



Mitigating Urban Heat Through Extended Cantilever Building Shading: A Street-Level Analysis

TECHNICAL ARTICLE

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ABSTRACT

In hot regions, high street temperatures can be a significant impediment for pedestrians. It can also negatively impact the urban heat island and increase the energy required for cooling. Street shading can assist in mitigating these problems. This research examines the effect of extended building projections beyond the building plot and over the pavement on street shading and the resultant thermal conditions in a hot, arid urban environment employing the ENVI-met simulation tool. Several projection configurations were analyzed in a Dubai mid-rise residential district. Projections extended beyond the real estate plot boundaries but not the walking pavement, to a maximum of 6 m. Two streets were analyzed within the selected neighborhood: a side street 10 m wide, building-to-building, and a main street 56 m wide. The simulations showed a direct correlation between configurations of larger building projections with improvements in outdoor air temperature, both ambient and radiant, and thermal comfort. The average temperature for the entire block dropped almost two degrees from 41.0 °C to 39.1 °C. Significantly, the radiant temperature decreased significantly from 63 °C to 57 °C. The PMV, according to Envi-met's scale, remained out of the comfort zone but still showed a significant improvement from 7.2 to 6.5. These results demonstrate that well-designed building projections can effectively reduce high temperatures, improve livability, and assist in mitigating the urban heat island effect of mid-rise urban sectors in hot regions.

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1. INTRODUCTION

The provision of street shading can significantly reduce the amount of solar radiation reaching the ground, which can lower the air temperature, reduce the Urban Heat Island (UHI) effect, and, to a larger extent, improve thermal comfort. Urban sprawls and urban expansion are characteristics of urbanization that have resulted in the widespread conversion of natural areas into artificial ones. As a result of this rapid change, there have been significant shifts in the environmental balance and thermal status of outdoor spaces in urbanized areas, which have spawned a number of significant problems, one of which is the Urban Heat Island (UHI) (Zhou and Chen, 2018) (Abulibdeh, 2021). Reducing the surfaces exposed to direct solar radiation and the cooling energy demands is one of the major benefits of reducing the UHI effects (M. Giguère, 2009). Shading outdoor spaces is a sustainable strategy to achieve this (Dialesandro, Wheeler and Abunnasr, 2019). Although it has been demonstrated that adequate shading can improve thermal comfort and enhance user experience in outdoor spaces, particularly in hot, arid regions, there are few studies on its application in contemporary urbanized areas and its effects on the UHI (Nasrollahi, Namazi and Taleghani, 2021). Looking back through time, shading played a significant role in traditional architecture and historical cities, as evidenced by the massive walls, dense urban fabric, narrow alleys, and distinctive arcades that told a story about how outdoor spaces were active and vital despite hot weather and the absence of cooling systems (Yildirim, 2020) and (Malaktou and Philokyrou, 2019).

In addition to shading, vegetation is also an important factor in regulating temperature in urban environments. Both vegetation and cantilevers serve the function of providing shade, thus reducing heat absorption by buildings and surrounding surfaces. By mitigating direct solar radiation, these shading strategies contribute to lower ambient temperatures and improved thermal comfort. Urban vegetation can regulate temperature through three main actions: shading the built environment (buildings, streets, parks), transpiration, and evapotranspiration (Palme, Privitera and La Rosa, 2020). Furthermore, street trees are an important driver of street microclimate through shading and transpiration cooling. A study by (Segura et al., 2022) found that street trees can reduce the surface temperature of the street and improve thermal comfort while it was found that the temperature is 1.3°C higher in Barcelona's street with sparser trees.

In an interesting paper, Yin S et al compared the cooling efficiency of shading strategies for thermal comfort in the shopping neighborhoods of Guangzhou, China (Yin et al., 2022). The study revealed that the effect of the height-to-width ratio of the street canyon had a slightly better cooling efficiency than tree coverage. Andreou E. and Elkhazindar both studied the thermal

effect of street geometry on the thermal conditions in the Mediterranean and Arabian Gulf (Andreou, 2014) (Elkhazindar, Kharrufa and Arar, 2022). Both agreed that traditional configurations offered better solutions. Those had narrower streets, relatively more shading, and no vehicular spaces. Paolini investigated the possibility of adding tents of different widths over the street at rooftop level (Paolini et al., 2014). The study concluded that it would decrease the temperature by around 2°C with the canopy in peak conditions but increase it during the nighttime. He also noted an overall improvement in the thermal comfort conditions.

Thermal effects notwithstanding, extended sunlight radiation exposure can lead to various health issues. Ultraviolet radiation from the sun increases the risk of skin cancer, including melanoma, basal-cell carcinoma, and squamous-cell carcinoma. It can also accelerate the aging of the skin, cataracts, and other eye damage (Djangalina et al., 2022). According to the World Health Organization, the Middle East Gulf region falls into the "high" to "Very High" categories of areas exposed to UV light with UV indices of 6.5 to 10.5 (GRID-Arendal, 2023) (world health organization, 2023).

Many streets in hot countries provide some form of shading. Figure 1 shows Al Rasheed Street in Baghdad, which was mainly built in the late 1800's to early 1900's. All the walkways are fully shaded by extended 1st floors supported by columns. Older traditional solutions use a more straightforward approach adopting narrow allies, and cantilevers. The image in Figure 2 shows a traditional street from old Baghdad where the alley is narrow with protruding cantilevers and windows, locally called Shanashel. All three assist in decreasing the sky view factor and increasing shading.

Dubai's hot-arid climate and unique urban characteristics make it an ideal choice for this research. Known for its rapid urbanization and extreme temperatures, it offers a diverse array of building designs and urban layouts for analysis. The city's climate presents significant challenges for urban heat management, making it a suitable case study for exploring effective shading solutions.

Dubai's ambient and radiant temperatures were measured in order to study the impact of direct sunlight on thermal conditions in hot regions on the 14th of August 2023, a day clear from clouds, using an Extech HT30 heat stress meter that can measure radiant direct, and indirect sunlight. The results can be seen in Figure 3. It shows a clear distinction between ambient and radiant temperatures, especially in direct sunlight, where the maximum difference at 10:00 in the morning of that day was 13.55 °C. Over the course of the day, the average difference between radiant temperature in direct sunlight and ambient temperatures was 7.1 °C; and 4.6 °C compared to shaded areas. This emphasizes the importance of shading in sun-rich and zones such as the Middle East and similarly hot regions.



Figure 1 Traditional residential street from old Baghdad showing shading solution (ID 143067882, © Rasool Ali | [Dreamstime.com](#)).



Figure 2 Colonial style architecture in Rasheed Street in Baghdad showing the shaded walkways (Authors).

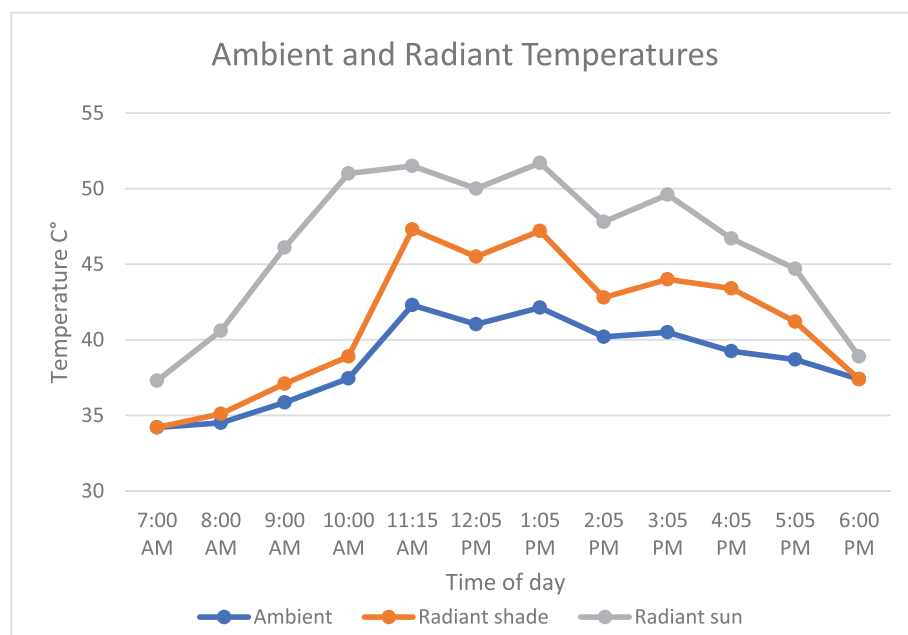


Figure 3 Measurements of ambient and radiant temperatures in Dubai in August 2023 (author).

During the hot season, average daily temperatures in Dubai reach 42°C (Weather and climate, 2023). This is far from comfortable, especially for walking in the sun. Adding shading can significantly increase walkability within the city and improve its sustainability indicators. Currently, most movement within the city is vehicular to make use of car air conditioning, even for short distances. Shading of street pavements would certainly improve this and consequently decrease vehicular traffic, improve the city dwellers' health, and reduce the impact on the urban heat island.

Kharrufa et. All in their study, which surveyed the building stock in Dubai, showed that in terms of functional built-up area, mid-rise multi-story buildings 6–13 stories high, both residential and commercial, contain spaces that account for around 53% of all interior functional spaces in the city (Kharrufa et al., 2022).

Using Dubai as a case study, this paper will examine the effect of exaggerated building cantilevers that extend beyond the property line. The extensions will be tested in as much as it is practical from a city planning point of view. The end of the walking pavement will be the testing boundary as beyond that the extensions will start to affect vehicular traffic, specifically large high trucks and buses. The neighborhood that was selected is comprised of relatively tall buildings. More people will benefit from the increased shading in such a dense section of the city. Such a solution violates standing planning regulations and is a novelty that has not been tested in the modern era although such solutions were

used extensively in traditional architecture. It may thus be especially beneficial in the hot Gulf region of the Middle East. In such an area with such harsh summers, the benefits may be significant.

2. METHODOLOGY

Using case studies and computer simulations, this research employs a quantitative methodology utilizing measurements, see Figure 3, and simulations. It is based on the best practices found in research papers as mentioned in the literature review. This approach enables a more rigorous analysis of the phenomenon under investigation. The visualization of the research process can be found in Figure 4, providing a graphical representation that aids in comprehending the steps and components involved.

The specific case study location chosen for this research is a parcel of land situated within a contemporary urban setting in Dubai, dominated by medium rise 6–13 story buildings.

The primary objective of this study is to examine the effect of various, non-conventional, building cantilevers and projections on enhancing street shading and, consequently, on the climatic conditions of the surrounding area. The building regulations in all sectors of the city similar to this one in age, land use, and height, stipulate a setback of zero for the front of the property. This study will extend the building's projections beyond

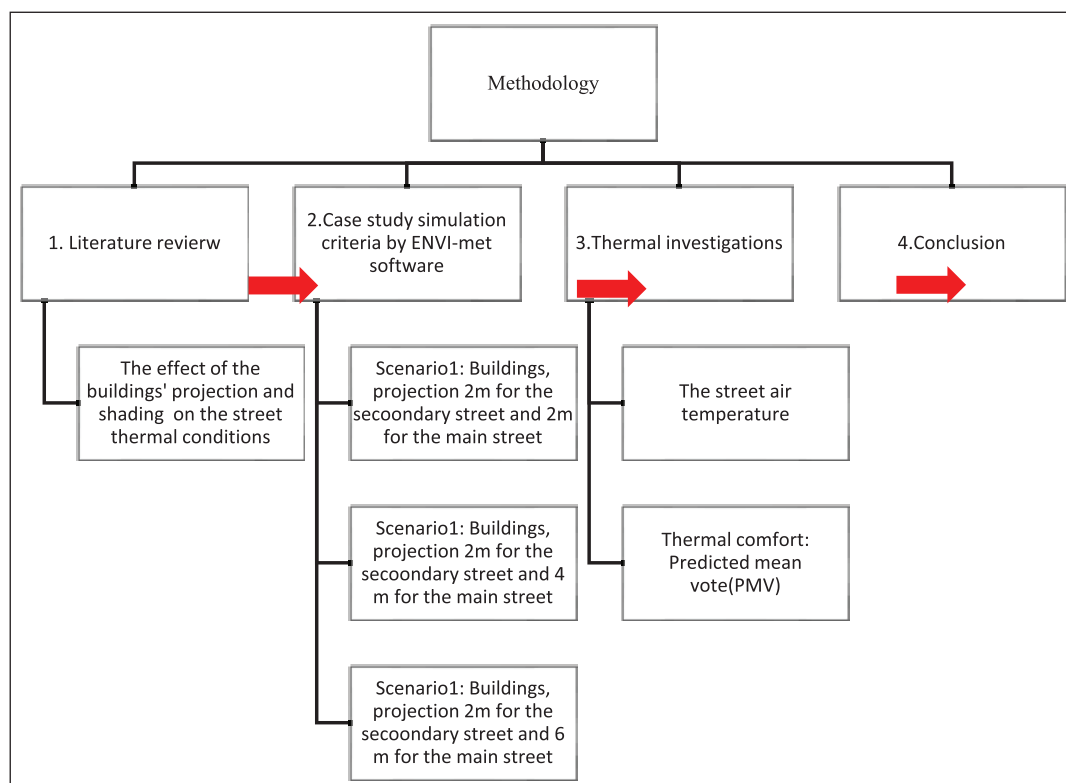


Figure 4 Methodology outline for the research.

that, up to the edge of the pavement or 6 meters, whichever comes first. The extensions will be in 2 meter intervals, and will be applied to all the buildings in the sector being simulated.

To carry out this analysis, the “ENVI-met” urban simulation software was employed. ENVI-met possesses the capability to make predictions about various pertinent variables. These variables include the ambient air temperature and the Mean Radiant Temperature (MRT), both critical factors in assessing the overall thermal environment. It also simulates the Predictive Mean Vote (PMV), a metric used to quantify thermal comfort. In the context of outdoor spaces, the assessment of thermal comfort through the PMV is pivotal. The software employs a scale that ranges from -4 , indicative of cold conditions, to $+4$, representative of hot conditions. This range facilitates a nuanced evaluation of the outdoor thermal experience, considering factors that influence comfort levels. The application of this approach helps in comprehending how the design interventions, such as building cantilevers and projections, impact the outdoor environment’s thermal qualities (ENVI-met, 2023).

2.1 THE RESEARCH CASE STUDY AND CLIMATE CONDITIONS

The research was carried out in the residential district of Deira. An image of one of the main streets in the area is depicted in Figure 5a. The location of the area designated for analysis is encircled in 5b.

The weather in Dubai is characterized by hot summers and mild winters. During the summer months, which extend from May to September, temperatures can soar to extreme levels, with average highs reaching around 41°C (Lawrie, Linda K, 2019). The region is subject to intense heat and dryness, creating a challenging environment for outdoor activities. In contrast, the winter season in Dubai, from November to April, brings more pleasant weather with average temperatures between $24\text{--}26^{\circ}\text{C}$ (Lawrie, Linda K, 2019). The evenings can become cooler, especially in December and January, with average lows

dropping to around 15°C . These milder temperatures offer a welcome relief from the summer heat. Dubai experiences very little rainfall throughout the year, with the majority of it occurring during the winter months between December and March (Energy, NASA Prediction Of Worldwide, 2023). Rainfall is typically infrequent and light, contributing to the arid nature of the region. The prevailing wind in Dubai is predominantly from the Northwest (Iowa State University, 2020), bringing some relief during the summer months.

2.2 THE THERMAL SIMULATION TOOL VALIDATION

Due to its advanced capabilities for modeling thermal conditions in urban layouts, ENVI-met software was used for this research. The program has been used in multiple papers and in various climatic conditions (Lee, Mayer and Chen, 2016), (Paas and Schneider, 2016), (Salata et al., 2016) and (Salameh, Mushtaha and El Khazindar, 2023). It is described as a “cutting-edge 3D micrometeorological modeling program that can precisely replicate a variety of parameters, including outside air temperature, plant impact, humidity, water components, and thermal comfort” (Huttner, 2012). ENVI-met has been validated by several academics and professionals for different studies related to the urban microclimate, such as (Wang et al., 2023), (Alyakoob et al., 2023), (Ghaffarianhoseini, Berardi and Ghaffarianhoseini, 2015), (Salameh and Touqan, 2022), (Salameh and Touqan, 2023), (Lee, Mayer and Chen, 2016), (Taleghani, Tenpierik and van den Dobbelen, 2014), and (Forouzandeh, 2018), to mention a few. The authors also validated the results of the simulation in a residential street for the climate of the UAE in (Salameh, Mushtaha and El Khazindar, 2023), through average tracked air temperature values. The location of the latter validation test can be seen in Figure 6. The temperatures were collecting with an Extech 4 in 1 model number 45170 in four locations. The results were compared with their related average data for air temperature points from the simulation via ENVI-met on the 21st of the month of August 2020, seen in Figure 6

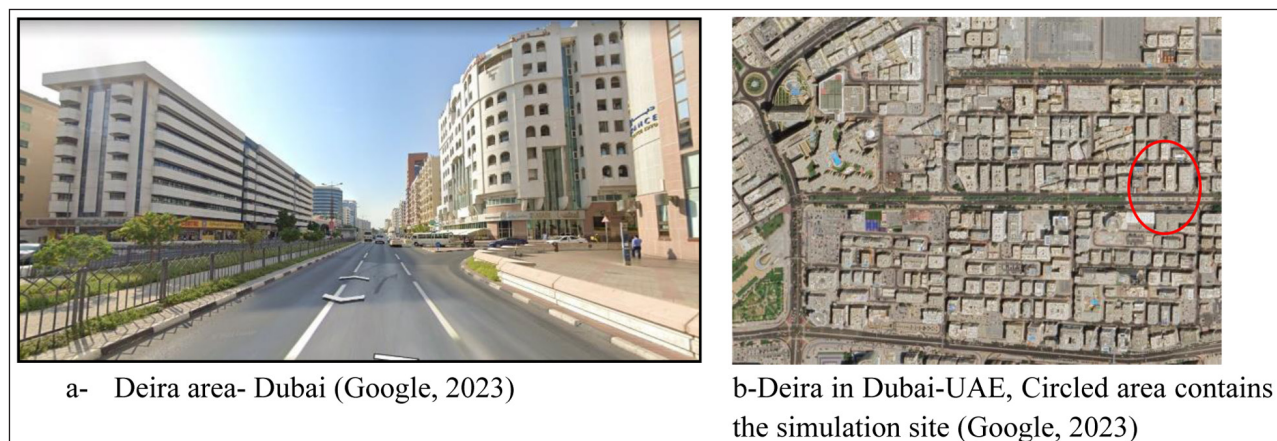


Figure 5 Location and image of case study site.

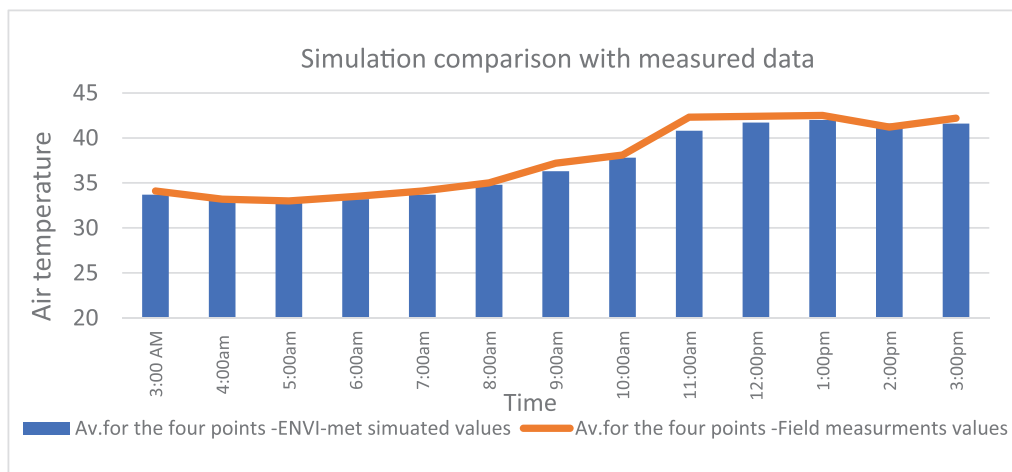


Figure 6 Validation information (Salameh, Mushtaha and El Khazindar, 2023).

which shows the 12-hour air temperature data for both simulated and measured cases on that date. Notably, some fluctuations in temperature become apparent during the midday hours, specifically between 10:00 am and 1:00 pm. It is noteworthy that the measured air temperatures during this period registered slightly higher values than those predicted by the simulation. This observed increase in midday air temperature may be attributed to factors such as increased vehicular activity, heat emission, and solar radiation exposure. Importantly, it is worth noting that the ENVI-met software presently lacks the capability to account for these influences in its calculations. Nevertheless, the comparison shows a close resemblance between the simulated and measured temperatures.

2.3 SITE SELECTION AND SIMULATION ANALYSIS CRITERIA

The Deira area is considered part of the Central Business Districts (CBD) of Dubai. It is a densely populated section of the city, featuring a typical urban configuration that is commonly repeated throughout Dubai, regardless of height variations in different areas. Additionally, Deira has wide sidewalks for pedestrians, which facilitates the implementation of cantilever projections.

The base case for investigating the site was a residential midrise section comprising a number of detached buildings. The simulated area was around 250*180 m in a grid pattern layout with straight, wide streets. A plan and the basic characteristics of the site can be seen in Table 1. The plot has one secondary street to the northeast, codenamed for our purposes as S1, and one main street to the southwest of the plot codenamed named S2. S1 has a 4 m sidewalk on one side, a 6 m vehicular road, followed by a another 2 m sidewalk on the other side, as seen in Figure 7b. The total width is around 12 m. S2 has a 10 m sidewalk, a 9 m vehicular road, a 12 m green island, another 9 m vehicular road, and then a 12 m sidewalk on the other side, as seen in Figure 7c. The width is around 50 m. Most of the residential detached

buildings on both sides of the streets are multi-story buildings with heights that range between 32 m-44 m, with the exception of a single 5-story building, which is around 18 m high.

In order to investigate the effect of the various building horizontal projections on the street's thermal conditions, three configurations that were applied to both sides of the two main and secondary streets, S1 and S2, were analyzed, as seen in Figure 7a. Table 2a illustrates where the projections were made and how far they extended for each configuration. The base case scenario and the three suggested configurations display various designs in terms of building projections along the primary and secondary roads. Specifically, the buildings situated along the main road (S2) have varying projections of 2 m, 4 m, and 6 m as seen in Figure 7c. Conversely, the buildings along the secondary road (S1) maintain a consistent projection of 2 m, as this aligns with the maximum width allowed for pedestrian sidewalks, as shown in Figure 7b.

Three configurations were studied: P1, P2, and P3. The projections from the two streets, S1 and S2 are further illustrated in Table 2. The configurations are based on a 2-meter module of projections that was added starting from the second floor above 4 m, these configurations are summarized as follows:

- 1- Proposed configuration P1 (2,2)** is the first configuration where 2 m projections are implemented on both sides of S1, and 2 m projections on both sides of S2
- 2- Proposed configuration P2 (2,4)** is the second configuration where 2 m projections on both sides of S1 are used, but 4 m on both sides of S2
- 3- Proposed configuration P3 (2,6)** is the third configuration where 2 m projections on both sides of S1 are still used, but 6 m to both sides of S2

These are all the possible configurations for a 2 m module after extending the cantilevers.

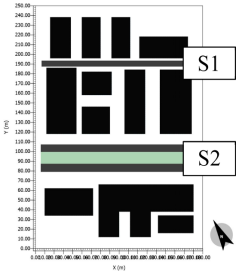
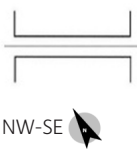
LOCATION MAP	GROUND AND BUILT-UP AREA	PLOT AREA	URBAN LAYOUT	STREET ORIENTATION	STREET WIDTH	BUILDING TYPE	BUILDING HEIGHT
 (Google, 2023)		Plot area = 250 * 180 m ²	Grid pattern layout		The streets are straight and wide, stretching up to 50 meters in width. They are accompanied by sidewalks on both sides and a central island dividing the vehicular lanes.	Residential, midrise detached buildings.	The majority of the buildings range in height from 8 to 11 floors, with the exception of a single 5-story building.

Table 1 Case study- *Base Case* -Al Rigga road, Deira district characteristics (existing configuration).

Both the existing and proposed urban configurations were. The software requires that a pre-set grid size be identified. The simulation utilized a grid size of 2 meters in the x, y, and z axes, which allows for a detailed representation of the environment. The duration of the simulations spanned 24 hours, commencing from 12:00 am to 11:59 pm on August 20th.

To ensure a realistic representation, the selected site for simulation was designed to emulate real-world conditions in terms of orientation, building materials, built-up area, street geometries, street orientations, and 3D geometries. August 20th was chosen as the date for investigation due to its significance in the UAE, as it represents the hottest day in the hottest month of the year. This should present an indication of the thermal conditions in the area at its most extreme, enabling the evaluation of potential heat stress factors and thermal discomfort. During this period, the average air temperature reaches a high of around 41°C and a low of 34°C (Lawrie, Linda K, 2019). These temperature readings exceed the thermal comfort range defined by ASHRAE who propose a range between 20 to 27 Celsius in accordance with “ASHRAE 55”, thermal comfort diagram (Meg Jenkins, 2023).

The simulated urban layouts incorporated predetermined factors such as the geographical location in the UAE, climatic data indicating an arid and hot climate, and specific building materials such as concrete walls with moderate insulation, asphalt roads, red stones for pedestrian paths and sidewalks, and sandy soil for unpaved areas. On the other hand, independent factors such as building projections, sky view factor, and built-up area-to-plot area ratio were input variables within the simulations. The outcomes of the simulations calculated dependent factors, including outdoor air temperature, wind speed, relative humidity, mean radiant temperature, and predicted mean vote (PMV). These were the factors analyzed to determine the impact of each proposed urban cantilever projection configuration.

All the results were derived from simulations run using ENVI-met software,. This approach allowed for detailed

analysis of microclimatic conditions and the effects of cantilever shading in a controlled virtual environment, which was supported by the measurements seen in Figure 3.

3. RESULTS AND DISCUSSION

Three distinct configurations were simulated, as explained in section 2.3 of the study. The primary intention behind these configurations was to devise urban design interventions that could effectively ameliorate the thermal conditions within the designated areas. This was to be achieved through a twofold approach: firstly, by reducing the prevailing outdoor ambient and radiant temperatures, and secondly, by improving the overall thermal comfort experienced in these areas.

To scrutinize the efficacy of the proposed configurations, an in-depth analysis was conducted specifically on two types of streets within the locality. The streets chosen for this assessment were categorized into a secondary street, denoted as S1, and a main street, labeled as S2. These street selections were made to ensure a representative sample encompassing different typologies of streets within the area under investigation. By focusing on these streets, the research aimed to gauge how each of the three configurations interacted with, and influenced, the microclimate and thermal environment in different existing configurations.

Figure 8a visually demonstrates the distribution of air temperatures on August 20th at 2:00 p.m., showcasing not only the differences within the street boundaries but also encompassing the entirety of the plot’s microclimate.

The histograms featured in Figure 8b offer a representation of the air temperature characteristics for the different configurations. Notably, the maximum air temperature observed in the base configuration B1 reached 42.5°C. With the introduction of the proposed cantilever configurations, a gradual improvement, particularly as the extent of the projections increased. This improvement culminated in an average reduction

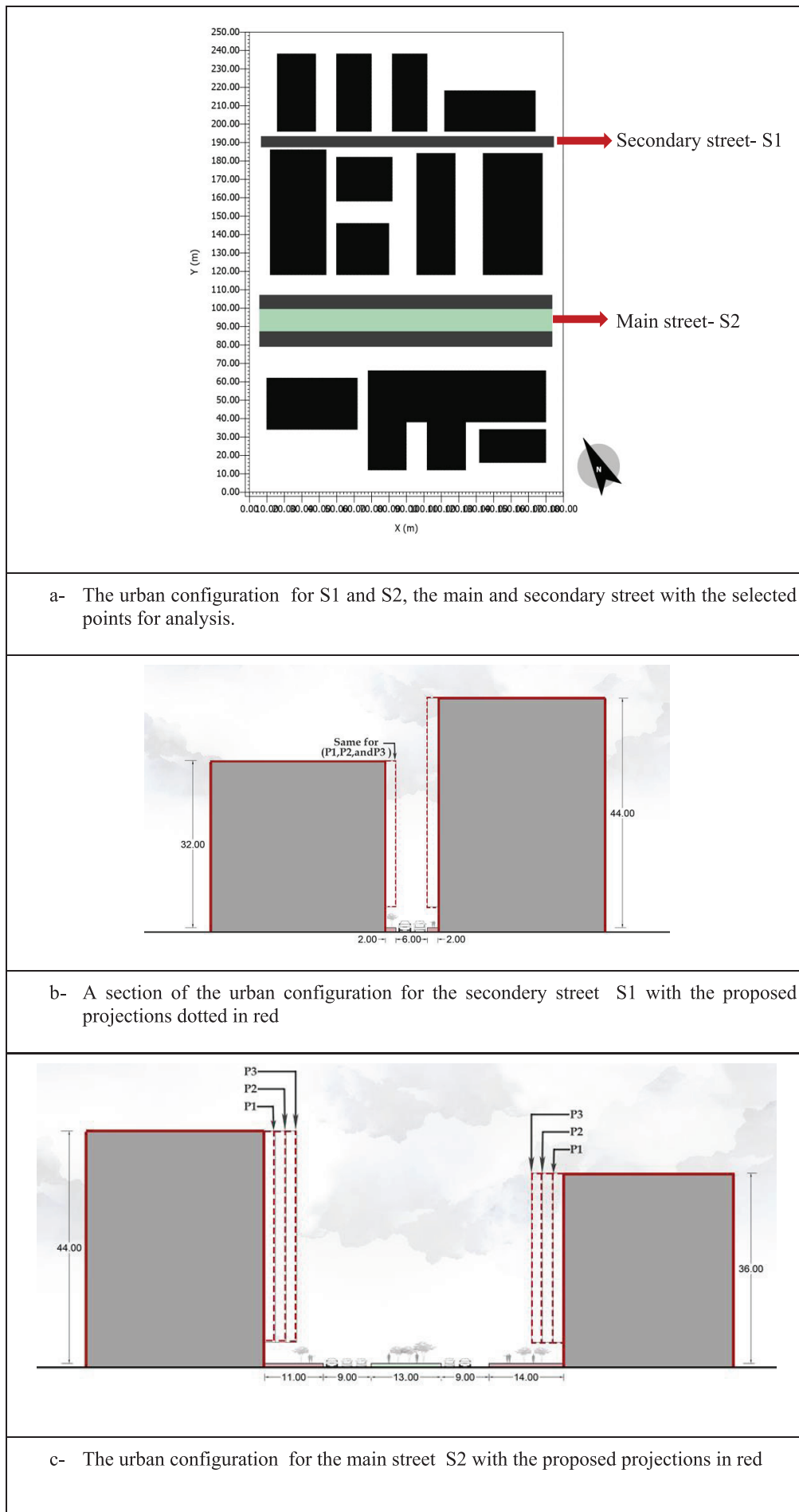


Figure 7 Illustration showing the location and projections for each of the two streets S1 and S2.

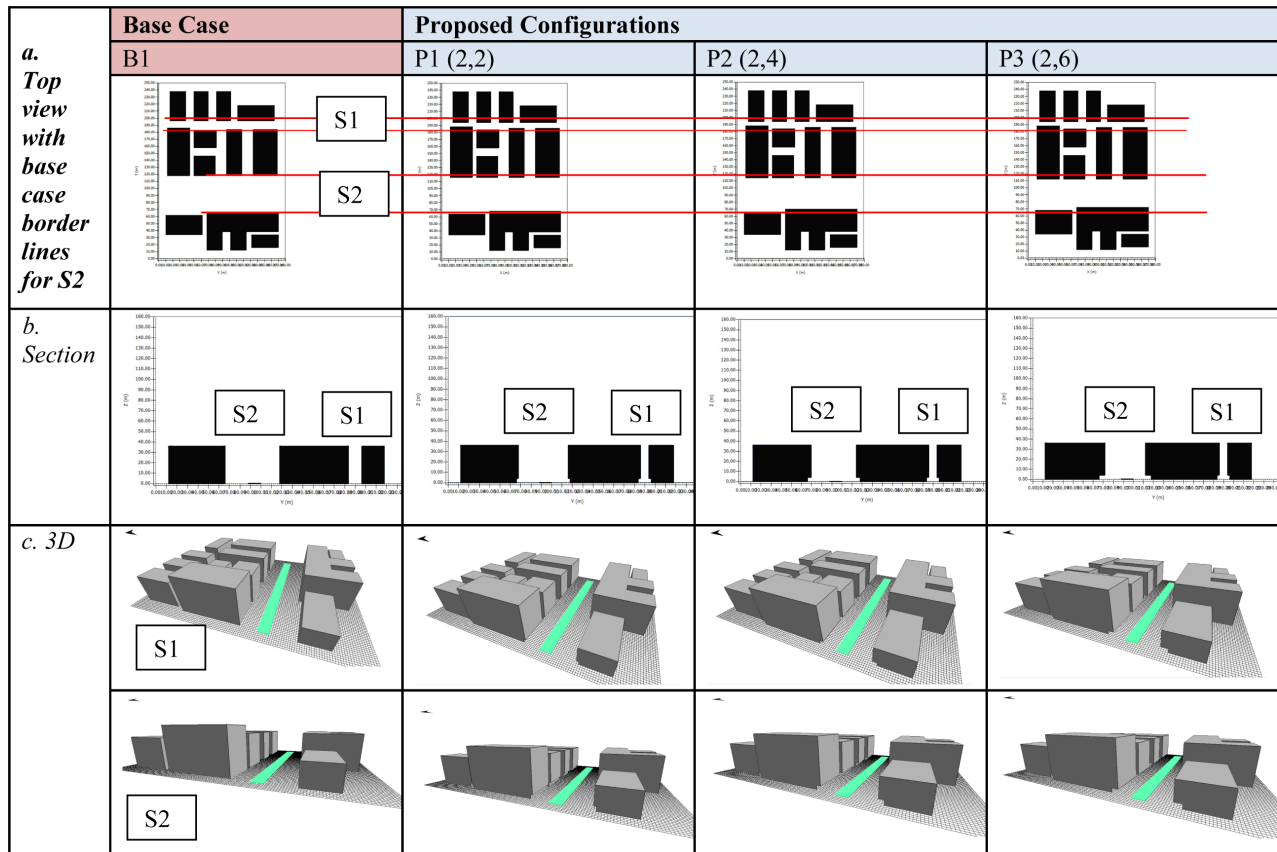


Table 2 Case study- Deira district proposed building projection configurations P1, P2, and P3.

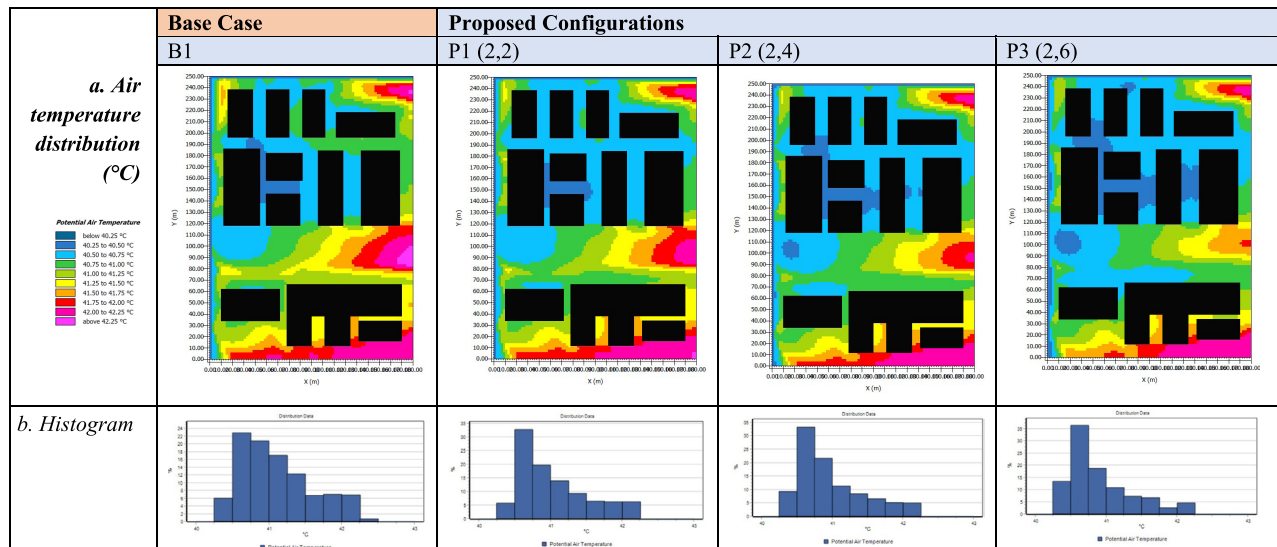


Figure 8 Air temperature distribution on August 20 at 2:00 p.m. for the Base case and the proposed group of configurations.

of about 2.0°C in the P3 configuration compared to the base, B1.

Furthermore, the analysis unveiled valuable insights regarding the prevalence of specific temperature levels across the plot. For instance, configuration P3 succeeded in reducing the outdoor air temperature for 4% of the plot area. Additionally, the configurations that featured the lowest air temperature, hovering around 40.5°C, covered a substantial portion of the district. Specifically, P3 managed to encompass 13% of the total district area, while P2 covered 9%, and P1 and B1 each encompassed 6%. This shift toward lower temperatures, especially

in configuration P3, expanded the area experiencing reduced temperatures of 7%.

This notable enhancement in thermal conditions primarily attributed to configuration P3 can be attributed to its design features. Notably, P3 incorporated projections with a span of 6 meters on both sides of S2 and 2 meters on S1. This arrangement led to a more extensive coverage of shaded areas, effectively mitigating solar exposure and reducing air temperatures. The expansive projections facilitated increased shading, offering a plausible explanation for P3's superior performance compared to other configurations.

For a deeper understanding of the variation of the thermal conditions in the streets of the three configurations, 6 points were selected - in the pedestrian lanes- which were A, B, C, D, E, and F for a comparison of the outdoor air temperature as shown in Figure 9.

The recorded data from the six points between 8:00 am to 6:00 pm, the hottest time of the day, further clarified the effect of the building projections, mainly on the sides of the streets on the pedestrian lanes, as seen in Figure 10. The difference was clearer at points B and F than the other points, as at the peak hour at 14:00 at point B-P3(2.6) recorded 40.6°C while it recorded 40.9°C in the base case with a reduction in the air temperature of around 0.3°C. Similarly, point F in P3 recorded 40.8°C while it recorded 41.2°C in the base case with a reduction in the air temperature around 0.4°C as seen in Figure 11. Despite the fact that the reduction in the air temperature was not large, it does contribute to improvement in the thermal comfort on both sides of the streets.

Point F as seen in Figure 12 recorded a clear improvement in air temperature compared to the other points. At the peak hour of 14:00, F recorded a reduction of around 14°C in the mean radiant temperature (MRT), compared to the corresponding F in the base case B1, shown in Figure 13a. That helped improve the PMV reading for thermal comfort by a significant 1.5 on the Envi-met PMV scale out of 8, scale as illustrated in Figure 13b.

Based on the findings of the research, the significant improvement in air temperature and thermal comfort observed at point F can be by several factors:

- **Shading Effect:** Point F is in the second half of a street tunnel, suggesting it benefits from shading provided by the surrounding built environment. Shading helps reduce direct exposure to solar radiation, leading to lower temperatures compared to other points.
- **Orientation:** The orientation of the street, from northwest to southeast, may play a role in increasing the influence of shading point F. This orientation results in limited direct sunlight exposure during peak hours, contributing to cooler temperatures.
- **Microclimate:** Simulating extended shading across the entire sector being studied leads to a cumulative improvement in each of the individual parts.

Overall, the combination of shading, street orientation, and microclimate conditions at point F contributes to the observed improvement in air temperature and thermal comfort. These factors demonstrate the complex interplay between urban design elements and environmental factors in shaping thermal conditions in urban environments.

Projecting the buildings towards the street resulted in a reduced sky view factor, limiting the amount of solar

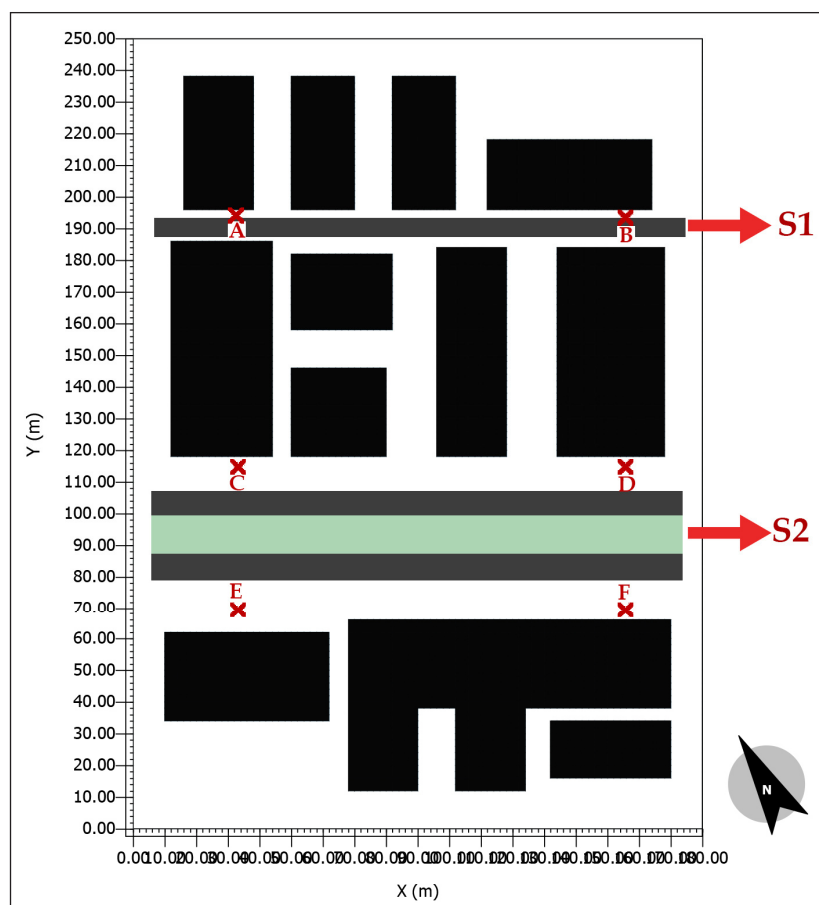


Figure 9 The six points that were selected for comparison of the outdoor air temperature in the two streets S1 and S2.

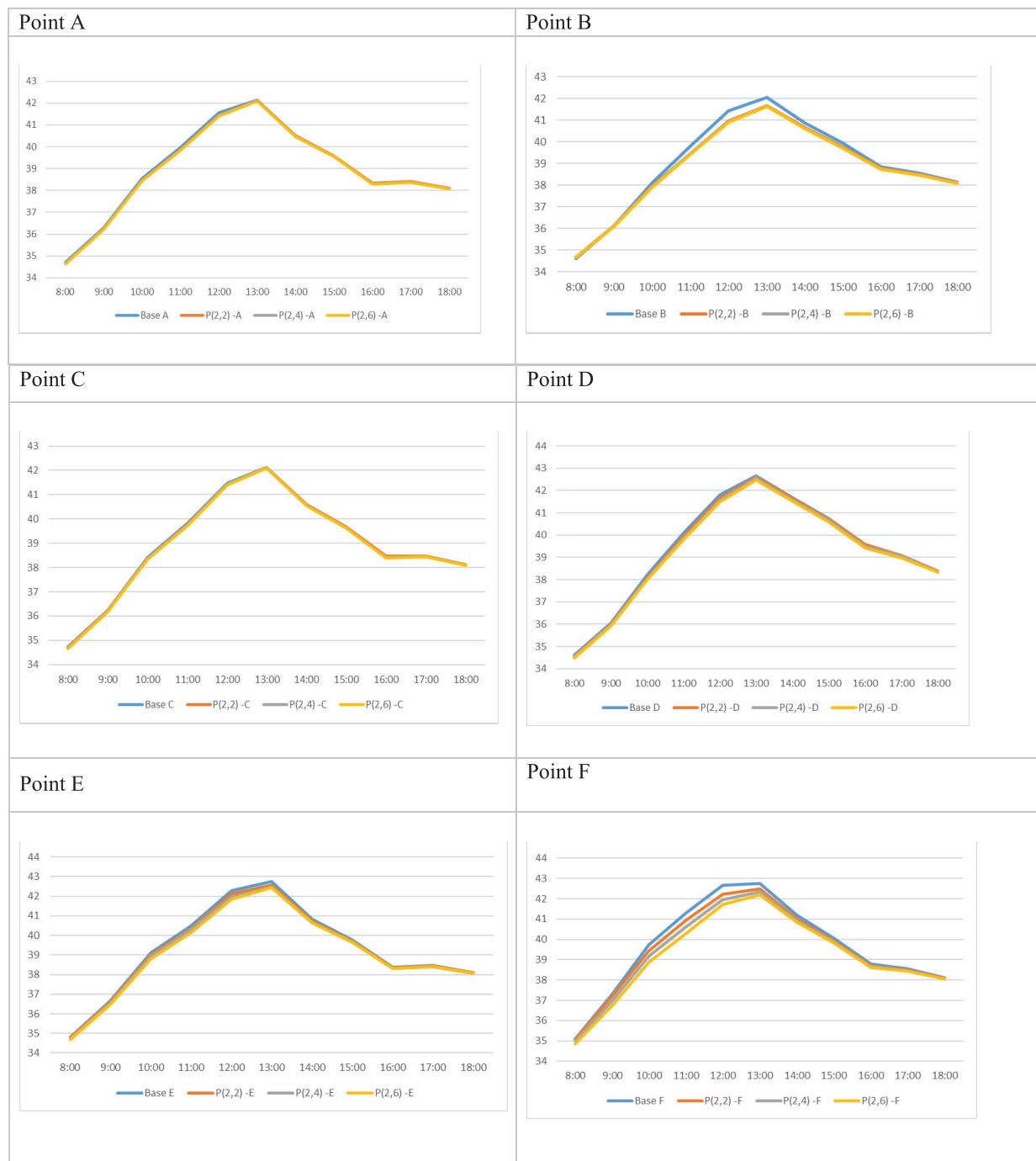


Figure 10 Air temperature from 8:00 am to 6:00 pm for the Base case and the proposed configurations.

radiation reaching the ground and urban building masses in the specific district. With the height of buildings fixed in the base case as well as the proposed configurations, P3 with the most projections on the sides of the streets, mainly the main street S2 with 6 m from each, led to a lower sky view factor and lesser solar radiation hitting the ground of the street and walls of the buildings, which increased the shading and decreased the air temperature; refer to Figure 14. The sky view factor (SVF) represents the proportion of the visible sky area to all observable areas from a specific location on the ground. It has a significant influence on air temperature, aligning with previous studies by (Ahmadi Venhari, Tenpierik and Taleghani, 2019) and (Salameh, Elkhazindar and Touqan,

2023). These studies have demonstrated that reducing the SVF can effectively lower daytime air temperatures in urban areas.

An analysis of the predicted mean vote (PMV) was also performed using ENVI-met as an indicator for the effect of the buildings' projections on the pedestrian lanes' outdoor thermal comfort. For the purposes of the simulation in ENVI-met, the conventional PMV model was built for a person who is 35 years old, 1.75 meters tall, weighs 75 kg, and walks at a pace of 4 kph (ENVI-met, 2023). ENVI-met uses a Windows tool named Leonardo to display graphical results. Leonardo uses a 0.4 m unit to display heights starting at 0.2 m. Consequently, a height of 1.8 m was chosen to measure the PMV values since it



Figure 11 Air temperature at 2:00 pm for the selected points for the Base case and the proposed group configurations.

is the height closest to 1.75 m, as used by (Detommaso et al., 2021).

In Figure 15a, the Predicted Mean Vote (PMV) distribution can be seen and it shows that P3, the configuration with maximum projections, resulted in the best PMV of all the cases at 14:00 p.m. Figure 15b shows that although the simulated mean vote distributions for each configuration was greater than the Envi-met range of -4 to $+4$ over the day, the PMV for the P3 configuration was still able to reduce the spread of the maximum PMV reading, which was 8.5, to a small area of the neighborhood that represents only 0.5% of the

district's area compared to 2% for the base case B1, at the hottest time of the day. P3 also resulted in increasing the spread of the minimum PMV reading, which was 6, to 8.5% of district's area compared to 0.3% for the base case B1. This shows that the P3 configuration provided the best thermal comfort during the period of peak air temperature when compared to the P1, P2, and B1 configurations.

After calculating the average PMV for all the cells for both the basic case and best case P3 districts based on their related histograms, it was found that the P3 recorded about a 0.7 reduction on the PMV scale

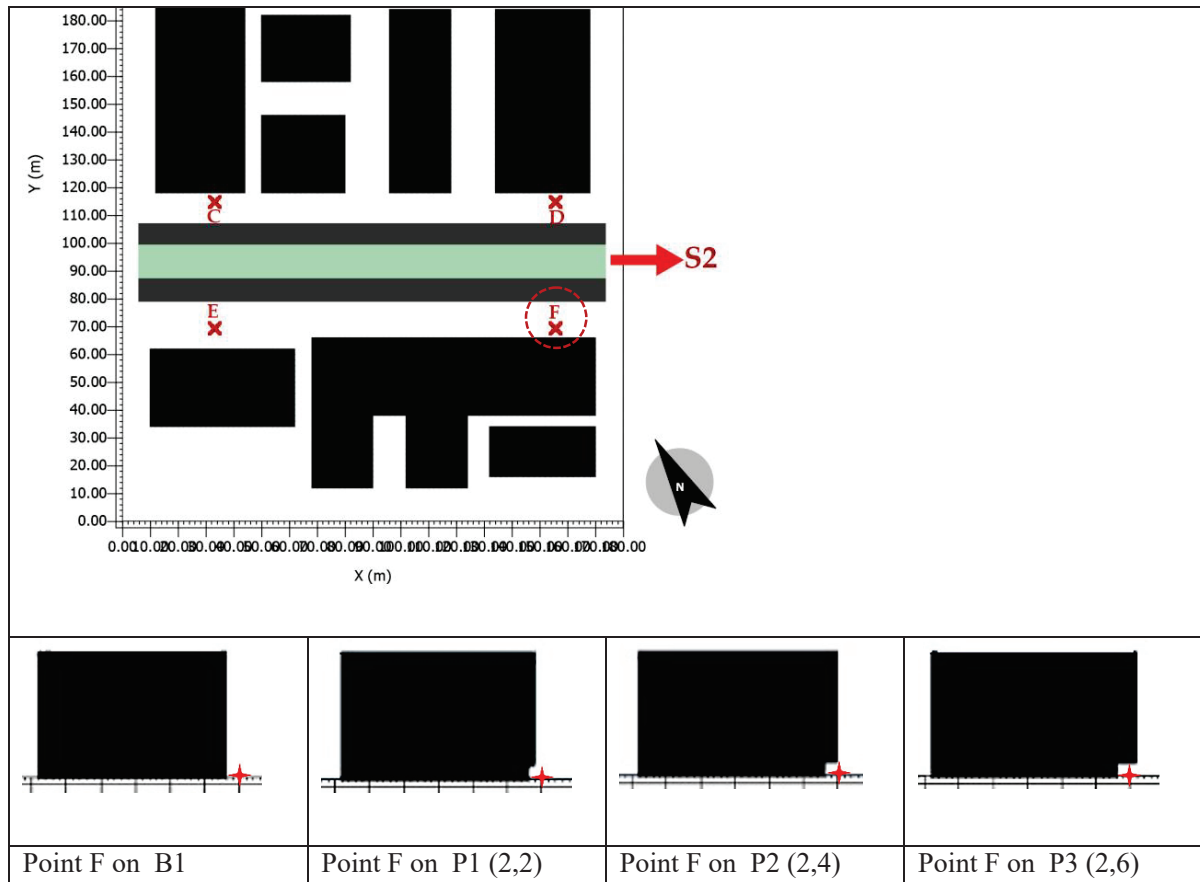


Figure 12 Point F in basic scenario and in the proposed three scenarios.

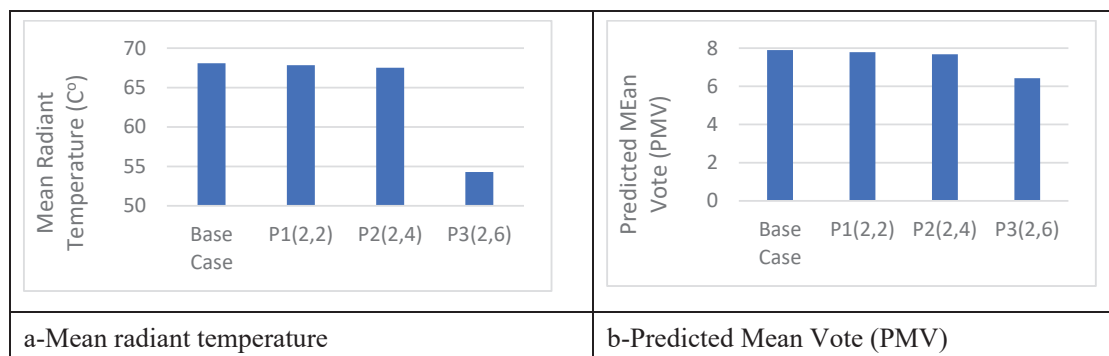


Figure 13 Mean radiant temperature and Predicted Mean Vote (PMV) for Point F.

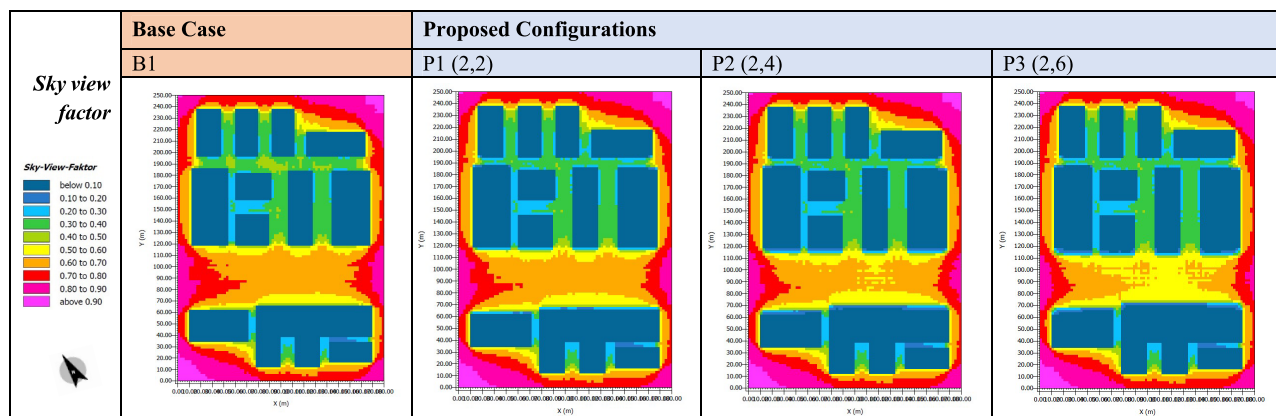


Figure 14 Sky view factor results for the Base case and the two group configurations on August 20 at 2:00 p.m.

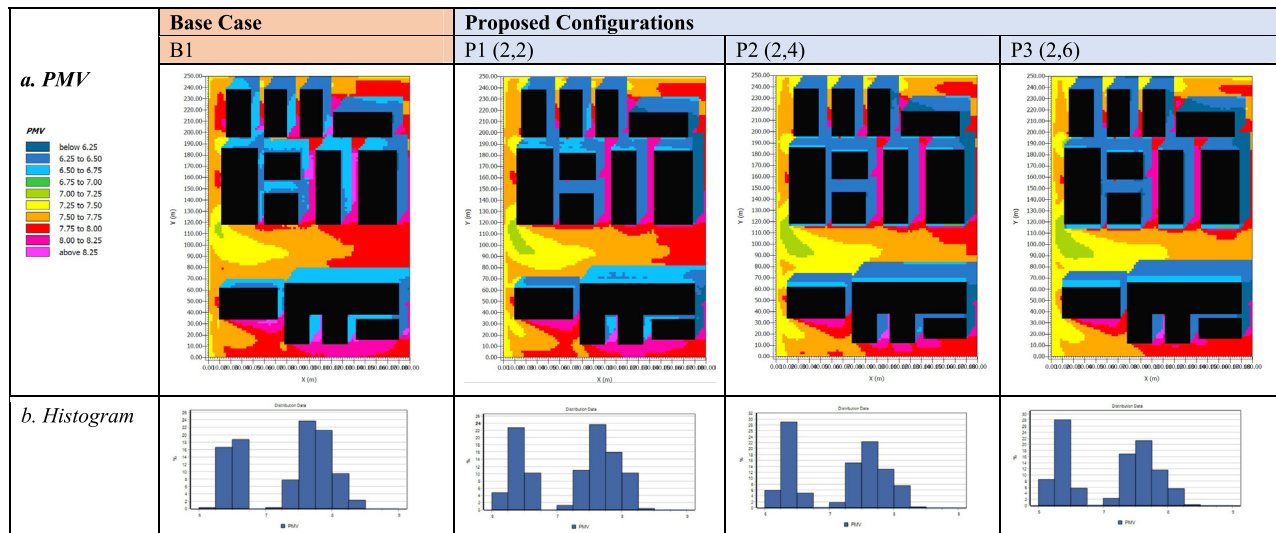


Figure 15 PMV results for the Base case and the proposed configurations on August 20 at 2:00 p.m.

compared to the B1. This can be explained by the fact that P3 had the lowest SVF values, which improved the thermal conditions in the street's pedestrian lanes compared to the other cases. Ahmedi et al (Ahmadi Venhari, Tenperik and Taleghani, 2019), and Salameh et al (Salameh, Elkhazindar and Touqan, 2023) also mentioned that lower SVF readings can increase user comfort in their studies.

For all occurrences, the PMV values were influenced by the Mean Radiant Temperature (MRT) component of the universal thermal climate index (UTCI). The ambient temperature, mean radiant temperature, wind speed, and relative humidity are some of these elements. With the best PMV readings, the MRT in the P3 configuration reported a maximum reading of 69°C for 1% of the district's area and a minimum MRT of 5.3°C for 8% of the district's area at 2:00 p.m., while the basic case, B1, recorded a higher maximum MRT reading of 70°C for 2% of the district's area and minimum MRT 54°C for 4% of the district's area at the same time, as seen in Figure 16a and 16b. After calculating the average MRT for all the cells for the basic case and best case P3 districts based on their related histograms, it was found that the P3 recorded about 6.0°C reduction compared to the B1.

Figure 17a and b compares the average wind speeds for the various configurations and reveals that despite the changes in wind speed were slight, the P3 configuration, with lower readings for MRT and PMV had the lowest average wind speed at 2:00 pm. Thus, the wind speed didn't affect the PMV as the MRT did. Furthermore, the wind at that time was relatively hot which also explains how it did not help in improving the thermal comfort.

The data for relative humidity is shown in Figure 18a and b again at 2:00 p.m. in the P3 configuration, which had the best PMV measurements. The figures were slightly higher than the basic case, as the lowest relative

humidity reading for P3 was 29% for 2% of the districts area, while the lowest reading for the basic case was 28% for 1% of the districts' area. When comparing the second lowest readings, the P3 had 30% relative humidity for 6% of the districts area, while for the basic case the relative humidity was 29% for 3% of the districts area. This means that the P3 configuration which had the best PMV and lowest air temperature, recorded slightly lower readings for the wind speed and higher readings for the relative humidity. That agrees with Salameh (Salameh and Touqan, 2022) where the better PMV readings were related to higher readings of the relative humidity plus lower readings of MRT more than they did the wind speed.

While the current study references previous research by Salameh and Touqan (2022, 2023) and Salameh, Mushtaha, and El Khazindar (2023) regarding the shading effect on thermal performance in old and new districts and heritage areas, respectively, it is important to note significant differences between these studies and the current research. One notable distinction is the focus on modern novel districts insights specific to modern urban environments characterized by high-rise buildings, whereas the referenced studies primarily examined shading effects in older or heritage districts with different architectural characteristics. The second is that this paper examines hypothetical situations that contravene current building regulations that do not allow projections to extend beyond the plot limits.

4. CONCLUSION

The research indicates that the implementation of extended cantilever building shading beyond the plot limits can effectively decrease air temperatures and enhance thermal comfort in street-level walking areas

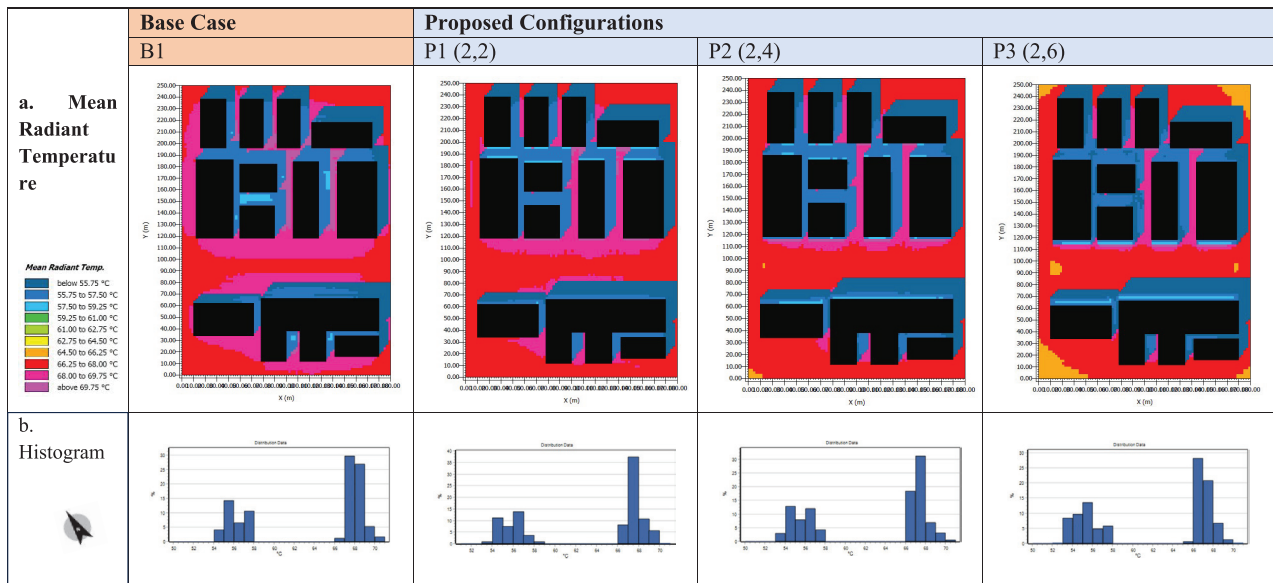


Figure 16 Mean radiant temperature distribution on August 20 at 2:00 p.m. for the Base case and the proposed group configurations.

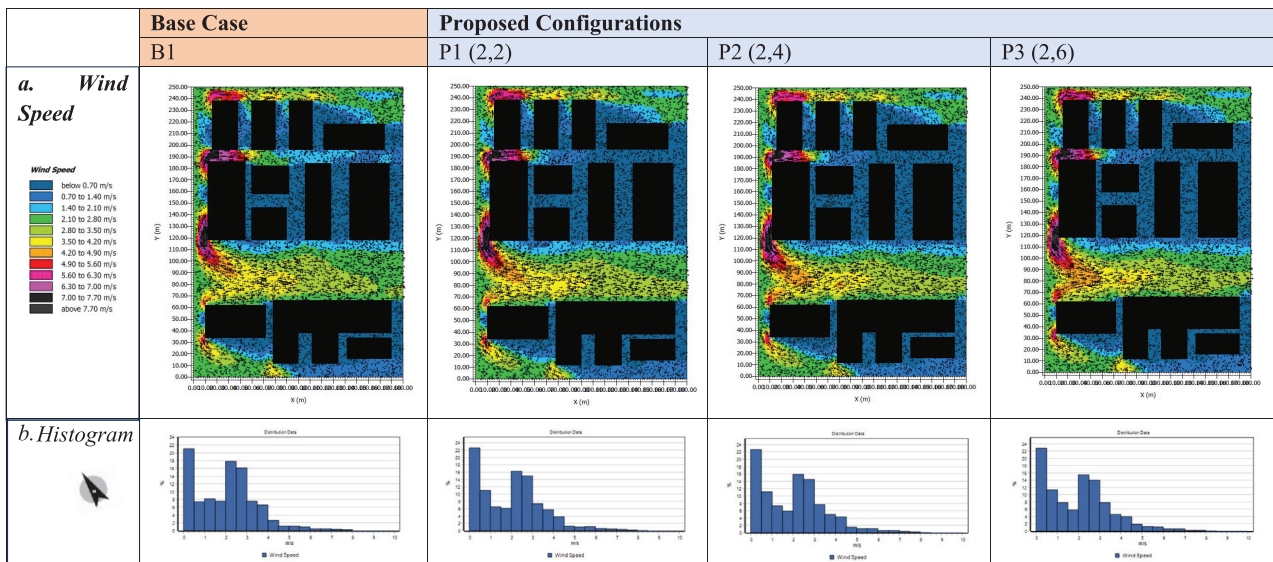


Figure 17 Wind speed distribution on August 20 at 2:00 p.m. for the Base case and the proposed group configurations.

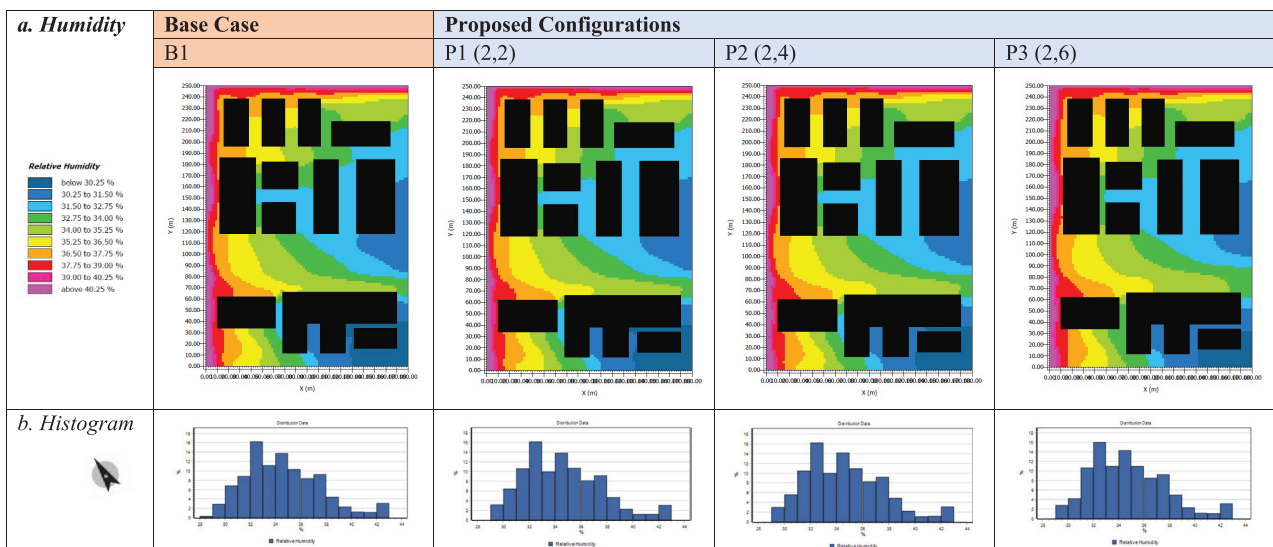


Figure 18 Relative humidity distribution on August 20 at 2:00 p.m. for the Base case and the proposed group configurations.

to a significant degree. These findings provide valuable insights for architects, urban planners, and policymakers in hot arid regions, aiming to improve human comfort and decrease cooling energy demands, and increase walkability to a longer period of the year. Specifically, the study examined different projection designs in Dubai, UAE, revealing that configuration P3 with wider span projections demonstrated the most significant decrease in air temperature and the highest levels of thermal comfort. Despite the Predicted Mean Vote (PMV) distributions being hotter than desired, P3 outperformed other configurations during peak air temperature periods, attributing its success to lower Sky View Factor (SVF) values leading to improved thermal conditions.

The data indicated that while the three suggested configurations recorded a maximum air temperature of 42.25°C, it was observed in 4% of the district's area for P3, 4.5% and 7% for P2 and P1 respectively. Conversely, the configuration with the lowest air temperature was about 40.5°C, observed in 13% of the district's area for P3, 9% for P2, 6% for P1, and 6% for B1 as well. Consequently, P3 showed a 7% increase in the district's area with cooler air temperature due to its wider span projections, resulting in more shaded regions and cooler air temperatures.

Although the Predicted Mean Vote (PMV) distributions for all configurations was consistently hotter than the desired range, the PMV distribution for P3, with the highest projections, exhibited the best performance at 2:00 p.m. compared to the base example B1. During this time, the P3 configuration was able to lower the district's area with the maximum PMV to 0.5%, while increasing the district's area with the lowest PMV to 8.5%, compared to B1's 2% and 0.3% respectively. Thus, P3 offered the best thermal comfort during peak air temperature compared to other configurations, attributed to its lower Sky View Factor (SVF) values leading to improved thermal conditions in street pedestrian lanes.

5. LIMITATIONS AND RECOMMENDATIONS FOR FUTURE STUDIES

While this research provides valuable insights into shading designs for hot arid climates, further investigation into optimizing shading designs for various climates is necessary. Additionally, exploration of additional measures to enhance thermal comfort in urban areas during hot weather is crucial. Although walking under shading systems was found to be less thermally stressful than walking in the sun during the simulated summer period, it was not entirely comfortable. Moreover, it's important to consider the potential extra heat or cost associated with implementing different types of shading systems, including analyzing material properties,

construction methods, and maintenance requirements. From an economic point of view, increasing the projection limit actually increases the value of the land as the total built up area that is possible in each plot would increase significantly.

These limitations underscore the need for comprehensive research to address thermal comfort challenges in urban environments. While the study offers valuable guidance for architects, urban planners, and policymakers in hot arid regions, additional measures such as incorporating greenery or increasing water availability may be necessary to further enhance comfort as mentioned by previous studies. Further exploration of shading's impact on thermal comfort in street walking areas is warranted to extend the period during which residents can comfortably traverse urban streets. By addressing these limitations, future research can provide tailored solutions to optimize building and street designs, ultimately enhancing human comfort and reducing the energy demands of cooling systems.

Finally future studies can explore variations in municipality regulations and collaborate with urban planners to review setback allowances for the span for projections. And to investigate adaptive reuse of existing buildings for shading solutions and advocate for pilot projects to showcase benefits. Foster public awareness on sustainable urban environments.

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COMPETING INTERESTS

The authors have no competing interests to declare. All Authors participated in all stages of the research from the concept, methodology, draft and final copy.

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