Mechartés

SIMULATION EXPERTS

Pedestrian Thermal Comfort

BEST PRACTICES

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What is Thermal Comfort Analysis?

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About Thermal Comfort Temperature Analysis

Thermal comfort is defined as the “condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation”.

With over half of the world’s population living in cities, and this figure rising even more by the end of the 21st century, the living standard of urban inhabitants is an important consideration in urban livability. The quality of the urban outdoor environment has an impact on the livability and the well-being of residents. And outdoor thermal comfort is an important indicator of the urban environment.

In outdoor environments where urban dwellers spend their time in commuting, leisure, and recreational activities, the thermal environment is more complex due to the constantly changing environmental conditions and the interplay between the human body and the ambient environment.

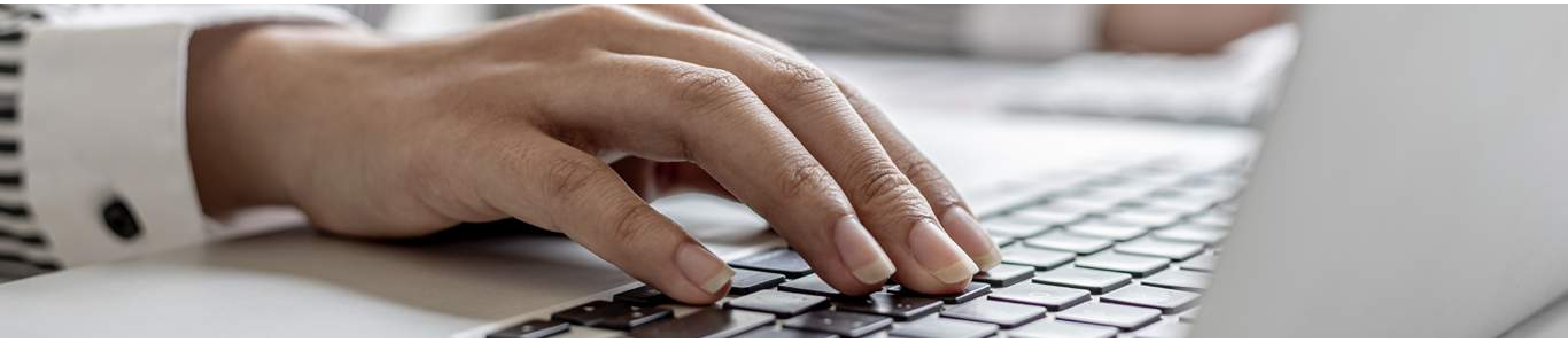
Meteorological factors such as air temperature, humidity, solar radiation, and wind speed are fundamental parameters of the immediate environment that one experiences.

As an important evaluation index of urban planning, landscape design, and architectural design along with geographical location, outdoor comfort can be used to determine the urban heat island area so that appropriate mitigation measures can be taken.

What is Thermal Comfort Analysis?

The major issues associated with outdoor thermal comfort in cities include low wind speeds, high temperatures due to urban heat island effects, solar access, etc. The outdoor environment has many factors affecting thermal comfort, such as:

- Meteorological factors: air temperature, relative humidity, wind speed and direction, solar radiation, etc.
- Demographic factors like age, gender, culture, economic status, etc.
- Other factors: climate, season, geographical location, etc.



The **urban heat island effect** is a special local temperature distribution phenomenon that occurs simultaneously with the development of the city. The increase in temperatures will have a serious impact on the health of urban residents. Studies have shown that high temperatures can lead to fatigue, dizziness, and increased breathing and heartbeats. More serious situations can even endanger life.

What is Thermal Comfort Analysis?

Outdoor thermal comfort studies have proven that urban design has a great influence on pedestrians' thermal comfort and its assessment helps one to understand the quality and usage of the pedestrian environment. However, most outdoor thermal comfort studies perceive pedestrian thermal comfort as "static". The dynamic multiple uses of urban spaces and the highly inhomogeneous urban morphology in high-density cities of the tropics are seldom considered, which leads to a lack of understanding about how pedestrians respond to the changes in the outdoor environment.

In recent studies, **Physiologically Equivalent Temperature (PET)** and **Universal Thermal Climate Index (UTCI)** are the most used indicators of outdoor thermal comfort study.

UTCI, along with the power of CFD Analysis, helps to figure out the relationship between shading effect and thermal comfort. Orientation of streets/pathways, tree plantations, solar index, wind patterns, etc., are some other factors that play an important role and should be considered before designing future healthier cities, district centers, etc. The above factors help contribute to improving urban geometry design in order to mitigate the thermal discomfort and create a better pedestrian environment.

What is thermal comfort temperature?

ASHRAE defines thermal comfort not solely as an environmental and physiological phenomenon but also as a condition of mind that expresses satisfaction with the thermal environment.

Here's the classification of thermal sensation and stress on the Physiological Equivalent Temperature (PET) scale.

PET (°C)	Thermal Perception	Grade of Physical Stress
> 41	Very hot	Extreme heat stress
35 to 41	Hot	Strong heat stress
29 to 35	Warm	Moderate heat stress
23 to 29	Slightly warm	Slight heat stress
18 to 23	Neutral (Comfortable)	No thermal stress
13 to 18	Slightly cool	Slight cold stress
8 to 13	Cool Moderate	cold stress
4 to 8	Cold	Strong cold stress
< 4	Very cold	Extreme cold stress

Outdoor Thermal Comfort Analysis

Objective Parameters / Considerations

1. UTCI Analysis

The Universal Thermal Climate Index (UTCI) provides an assessment of outdoor thermal comfort conditions, taking into consideration the air temperature, radiation, humidity, and wind velocity, and providing a holistic overview of the comfort levels.

UTCI is an accepted, easy-to-determine human thermal index that can be used to map human bioclimatic maps and can be used to determine the effects of urban and landscape planning and design on outdoor human thermal comfort.

To evaluate the UTCI temperatures, the ambient conditions and the buildings' shading effects are considered. Based on the latest long-term climate statistics relevant to the UTCI assessment, the analysis will provide the UTCI temperature values with respect to detailed site-specific climate models.

The UTCI temperature scales showing the corresponding levels of thermal stress are tabulated in the table below. From the table, we can see that the UTCI temperature of 9 to 26 is categorized as no-thermal stress (Level 0), 26 to 32 as moderate heat stress (Level +1), 0 to 9 as slight cold stress (Level -1) & so on.

Thermal stress classification for the Universal Thermal Climate Index (UTCI) are as follows:

Outdoor Comfort Level (Condition of Person)	UTCI (°C)	Stress Category
Level +3 and above	UTCI > 46	Extreme heat stress
	38 < UTCI < 46	Very strong heat stress
Level +2	32 < UTCI < 38	Strong heat stress
Level +1	26 < UTCI < 32	Moderate heat stress
Level 0	9 < UTCI < 26	No thermal stress
Level -1	0 < UTCI < 9	Slight cold stress
Level -2	-13 < UTCI < 0	Moderate cold stress
Level -3 and below	-27 < UTCI < -13	Strong cold stress
	-40 < UTCI < -27	Very strong cold stress
	UTCI < -40	Extreme cold stress

2. Shading Analysis/Solar Exposure Analysis

The shading assessment helps in identifying the areas that are protected from direct solar radiation and it provides insights into the percentage of shading achieved. The analysis is carried out by considering the shape, orientation of the buildings, angle of the sun, and various shading elements to evaluate the area of outdoor space covered with shade.

Based on the shading analysis the client will be able to decide on the type of shades, canopies, and trees to be used in the region for proper shading.

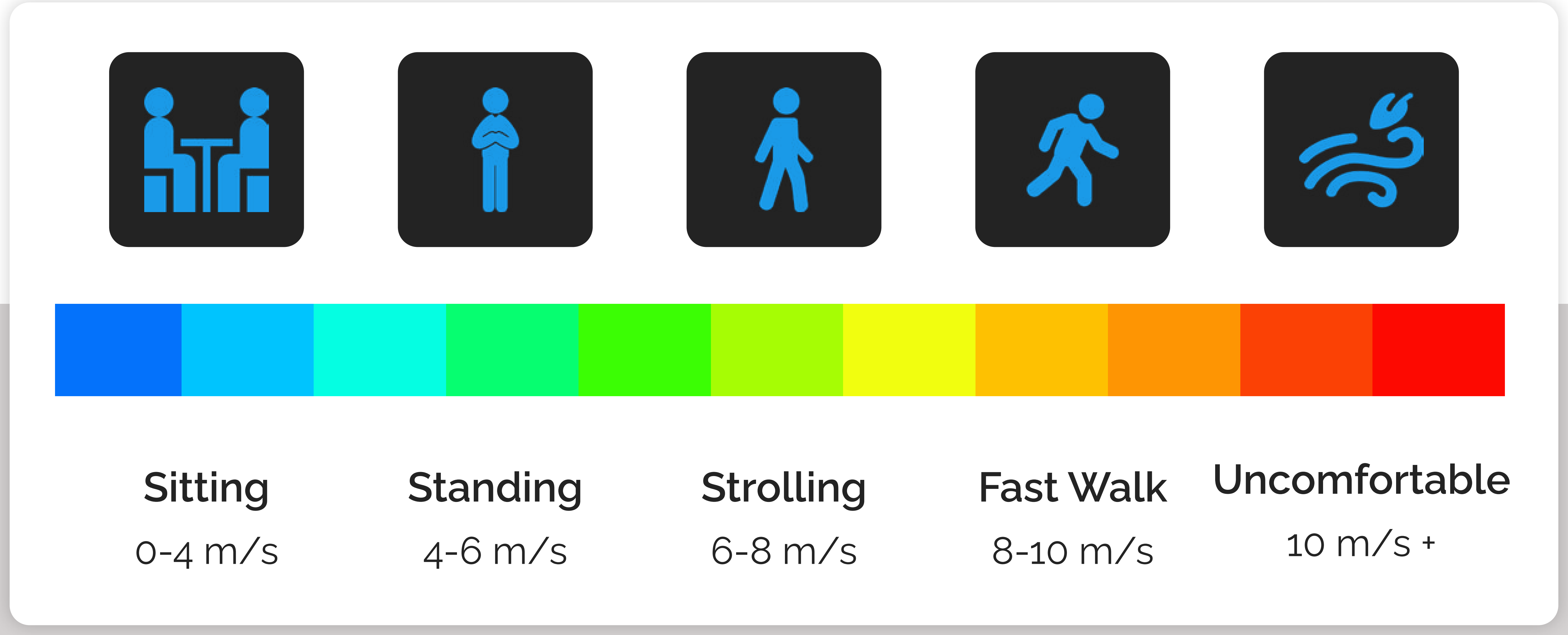
3. Wind CFD Analysis

Wind analysis is widely used in evaluating the comfort, wind loading on the structures, determining the pollutant levels, and studying if passive or active ventilation is required.

In large district center projects, Wind analysis also helps in identifying the direction, frequency, and speed of winds enabling engineers to optimize the street orientation as well as wind strategies.

There are many criteria and standards available today to help assess the expected wind climate in the design stage, by providing parameters of what should be achieved to stay within favorable conditions.

The velocity scale for various outdoor activities to assess the pedestrian wind comfort is shown in figure-2 below which is based on the Lawson LDDC (London Docklands Development Corporation), which is the most famous criteria for assessing wind comfort.



LDDC is comprehensive, as they address a wide range of activities, including:

- Sitting/standing,
- Strolling,
- Fast walk.

CFD Analysis helps designers in building the complete 3D Model and to visualize the flow path and temperatures during the design stage and to decide on the type of cooling strategy required if any.

Below we discuss one of the case studies to elaborate more on the UTCI, Shading, and CFD Wind analysis.

Sample Project by Mechartes

In the case study section, we are going to discuss a large district center, located in Riyadh. In the project, an outdoor thermal comfort study was carried out by using various analysis methods, including the UTCI, Shading, and CFD wind analysis to determine if active or passive cooling will be required. Based on the analysis, a comprehensive report was provided to the client in assessing the current condition and recommendations to improve the comfort levels.

1. UTCI Analysis

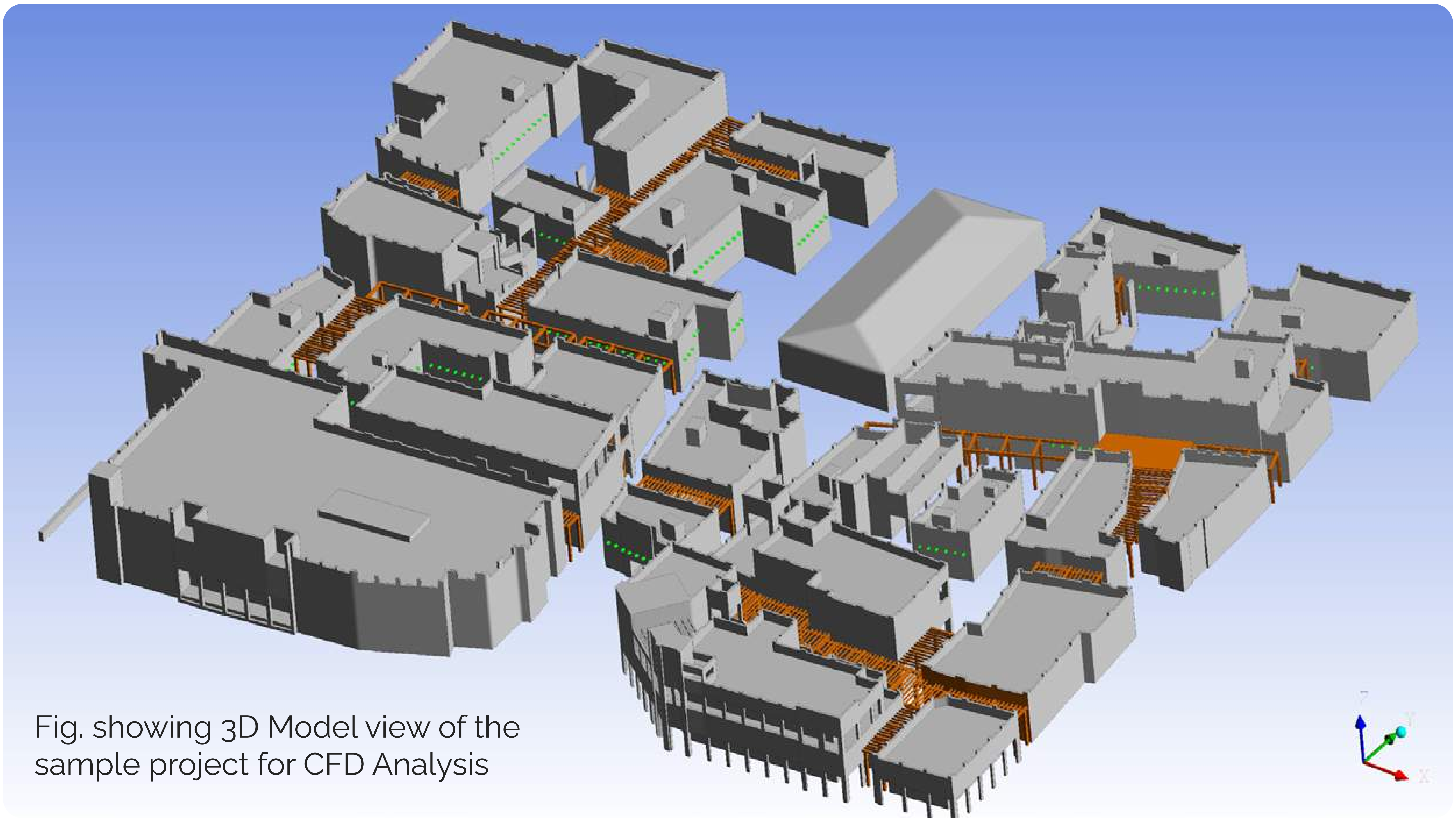


Fig. showing 3D Model view of the sample project for CFD Analysis

Outdoor Thermal Comfort Analysis

- A detailed investigation of Riyadh's weather condition results for various points in the district is performed throughout the year with special attention being paid to the shoulder months of March and September.

- UTCI temperatures were analyzed hourly during the year for various focus points within the concerned area without & with shading (canopies & trees) to evaluate the effect of shading on temperature improvement and determine the time of year when shading changes the temperature.

- The recommendations from the UTCI study are as below:

  I. Passive elements with additional shading elements
  II. Active elements with mechanical cooling systems (wherever the passive elements do not improve the UTCI levels)

- The impact of the shading on the number of comfortable hours for each zone of the district center was provided to the client.

- The comparison of without and with shading elements for each zone was provided, indicating the shading benefits and the improvement in the UTCI temperature.

Outdoor Thermal Comfort Analysis

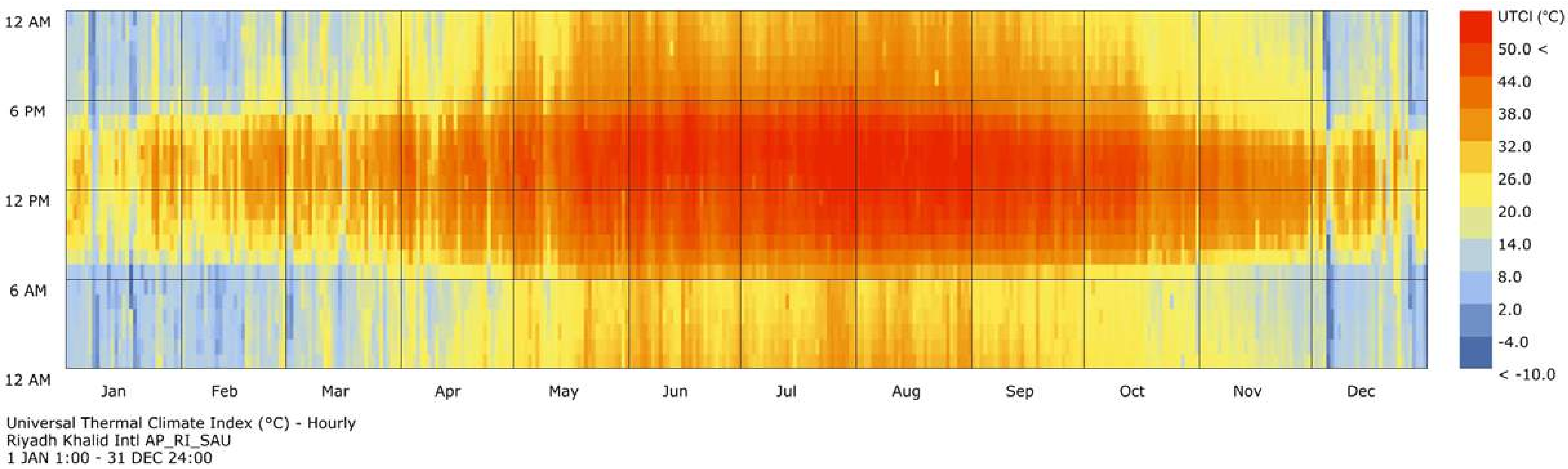
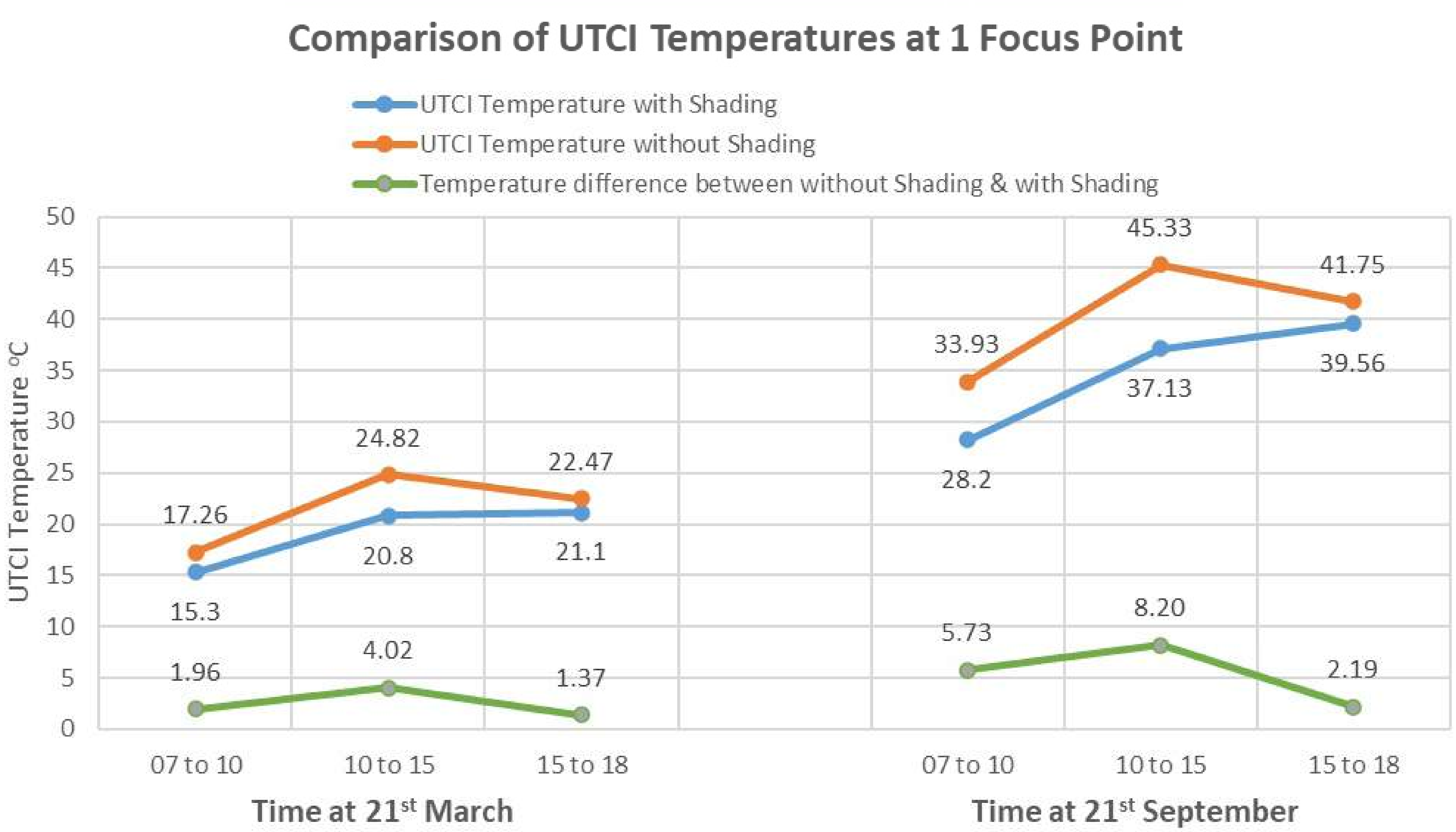


Figure: Typical Temperature Reference of Riyadh City



2. Shading Analysis/Solar Exposure Analysis

- The purpose of the shading assessment is to identify the areas of the structure that will be protected by direct solar radiation, providing insights on the percentage of shading achieved.

- The shading analysis is carried out by considering the shape, orientation of the buildings, and various shading elements to evaluate the percentage of outdoor space that needs to be covered with shade.

- For the shading analysis, the Mostadam Guideline was considered for the project.

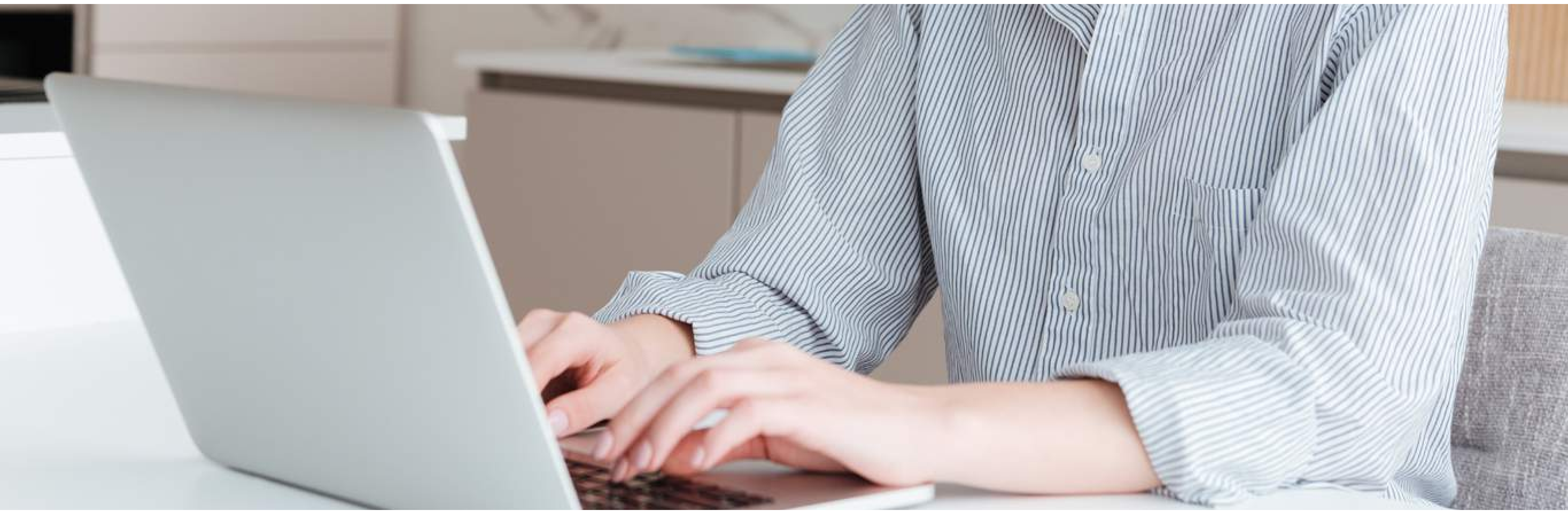
- Shading analysis was carried out between 12:00 and 14:00 within one week of the equinox (either vernal or autumnal) and summer solstice as per the Mostadam Requirements.

- As per the Mostadam guidelines for the concerned District Center, below were the minimum requirements considered in the shading analysis study:

  I. Public realm parks, playgrounds, and parking areas to target 50 shading from either canopies, architectural elements, or soft landscaping, this is also the condition for where the same occurs in a building plot.

II. Public realm pedestrian walkways and bicycle paths to target 20 shading at least on one side of the street from either canopies, architectural elements, or soft landscaping, with shade refuges every 100 meters.

III. Provide a minimum of 75 shading cover the following within a plot --"Pedestrian walkways, playgrounds, car-bicycle parking"



- Upon completion of the study of the two conditions of equinox and summer solstice, the percentage of the shading achieved for each zone was provided.

- Based on the shading analysis results, the recommendations for design adjustment mitigation measures with additional shading elements were suggested to improve the shading.

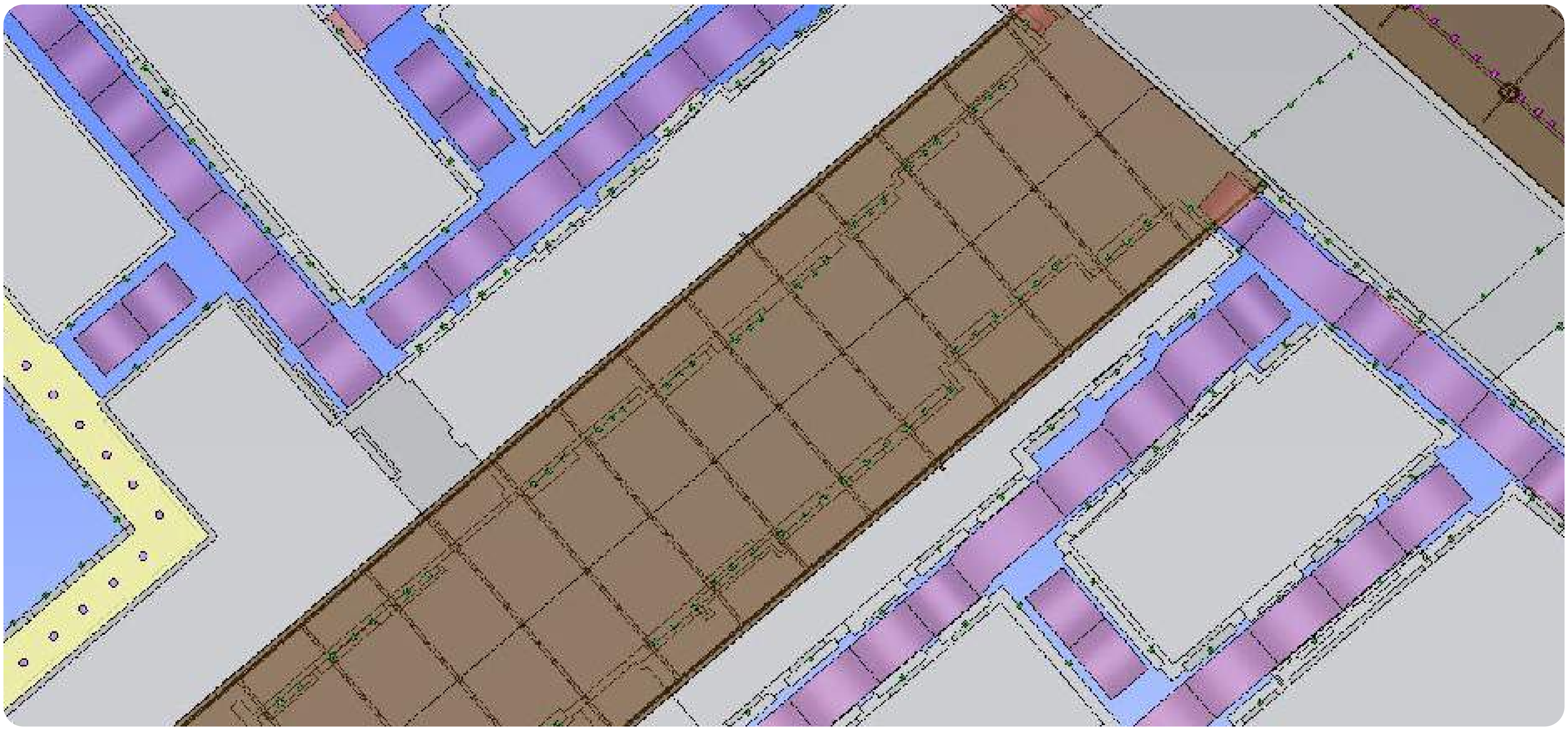


Fig. showing Shaded area B/w Block B-04,05&06.

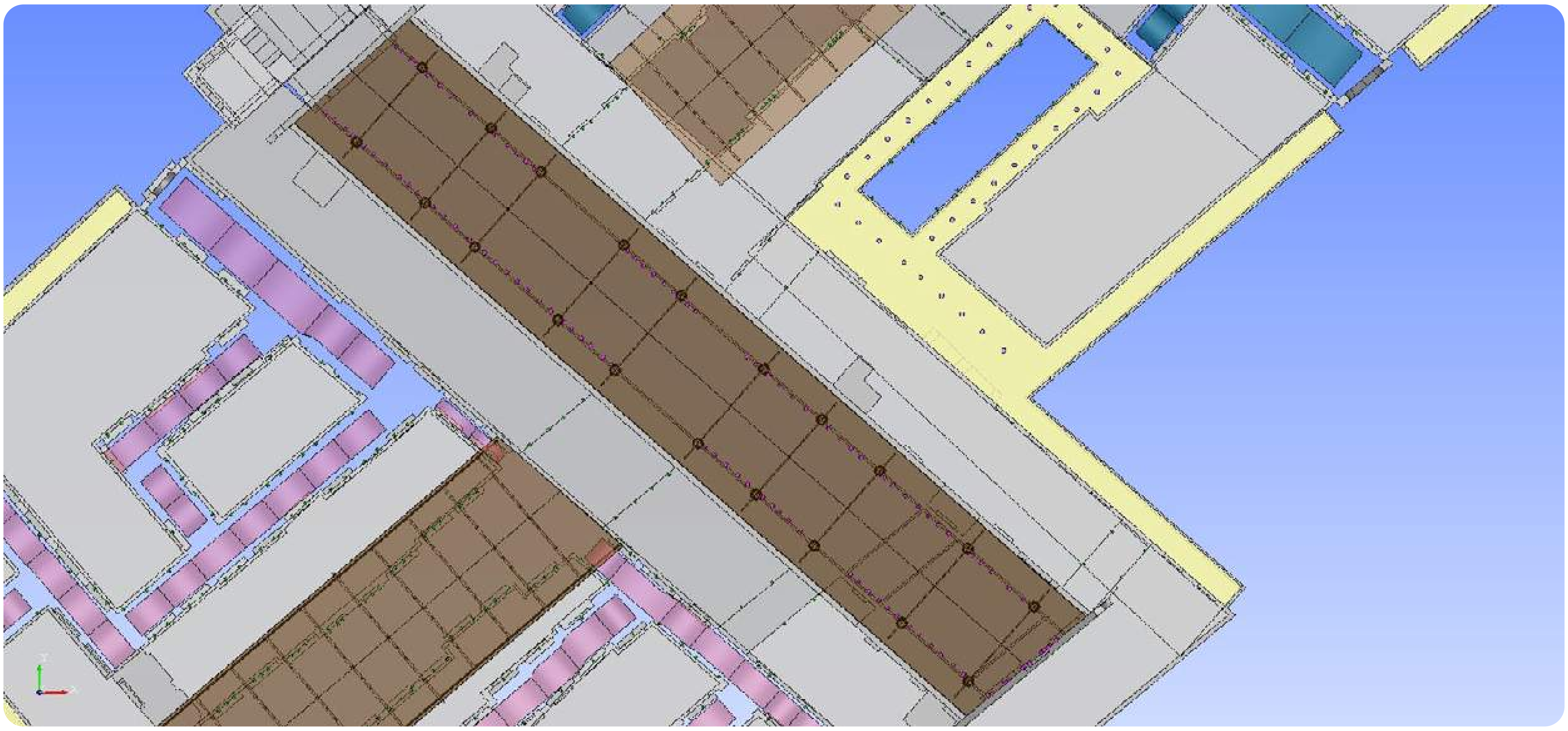


Fig. showing Shaded area B/w different Blocks.

3. Wind CFD Analysis

- A CFD 3D model is built for the complete district, considering all the obstruction and shading elements.

- The shape and orientation of the buildings and the effect of wind velocity, along with its direction were considered in the wind CFD analysis.

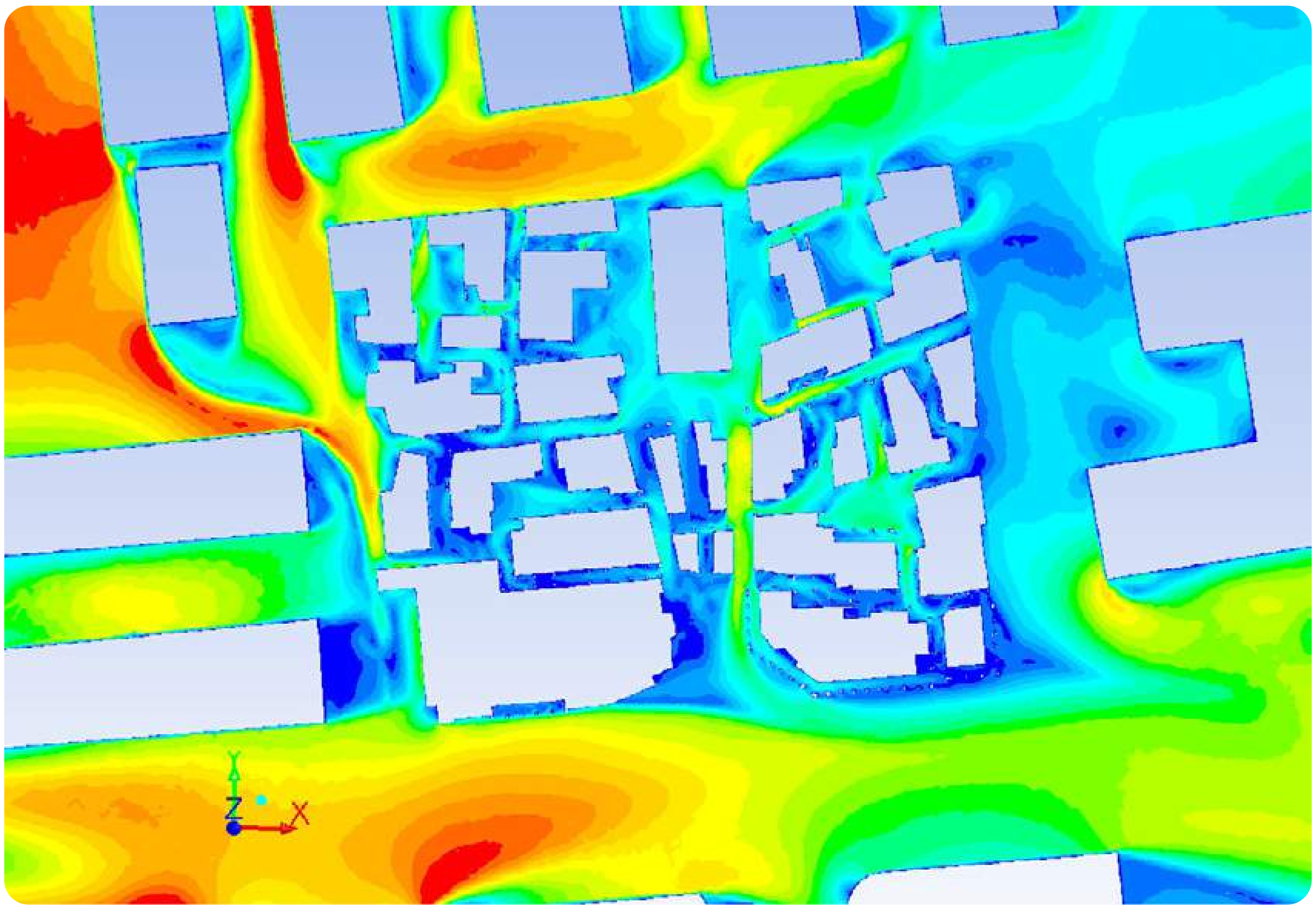
- Two wind conditions are chosen for the project as below,

  I. Comfortable wind condition

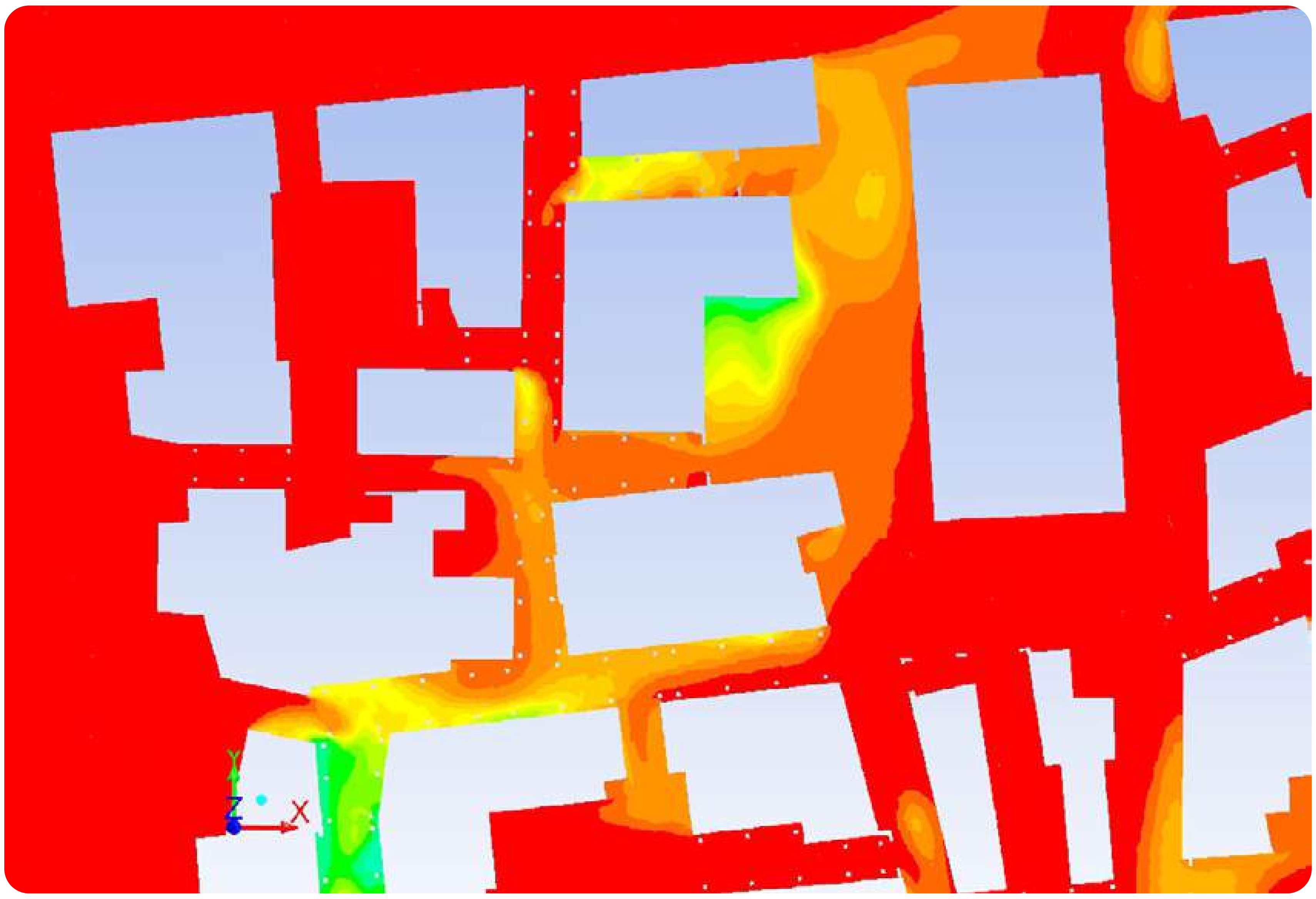
  II. Uncomfortable wind condition

- The CFD results of velocity profiles were analyzed at the height of 1.5 meter from the ground level to demonstrate the velocity profiles at various locations to understand whether the velocity is within the suitable level for pedestrian comfort or not.

- The locations of low velocity and very high velocities are identified, recommendations were provided to improve the velocity profiles.



Velocity at occupancy level



Temperature at occupancy level

Benefits of Outdoor/ Pedestrian Thermal Comfort Analysis

Benefits of Outdoor/Pedestrian Thermal Comfort Analysis

From the case study discussed in the previous chapter, we can conclude the following benefits:

- From the UTCI analysis, the client can understand if the shading elements will be sufficient to meet the desired comfort conditions. If it isn't sufficient, the study helps in understanding the requirement of additional elements, including the addition of fountains with additional tree coverage.

- The percentage of shading achieved shall be determined by the shading analysis for each area.

- These studies will help engineers determine the requirement of an active cooling system i.e., mist cooling and radiant cooling system, depending upon the feasibility.

- The addition of mechanical active cooling systems for large outdoor areas is not possible. It's ineffective due to a large amount of ambient air entrainment and high installation and running maintenance costs involved. So, the results help in analyzing the zones which can have an active cooling system.

- Once the active cooling system for the zone is designed, detailed CFD wind modeling will help in evaluating the performance of the design.

About Mechartes' Services

Services offered in the Building and Construction Sector are:

- CFD CO and Fire/Smoke analysis for Car Parks and tunnels.
- Thermal comfort analysis for Indoor and outdoor domains, including pedestrian comfort study.
- UTCI Analysis
- Shading Analysis/Solar Exposure Analysis
- Wind Analysis
- HVAC analysis of Chiller Yard/ Generator Yard Study
- Hot Air Recirculation study for cooling towers, chillers, AHUs
- Stack effect on high rise buildings
- TES (Thermal Energy Storage Tanks) and Buffer Tank Design
- Acoustic Modeling
- Surge Analysis
- Piping Stress Analysis and Support Design
- Seismic Analysis

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