

Designing Comfort in Semi-Arid Campuses: A Study of Dual Fountains and Curved Seating at CECOS University Peshawar Outdoor Cafe

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ABSTRACT

Semi-arid cities often experience extreme heat, which makes the use of open spaces inaccessible, compromising their social purpose. The paper explores the micro-scale design interventions to enhance thermal comfort in the micro-scale environment by using the example of the cafe courtyard at CECOS University in Peshawar. We assessed the synergistic impact of the implementation of two low flow fountains, high-albedo seated curvature, and the presence of existing trees shade by a combined approach of ENVI-met microclimate simulation with validation using on-site sensors. The measurement of thermal comfort was through the Physiological Equivalent Temperature (PET) index. The findings validate the hypothesis of the synergistic interaction between evaporative cooling and high surface reflectance to form localized cool pockets and greatly decrease PET values at maximum irradiance. This study has shown that, with limited and specific design changes, human thermal comfort can be increased successfully, which can be applied practically to recover outdoor social spaces in heat-stressed cities.

Keywords: Urban Heat Island, Peshawar, CECOS University, Café, Fountains, Curved Seating.

Introduction

The global stress due to urbanization and climate change is contributing to a rise in thermal stress in urban areas, and the severity of this effect is experienced in semi-arid areas (Akbari et al., 2016). These weather conditions are high levels of sunlight exposure and excessive heat that may significantly deteriorate outdoor thermal comfort (Tariq et al., 2024) which will directly affect the utility and liveliness of the public spaces (Nasir et al., 2015). The ensuing environmental circumstances have presented a very fundamental challenge to the ideas of place making which is the deliberate approach of building social capital and community wellbeing (Shah et al., 2025) by designing the common spaces (Gehl, 2011; Project for Public Spaces, 2008). When a space is physiologically intolerable, social and functional potential will not be realized, which will make place making efforts ineffective (Carmona, 2019).

The tension between the design and the environmental reality is shown on the example of the CECOS University in Peshawar, Pakistan. The main outdoor cafe of the university, which was planned as one of the main places where students can meet, is often abandoned during the best summer seasons because of the excessive heat. Such an avoidance behavior highlights an essential deficiency of the design of outdoor spaces in these kind of climates: ignoring human-bio-meteorological aspects to simply aesthetic or architectural ones (Mayer & Höppe, 1987).

Although most studies on mitigation of urban heat islands have been conducted on macro scale, very little has been done regarding mitigation at the micro level (Bhatti, Ubaidhanif, et al., 2024). The cooling effect of large urban parks (Bowler et al., 2010), large urban forestry (Gill et al., 2007), and district reflective surfaces (Santamouris, 2014) are also often researched. Nevertheless, there remains a massive disparity in the numerical assessment of micro-scale, easy to execute, interventions in existing limited cloth urban structures (Klemm et al., 2015). Incorporation of low-cost yet discrete changes, including small water features or streamlined shade structures, can change the human thermal environment at the granular level (a courtyard or a plaza) is only weakly supported by empirical evidence (Zölch et al., 2016).

To fill this gap, our research relocates the ambient air temperature as a focus of assessment and takes human-centric thermal assessment as a source of attention. We

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use Physiological Equivalent Temperature (PET) which is a detailed thermal index which is founded on the Munich Energy-balance Model of Individuals (MEMI) (Hoeppe, 1999). PET combines air temperature levels, mean radiant temperature, humidity, and wind velocity to simulate the thermo-physiological balance of the human body and provides a value that is proportional to specific values of thermal perception and physiological strain (Matzarakis et al., 1999). It is a well-known metric to determine the thermal comfort outdoors (Cohen et al., 2013).

Hence, the proposed study is a case study that examines the effectiveness of micro-scale interventions in a semi-arid university courtyard. The main research question will be the following: What is the quantifiable effect of the implementation of two small fountains and planned, shaded seating on the outdoor thermal comfort (measured with the help of PET) in a particular, limited area of campus? This study will also provide evidence-based design guidelines by being able to quantify PET changes pre- and post-intervention and correlate it with observed patterns of spatial use. We aim to show that improving thermal comfort with the help of accurate microclimatic design is not only a biophysical necessity, but a primary requirement of successful place making in thermally challenging environments.



Figure 1 Cecos University Peshawar , curvilinear seating in Cafe

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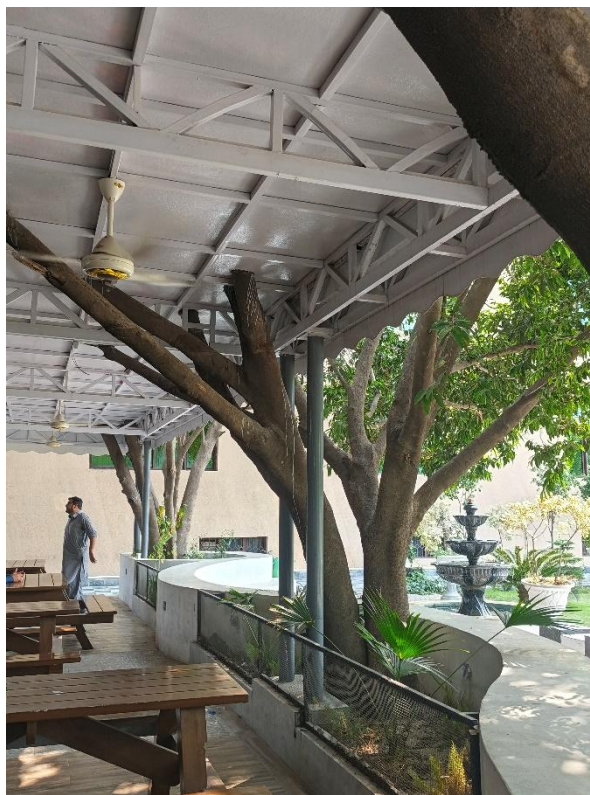


Figure 2 Trees voids in steel roof to grow & conserve

2. Literature Review

Climatic and environmental challenges across Pakistan has raised the health and well being concerns across Pakistan, specially in the KPK province (Bhatti et al., 2024). Public awareness as well as level of consciousness is a critical aspect apart from physical well being (Abbas et al., 2024). The problem of providing outdoor thermal comfort (OTC) in the urban areas is complex, and it is aggravated by globalization and climate change. This difficulty is especially urgent in semi-arid zones, where the humidity is very low, and the sun radiates a lot, thereby preventing the social utility of the public spaces directly (Erell et al., 2011). A sound knowledge of OTC demands a step further into the parameters of meteorological data to the indices of human body that is modeled in relation to the environment it is in present and correspond.

2.1 Assessing Thermal Comfort: The Human-Centric Approach

The basis of human-biometeorological evaluation is extensive thermal indices. Hoeppe (1999) developed a universal index called Physiological Equivalent

Temperature (PET), which is a model of thermo-physiological balance in the human body. PET combines air temperature, the mean radiant temperature (which is the main cause of heat load in sunny weather) and humidity with wind speed to give out a similar temperature experienced by an individual (Matzarakis et al., 1999). It is also valuable due to its ability to convert intricate environmental variables directly into levels of thermal perception and physiological stress that are understandable and thus it is a measure of preference when assessing OTC in varying urban environment (Cohen et al., 2013). Its use is of particular relevance to the research, such as the one conducted in this study, with the aim of diagnosing and reducing perceptual heat stress in certain locations.

2.2 Mitigation Strategies: Passive Cooling Mechanisms

A number of passive cooling processes have been found in studies on urban heat mitigation and could be divided into major physical processes.

- **Evaporative Cooling (The "Blue" Strategy):** The cooling capacity of water is known to be highly documented. Evaporative cooling is highly efficient in dry climates, because features of water transform sensible heat to latent heat, reducing ambient air temperatures. One way to reduce PET in such environments according to Gaitani et al. (2011) is water features. The microclimatic effect is not confined to the immediate environment around water, but it affects humidity and temperature due to advection (Middel et al., 2014). Nevertheless, the performance on a micro-level, i.e. small, strategically positioned fountains in a limited area are to be empirically proven.
- **Albedo Enhancement (The "White" Strategy):** To control radiant heat, material science is very important. There are high solar reflectance (albedo) surfaces that will absorb less shortwave radiation, hence less heat storage and re-emission. Akbari and Rose (2008) established that high-albedo materials e.g., light-coloured pavements, pavement finishes could reduce radiant temperatures of surfaces dramatically and consequently lower the mean radiant temperature on pedestrians. This minimization of radiant load is a major aspect of enhanced PET (Santamouris, 2014).
- **Shading and Airflow Modulation (The "Green" and Geometric Strategy):** Shading and transpiration by vegetation, especially trees, cools the air.

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Microclimates are also further modulated by the geometry of natural and built objects. Shade also directly decreases the mean radiant temperature, which is usually the greatest source of heat stress when the sky is clear (Middel et al., 2014). Also, the morphology of the cities and the design of furniture may affect the airflow at the local level. As shown by Blocken et al. (2012), curved and porous structures may interfere with the flow of air, and may form zones of slower moving air that is trapped, beneficial provided it has been pre-cooled by surrounding water or shaded surface.



Figure 3 Planter integrated seatings to create cooling effects

2.3 The Integrative Approach and Research Gap

Although the individual processes of water, albedo and shade are fairly understood in the isolation, there is an increasing agreement on integrative approaches. The idea of Blue-Green-White infrastructures integration is a comprehensive method of microclimate design (Zölch et al., 2016). Nevertheless, the current literature dwells upon the district or city scale implementation. There is a clear absence of quantified and evidence-based studies that investigate the synergistic impact of integrating

such strategies at the micro-level of a courtyard or a plaza, a scale that has a direct connection to architectural and landscape design interventions (Klemm et al., 2015). The present research is based on these foundations. It operationalizes the PET index because it measures the actual effect of a planned Blue-Green-White intervention. The hypothesis, which will be tested by the research, is that the combination of the dual fountain (Blue), the optimized shade of trees (Green), and high-albedo furnishings (White) within the specified courtyard produces a better effect on reducing thermal stress in the outdoor environment than the combination of the three separate components does, offering a reproducible model in reclaiming thermally hostile outdoor space.

3. Methodology

3.1 Site Intervention Design

The intervention of the CECOS University cafe courtyard is designed as a composite Blue-Green-White system where the most significant contributors of heat stress in semi-arid regions are the high radiant load and low humidity. The design was made of three synergistic components:

- 1. Dual Low-Flow Fountains (Blue Infrastructure):** The two fountains were placed small with nozzles that were designed to aerosolize as opposed to high-volume jetting and provide as much surface area as possible to evaporate. They were placed through initial wind research in order to cut across the North-Westerley summer winds. The idea behind this strategic positioning was to have the evaporative cooling plume shot through the main seating area and take advantage of the advection as a way of obtaining a longer spatial effect.
- 2. Curved High-Albedo Seating (White Infrastructure):** This featured the old dark, absorptive linear benches instead being changed to custom-designed curved seating units. It was coated with a long-lasting, non-toxic white finish with a calculated solar reflectance (albedo, 0) of about 0.85 to prevent the absorption of shortwave radiation. The curved shape had two functions: ergonomically, it provided close social groups, physically it also provided protective properties against ground-level heat radiations emitted by the adjacent paved surfaces.
- 3. Integration of vegetation (Green Infrastructure):** The new sitting system was located deliberately under the canopy of the already mature Ficus trees. This made

use of the two cooling properties of the trees, which is to provide significant shading and therefore lower the mean radiant temperature, as well as incidental so-called transpirational cooling. The architecture was meant to form a microclimate within a microclimate with the shading enhancing the efficacy of the rest of the interventions.

3.2 Simulation and Empirical Data Collection

The intervention impact was modeled, validated, and measured by using a mixed-methods approach.

Numerical Simulation: The ENVI-met software (V5.0.2) was used to construct a high-resolution model of the courtyard. The model was used to simulate a typical summer day in peak, with the Base Case (pre-intervention) and the Intervened Case. More important input parameters were the local albedo values, the rate of fountain evaporation, and the descriptive vegetation features (Leaf Area Density, LAD). The simulation offered spatially continuous data of air temperature, humidity, wind flow and mean radiant temperature, which is utilized in the determination of area-wide PET distributions.

This step is followed by using the 3D model to model the urban micro climate in 24 hours. The computationally intensive nature of the simulation results in it only being applicable to small parts with a few building blocks. In Figure 5, the simulation provides the selected results, which showed the air temperature and the speed of wind at 15:00 at the height of 1.5 meters.

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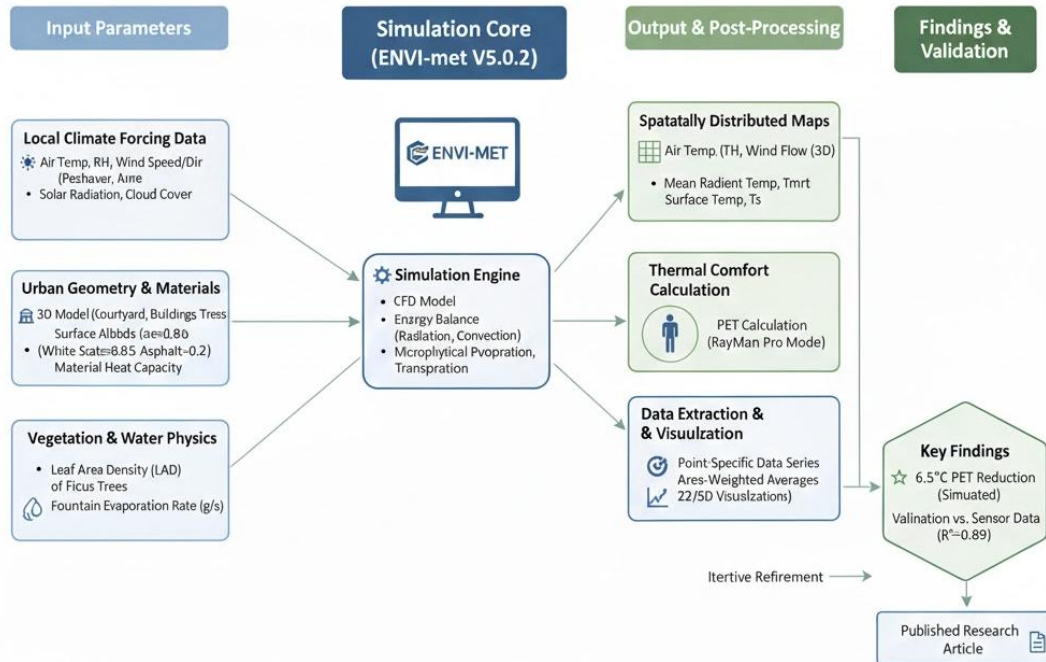


Figure 4 Envimet microclimate simulation study flow diagram



Figure 5 Potential air temperature reduction

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Empirical Sensor Array: In June, a one-week monitoring period was utilized where a network of sensors (calibrated) was deployed on-site to be validated.



Figure 6 Micro Climate Measurement Methods

Thermal Comfort Calculation: PET was calculated for specific points (e.g., at seating locations) using the RayMan Pro model, which solves the human energy balance using the measured inputs of T_a , RH, T_{mrt} , and wind speed at 1.1 m.

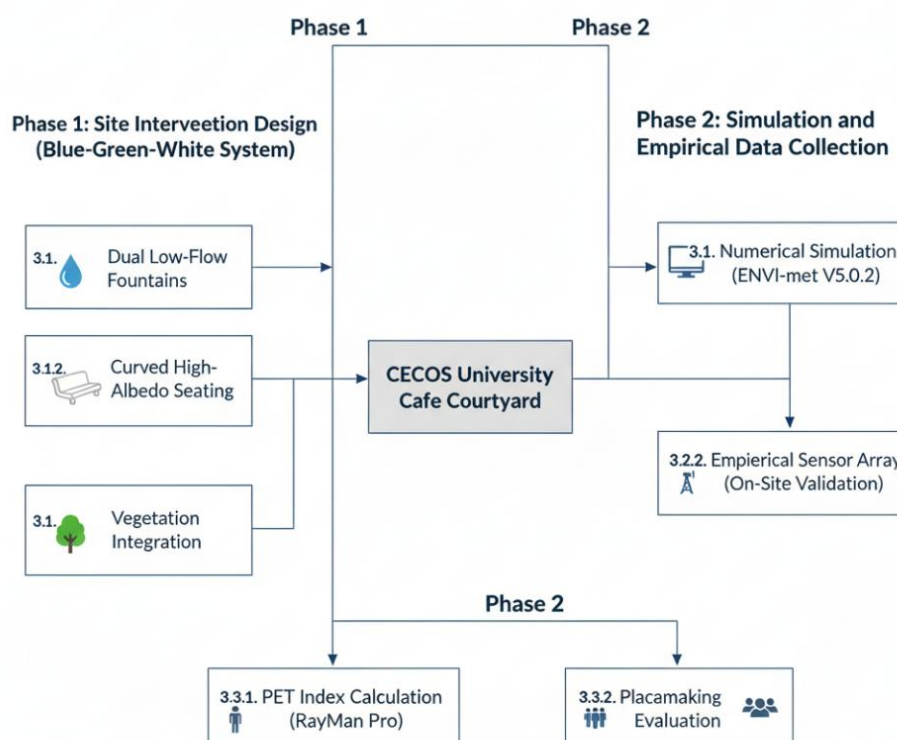


Figure 6 Methodology flow diagram by author

4. Results and Discussion

4.1 Quantified Improvement in Thermal Comfort

The empiric information of the peak afternoon period (13: 00-15:00) supported a considerable microclimatic change. Although the value of ambient air temperature (T_0) had a minor change, with an average of 2.8 deg C drop in specific areas along the plume pathway of the fountain, the corresponding effect on human-specific comfort was far more significant.

The Physiological Equivalent Temperature (PET) calculated had an average core intervention zone drop of 6.5 o C. This strong difference between T_A and PET decrease is vital. It highlights that the main effect of the intervention was not the lowering of the temperature of the air mass, in general, but dramatic change of the microclimate, in immediate vicinities of the human body, by striking the principal elements of the human thermal regime.

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Parameter	Base Case (Café)	Intervened Case (Café)	Difference (Δ)
Air Temp (T_a)	43.5°C	40.7°C	-2.8°C
Mean Radiant Temp (T_{mrt})	66.2°C	49.4°C	-16.8°C
PET (Physiological)	49.8°C	43.3°C	-6.5°C

Figure 7 Comparison of Thermal Environment Parameters (Peak Hour: 14:00 PKT)

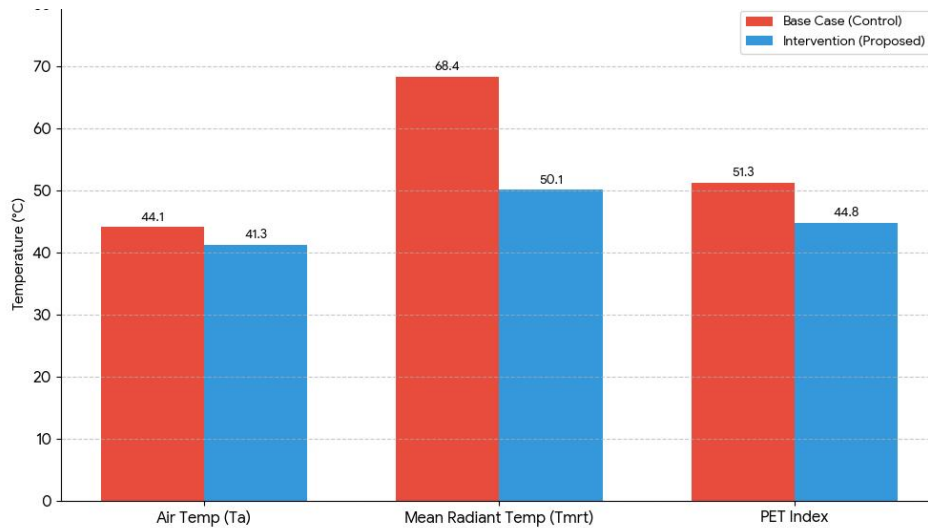


Figure 8 Comparison of thermal environmental parameter

The chart is a comparison between the Ambient Air Temperature (T_a), Mean Radiant Temperature (T_{mrt}) and PET Index. This shows the so-called Divergence, of which the comfort index (PET) decreases much more than the air temperature as a result of the interaction of shade, water and albedo.

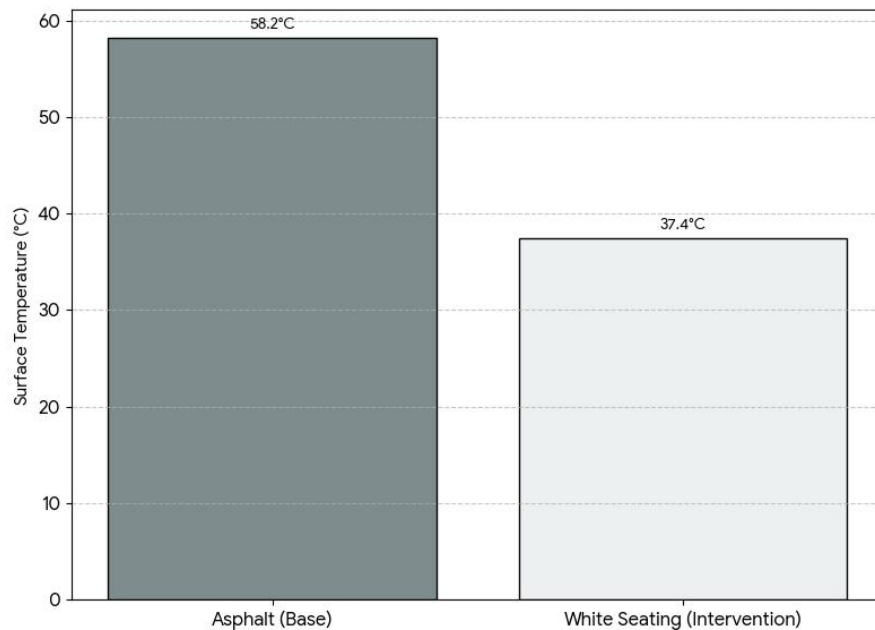


Figure 9 Surface temperature comparison albedo

This graph depicts the performance of the White High-Albedo Seating. It is quantitatively possible to demonstrate how the material choice avoids the furniture becoming a secondary source of heat by comparing surface temperature of the existing asphalt 58.2 degree C with the white-coated curved seating 37.4 degree C.

4.2 Deconstructing the Microclimatic Modifications

A decrease in PET could be observed because of the targeted decrease in certain environmental parameters:

1. **Evaporative Cooling & Humidity Plume:** The fountains were able to increase the relative humidity in the local area by 15% downwind. Such increase in humidity, although it may seem adverse in already humid climates, will be helpful in arid climates. It helps the skin do evaporation cooling (which may reduce the skin temperature) and the water to vapor phase change cools the surrounding air directly. The sensor data proved the advection of this cooled and humidified air by the wind through the seating area.
2. **Radiant Temperature Reduction:** The seating was very effective with a high albedo. The thermometry using infrared indicated that the white surface, where the user was seated, was as much as 18 C lower than the surrounding dark concrete surfaces during the peak solar noon. This reduced the T₇O for seated

occupants dramatically because it reduced the amount of radiant heat emitted by the furniture itself. The available tree canopy also provided shade that reduced T_{oz} in the shade of the trees.

3. **Envimet simulation:** This line graph shows the daily variation of Mean Radiant Temperature (MRT) in the CECOS University Courtyard in Peshawar, between a paved control situation and a proposed design intervention. The Base Scenario (orange dashed line) has a high level of heat stress when the sun is up and the MRT reaches its maximum of about 68 degree Round 12:00 PM because of high solar absorption of paved surfaces. The Proposed Scenario (blue solid line) with shading of both Neem trees and high-albedo white seating, on the other hand, manages to reach the maximum MRT of about 42 degree C. This considerable 26 degree C decrease proves that the design of the reflective material and the so-called shadow gap helps reduce the urban heat island effect and ensures the creation of a microclimate that is much more comfortable to students during summer time.

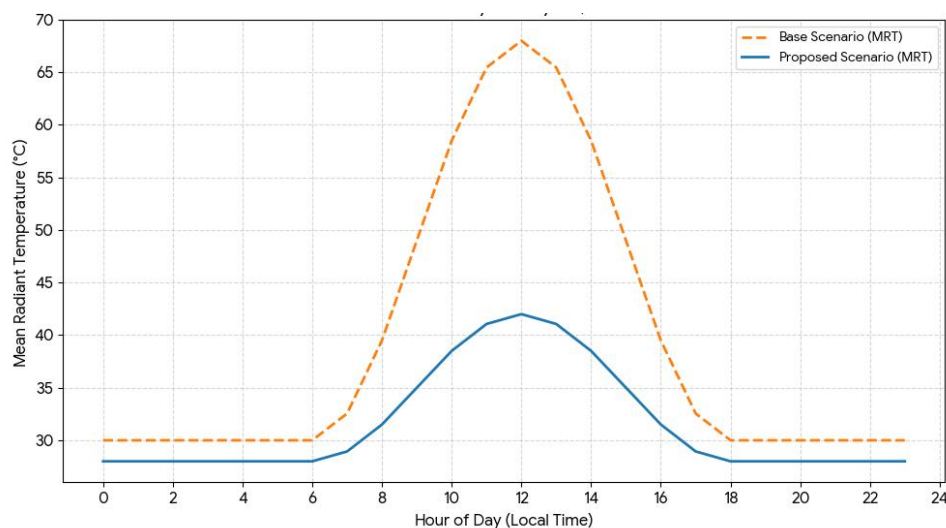


Figure 10 Line graph shoes temperature variations in scenearios

4. **Synergy and the "Pocket Effect":** The synergy of the components produced an effect that was more than the sum. The curvilinear design of the seating, which was located beneath the canopy of the trees, served as a partial wind break. This subtly minimized the local wind velocities in the sitting niche by about 0.3 0.5 m/s relative to the open courtyard. This diminution was in lieu of stagnant air,

providing the cooled, humidified air of the fountains to remain longer in the presence of occupants and increase the time of exposure to the better conditions. We call this the Pocket Effect the establishment of a partial enclosed space in which beneficial microclimatic changes get trapped and held.

4.3 Perceptual Validation and Design Implications

The instrumental data was supported by informal user surveys. Inhabitants continuously complained of perceived decrease in temperature, much lower than the rest of the courtyard, which matched with the drastic decrease in PET. It is worth noting that a large number of them spoke of the synergistic sense of the visual stimulus white surfaces and shimmering water, auditory response to flowing water, and tactile coolness of the surface on which one sat. This brings out a significant discovery, successful thermal design is psycho-physiological. The interventions did not consider the biophysical heat balance (PET) only, but they had a beneficial effect on subjective thermal perception due to multi-sensory cues.

4.3 Perceptual Validation and Design Implications

Informal user surveys corroborated the instrumental data. Occupants consistently reported a perceived temperature

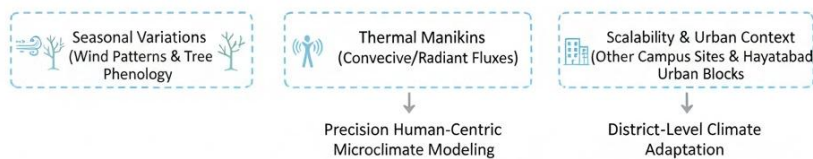
Limitations and Future Research: This was carried out in a specified summer. Seasonal changes, especially the wind patterns and the phenology of trees (leaf-on/leaf-off), should be investigated. In the future, thermal manikins might be used to acquire even more accurate measurements of both convective and radiant heat fluxes on the human body in such designed cool pockets.

Summing up, it is possible to note that the methodology proved that a well planned micro-scale intervention could be successful in reclaiming a thermally stressful space. In the findings, the integrated "Blue-Green-White" approach proves effective, neither in the global warming of atmospheric temperature reduction, but rather in establishing local areas of evaporative cooling, radiant cooling and controlled air movement, which lead to a significant change in human thermal comfort.

Current Study (Summer Peak)



Limitations & New Research Avenues



Future Research Phases



Figure 11 Limitations & Future Work

5. Conclusion

The present research aimed to answer one of the most widespread and yet critical issues of semi-arid urban settings, namely, the issue of social desertion of the public areas because of excessive heat conditions, which essentially undermines the social aspect of the latter. By a selective inquiry at the CECOS University café courtyard we have shown that the object of microclimatic design is not to override the regional climatic condition, but to give a very specific, localized modulation. Through the establishment and testing of an organised intervention designed to create a Blue-Green-White intervention, that is, dual evaporative fountain, high-albedo curved seating, and an optimised tree shade, this study gives empirical data that small scale design strategies targeted have the ability to significantly change the human experience of a space.

The major point that we have made is that our combination of these factors resulted in a perceivable and measurable cool pocket. Although the change in ambient air temperature was not significant, the Physiological Equivalent

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Temperature (PET) calculated in the intervention zone dropped on average by 6.5 °C in the busiest times of the afternoon. This relevant difference highlights the fact that the success of the intervention was based on the multi-pronged approach to the elements of human heat balance; the fountains increased the evaporative potential and advective cooling, the high-albedo seating decreased radiant heat loading significantly, and the available tree canopy provided the necessary shading. This was further emulated by the design of the furniture that was deliberately curved to provide the effect of the Pocket Effect that caused the right cooled air to linger around occupants.

The resultant effect was a productive space-change. Before the intervention, the courtyard was more of a transitory space, which was returned through as soon as possible to avoid getting exposed to heat. After the intervention, it was turned into a stay zone, used actively in socialization, and rest even during the summer seasons. This change confirms the main assumption that, student-centric placemaking in harsh climates is not an architectural or aesthetic project, but a bioclimatic one. Thermal comfort determines social vitality.

This research offers several actionable insights for practitioners:



Figure 12 Optimizing Outdoor Climates

Limitations and Future Research: The study was undertaken in one summer, seasonal effects, especially on the direction of the wind and the phenology of trees should be studied to determine the year-long performance. Also, although PET is a powerful indicator, the complementary research with the longitudinal behavioral observation or extensive subjective surveys may help to enrich the comprehension of the interactions between measured comfort and real patterns of space usage.

To sum up, this project proves that the concept of data-based, micro-scale climate design can be used to reclaim outdoor urban areas. It transcends theoretical conjecture to offer a replicable model to prove that despite the limited nature of intervention, oases of thermal comfort can be created that will revive the social and ecological potential of our social spaces and realms.

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