the major area of the urban art park plaza remains within 3 m/s. Lawson came up with a comfort criterion for the pedestrian's outdoors. Lawson's pedestrian comfort criteria can be seen on the right. The local wind velocity for wind coming from both the directions are binned into Lawson's comfort criteria and are plotted in the maps shown above.

It can be seen from the comfort plot that the urban art park plaza remains comfortable for outdoor activities such as **seating, standing,** and **leisurely walking**. The areas not recommended to seating and only leisurely standing can be clearly observed in the light blue color.

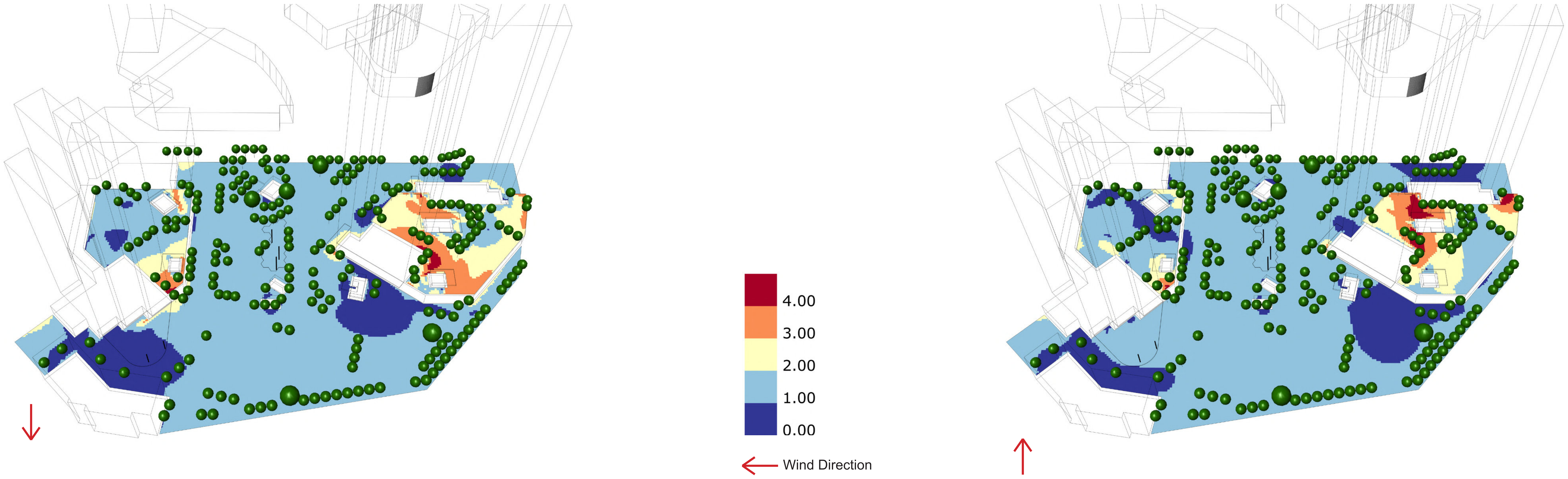
0 = velocity < 4 m/s = seating (outdoor cafes, patios, terraces, benches, gardens, parks, fountains, monuments)

1 = 4 m/s < Velocity <6 m/s = standing (building entrances or exits, bus stops, children's play areas)

2 = 6 m/s < Velocity <8 m/s = leisurely walking (general areas of walking, strolling and sightseeing, window shopping, public/private sidewalks, pathways, public spaces)

3 = 8 m/s < Velocity <10 m/s = business walking (walking from one place to another quickly, or where individuals pass rapidly through local areas around buildings, public/private vehicular drop-off zones, roads and car parks, cyclists pathways)

4 = Velocity > 10 m/s = Uncomfortable (uncomfortable for all pedestrian activities)



Beaufort scale was originally developed for the British Royal Navy. Later on the scale was modified for use in the meteorological observations. The scale is developed based on the empirical observations of the influence of the wind on physical objects in typical surroundings.

Above, Beaufort criteria is applied to the local wind velocity in the rban art park plaza for both the wind directions. The Beaufort scale with its observations can be seen on the right.

The Beaufort scale extends beyond scale 4 and goes up to the scale of 12. Where 12 represents a hurricane situation. Since the local wind velocity at the urban art park plaza remains within 3 m/s for the most part, as per Beaufort scale, the local wind shall not interfere with the outdoor activities of leisurely walking, and seating. At the terraces however, areas that are likely to experience wind velocities not normal for a leisurely seating can be clearly observed.

0 = velocity < 0.3 m/s = Smoke rises vertically
1 = 0.3 m/s < Velocity < 1.5 m/s = Direction shown by smoke drift but not by wind vanes
2 = 1.6 m/s < Velocity < 3.3 m/s = Wind felt on face; leaves rustle; wind vane moved by wind.
3 = 3.4 m/s < Velocity < 5.5 m/s = Leaves and small twigs in constant motion; light flags extended.
4 = 5.5 m/s < Velocity < 7.9 m/s = Raises dust and loose paper; small branches moved.

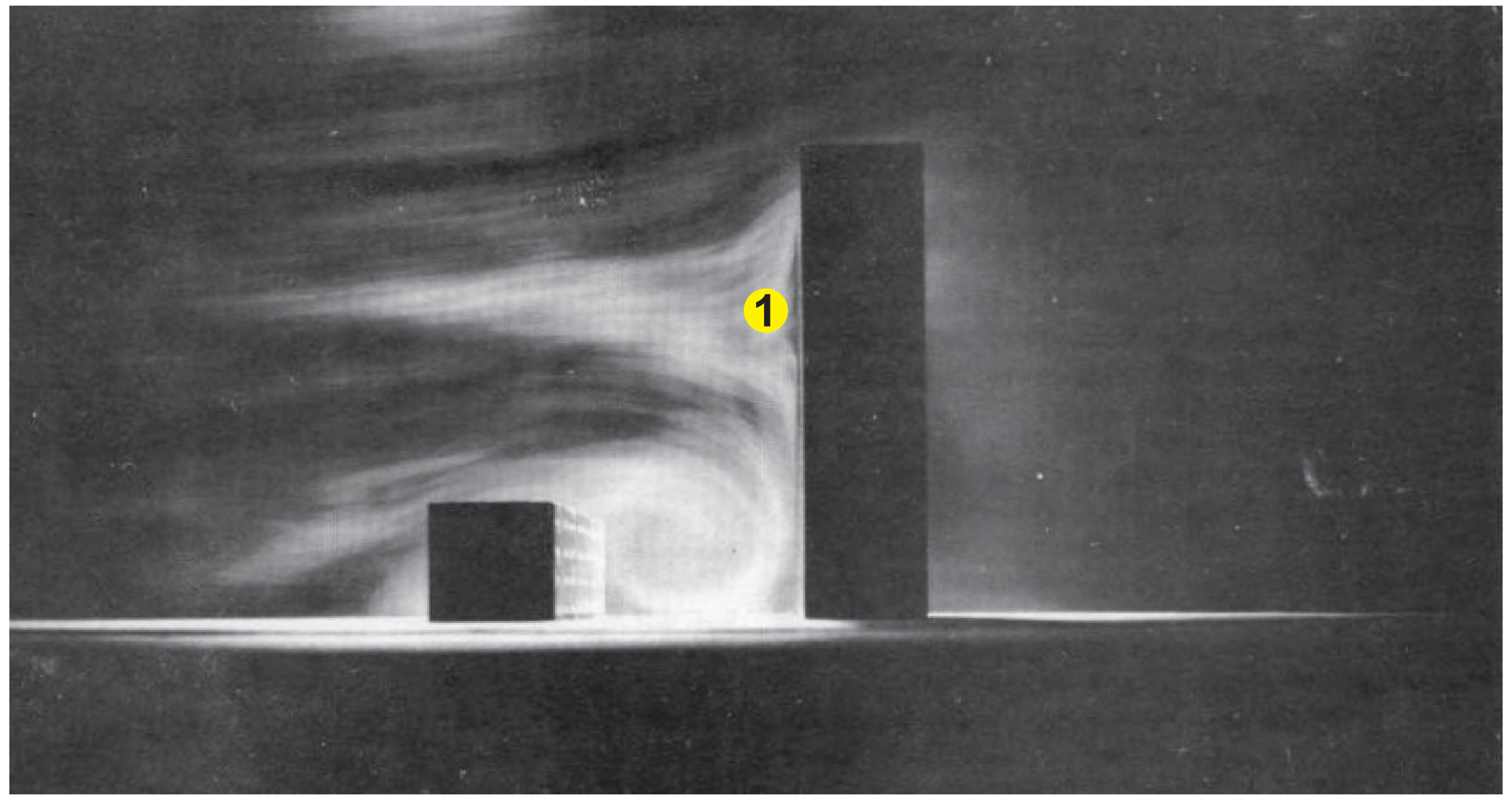


Figure 01

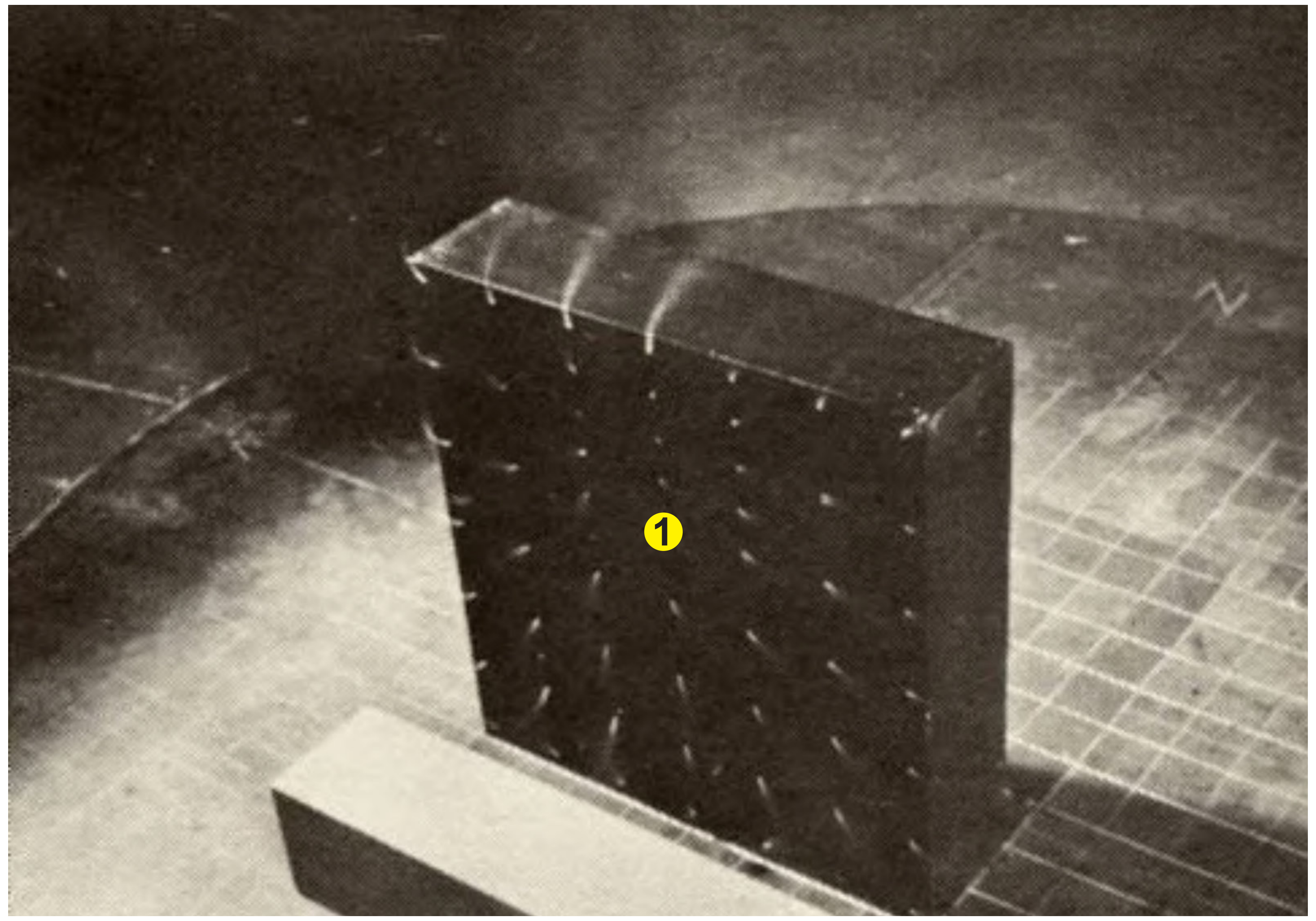


Figure 02

While computational fluid dynamics [CFD] is used for the project of Business Bay to simulate site level wind velocities, the other way to measure the effect of wind on proposed design is through a physical wind tunnel. Figure 01 shows a picture of two buildings of different height being tested in a physical wind tunnel. In figure 01, the wind approaches the building from the left. The face of a building that receives the wind is the **windward** side of the building and the face at the opposite end is the **leeward** side of the building.

When wind hits the building, at approximately 2/3rd height of the building one can observe the wind being split in different directions [figure 03]. This point is called the **stagnation point [1]**. As can be seen from images, the downward wind from this point creates a vortex between the buildings.

Wind factor is the ratio of wind velocity at site as if there was no building, and wind velocity measured at site with the buildings. Figure 04 shows the wind factors around the buildings. It is to be noted that the maximum wind factor [1.3] is observed at the ground inside the vortex. By use of a canopy similar to a porch, such vortex can be addressed.

The windward side of the building experiences positive pressure and leeward side of the building experiences negative pressure. Due to this pressure difference, acceleration around the corner of a building can be observed. Therefore, it is advised to avoid such corners for entrance to the building or outdoor waiting area such a bus top.

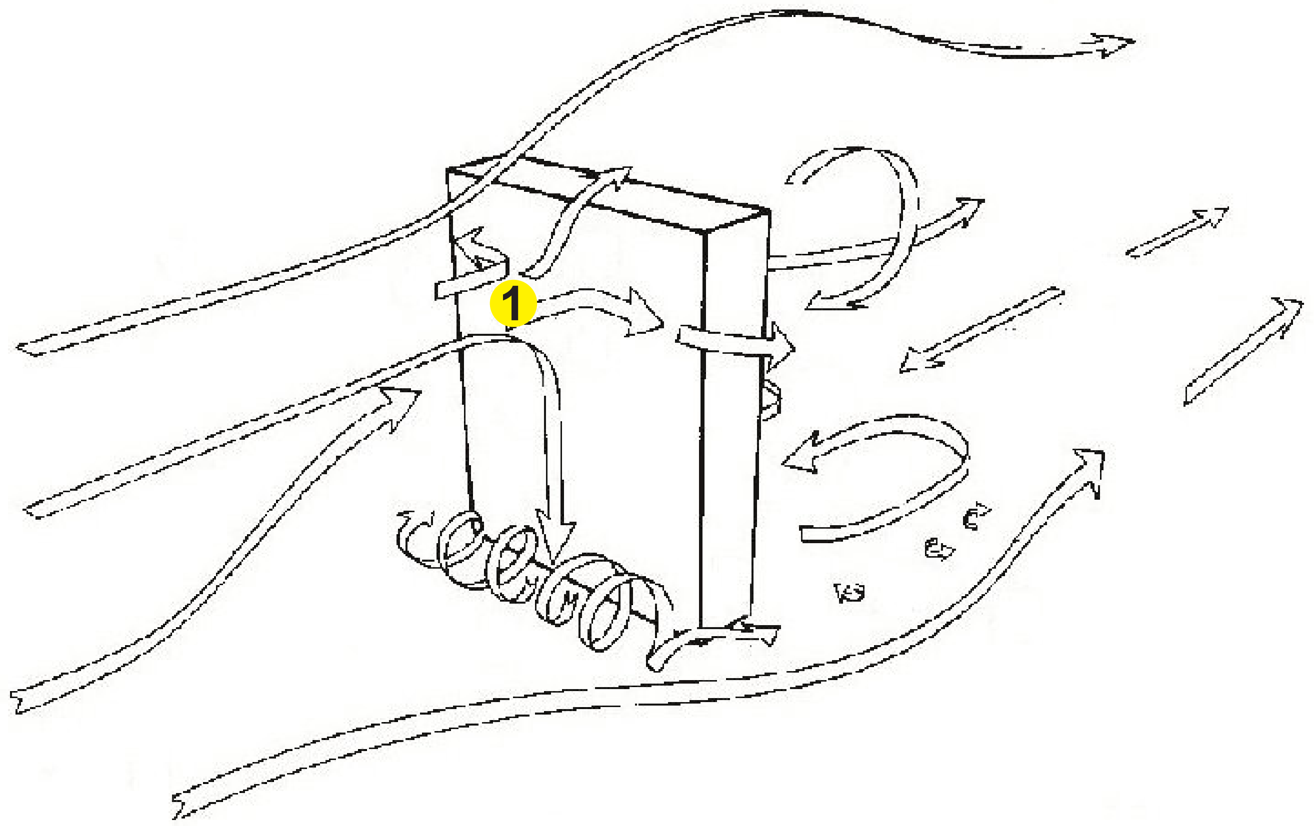


Figure 03

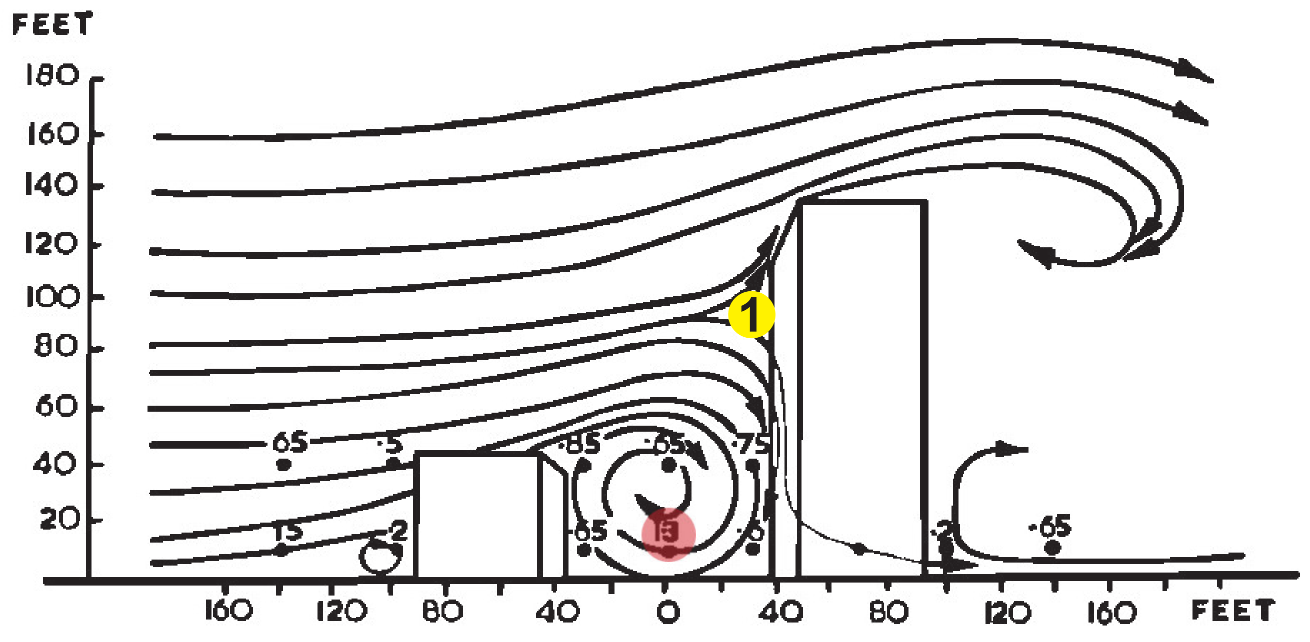
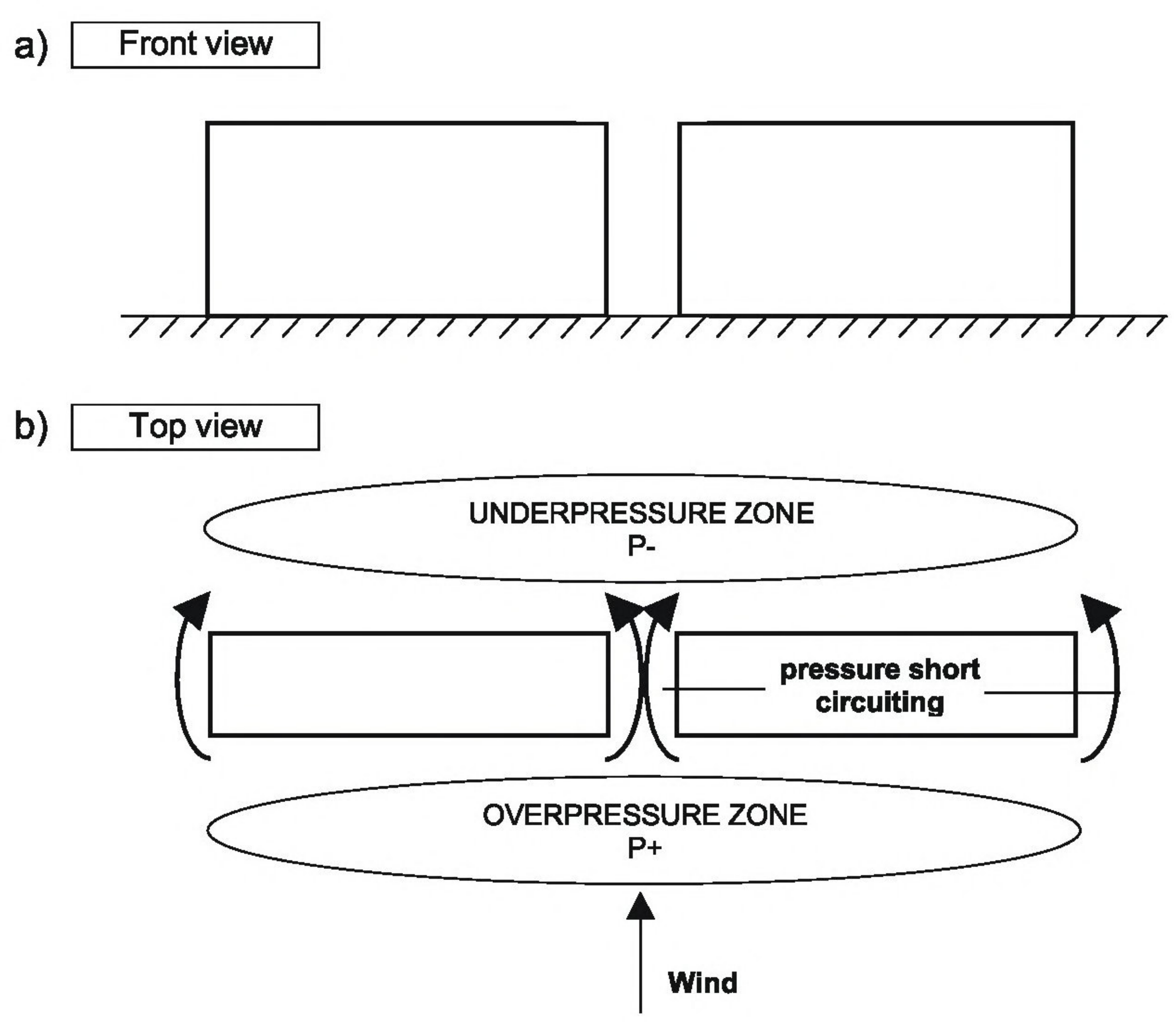
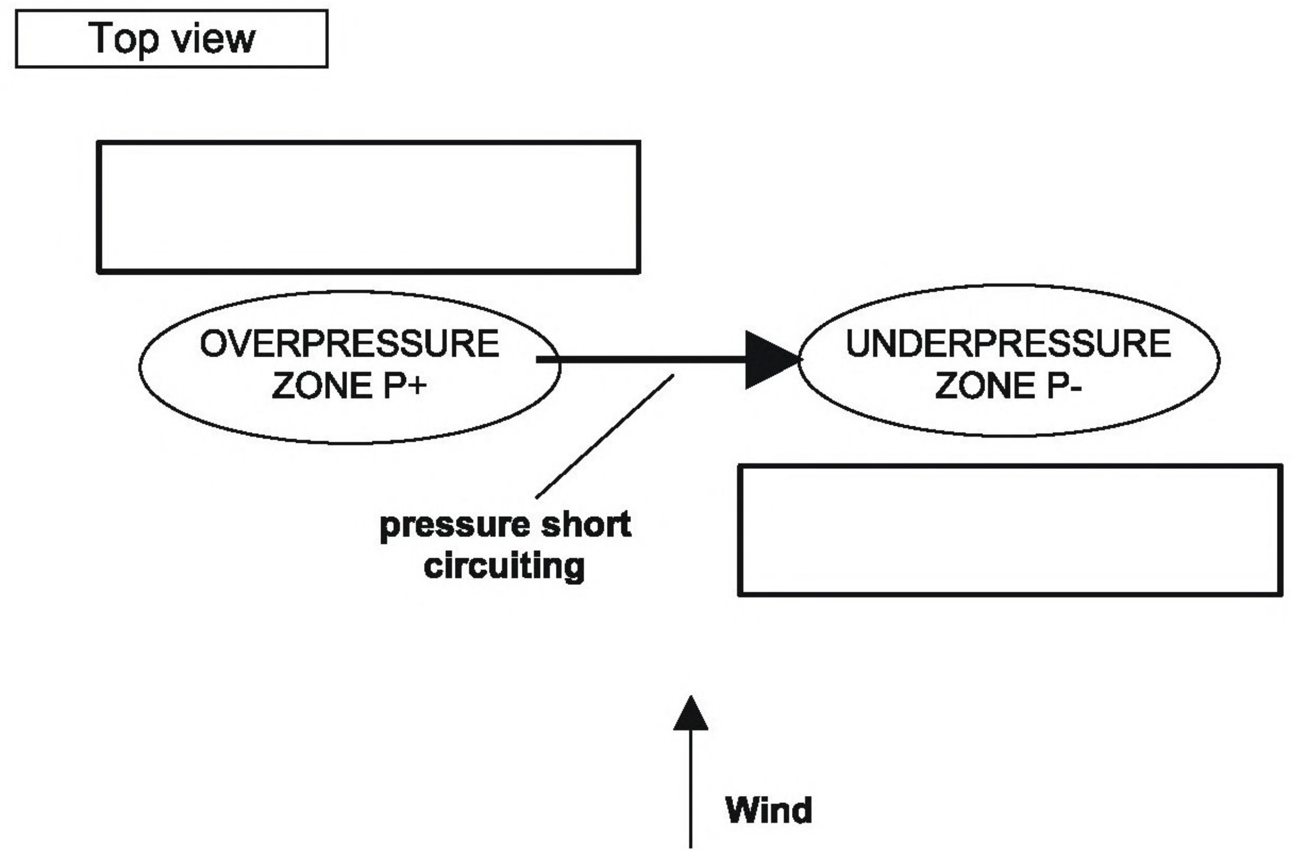


Figure 04

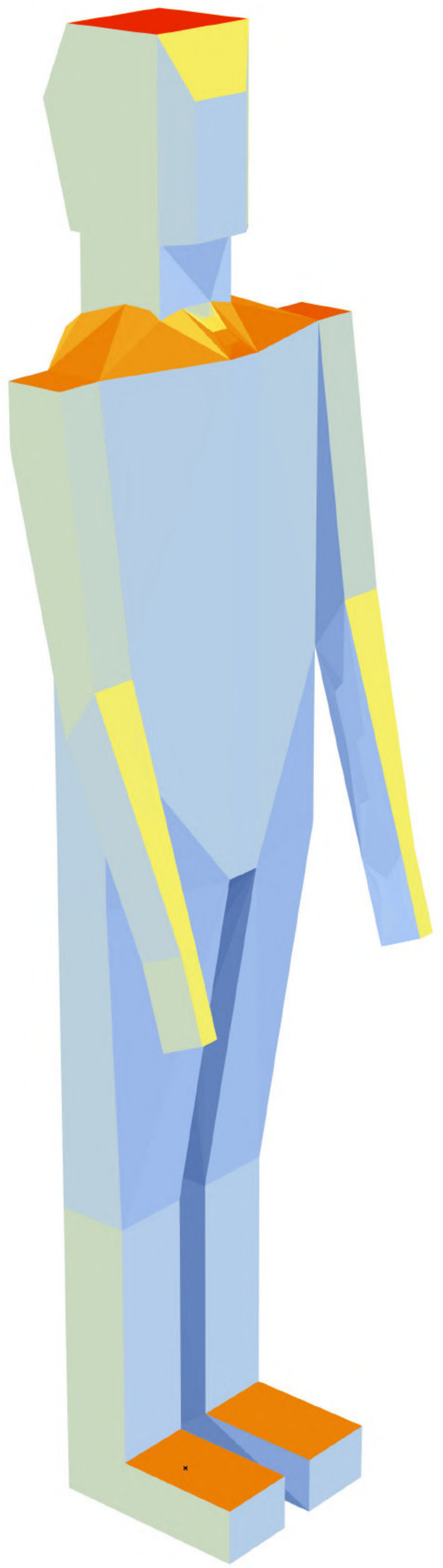
Image credit [all images on the page]: Blocken B, Carmeliet J. 2004. Pedestrian wind environment around buildings: Literature review and practical examples. Journal of Thermal Envelope and Building Science 28(2): 107-159

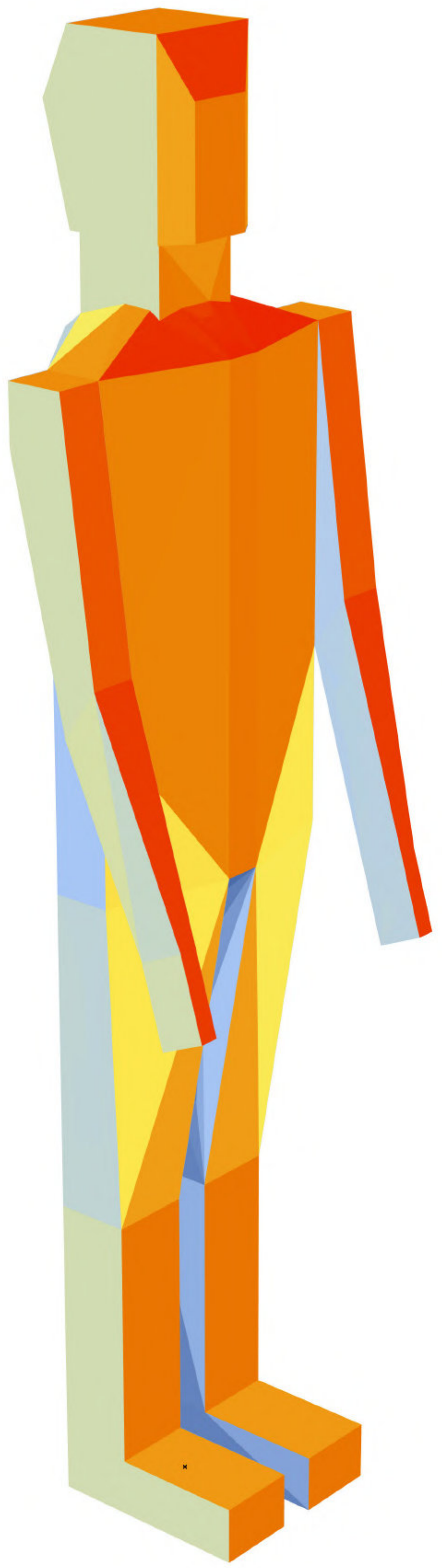


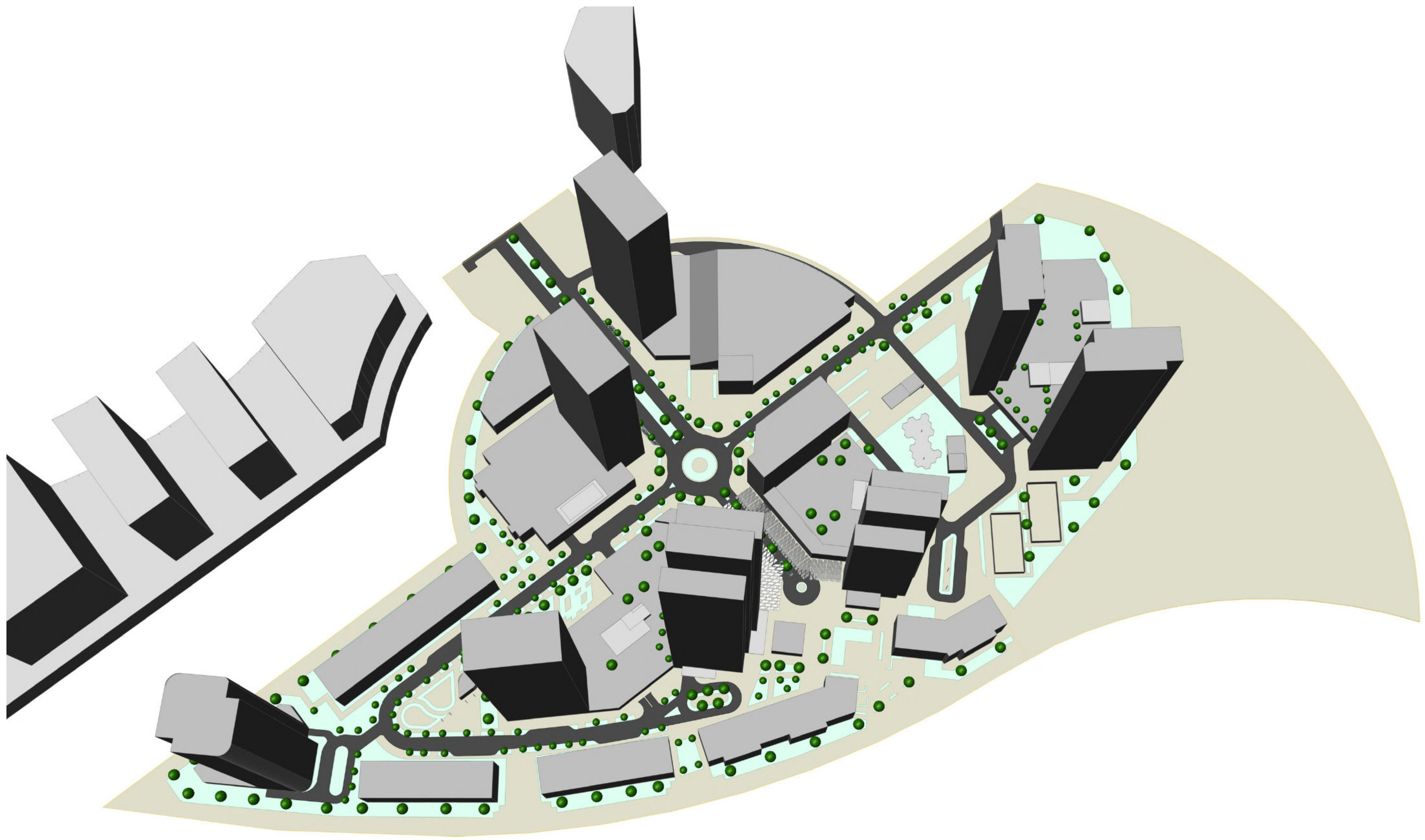


As shown in both the figures on the page, the through passages between buildings tend to create **pressure short circuiting**. The pressure short circuiting is responsible for wind acceleration experienced at the such passages between the buildings.

Image credit [all images on the page]: Blocken B, Carmeliet J. 2004. Pedestrian wind environment around buildings: Literature review and practical examples. Journal of Thermal Envelope and Building Science 28(2): 107-159







Urban heat island effect (UHI) is known as the increase in air temperature observed in urban environments compared to the undeveloped rural surroundings. Heat emission from the buildings, vehicles, higher density of the pavement materials, less vegetation, and many other factors contribute to this effect. It is typical to experience a degree or two higher outside air temperature in an urban area compared to its rural counterpart.

Climatic parameters of the environment are considered as the boundary condition for the evaluation of the indoor thermal comfort and the energy consumption of the buildings. **While the environment influences the buildings, buildings also influence the outdoor environment.** This reciprocal interaction of the building and the urban environment has been the domain of meteorologist until a few years.

Recently, a methodology called the **Urban Weather Generator (UWG)** has become available to the designers. UWG integrates building energy and the urban climate. UWG transforms the available weather data file measured at a weather station into a site-specific urban weather file. It is to be noted that this transformation happens mainly in the recorded dry bulb temperature in the weather file.

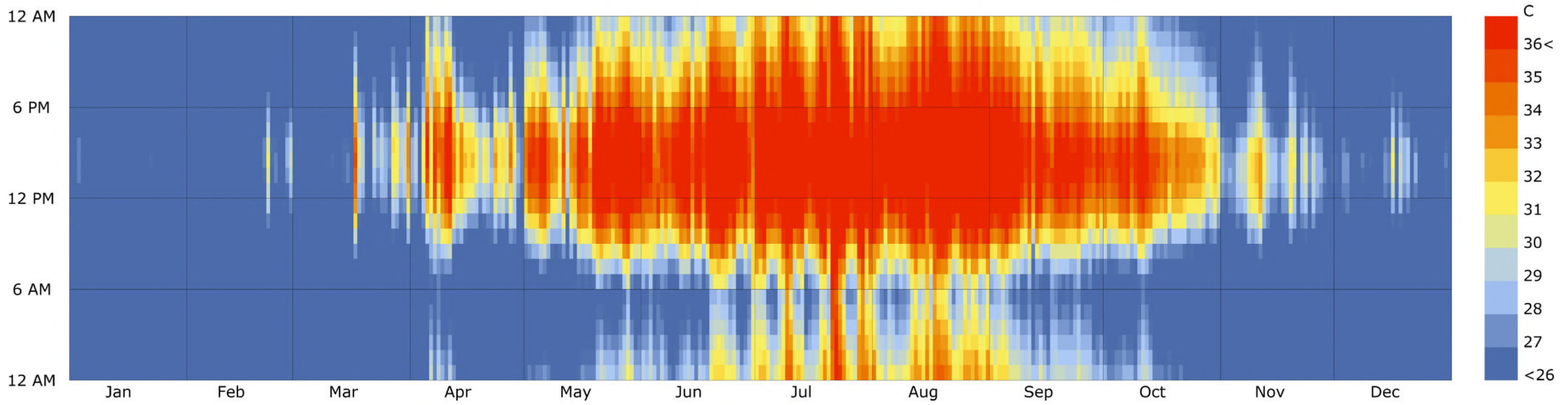
The UWG takes into account the heat being dumped in an urban area by the buildings, vehicles, heat emitted by the paved areas, and the effect of evapotranspiration by the vegetation on the ultimate heat balance of an urban area.

In the present study following parameters were used in the UWG for a UHI analysis of the Business Bay peninsula.

Building height:	From architecture 3D model
Floor to floor height:	3.5 meters
Building Typologies:	Residential, Retail, Hotel, Villa, Office
Glazing ratio:	80%
Glazing SHGC:	35%
Wall Albedo:	70% [For concrete with portland cement]
Roof Albedo:	33% [For gravel covered roof]
Pavement Albedo:	55% [For concrete pavement]
Roof vegetation:	10%
Vegetation Albedo:	35%
Sensible heat from Vehicles:	2 W/m2 [For a residential area in Singapore, recorded sensible heat from vehicles is 4 W/m2]
Soft-scape area and Tree canopies:	As per landscape plan

*Albedo is a ratio of solar radiation being reflected from a surface

Simulation Parameter



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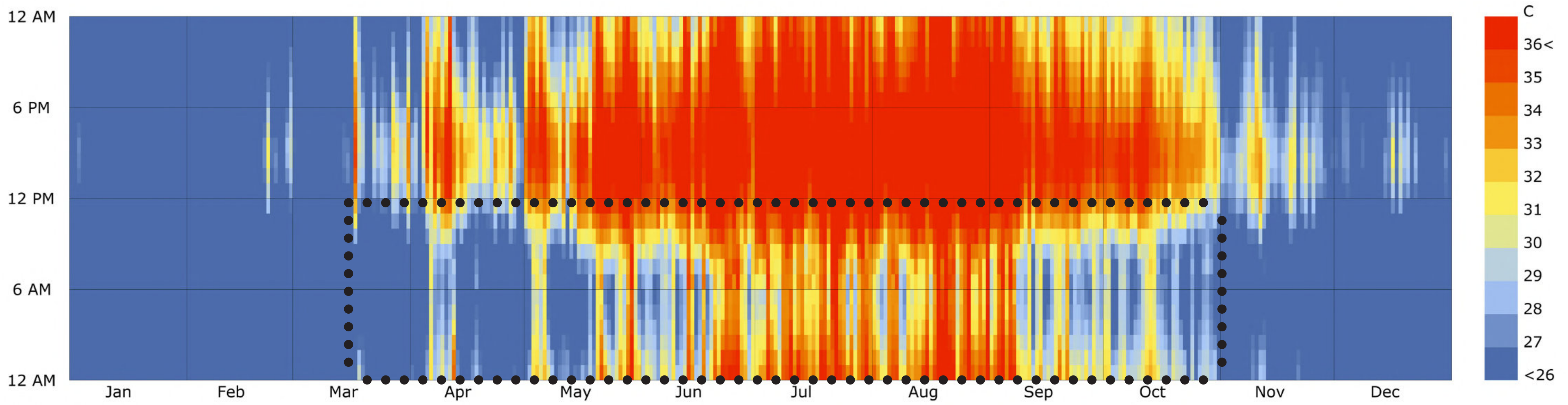

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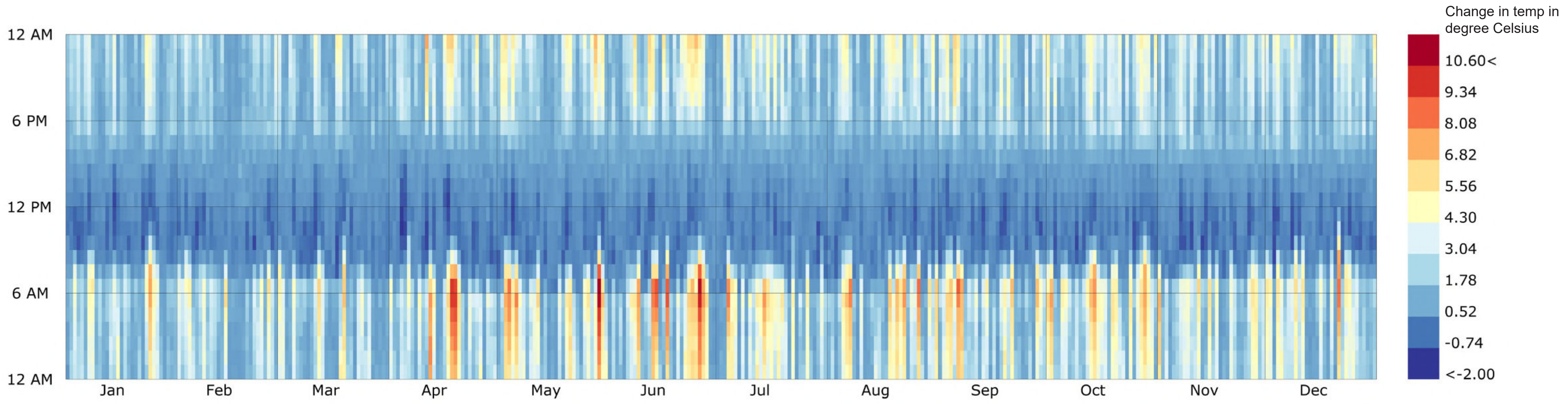


1 JAN 1:00 - 31 DEC 24:00

Based on the UWG simulation, a morphed weather file is created and dry-bulb temperature in the weather data recorded at the weather station and morphed weather file are compared on the left. The first chart shows the dry-bulb temperature in the recorded weather data at the weather station. The second chart shows the dry-bulb temperature in the morphed weather file. The third chart shows the difference in the dry-bulb temperature for both the files.

It can be observed that during summer months the urban heat island effect is prominent. Higher temperatures are recorded after the sunset hours. The concrete paved surfaces in the urban climate are high density surfaces with a high specific heat. The **delayed heating** observed on the chart after the sunset hours is due to heat being released by the pavement and building after the sunset hours. On the third chart, around noon, minor decrease in temperature also is to be observed.

This morphed weather file was used to conduct further UTCI analysis.

Urban Heat Island - Weather Data Comparison

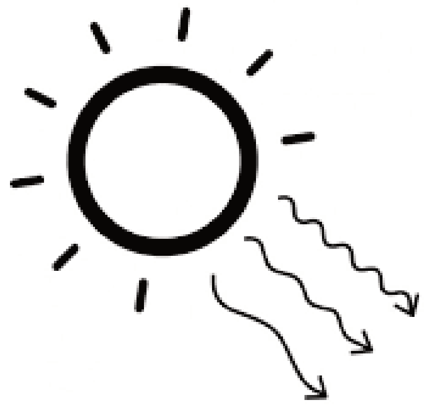
OCTOBER 2018

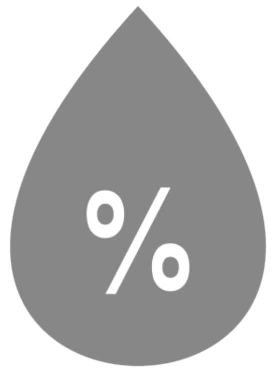
Measuring the thermal comfort of a human outdoors is a complex process due to the fact that there's a great variation in the magnitude of variables that influence the thermal comfort of a human. While we have sophisticated mechanical systems to maintain comfort situations indoor, the same cannot be achieved outdoor with mechanical means due the dynamic nature of the environmental variables. These variables that influence human thermal comfort outdoors are outside air temperature, relative humidity, wind speed, mean radiant temperature, metabolic rate of activity, and clothing value.

The sensation a human feels outdoor is highly qualitative, yet in recent times, a metric named **universal thermal climate index (UTCI)** has gained popularity among the researchers and the practitioners alike. UTCI takes into consideration all the environmental variables mentioned above and reports on how an individual will feel on a scale of -3 (too cold) to 3 (too hot).

Anyone who has heard a weather report on television knows what UTCI is. The **"feels like"** temperature reported by weathermen is in fact the UTCI. The UTCI reported by the weathermen is calculated using the nearest available weather data. While analyzing weather data can help in formulating a city scale understanding of UTCI, it is really important to take in to consideration the macro-climate of the site to create a site specific forecast of UTCI. The next sections of the report show the contribution of different variables on a UTCI map of the urban art park area.

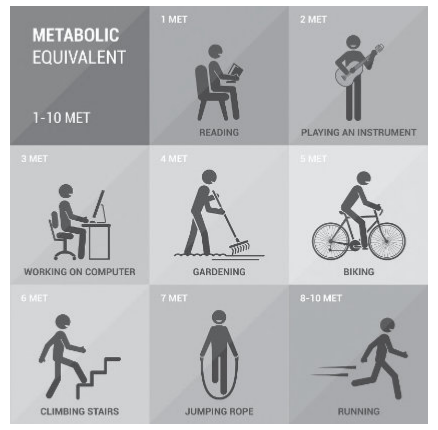

Air temperature


Solar Radiation

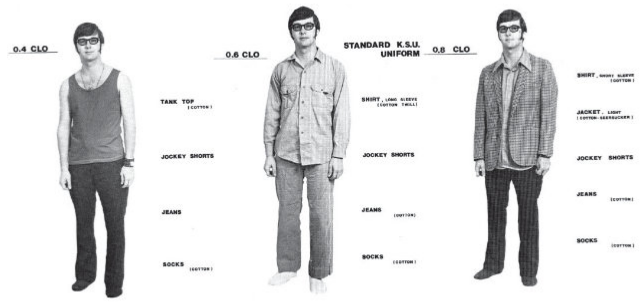

Relative Humidity


Wind


Buildings



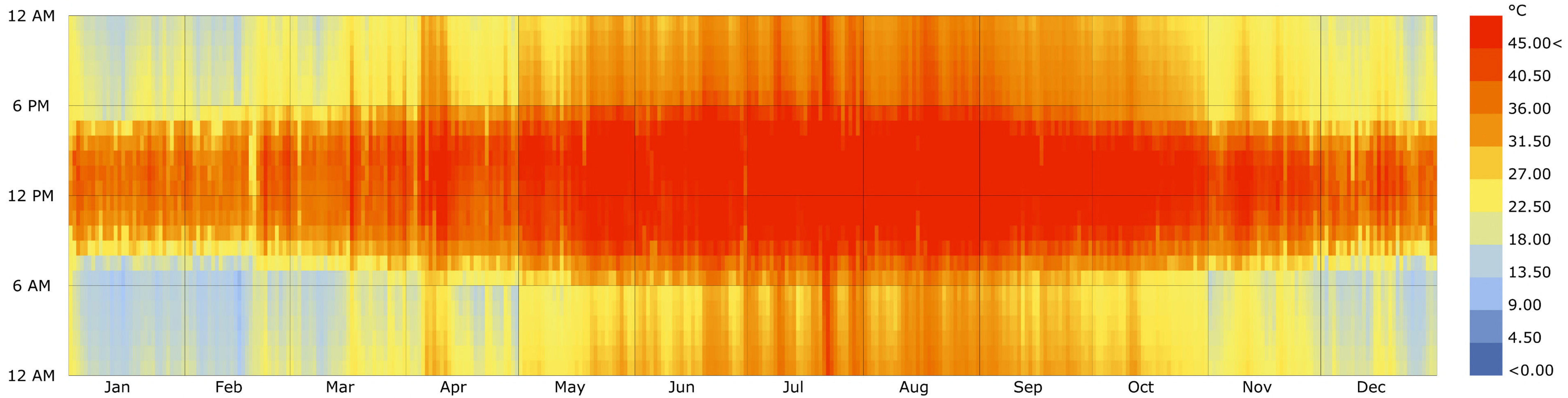
Metabolic Activity


Clothing Level

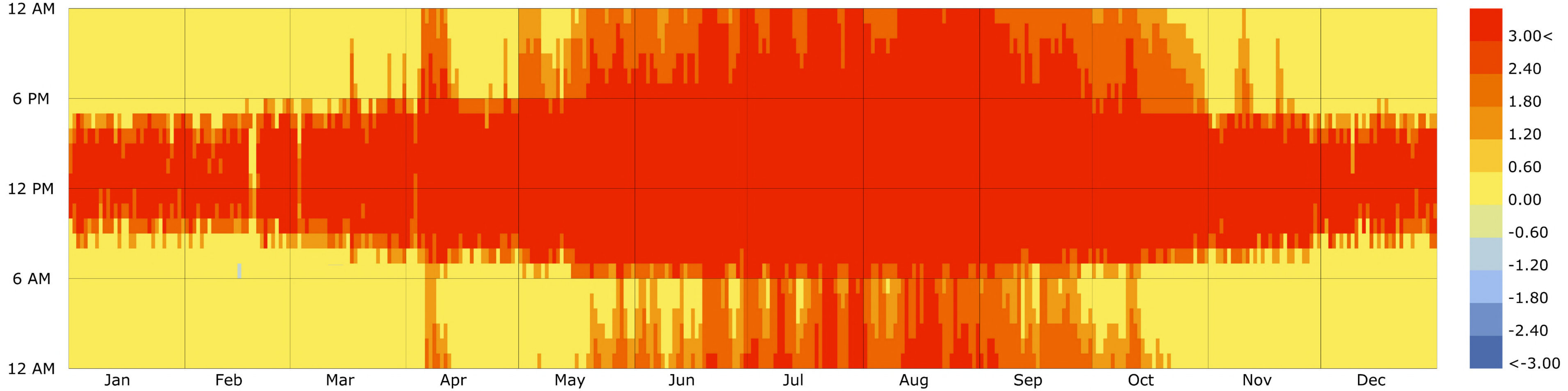
Before moving to the site level UTCI, city level UTCI is calculated to establish sensitivity of the variables that affect the UTCI. Following few slides show capture the effect of different variables on the city level UTCI.

Temperature	As per morphed weather file
Humidity	As per morphed weather file
Wind Velocity	Wind Velocity at 1.2 meter height
Radiant Temperature	The SolarCal model is used to calculate the solar adjusted MRT. Mean Radiant Temperature (MRT) is the average of the surrounding surface temperatures. Here, In the calculation of UTCI, the solar adjusted MRT is use which is the effect of the short-wave solar radiation on a human based on the fraction of the body exposed to the sky dome and the sky view factor.
Metabolic Rate	Metabolic rate of 1.6 met is considered for standing and light shopping activity.
Clothing Value	Clothing value of 0.7 clo is considered for conservative middle eastern clothing
Analysis plane height	1.2 meters
Grid size	1m x 1 m
Shading objects	Buildings, tree canopies and other shading elements

Simulation Parameter



Universal Thermal Climate Index (°C) - Hourly
EPW Dubai Intl Airp._ARE
1 JAN 1:00 - 31 DEC 24:00

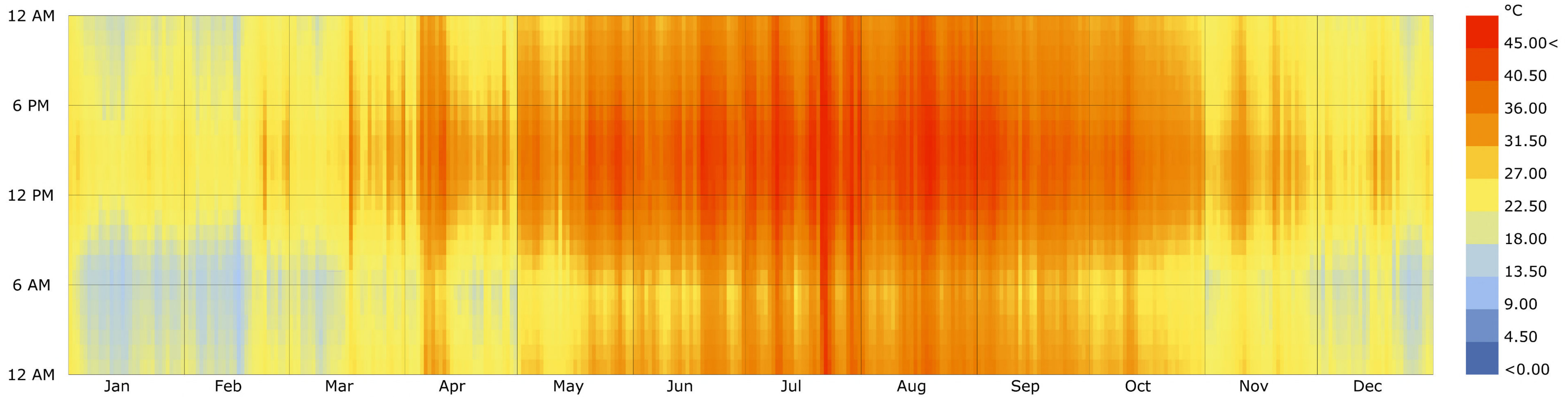


Outdoor Comfort (-3 = Extreme Cold | -2 = Cold | -1 = Cool | 0 = Comfort | 1 = Warm | 2 = Hot | 3 = Extreme Heat) - Hourly
EPW Dubai Intl Airp._ARE
1 JAN 1:00 - 31 DEC 24:00

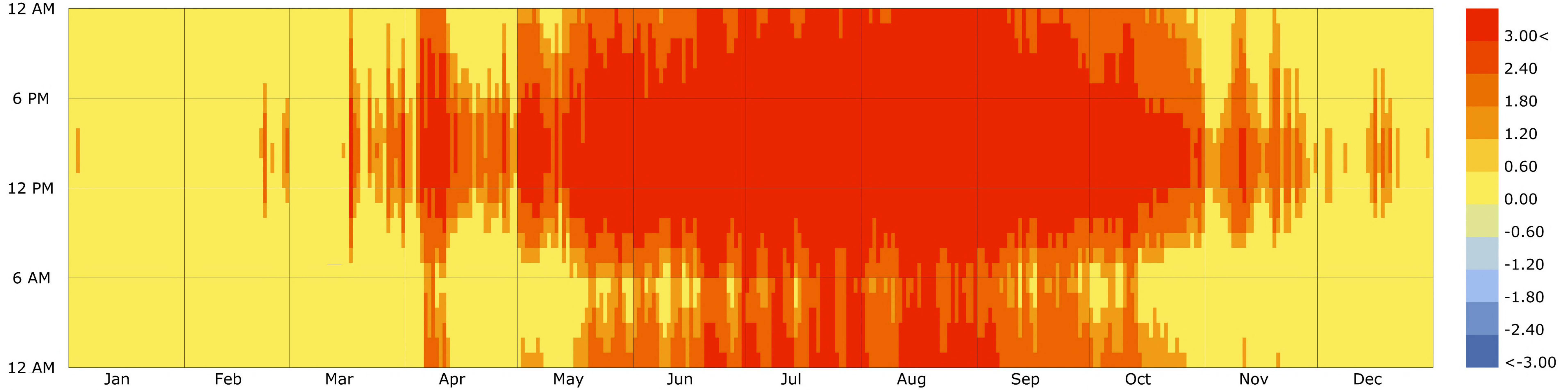
The chart on the left shows the city level UTCI temperature for a person standing in the **direct sun**.

The effect on the direct sun on the outdoor comfort is evident from the chart. Even during the winter months, during certain hours of the day, standing exposed to the sun can cause serious discomfort to an individual.

For this particular case, for about **39.46%** of the time a human can feel satisfied with the outdoor environment.



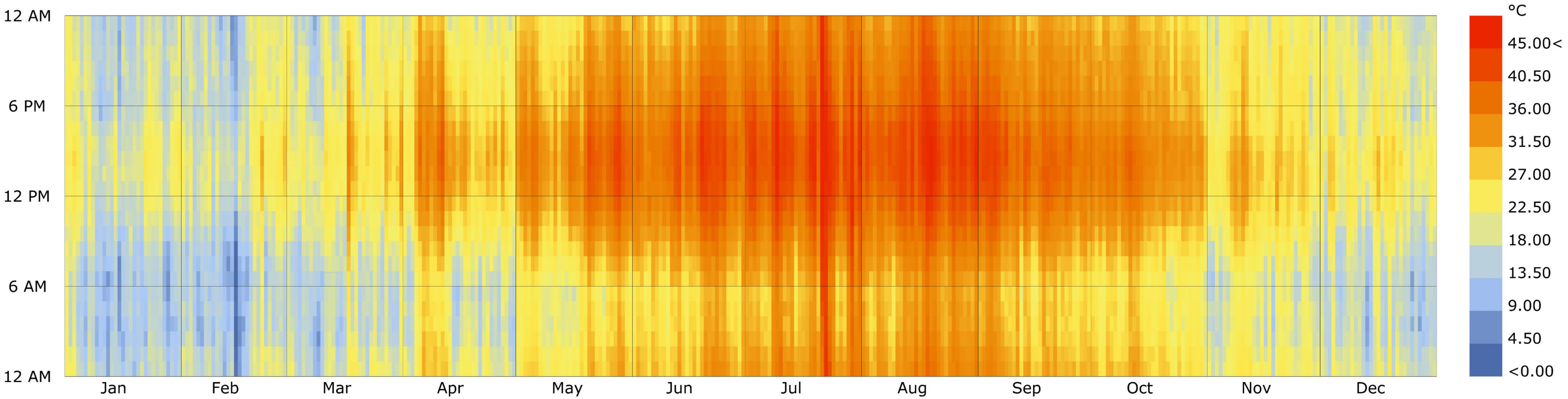
Universal Thermal Climate Index (°C) - Hourly
EPW Dubai Intl Airp._ARE
1 JAN 1:00 - 31 DEC 24:00



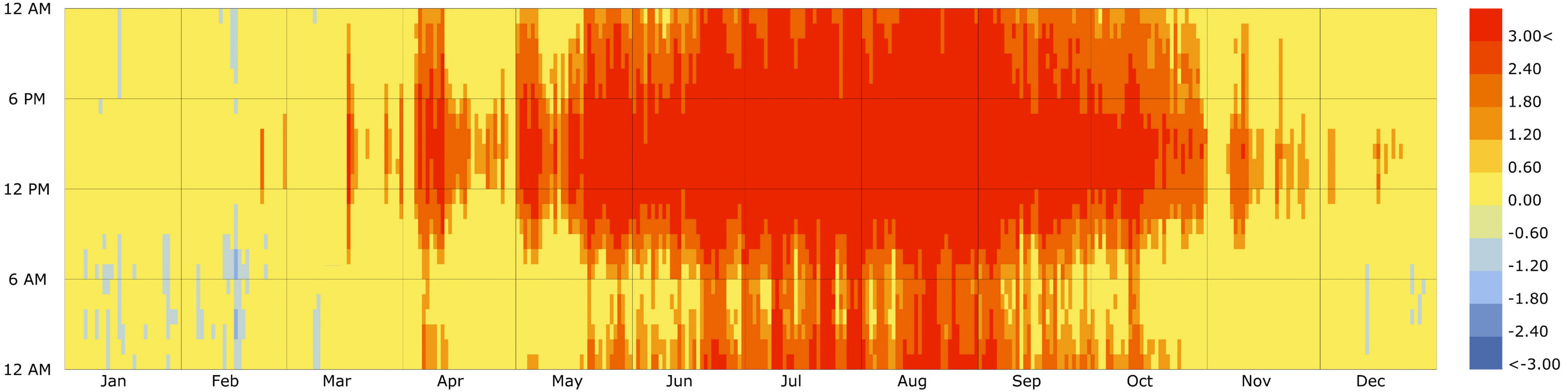
Outdoor Comfort (-3 = Extreme Cold | -2 = Cold | -1 = Cool | 0 = Comfort | 1 = Warm | 2 = Hot | 3 = Extreme Heat) - Hourly
EPW Dubai Intl Airp._ARE
1 JAN 1:00 - 31 DEC 24:00

The chart on the left shows the city level UTCI temperature for a person standing in the **shade**. The reduction in heat stress is evident from the chart.

For this particular case, for about **44.03%** of the time a human can feel satisfied with the outdoor environment.



Universal Thermal Climate Index (°C) - Hourly
EPW Dubai Intl Airp._ARE
1 JAN 1:00 - 31 DEC 24:00

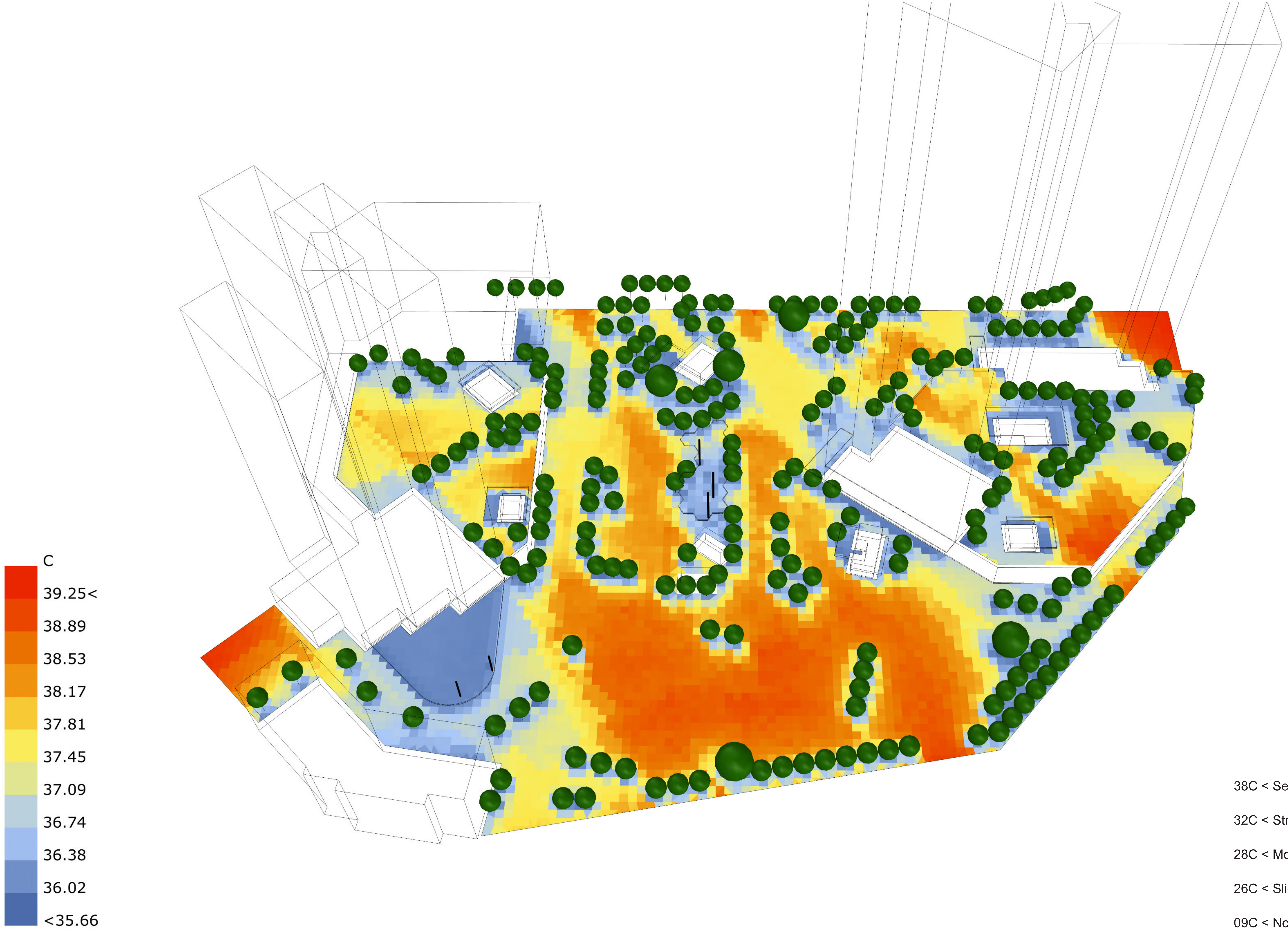


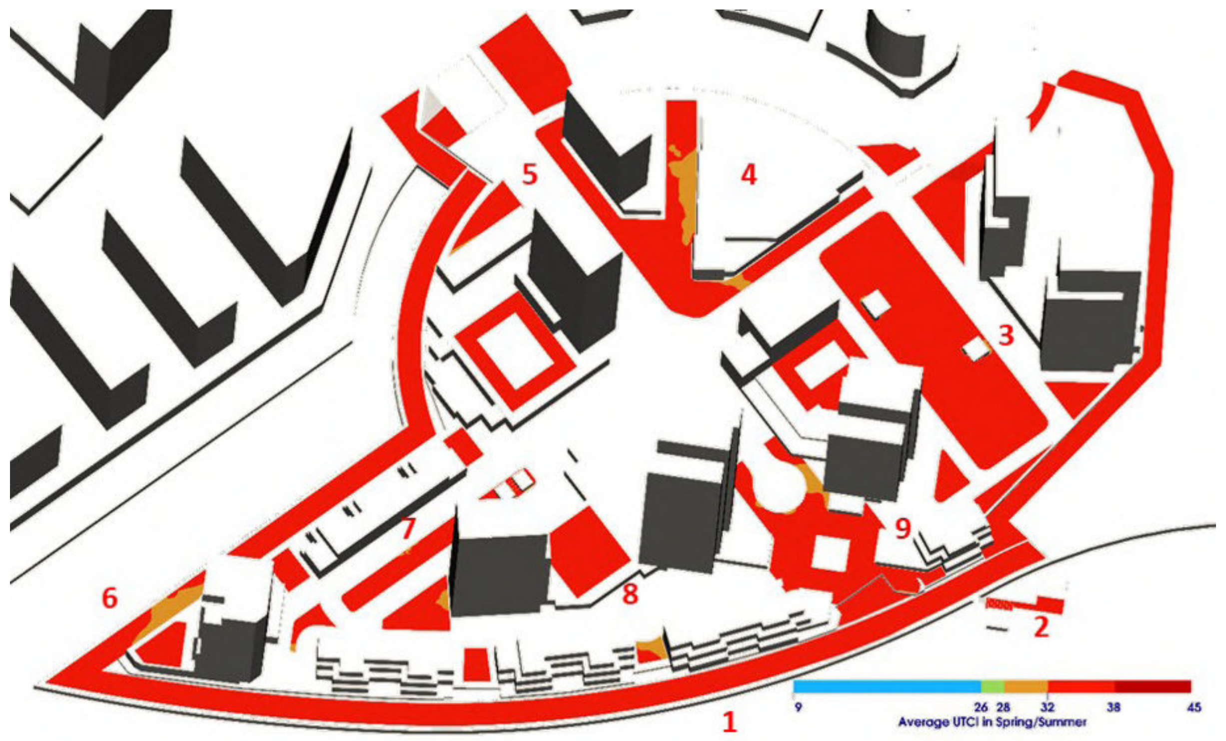
Outdoor Comfort (-3 = Extreme Cold | -2 = Cold | -1 = Cool | 0 = Comfort | 1 = Warm | 2 = Hot | 3 = Extreme Heat) - Hourly
EPW Dubai Intl Airp._ARE
1 JAN 1:00 - 31 DEC 24:00

The chart on the left shows the city level UTCI temperature for a person standing in the shade and **experiences higher wind velocity**.

The wind velocity recorded at the weather station is typically recorded at 10m height. Therefore, wind velocity at the height of 1.2m was calculated using the power-law function and the same was used in the calculation of UTCI in earlier two cases. In this case, the wind velocity recorded at the weather station is considered, which is always higher than the one calculated at 1.2 meter height. The higher wind velocity certainly has its effect on the UTCI.

For this particular case, for about **50.82%** of the time a human can feel satisfied with the outdoor environment.

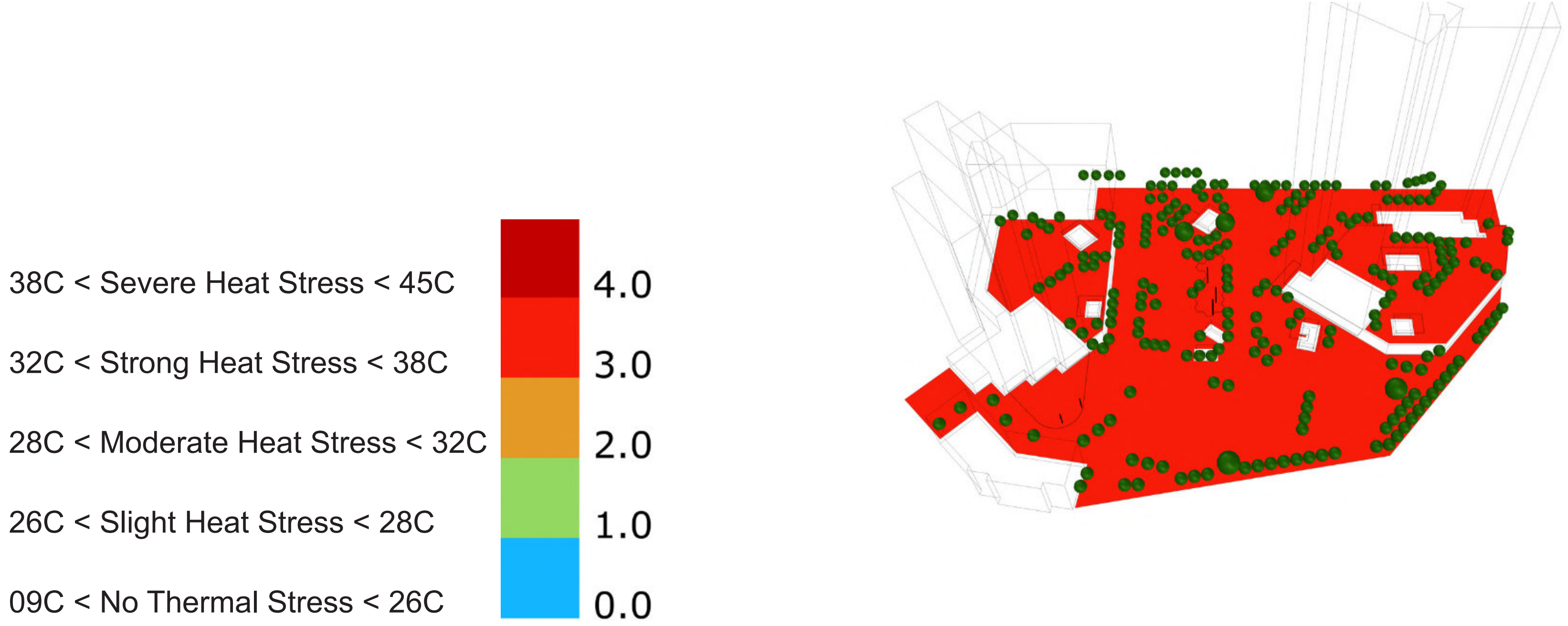




UTCI Map Stage 3.1 shown here for reference only

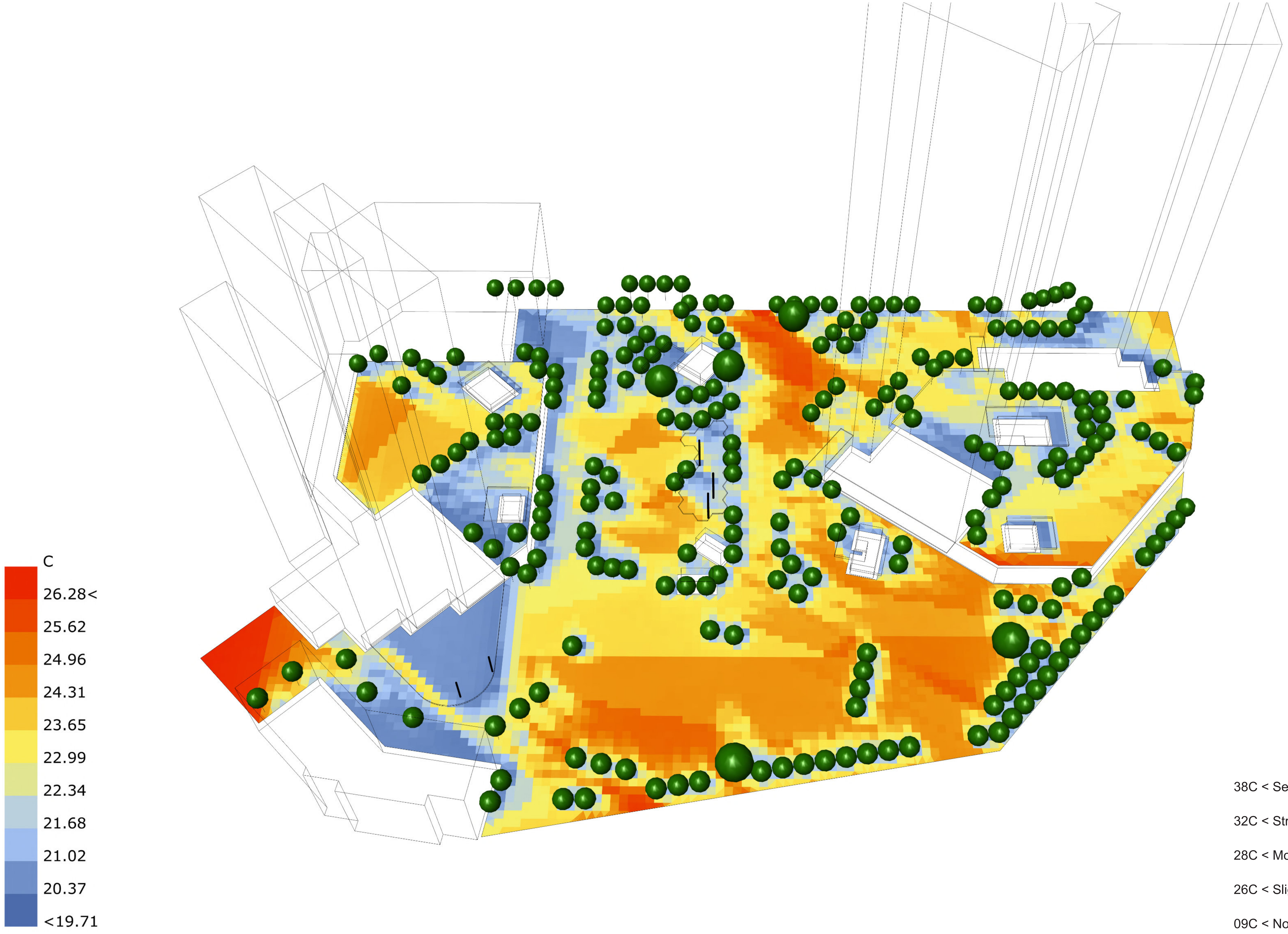
The chart on the left show the UTCI plotted in the urban art park plaza for hot day in summer between the time of 9am to 9pm. As reported in the city scale UTCI, the solar radiation shows the biggest influence on the UTCI in the hot and dry climate of Dubai.

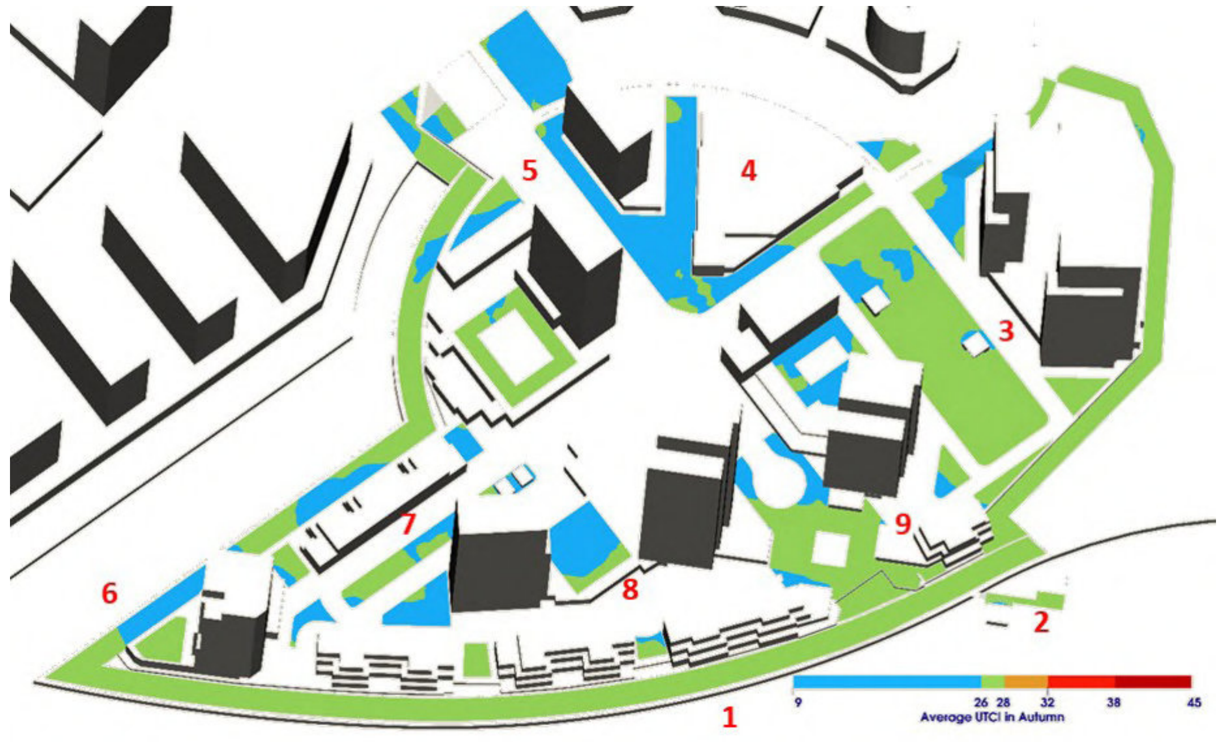
A person standing in the shade will experience at least **2 - 3 degrees** lower temperature than the person standing exposed to the direct sun. In the climate of Dubai, shading is the key to outdoor thermal comfort. As per UTCI scale, strong thermal stress will be experienced throughout the area.



Analysis - Site Level UTCI - 9am to 9pm in **Summer**

OCTOBER 2018

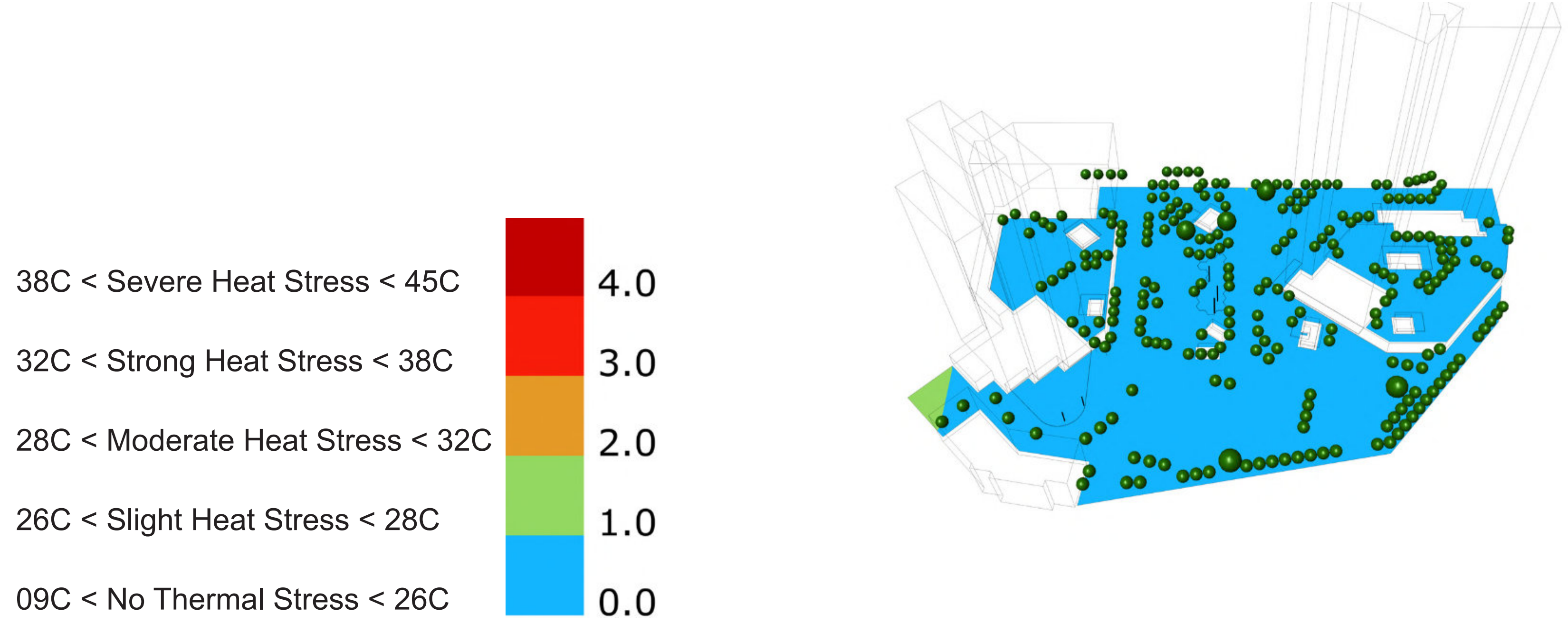




UTCI Map Stage 3.1 shown here for reference only

The chart on the left show the UTCI plotted in the urban art park plaza for a day in autumn between the time of 9am to 9pm.

As per UTCI scale, the whole area will remain comfortable for outdoor activity.



Analysis - Site Level UTCI - 9am to 9pm in **Autumn**

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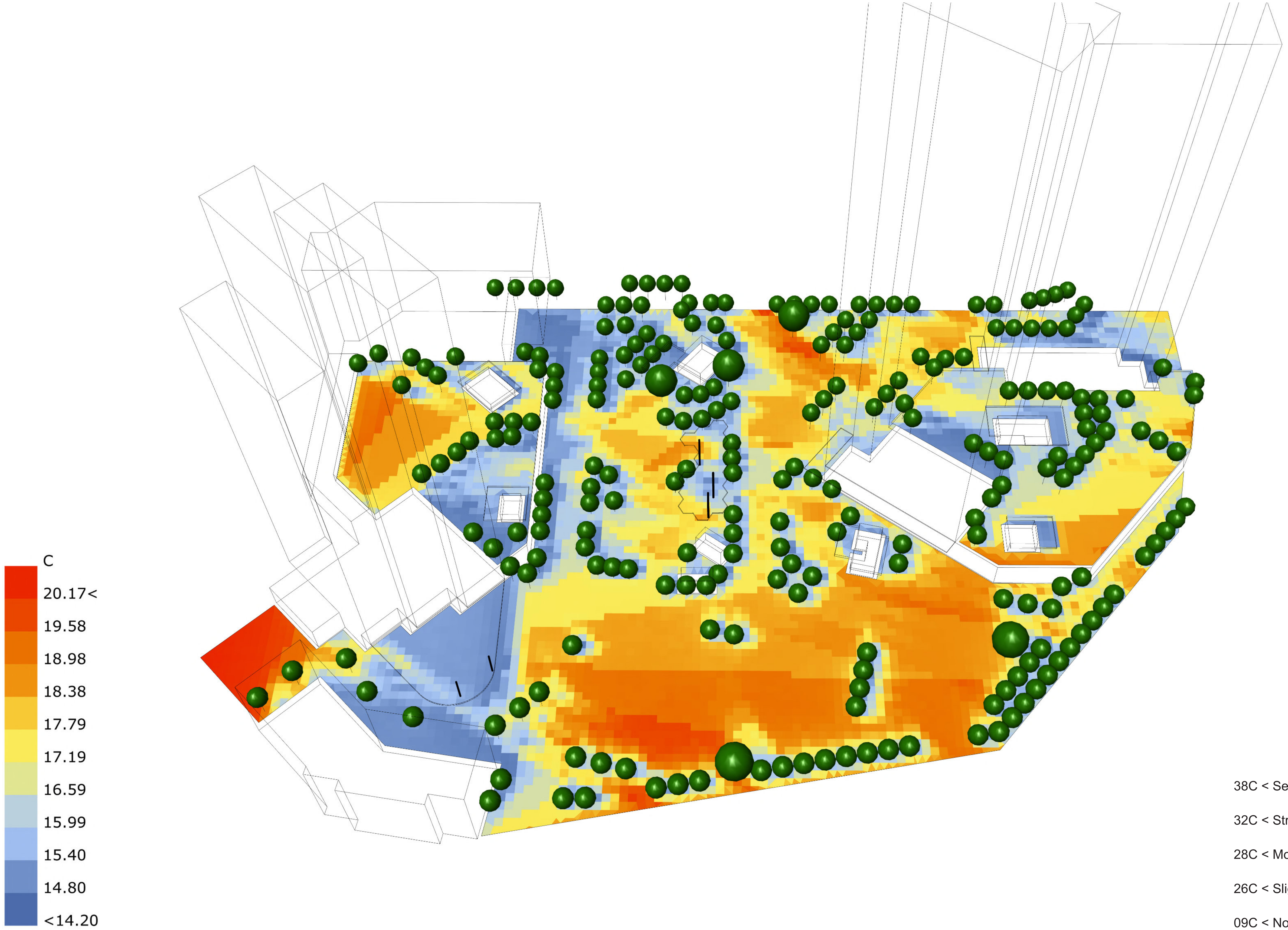
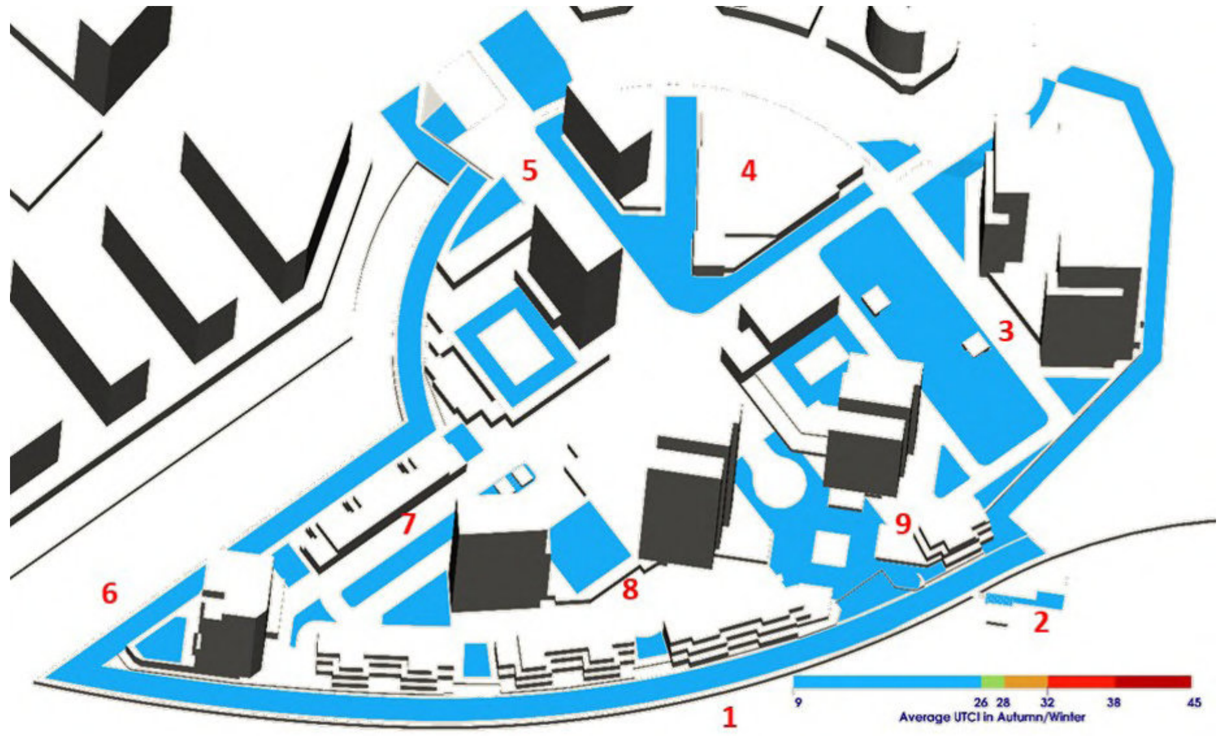
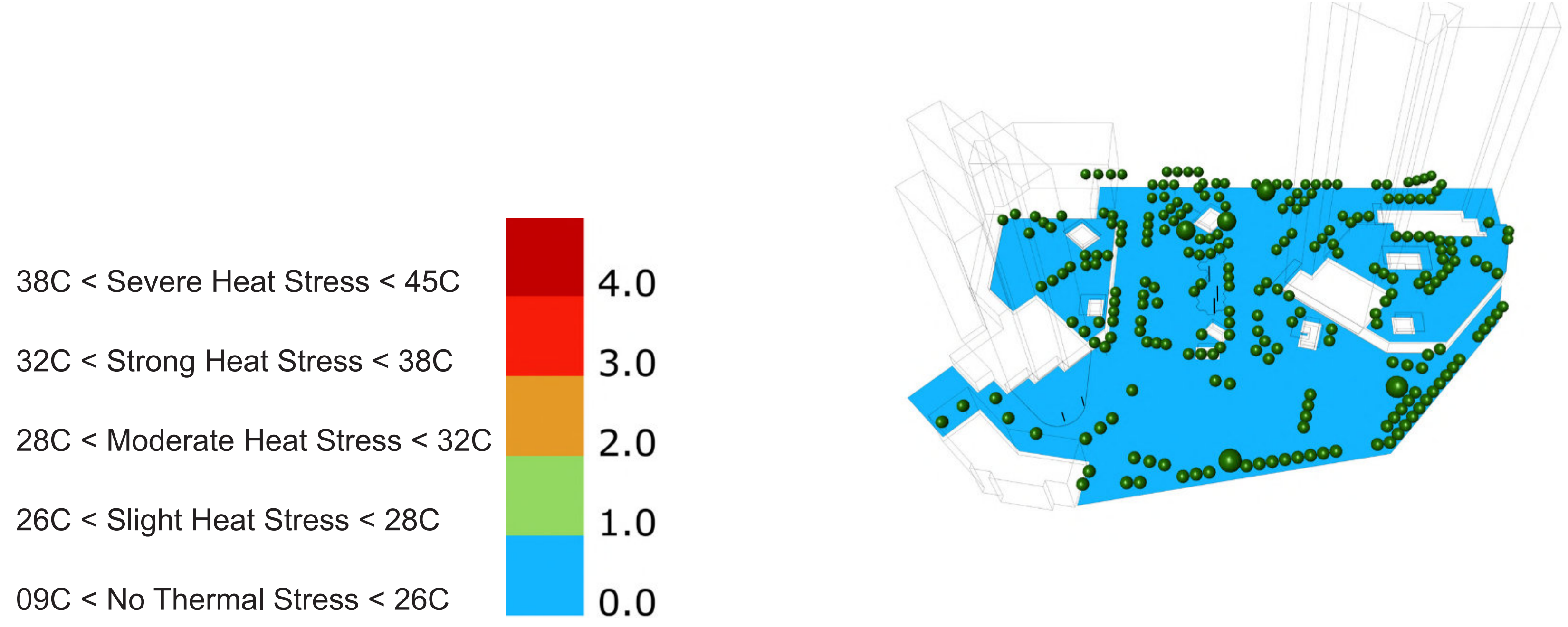




UTCI Map Stage 3.1 shown here for reference only

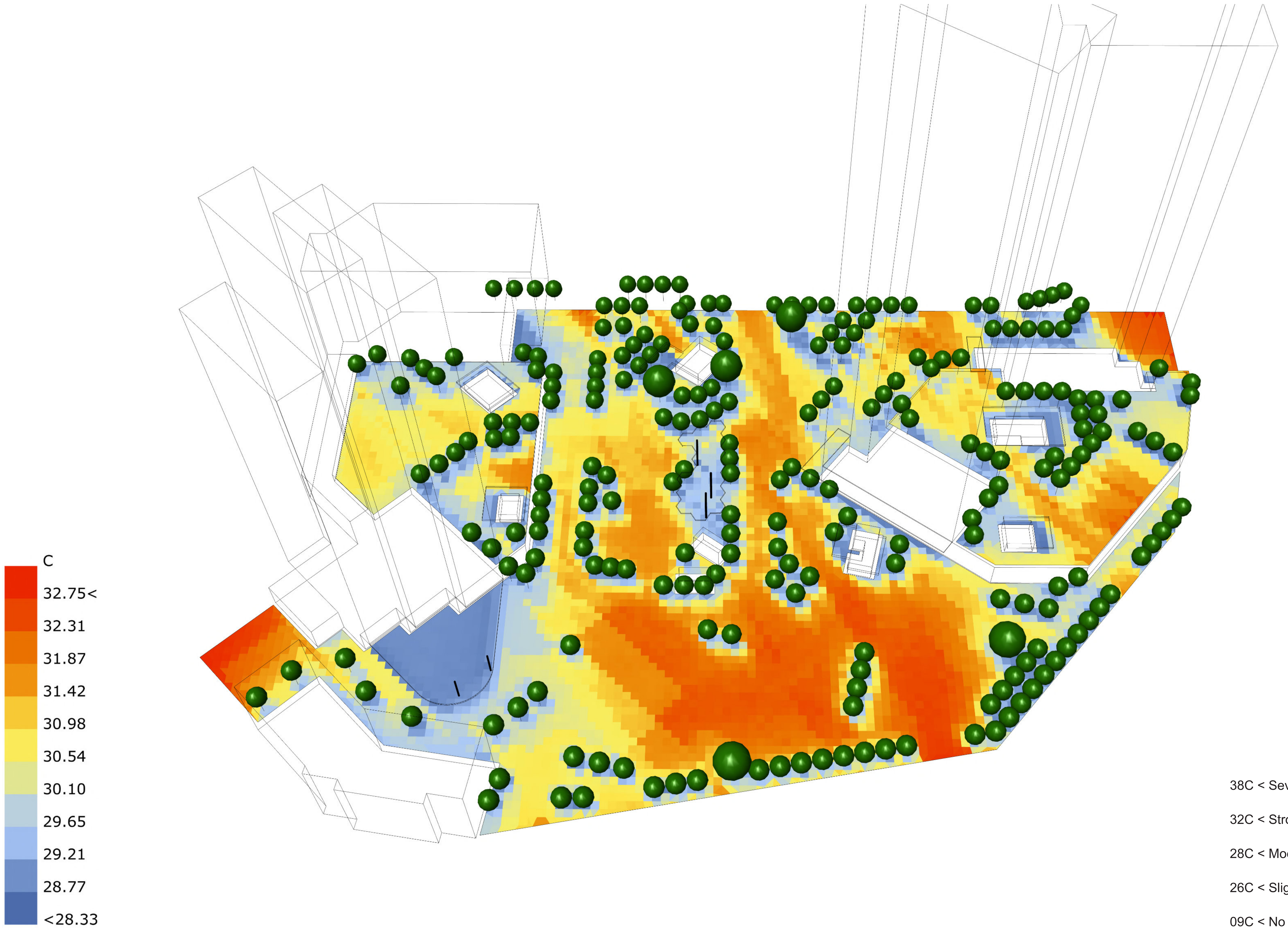
The chart on the left show the UTCI plotted in the urban art park plaza for a day in winter between the time of 9am to 9pm.

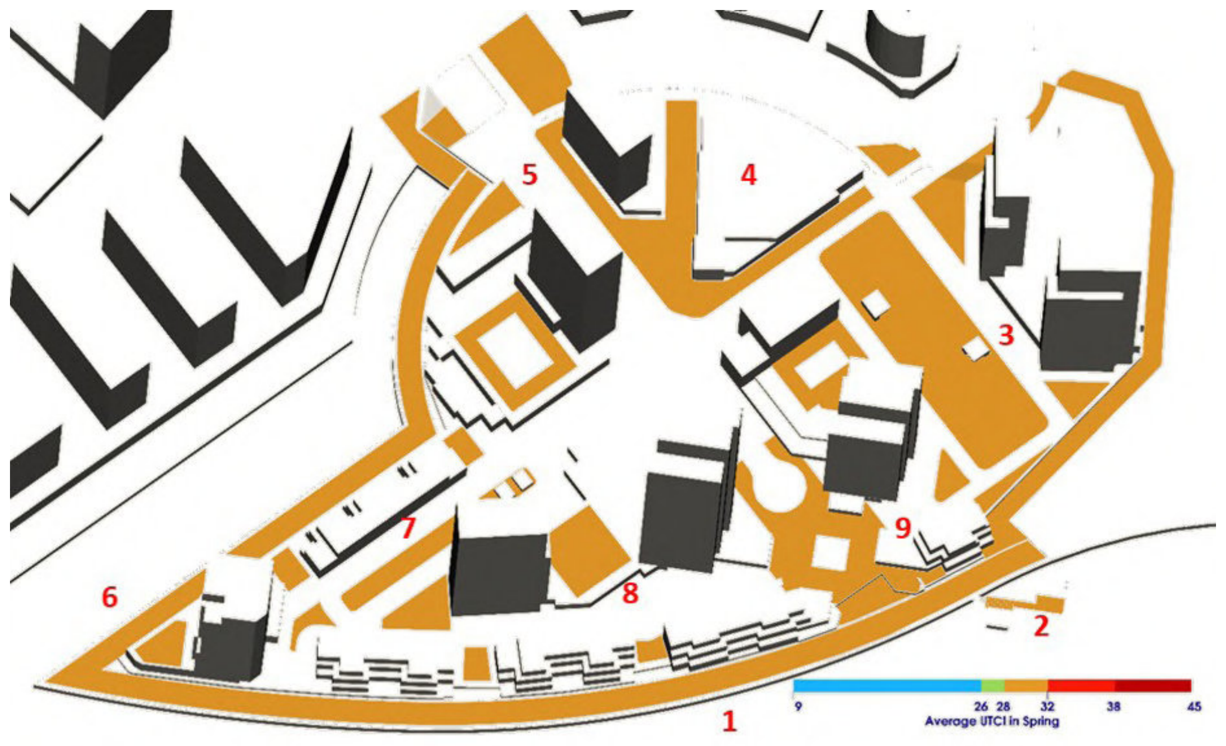
As per UTCI scale, the whole area will remain comfort-able for outdoor activity.



Analysis - Site Level UTCI - 9am to 9pm in **Winter**

OCTOBER 2018

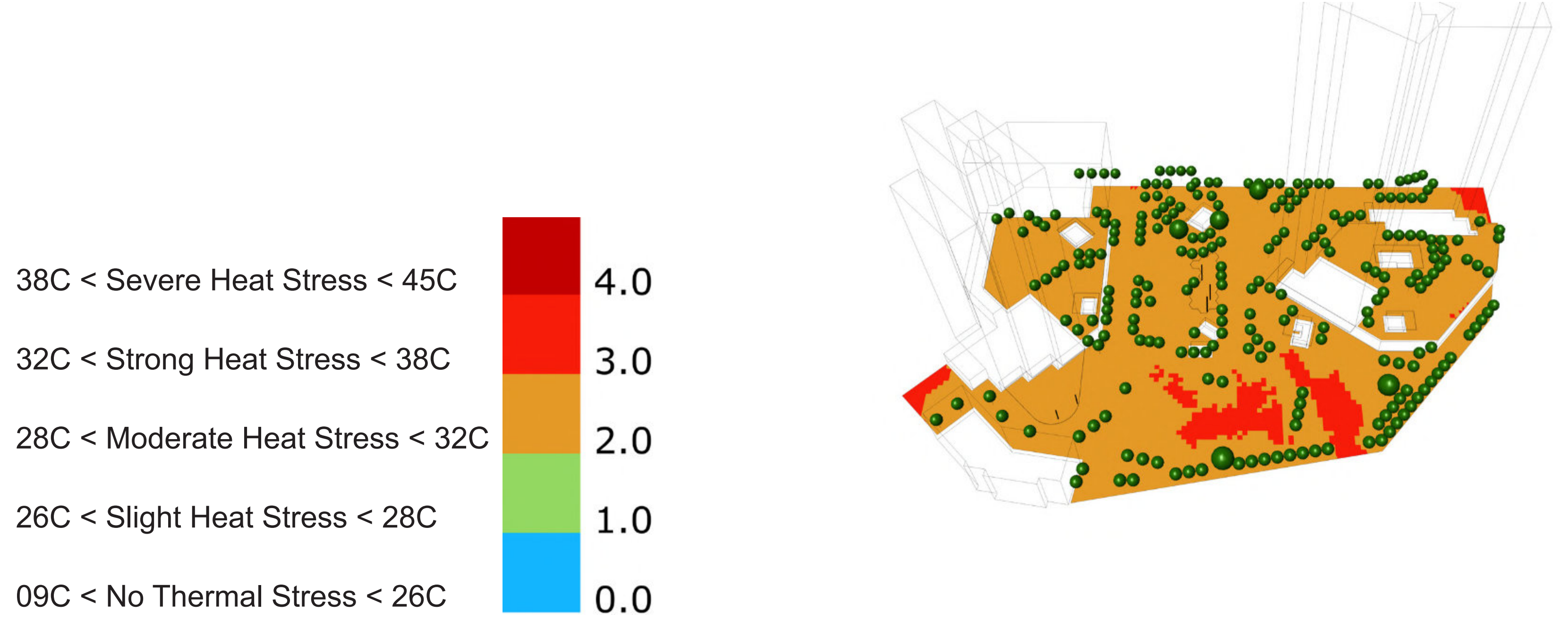




UTCI Map Stage 3.1 shown here for reference only

The chart on the left show the UTCI plotted in the urban art park plaza for a day in spring between the time of 9am to 9pm.

As per UTCI scale, moderate thermal stress will be experienced in the majority of the area with high thermal stress at a few pockets of the plaza.



Analysis - Site Level UTCI - 9am to 9pm in **Spring**

OCTOBER 2018

It is observed from the city scale UTCI plots and the site level UTCI maps that the **direct solar radiation** has the largest influence on the temperature one is likely to experience outdoors. In alignment with that observation, many other research works have found the UTCI to be highly sensitive to the incident solar radiation. While heat coming out buildings registers an impact on the UTCI, the impact of direct sun hitting a human body has a **washout effect**. Also, although the UWG considers evapotranspiration from the vegetation[Trees] in the area of the study, not a noticeable impact on the UTCI is observed.

It shall also be noted that the variable that has the biggest impact on the UTCI is also the that is the easiest to address by the designer by making use of clever orientations and the shading design. It is highly recommended that in a climate of Dubai, the solar exposure or shadow studies shall always be the precursor to any UTCI study. In this hot and dry desert climate, a **comprehensive shading scheme** for the whole master plan based on solar exposure studies is highly recommended.