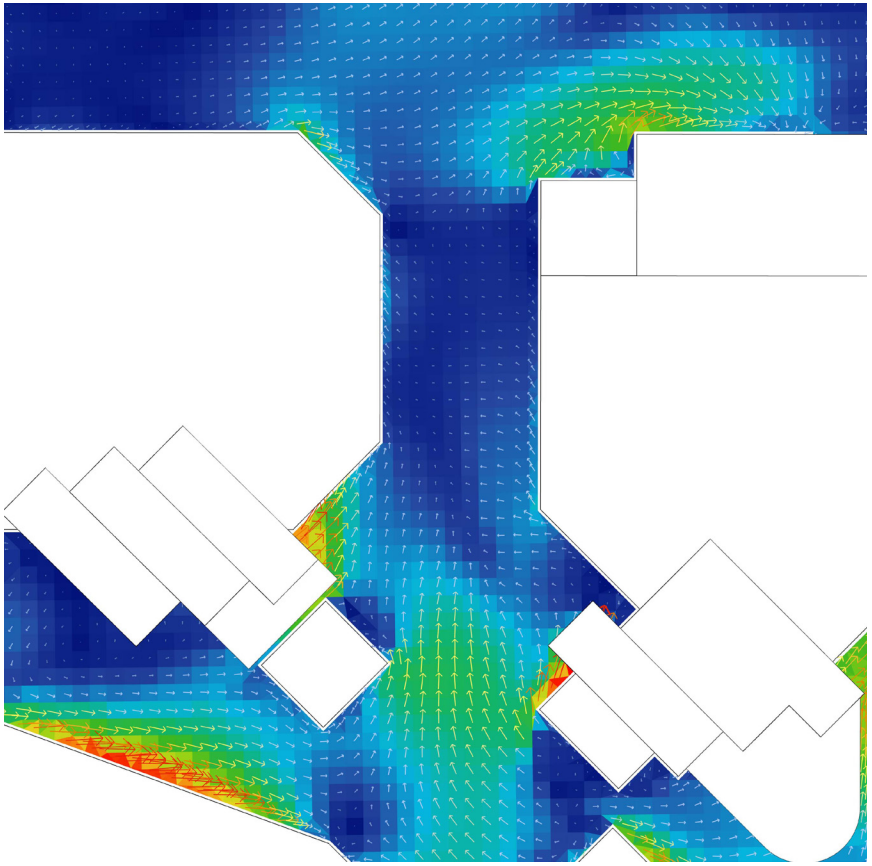


Business Bay

A Report on Outdoor Thermal Comfort

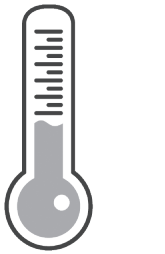
Last updated on 03rd, Jun 2018

Analysis Background

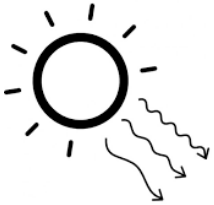
Measuring the thermal comfort of a human outdoors is a complex process due to the fact that there's a great variation in the magnitude of variables that influence the thermal comfort of a human. While we have sophisticated mechanical systems to maintain comfort situations indoor, the same cannot be achieved 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).

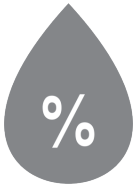
Anyone who has heard a weather report on television knows what UTCI is. The **"feels like"** temperature reported by weathermen is in fact the UTCI. The UTCI reported by the weathermen is calculated using the nearest available weather data. While analyzing weather data can help in formulating a city 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 final UtCI map of the area at the Business Bay Signature plot.



Air temperature



Solar Radiation



Relative Humidity

Wind

Buildings

Metabolic Activity

Clothing Level

Wind Velocity, Metabolic rate and Clothing value

For any activity, metabolic rate for a human body is mentioned in MET. For the UTCI calculation, MET value of **1.6** is considered.

Reclining - 0.8
Seating - 1.0
Car driving - 1.2
Sedentary activity (office, dwelling, school, laboratory) - 1.2
Standing - 1.2
Standing (light activity: shopping, laboratory, light industry) - 1.6
Standing (medium activity: shop assistant, domestic work) - 2.0
Walking (4 km/h) - 2.32
Walking (5 km/h) - 3.4
Washing dishes standing - 2.5
Domestic work (raking leaves on the lawn) - 2.9
Domestic work (washing by hand and ironing) - 2.9
Iron and steel (ramming the mold with a pneumatic hammer) - 3.0
Building industry (brick laying) - 2.2
Building industry (forming the mold) - 3.1
Building industry (loading a wheelbarrow with stones and mortar) - 4.7
Forestry (cutting with chainsaw) - 3.5
Forestry (working with an Axe) - 8.5
Agriculture (digging with a spade) - 6.5

Clothing insulation of a person in CLO units. It ranges from 0 (nude person) to 4 (polar outfit). To reflect the conservative clothing of the people of the middle east, a clo value of **0.75** was chosen for the UTCI calculation.

Following are some the clo values as a reference;
0.20 - very light summer clothes (shorts/skirt, t-shirt, slippers, no socks)
0.55 - summer clothes (light trousers, short sleeves or blouse)
1 - street-business suit or Typical indoor winter clothing
1.5 - suit and cotton coat
2 - winter suit and coat
2.58 - firefighting clothes
4 - heavy polar outfit (fur pants, coat, hood, gloves...)

In order to plot UTCI, wind velocity at **1.5** meter height off the ground was calculated using the power law function. The wind speed in the weather file is assumed to be measured at a meteorological station located in an open field at a height of 10 m. To adjust for different terrain at the building site and differences in the height of building surfaces, the local wind speed is calculated.

The wind speed is modified from the measured meteorological wind speed by the equation mentioned below. This equation comes from **ASHRAE 2001**.

The wind velocity generated at 1.5 meters height from the **power-law** equation is used to generate wind roses and calculate UTCI at that height.

$$U_{\infty} = V_{met}\left(\frac{\delta_{met}}{Z_{met}}\right)^{a_{met}}\left(\frac{Z}{\delta}\right)^{a}$$

Where,

Z is the height at which the velocity is calculated

Z_{met} is the height of the standard meteorological wind speed measurement

a and δ are terrain dependent coefficients

a is the power – law exponent

a_{met} Is the power – law exponent for the weather station. Typically, a country terrain is considered for the weather station.

δ is the boundary layer height. The height above the ground at which wind speed become stable or at least the wind is at 95% if the max speed.

δ_{met} is the boundary layer height for the weather station. Typically, a country terrain is considered for the weather station.

Terrain	Description	Power-law Exponent	Boundary Layer Height (m)
1	Flat, open country	0.14	270
2	Rough, wooded country	0.22	370
3	Towns and cities	0.33	460
4	Ocean	0.10	210
5	Urban, industrial, forest	0.22	370

Ideal UTCI work flow and why this needs to be followed

The chart on the right displays the ideal work flow to develop highly accurate UTCI maps. It is evident from the chart that the process involves taking information from different sources and at different stages in order to develop highly accurate UTCI maps.

The TMY (typical meteorological year) weather data that is used for simulations is typically recorded at specific weather stations. In order to record the wind data, the stations need to be at a location where the wind is not massively influenced by the built environment. For this reason, most weather stations are located in the country terrain.

Due to above mentioned fact, the weather data recorded is a good representation of the weather at the city scale but not the micro-climate of a site. Calculation of UTCI expects the variables to be site specific and therefore, taking the weather data as a start point, additional studies are to be run to derive site specific variables.

City dwellers always tend to experience a few degrees of difference in the ambient air temperature compared to rural areas or the country side. This is due to the heat emission from buildings, industries, humans, vehicles. When calculating UTCI, site specific air temperature shall be used to account for the heat island effect. In this work flow, this is done by using the **UWG** (Urban Weather Generator). UWG takes geometry, TMY data, building programs, vegetation, and other inputs to develop local air temperature. These temperatures better represent the site micro climate.

As mentioned earlier, the TMY data is recorded at the weather stations. At site, at particular height, the experienced wind velocity is always different from that of the weather data due to the influence of the built environment surrounding the site. In order to account for the influence of the surrounding built environment, local **wind factors** are to be calculated. A wind factor is nothing else but the fraction of TMY wind velocity that is experienced at site when the wind is coming from a certain direction. In the interest of accuracy, wind factors for 36 wind directions shall be calculated. These wind factors are generated for all the directions for all the test points for which we wish to calculate UTCI. Eventually, these wind factors are used with the annual wind velocity data from TMY weather data to obtain local wind velocity values.

Next in the line of variables that influence UTCI is **mean radiant temperatures** of the surrounding surfaces. For this, a massing model is run through EnergyPlus to generate surface temperatures. Lastly, the variable that has the biggest impact on the outdoor thermal comfort of any individual is **direct solar radiation**. This is accounted for by the solarcal heat transfer method.

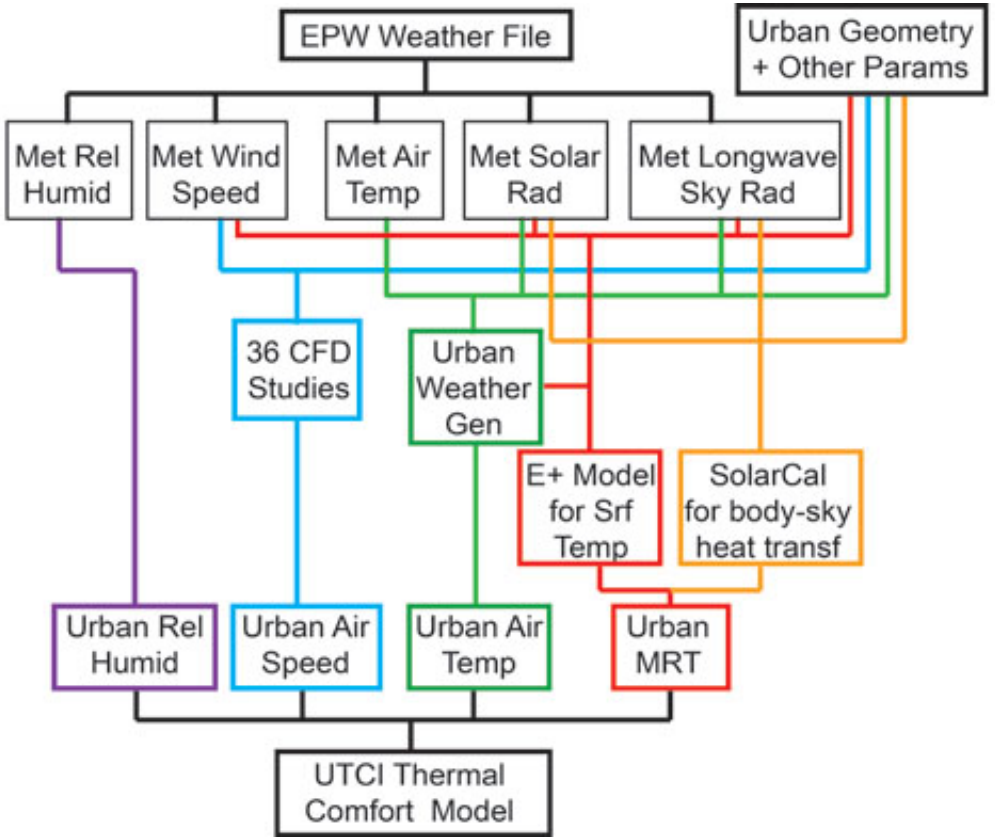
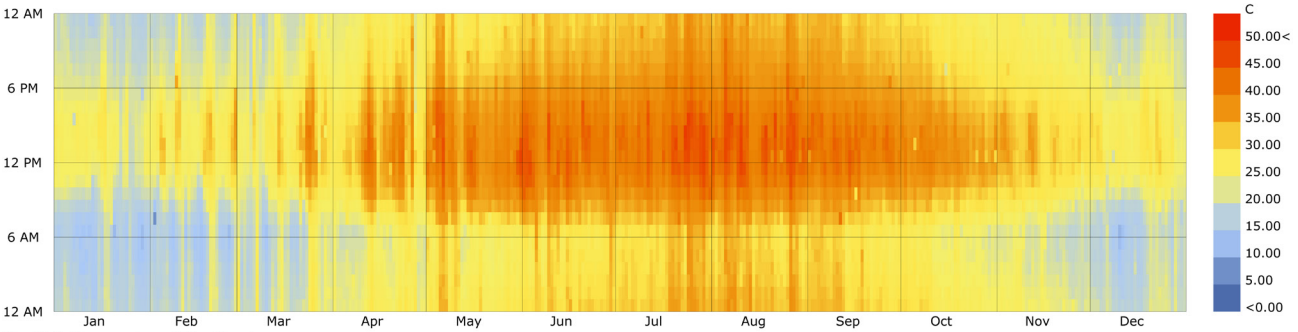


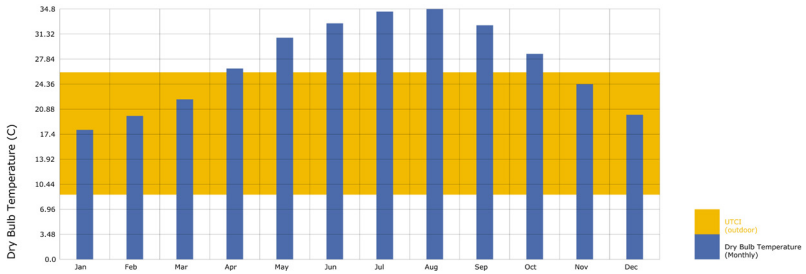
Chart Credit: Chris Mackey, Theodoros Galanos, Mostapha Sadeghipour Roudsari

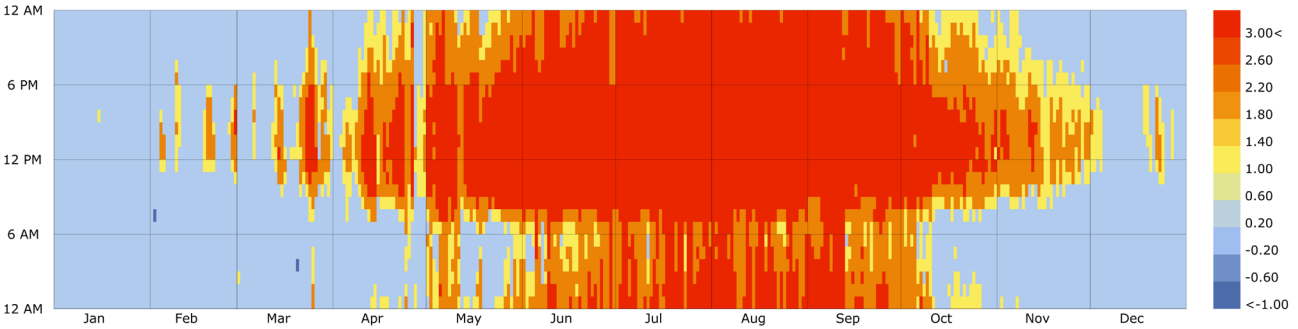
Air Temperature

The charts on the right show dry bulb temperature, UTCI, and the condition of person on a yearly basis. These charts are plotted simply based on the TMY weather data. Simply by looking at the UTCI charts at the city scale, one can make a good prediction about the hours of the year when one can expect to experience either thermal stress or cold stress.



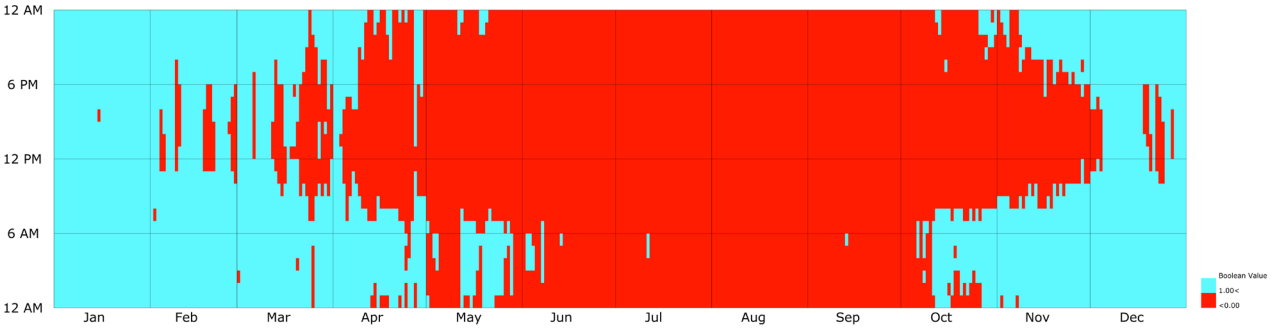
Dry Bulb Temperature (C) - Hourly
ABU DHABI_ARE
1 JAN 1:00 - 31 DEC 24:00





Outdoor Comfort (-3 = Extreme Cold | -2 = Cold | -1 = Cool | 0 = Comfort | 1 = Warm | 2 = Hot | 3 = Extreme Heat) - Hourly
ABU DHABI_ARE
1 JAN 1:00 - 31 DEC 24:00

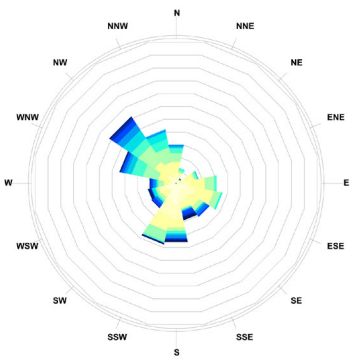
Similarly, the chart below show the average monthly air temperature against the UTCI scale. Such helps in quickly establishing the months of the year during which the outdoors can be comfortable.



Comfort or Not (Boolean Value) - Hourly
ABU DHABI_ARE
1 JAN 1:00 - 31 DEC 24:00

Wind Velocity & Direction

These are the wind roses for all the months of the year. These wind-roses are plotted only with the TMY weather data which is typically recorded in a country side and at the height of 10 meters off the ground.



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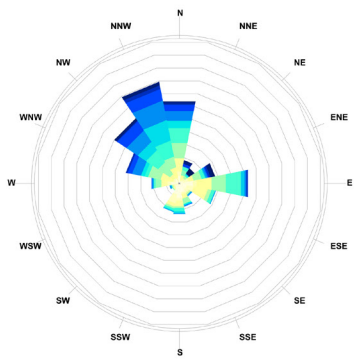

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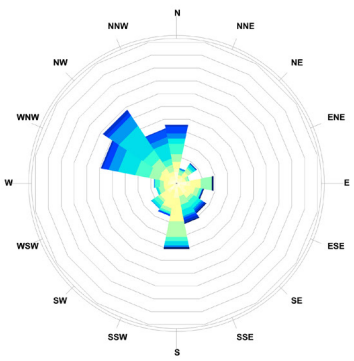

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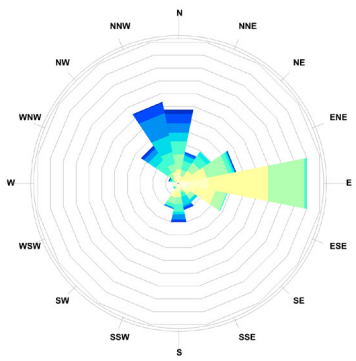

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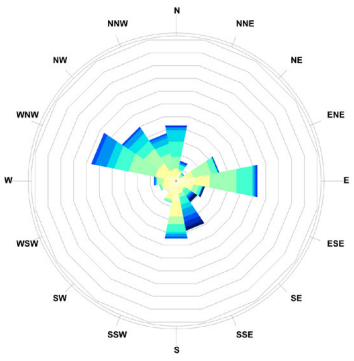

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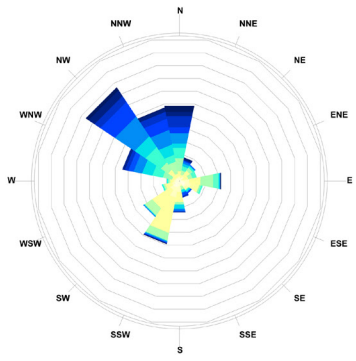

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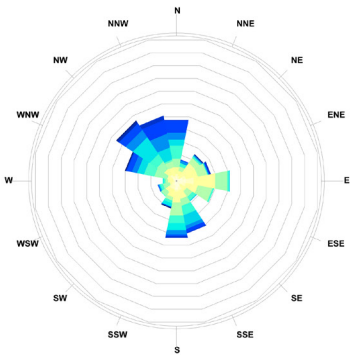

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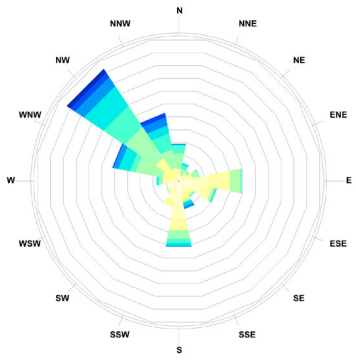

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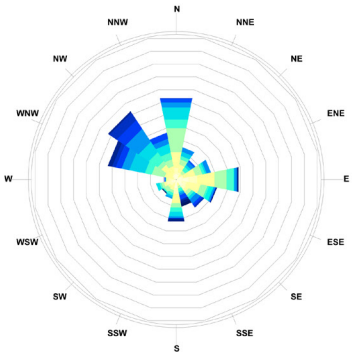

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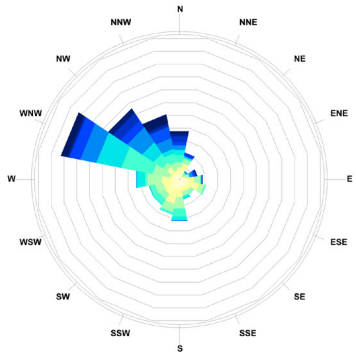

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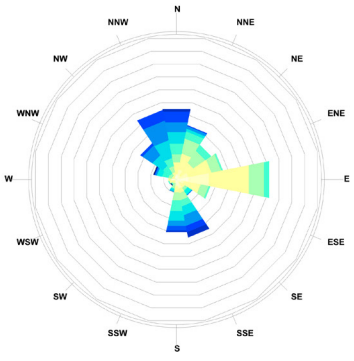

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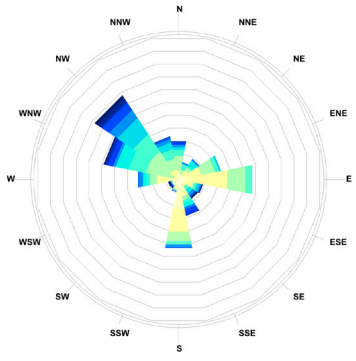
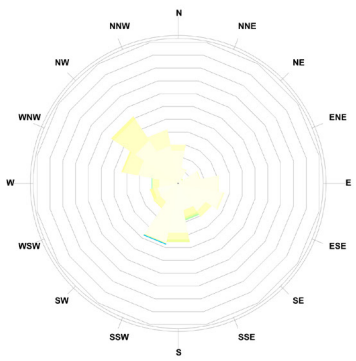


Dec

Wind Velocity & Direction

Wind roses plotted with wind velocity at 1.5 meter height as per power-law. The change in the wind velocity is evident in these wind roses.



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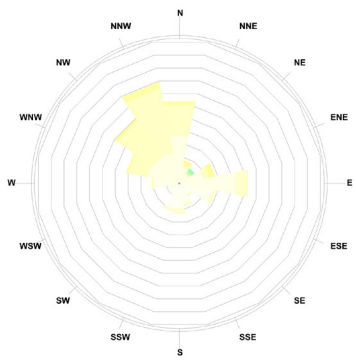

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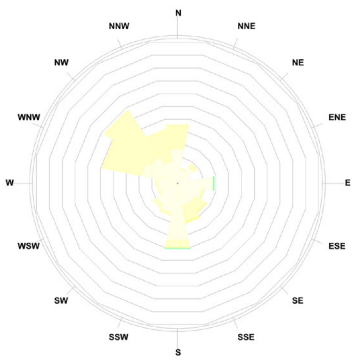

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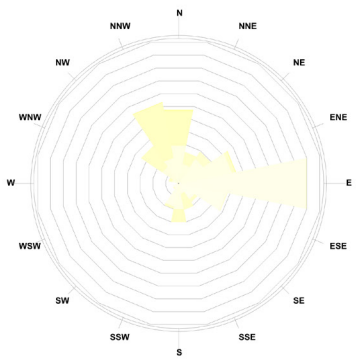

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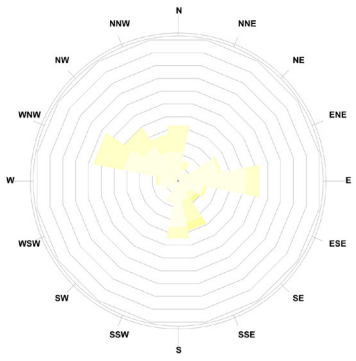

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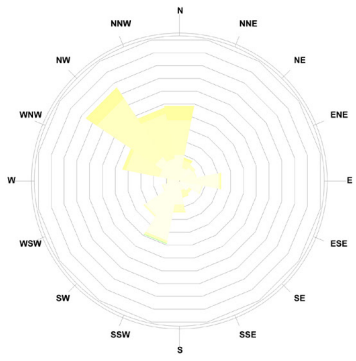

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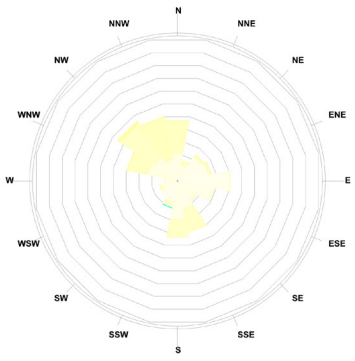

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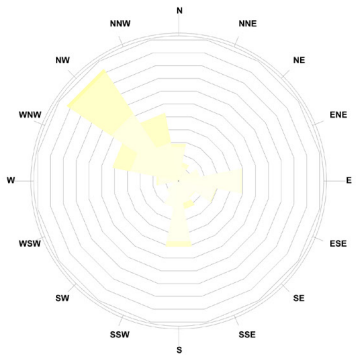

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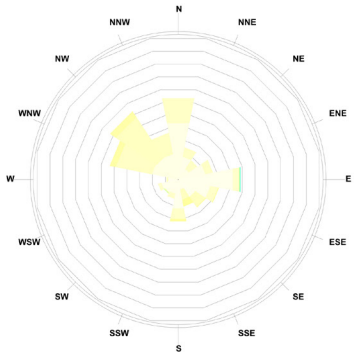

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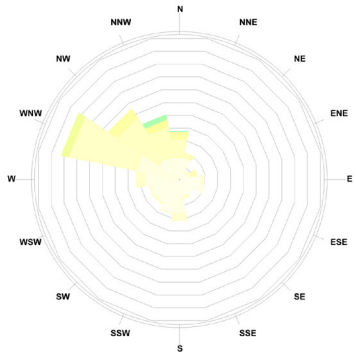

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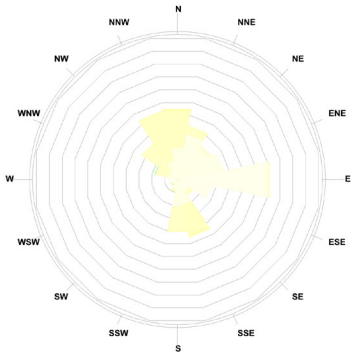

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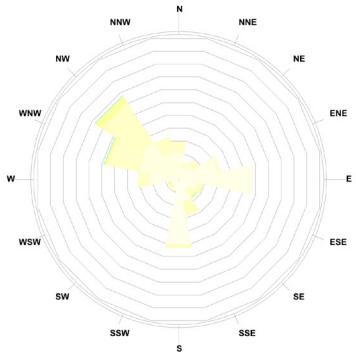
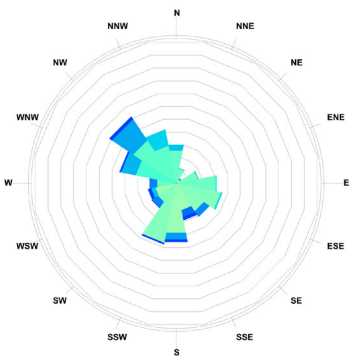


Dec

Wind Velocity & Direction

Wind roses plotted with wind velocity at 1.5 meter height as per power-law. Legend scale is adjusted in the interest of better visualization.



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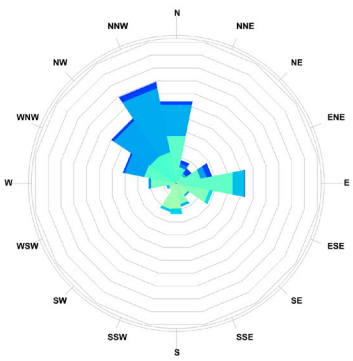

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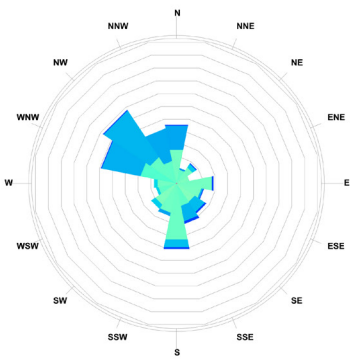

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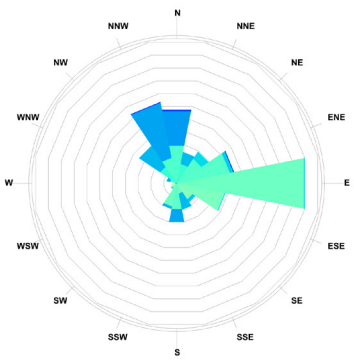

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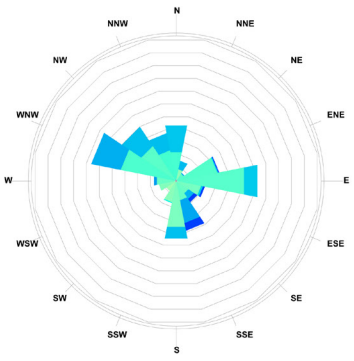

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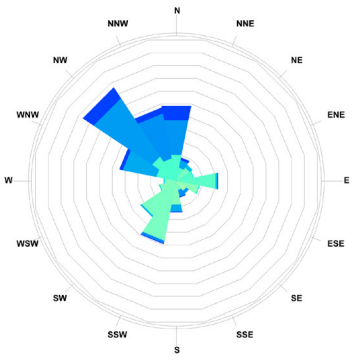

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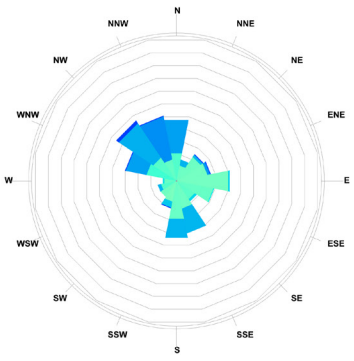

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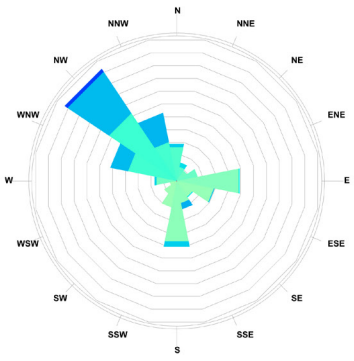

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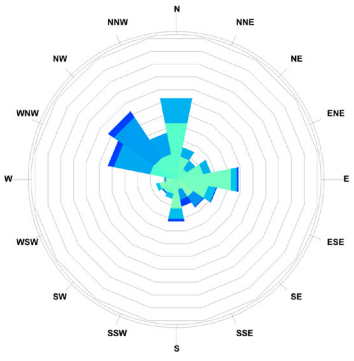

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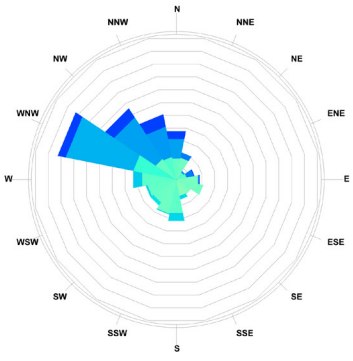

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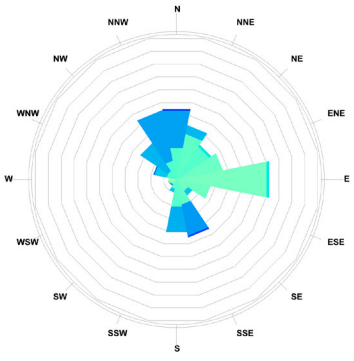

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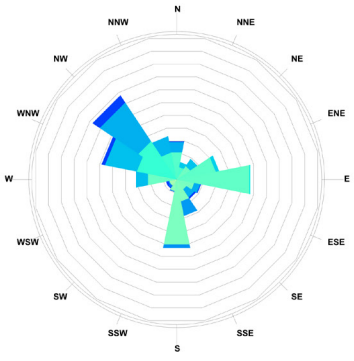
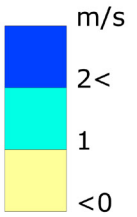


Dec

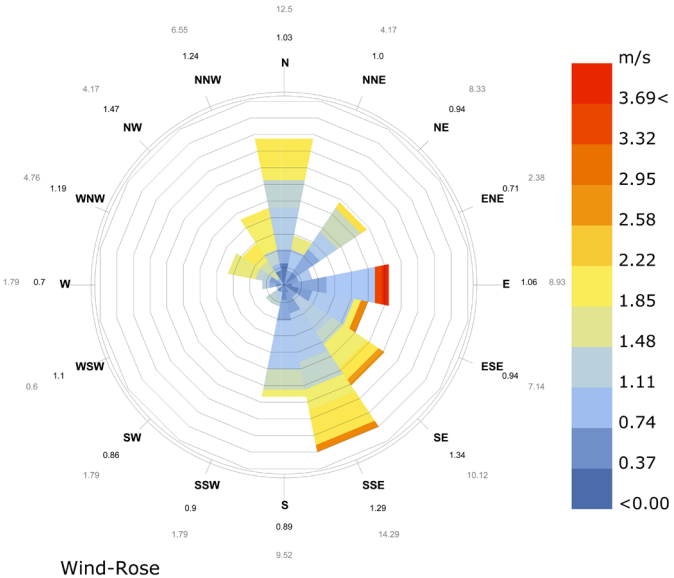


Analysis Period

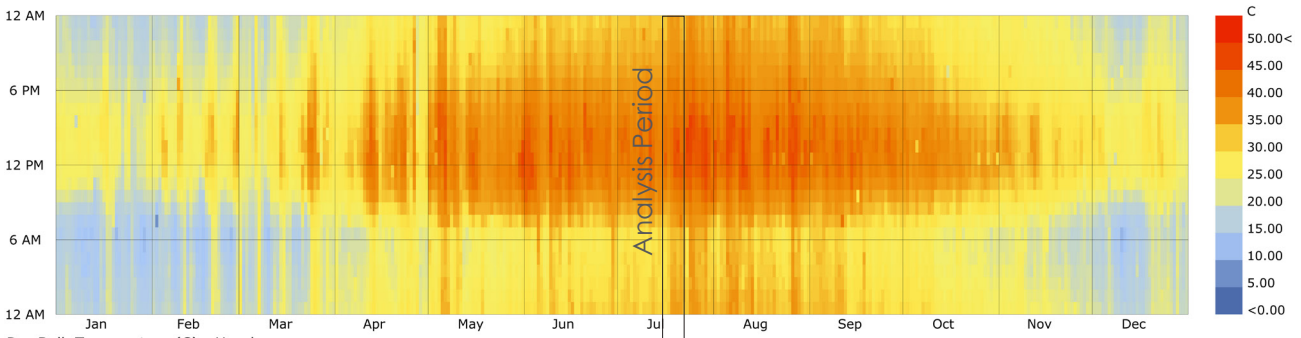
For the purpose of analysis, the extremely hot week was chosen based on the dry bulb temperature from the TMY weather data. This period occurs in the month of **July** between the dates of **20th** and **26th**.

The analysis period is marked on the charts of annual dry bulb temperature, UTCI, and relative humidity. The wind rose below shows the average wind velocity, and frequency of wind coming from 16 directions during the analysis period.

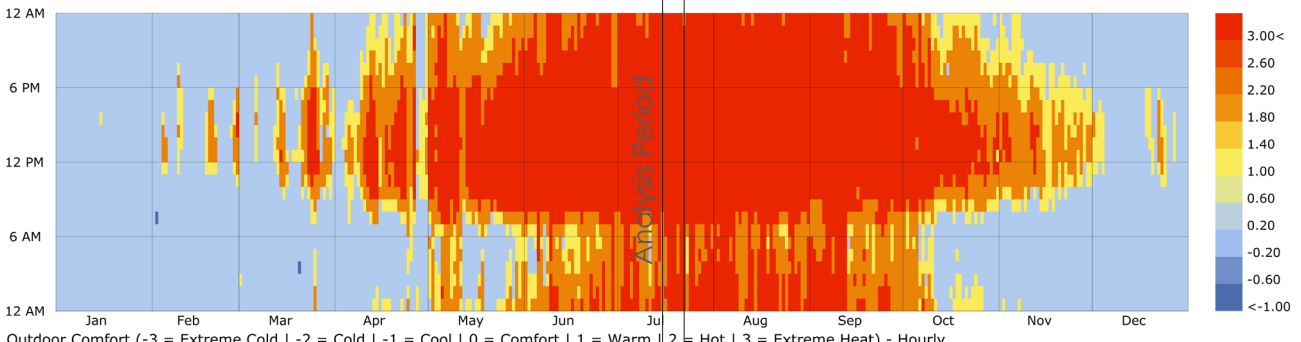
As evident from the wind rose, during this analysis period, the direction from where the wind is coming most of the time is 157.5 degrees clockwise from the North. Hence, wind analysis was conducted with the average wind velocity from this direction.



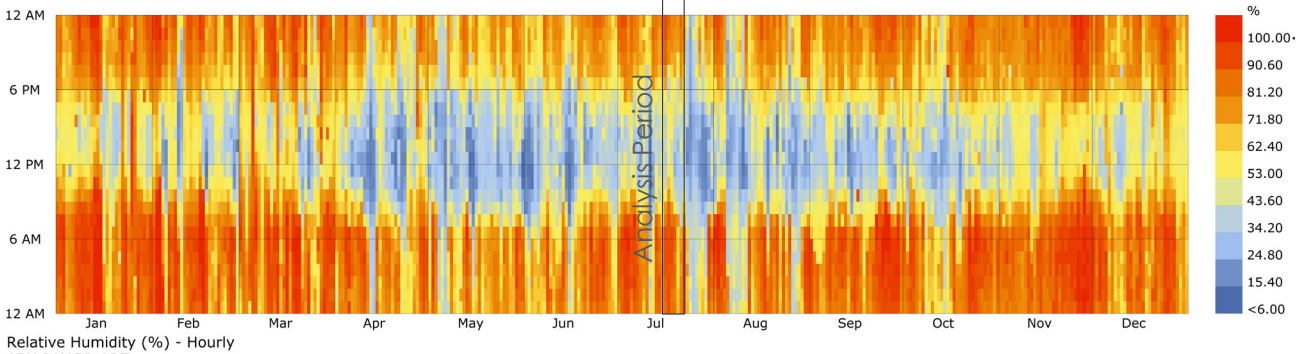
Wind-Rose
ABU DHABI_ARE
20 JUL 1:00 - 26 JUL 24:00
Hourly Data: Wind Speed (m/s)
Calm for 1.19% of the time = 2 hours.
Each closed polyline shows frequency of 1.4%. = 2 hours.



Dry Bulb Temperature (C) - Hourly
ABU DHABI_ARE
1 JAN 1:00 - 31 DEC 24:00

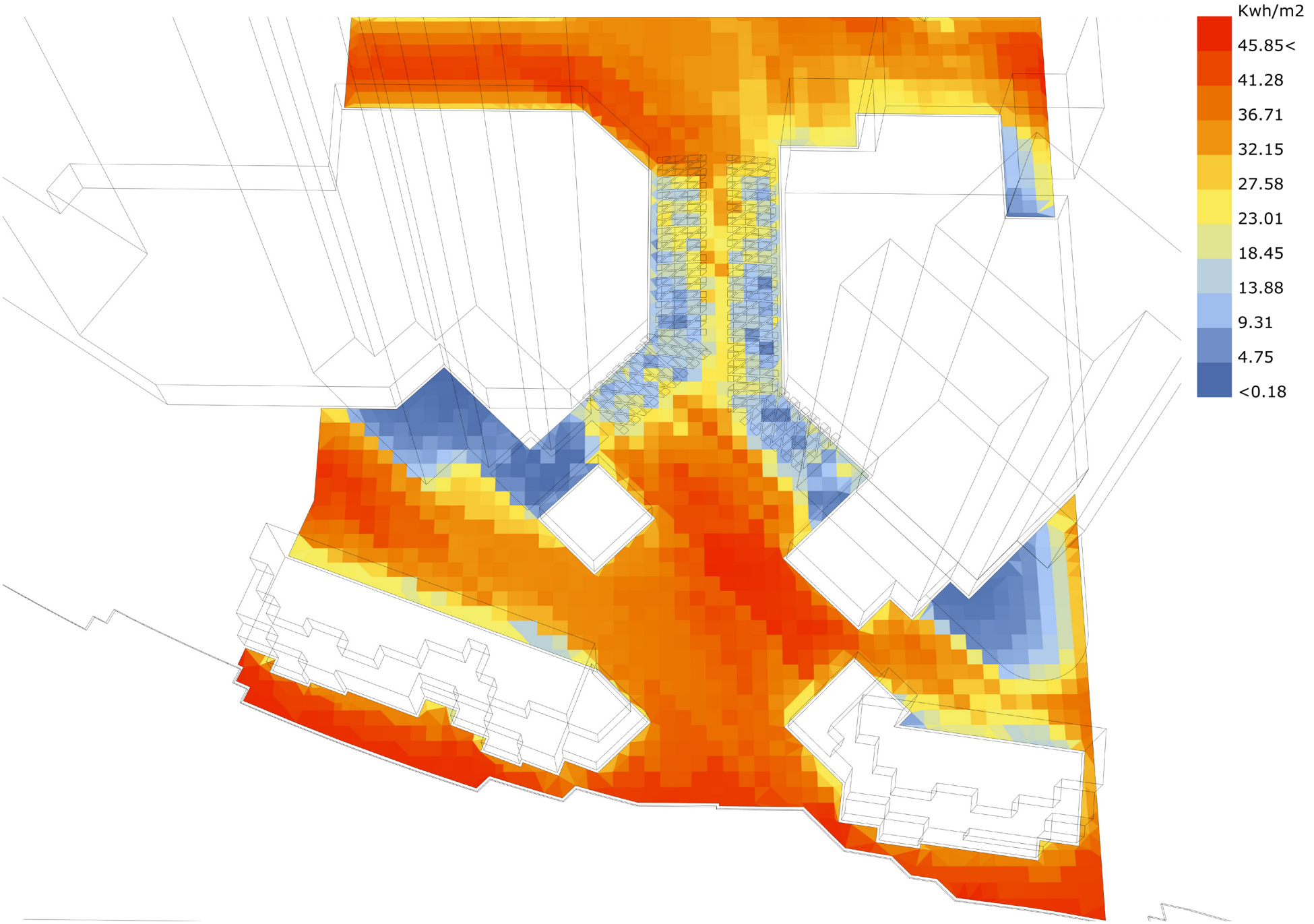


Outdoor Comfort (-3 = Extreme Cold | -2 = Cold | -1 = Cool | 0 = Comfort | 1 = Warm | 2 = Hot | 3 = Extreme Heat) - Hourly
ABU DHABI_ARE
1 JAN 1:00 - 31 DEC 24:00

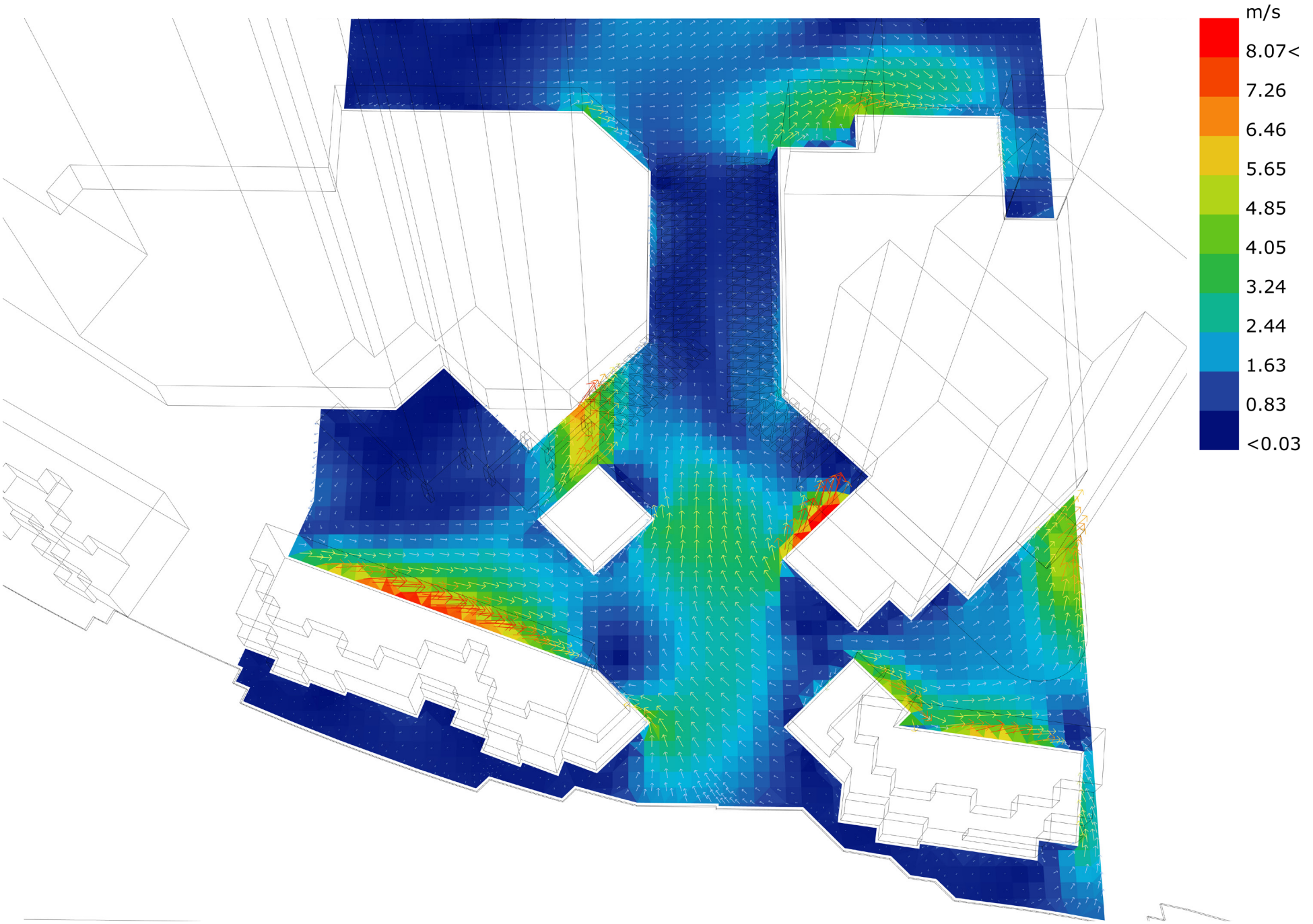


Relative Humidity (%) - Hourly
ABU DHABI_ARE
1 JAN 1:00 - 31 DEC 24:00

Radiation



Wind Velocity



Pedestrian Comfort

0 = velocity < 4 m/s
1 = 4 m/s < Velocity <6 m/s
2 = 6 m/s < Velocity <8 m/s
3 = 8 m/s < Velocity <10 m/s
4 = Velocity > 10 m/s

0 = sitting (outdoor cafes, patios, terraces, benches, gardens, parks, fountains, monuments)

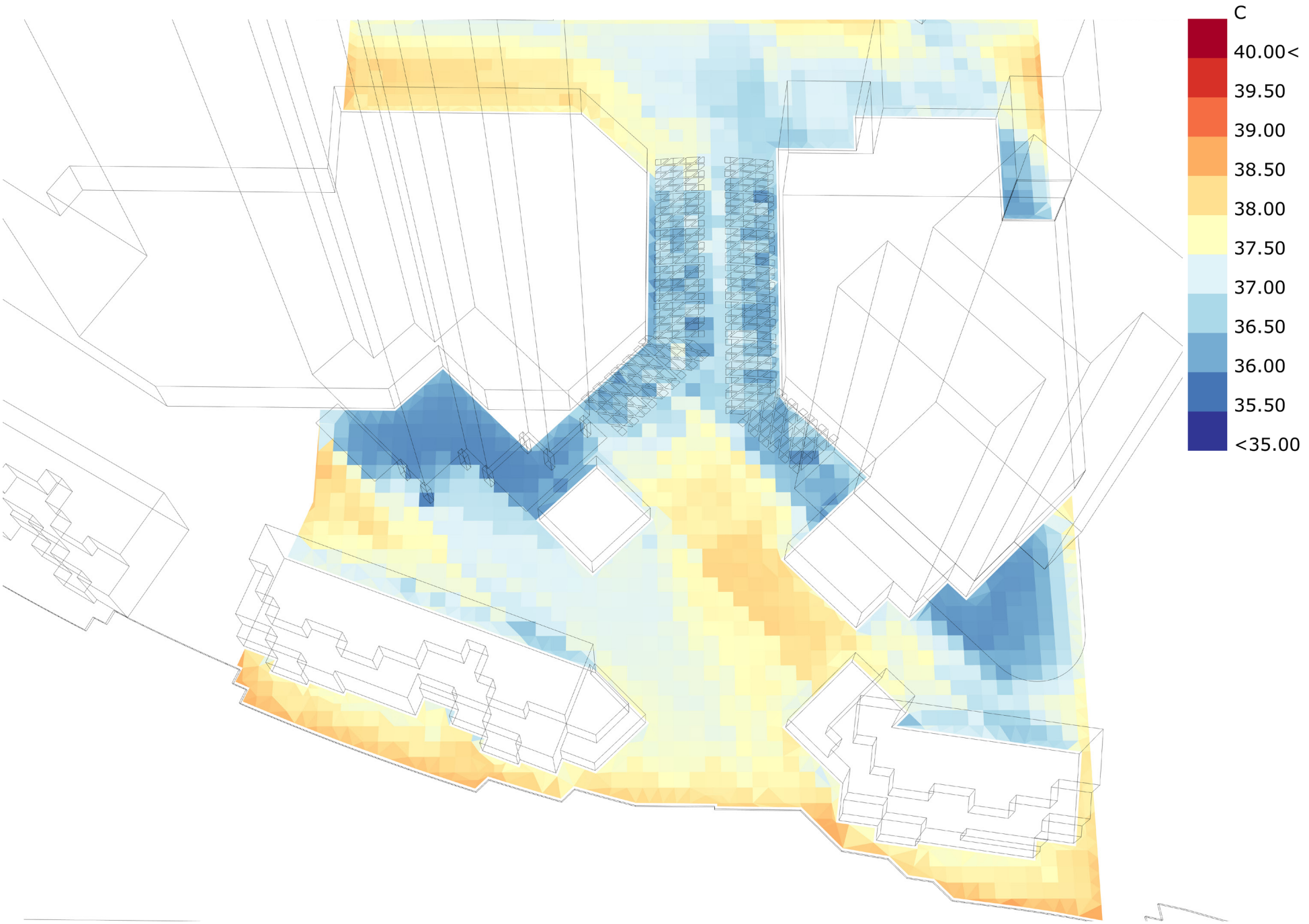
1 = standing (building entrances or exits, bus stops, children's play areas)

2 = leisurely walking (general areas of walking, strolling and sightseeing, window shopping, public/private sidewalks, pathways, public spaces)

3 = 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 = uncomfortable (uncomfortable for all pedestrian activities)

Outdoor Temp



Summary

As can be seen from the city level UTCI plot, a good estimation of UTCI can be made from the same. In line with the findings of other similar studies, it was found that the solar radiation has the biggest impact on the outdoor comfort of an individual and therefore the UTCI. It is recommended that the solar radiation study shall always act as a precursor to a detailed UTCI study. Only after necessary modifications are made in the buildings and / or shading geometry, and acceptable radiation profile has been achieved, UTCI studies shall be conducted. In this case, for the selected analysis period, the outdoor temperature for all the test points were above 32 degree Celsius, and therefore, they all share the same UTCI of +3 which indicates high thermal stress.