

# "The Impact Of Local Microclimate On Urban Spaces (Streets) In Arid Regions: The Case Of Béchar City"

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## Abstract

*This study investigates the impact of local microclimate on outdoor thermal comfort in urban spaces within arid environments, taking Toumi Tayeb Street in the city of Béchar as a case study. Situated within the broader discourse of urban climate adaptation, the research addresses the increasing challenges posed by rising temperatures and climate-incompatible urban expansion in desert cities. Using the ENVI-met simulation tool, three urban design scenarios were developed: one with no vegetation, another with sparsely spaced trees, and a third featuring densely planted *Ficus nitida* trees combined with a basic irrigation system. Climatic indicators such as potential air temperature, relative humidity, and the Physiological Equivalent Temperature (PET) were used to evaluate thermal performance. The findings reveal that the third scenario significantly enhances thermal comfort, with air temperatures reduced by up to 2°C, relative humidity increased by approximately 10%, and PET values lowered by 5 to 7°C. These results underscore the importance of climate-responsive design—particularly the strategic use of vegetation and moisture management—as a viable solution for mitigating urban heat stress. The study ultimately affirms that incorporating microclimate considerations into urban and street design is not merely beneficial, but essential for ensuring thermal resilience and livability in desert cities.*

**Keywords (in English):** Thermal comfort, urban spaces, desert regions, hot and arid climate, microclimate simulation, ENVI-met software, vegetation cover, humidity, street design, local microclimate.

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## INTRODUCTION

This study addresses the impact of local microclimate on open urban spaces in arid environments, with a focus on urban design elements that influence thermal comfort, such as street orientation, building height-to-width ratios, vegetation cover, and relative humidity. Several previous studies have demonstrated the importance of these interactions: Givoni (1998) highlighted the relationship between urban morphology and solar radiation exposure; Shashua-Bar & Hoffman (2003) emphasized the need to combine vegetation with urban structures to achieve effective cooling; Sodoudi (2018) discussed how vegetation interacts with humidity and airflow in dry climates to influence thermal dynamics. Similarly, Fazia Ali et al. (2006) demonstrated the effectiveness of combining vegetation and morphological parameters in improving microclimatic conditions in southern Algerian cities, while Song et al. (2019) showed that street configuration, including height and narrowness, can be just as impactful as vegetation in reducing ambient temperature.

Building on this theoretical foundation, the study aims to evaluate the influence of climatic and morphological variables on thermal comfort in the city of Béchar, by simulating design scenarios along Toumi Tayeb Street using ENVI-met, with the objective of generating design recommendations suitable for arid urban contexts.

## CASE STUDY – ENVIRONMENTAL ANALYSIS

The city of Béchar features a hot desert climate classified as BWh under the Köppen–Geiger system. It experiences high temperatures year-round and extremely limited rainfall. The average annual temperature is approximately 21.6°C, while annual precipitation does not exceed 102 mm, spread across about 16 rainy days per year.

The summer season, lasting from June to September, is long and intense, with July being the hottest month: the average high temperature reaches 40.9°C, and the average low stands at 27.7°C, accompanied by extremely low relative humidity—dropping below 15%. Solar radiation peaks at 361 hours/month, significantly increasing perceived heat levels.

In contrast, the cold season extends from November to March, during which temperatures drop significantly. January is the coldest month, with an average low of 3.3°C, and extremes falling as low as -4.8°C. Relative humidity rises slightly during this period, reaching between 43–45%, and November and December record the highest rainfall.

These climatic conditions demonstrate strong thermal variation on both daily and seasonal scales. With over 2,900 hours of annual sunshine, managing heat and solar radiation in urban spaces becomes a critical priority. These features underscore the need for precise design strategies that integrate shading, natural ventilation, and humidity control, particularly along urban streets such as Toumi Tayeb Street, where built morphology strongly interacts with climatic extremes to form distinct microclimates that shape users' thermal experiences (Oke, 1982 ; Emmanuel, 2005 ; Zhao et al., 2014).

## CASE STUDY CHARACTERISTICS AND JUSTIFICATION FOR SELECTION:

Tomi El Tayeb Street is located in the heart of the city of Béchar and extends over a distance of more than 800 meters within the modern urban fabric, specifically in the ZHUN residential area—one of the city's most densely populated and active urban zones. The street serves as a vital artery that combines commercial and service functions, making it a daily destination for local residents, especially during the evening hours when temperatures begin to drop.

However, the selection of this street is not based solely on its functional significance. It is also grounded in a set of scientific criteria that qualify it as a representative model for analyzing microclimatic effects in arid urban environments. Its location in a relatively exposed area, its north–south orientation, and its moderate width all contribute to prolonged exposure to direct solar radiation throughout the day. This makes it an ideal site for observing variations in thermal performance according to different physical configurations (Johansson & Emmanuel, 2006).

Moreover, the lack of vegetation cover and the absence of natural or artificial shading elements make it a prototypical case for studying the impact of urban design on thermal comfort in harsh climatic conditions. Additionally, the street offers easy access to field data and lends itself well to representation in digital simulation software. As such, Tomi El Tayeb Street can be regarded as a microcosmic model from which the performance of similar urban spaces—whether in Béchar or in other desert cities with comparable urban and climatic characteristics—can be inferred.

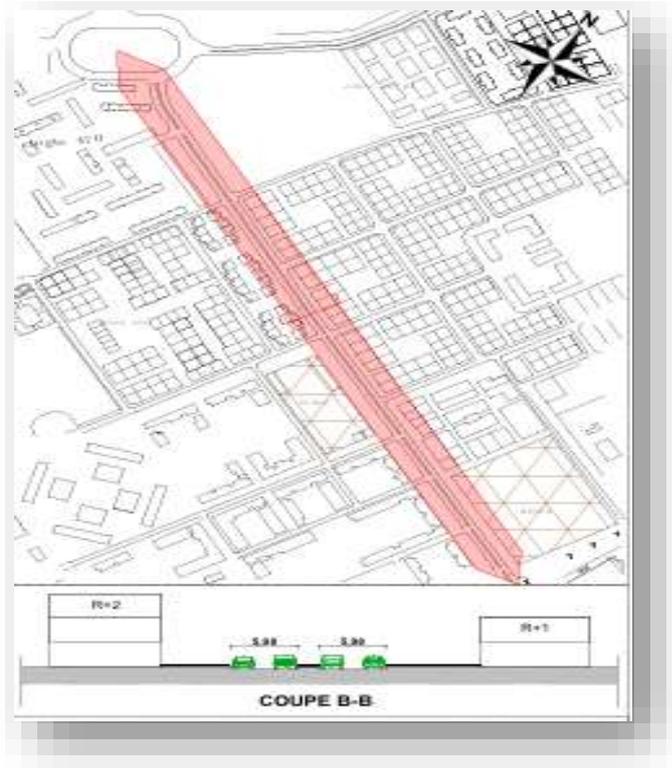


Fig 1 Tomi El Tayeb Street – Site Plan + Street Sections  
Source: Researcher, 2025

### **SIMULATION METHODOLOGY (ENVI-MET):**

In the context of this study, a digital simulation was carried out using ENVI-met 5.0 to model three different urban design scenarios, with the aim of analyzing the impact of vegetation cover on thermal comfort levels along Toumi Tayeb Street in the city of Béchar. Each scenario was constructed using a three-dimensional model that accurately reflects the existing urban fabric, including the layout and shapes of buildings, street widths, and adjacent open spaces.

The simulation process relied on real climatic data collected from the Weather Underground platform, in addition to official meteorological records from the National Weather Station of Béchar. These data included ambient air temperature, relative humidity, wind speed and direction, and solar radiation intensity, all of which were used to represent a typical hot summer day.

The simulation was conducted for August 4, 2024, at 16:00 (4:00 PM)—a time that, although not at the absolute summer peak (which usually occurs in mid-July), still represents a period of intense heat and solar radiation. This timing was chosen to simulate harsh but realistic thermal conditions typical of the hot season in Béchar, allowing for an effective assessment of the proposed design strategies under arid urban environmental stress (Scopus, 2024 ; Thomas et al., 2023 ; Qin & Zhou, 2025).

### **SCENARIO 1 – BASELINE CONFIGURATION (MINERAL STREET WITHOUT VEGETATION):**

This scenario reflects the current condition of Toumi Tayeb Street, characterized by the complete absence of any vegetation. The urban scene is dominated by hard mineral surfaces, including asphalt, concrete, and paved sidewalks, with no visible tree planting or green coverage. This setup was used as the reference

model against which the microclimatic performance of subsequent vegetation-based interventions was evaluated. No trees or natural elements were included at this stage, allowing for a clear observation of microclimatic behavior in an unshaded, vegetation-free urban setting.



Fig 2 Scenario 1 – Baseline configuration (mineral street without vegetation)  
Source: Authors, 2025

### SCENARIO 2 – TREE PLANTING (FICUS NITIDA, 10-METER SPACING)

The second scenario involves the integration of *Ficus nitida* trees (commonly known as Indian laurel fig or ornamental fig) planted along the sidewalks at regular intervals, with a spacing of 10 meters between each tree. This species is widely used in urban landscaping projects in arid and semi-arid regions due to several advantageous environmental characteristics, notably:

- Evergreen, dense foliage that provides continuous canopy coverage,
- High tolerance to harsh climatic conditions such as extreme heat and drought,
- Excellent year-round shading performance.

*Ficus nitida* is particularly well-suited to the desert climate of Béchar, which is characterized by intense solar radiation, high summer temperatures, and very limited rainfall. In this scenario, the species was selected to test its microclimatic impact under relatively sparse planting conditions, in order to assess the extent to which limited vegetation coverage can influence thermal comfort in an arid urban environment.

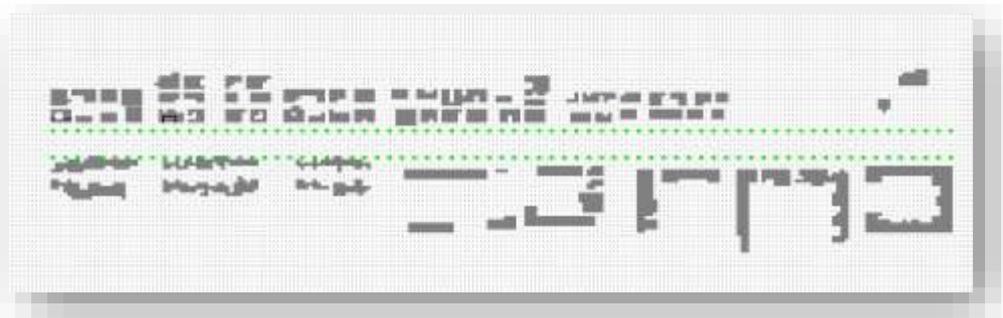


Fig 3 Scenario 2 – Introduction of *Ficus nitida* (10-meter spacing)  
Source: Authors, 2025

### SCENARIO 3 – ENHANCED TREE COVER USING FICUS NITIDA (6-METER SPACING)

The third scenario focuses on maximizing the cooling effect of urban vegetation by reducing the spacing between *Ficus nitida* trees to just 6 meters. This closer arrangement allows for the creation of nearly

continuous shaded pedestrian pathways and significantly reduces direct solar exposure, especially during peak sun hours ( ang, X., Zhao, L., & Bruse, M. (2013).

The tree distribution was carefully designed based on specific climatic and urban design considerations, including:

- The average mature height of the trees, which may reach up to 10 meters,
- The canopy diameter, typically ranging between 5 and 6 meters,
- The orientation of the street relative to the sun's daily path to ensure effective shading.

This configuration represents a deliberate and optimized approach to urban greening, embodying the principles of sustainable climatic design in arid contexts. It strikes a balance between improved thermal performance and technical feasibility, offering a realistic solution to mitigate heat stress in dry urban environments like B char.

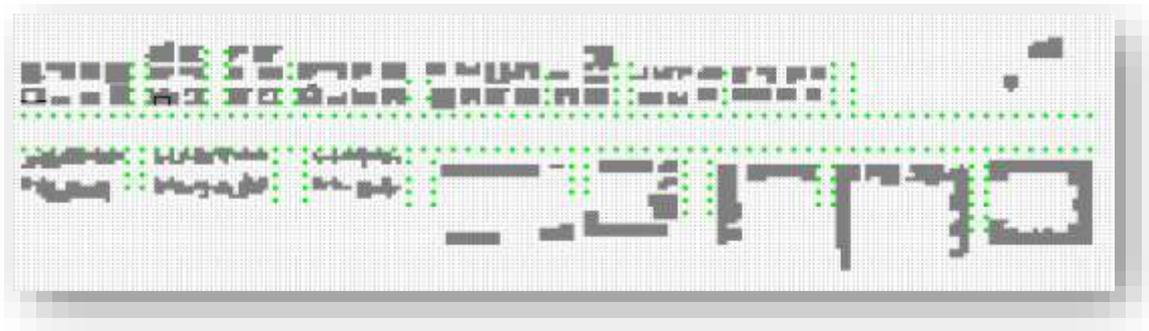


Fig 4 Scenario 3 – Optimized canopy using *Ficus nitida* (6-meter spacing)  
Source: Authors, 2025

### SCENARIO 3 – INTEGRATION OF AN IRRIGATION SYSTEM

In this third scenario, a simple irrigation system was incorporated to support the planted *Ficus nitida* trees. The intervention was designed to ensure consistent soil moisture and to enhance the surrounding air humidity—an essential component in improving thermal comfort levels, particularly in arid urban environments like B char. This system facilitates evapotranspiration processes and reduces excessive dryness in the lower air layers near pedestrian height, thereby mitigating heat stress and improving ambient comfort.

### SCENARIO 1 – BASELINE CONFIGURATION (STREET WITHOUT VEGETATION)

- **Potential air temperature range:** 42.12 C to 45.33 C
- **Observation:** The entire street area, including its surroundings, exhibits extremely high temperatures, with widespread zones exceeding 44.5 C—especially along exposed asphalt roads and sun-facing fa ades.
- **Interpretation:** The absence of vegetation or shading elements leads to excessive solar radiation absorption by hard materials like asphalt and concrete. This results in a significant rise in air temperature and a notable increase in thermal discomfort within the urban space.

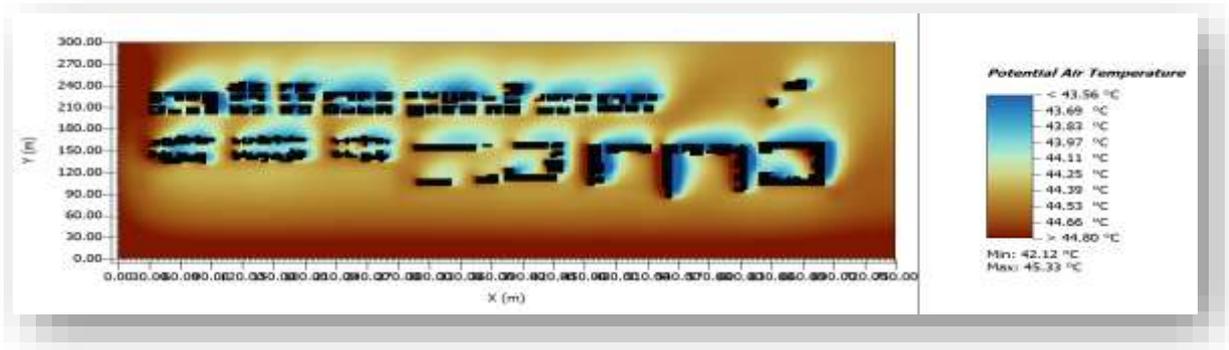


Fig 5 Scenario 1 – Baseline Configuration (Mineral street without vegetation)  
 Source: Authors, 2025

**Scenario 2 – Plantation Of Ficus Nitida Trees At 10-Meter Intervals**

- **Potential air temperature range:** 42.10°C to 45.33°C
- **Observation:** A slight improvement in air temperature is recorded near tree locations; however, the overall thermal distribution across the street shows no significant difference compared to the baseline scenario (ResearchGate, 2024 ; MDPI, 2023).
- **Interpretation:** Although trees were introduced, the wide spacing (10 meters between each tree) prevents the formation of continuous shade along the street, thereby limiting the vegetation’s effectiveness in modifying the local microclimate. The lack of canopy overlap reduces the efficiency of cooling via shading and evapotranspiration, resulting in maximum temperature values nearly identical to those of the first scenario. This reflects the limited impact of this configuration on enhancing outdoor thermal comfort.

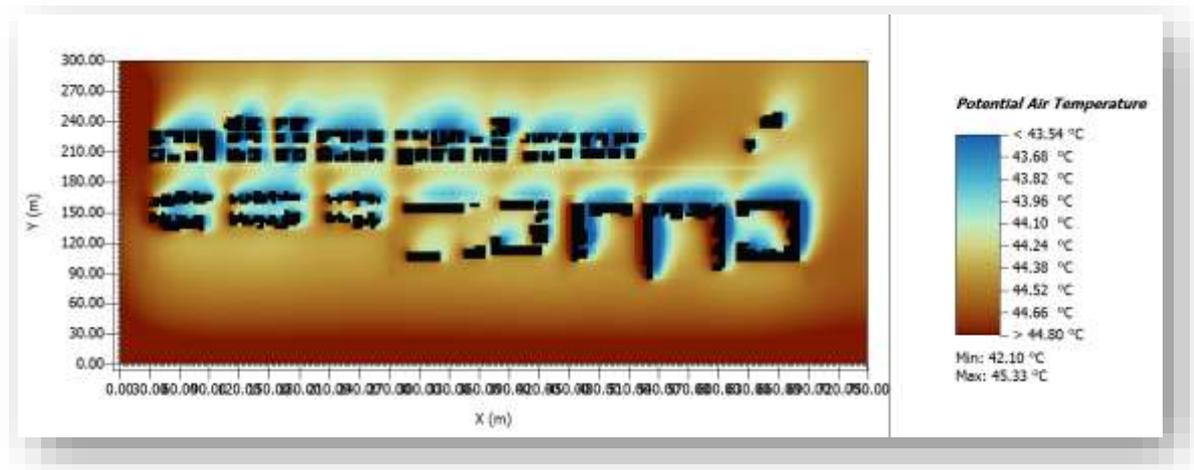


Fig 6 Scenario 2 – Introduction of Ficus nitida (10m spacing)  
 Source: Authors, 2025

**Scenario 3 – Enhanced Shading And Irrigation Support (Tree Spacing Of 5–6 Meters + Irrigation System)**

- **Potential air temperature range:** 39.56°C to 44.95°C
- **Observation:**
  - A significant drop in air temperatures is recorded along the entire street corridor.
  - Extensive cooler zones (below 43°C) are evident, especially near tree rows and pedestrian pathways.
  - A noticeable reduction in the extent and intensity of hot spots is observed when compared to the previous two scenarios.

This scenario demonstrates a high level of effectiveness in improving the thermal performance of the urban environment. The dense vegetation cover, combined with consistent ground moisture from the irrigation system, enhances both shading and evapotranspiration effects. As a result, it contributes substantially to mitigating heat stress and improving outdoor thermal comfort in a hot arid urban context. (ResearchGate, 2024 ; MDPI, 2023)

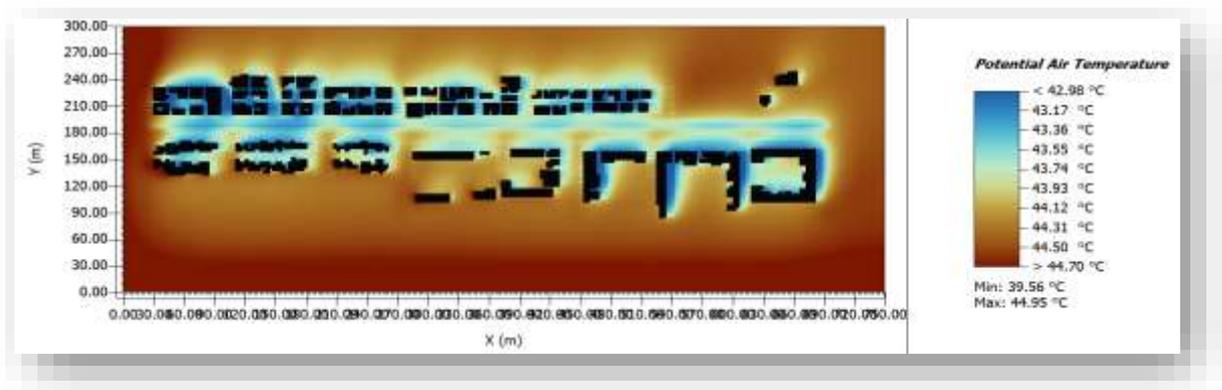


Fig 7 Scenario 3 – Optimized Shading and Hydraulic Support (6m spacing + irrigation)  
 Source: Authors, 2025

**INTERPRETATION:**

- The dense planting of *Ficus nitida* trees at regular intervals of 5 to 6 meters created a continuous shaded corridor along the street. This significantly reduced heat accumulation on exposed surfaces, especially in pedestrian zones.
- The integration of a simple irrigation system enhanced the cooling effect through evapotranspiration, which helped increase the relative humidity of the surrounding air.
- These combined interventions resulted in a reduction of potential air temperature by approximately 2°C at several critical points compared to the baseline scenario, thereby improving thermal comfort in the desert urban environment.

Properties	Scenario 1	Scenario 2	Scenario 3
Minimum potential air temperature (°C)	42.12	42.10	39.56
Maximum potential air temperature (°C)	45.33	45.33	44.95

Properties	Scenario 1	Scenario 2	Scenario 3
Type of vegetation cover	None	Ficus nitida	Ficus nitida
Tree spacing	–	10 meters	<b>6 meters</b>
Irrigation system	None	None	<b>Yes</b>
Shading extent	None	Partial	<b>Continuous</b>
Improvement in thermal comfort	–	Slight	<b>Significant</b>

Tab 1 Comparative Summary of Key Parameters  
Source: Authors, 2025

### ANALYTICAL CONCLUSION:

Scenario 3 demonstrated clear and measurable effectiveness in improving the thermal performance of the urban environment. The combination of dense vegetation (with regular spacing of 5 to 6 meters) and a supportive irrigation system contributed to a significant reduction in potential air temperature—exceeding 2 °C in the areas most exposed to heat stress. These findings underscore the importance of adopting enhanced urban greening strategies as a practical and sustainable solution to improve outdoor thermal comfort in arid urban environments, such as the city of Béchar, which faces harsh climatic challenges due to intense solar radiation and the scarcity of natural vegetation.

### SIMULATION RESULTS: RELATIVE HUMIDITY ANALYSIS

The following analysis compares the distribution of relative humidity across the three simulated scenarios using ENVI-met, focusing on data collected at 16:00—typically the hottest hour of the day. In dry climates like that of Béchar, maintaining sufficient humidity levels is essential to enhance thermal perception and reduce physiological stress.

#### SCENARIO 1 - BASELINE CONFIGURATION (NO VEGETATION OR IRRIGATION):

- **Relative humidity range:** 35.40% to 41.67%
- **Observation:** Relative humidity remains generally low across the area, with most values between 36% and 38%, indicating a locally dry microclimate.
- **Interpretation:** The absence of vegetation and soil moisture leads to a substantial drop in evapotranspiration rates, resulting in poor moisture retention and contributing to uncomfortable thermal sensations—particularly in hot urban settings.

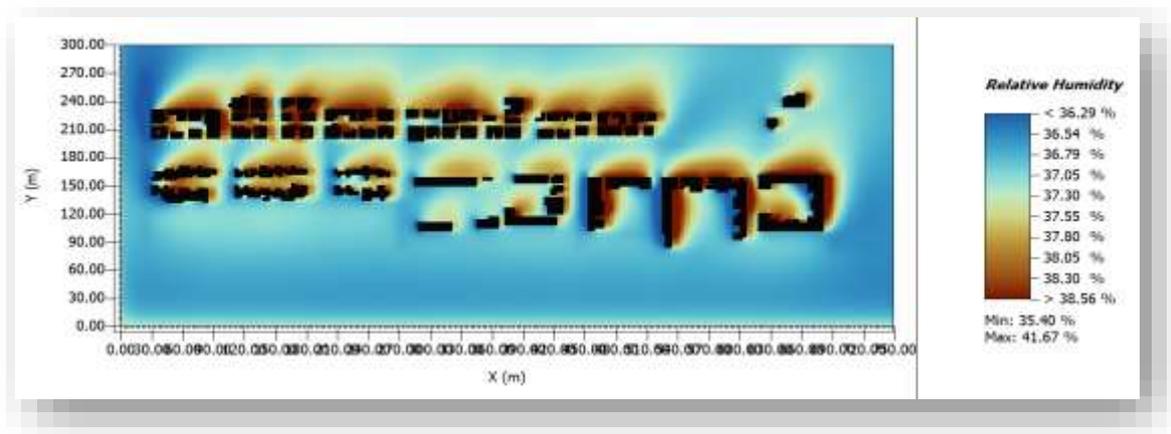


Fig 8 Scenario 1 - Baseline Configuration (No vegetation or irrigation)  
 Source: Authors, 2025

**SCENARIO 2 - TREE PLANTATION (FICUS NITIDA, 10-METER SPACING):**

- **Relative humidity range:** 35.40% to 41.69%
- **Observation:** Slight increases in humidity levels are observed near the tree bases; however, the overall spatial pattern remains largely similar to that of Scenario 1.
- **Interpretation:** Although the planting of *Ficus nitida* contributed marginally to raising humidity levels through evapotranspiration, the 10-meter spacing between trees does not allow sufficient canopy overlap or foliage density to generate a significant microclimatic humidifying effect. As a result, the impact remains localized, weak, and insufficient to alter the broader thermal environment. ((Emmanuel, 2005) + (Zhao et al., 2014)

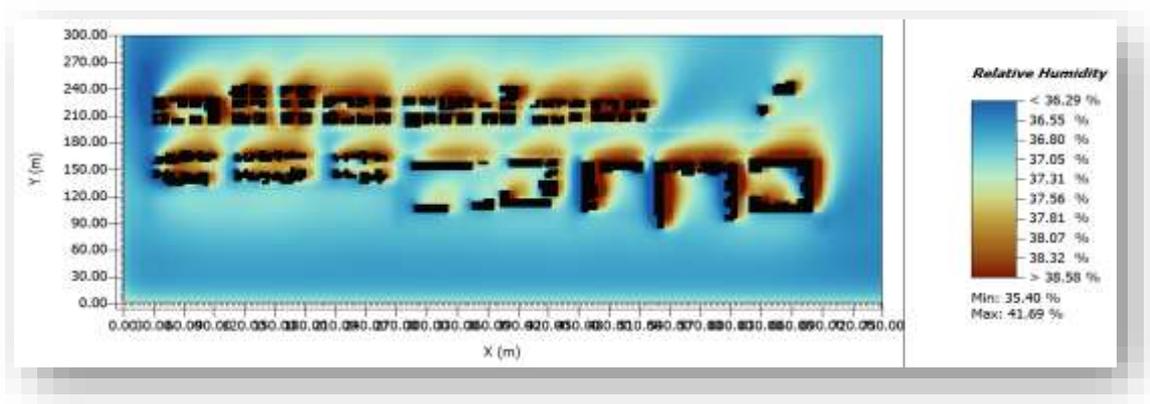


Fig 9 Scenario 2 - Tree Plantation (*Ficus nitida*, 10m spacing)  
 Source: Authors, 2025

**SCENARIO 3 - ENHANCED VEGETATION COVER WITH IRRIGATION SYSTEM:**

- **Relative Humidity Range:** 35.99% to 50.47%
- **Observation:**

- A clear and widespread increase in relative humidity levels is observed, with large portions of the area exceeding 39%, reaching up to 50% in shaded zones and beneath tree canopies.
- The improvement is particularly noticeable along pedestrian walkways bordered by closely spaced trees.

This indicates a strong microclimatic benefit resulting from the combination of dense tree planting (at 5–6 meter intervals) and soil moisture provided by the irrigation system. Together, they enhance evapotranspiration and moisture retention in the lower atmospheric layers, effectively improving outdoor thermal comfort in this arid urban setting.

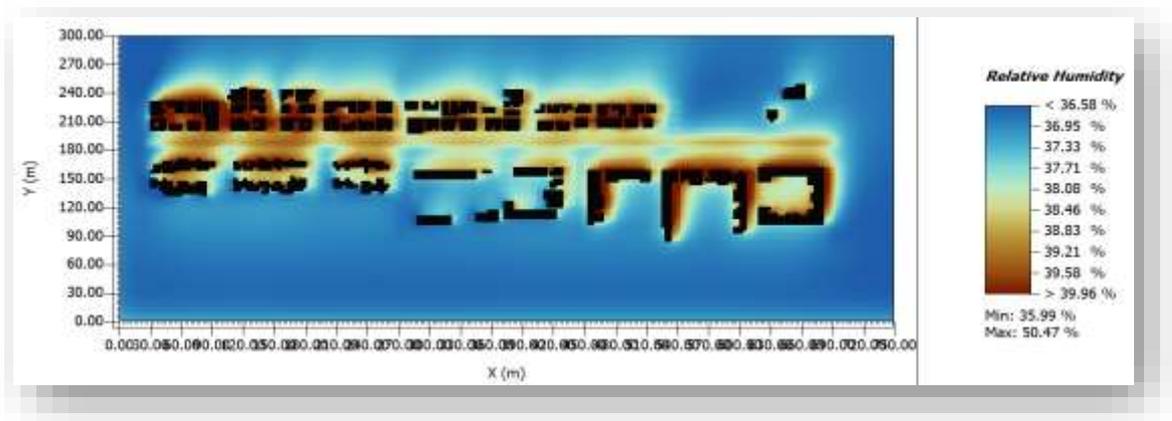


Fig 10 Scenario 3 – Optimized Vegetation and Irrigation  
 Source: Authors, 2025

**INTERPRETATION (SCENARIO 3):**

- The combination of close tree spacing (6 meters) and consistent soil moisture through irrigation significantly enhances the process of evapotranspiration, leading to a substantial rise in local air humidity.
- This not only improves air cooling efficiency but also reduces perceived dryness, especially during peak heat hours, thereby contributing to improved thermal comfort for pedestrians.

Characteristic	Scenario 1	Scenario 2	Scenario 3
Min. Relative Humidity (%)	35.40	35.40	35.99
Max. Relative Humidity (%)	41.67	41.69	50.47
Vegetation Type	None	Ficus nitida	Ficus nitida
Tree Spacing	—	10 meters	6 meters
Irrigation System	No	No	Yes
Humidity Increase (Local)	Absent	Slight	Significant

Characteristic	Scenario 1	Scenario 2	Scenario 3
Dryness Relief	Absent	Limited	Strong/Effective

Tab 2 Comparative Summary of Humidity Levels  
 Source: Authors, 2025

This comparative table highlights the superior performance of Scenario 3 in improving relative humidity and mitigating the effects of dry, hot urban climates typical of desert cities like Béchar.

#### ANALYTICAL CONCLUSION:

Scenario 3 demonstrated a significant improvement in relative humidity levels, with an increase of approximately 10 percentage points in critical zones compared to the baseline scenario. This confirms the essential role of irrigation systems and strategic tree planting in mitigating the dryness and discomfort that characterize desert cities. Enhanced humidity supports more efficient evaporative cooling and contributes to an overall improvement in pedestrian thermal experience.

#### Simulation Results: Comparison of PET Index (Physiological Equivalent Temperature)

The PET index represents perceived thermal stress, integrating factors such as air temperature, solar radiation, humidity, wind speed, metabolic rate, and clothing. It is especially critical in arid urban environments, where high solar load and dry air exacerbate thermal discomfort.

The simulation results were analyzed at 16:00, the hottest time of day in Béchar, to represent peak thermal stress conditions for pedestrians.

#### Scenario 1 – Baseline: No vegetation, no water system

- **PET Range:** 54.95°C to 63.20°C
- **Observations:**
  - Most areas exhibited extremely high PET values, exceeding 60°C.
  - Built-up and paved zones radiate intense heat without any shading protection.
- **Interpretation:**
  - This scenario represents very high thermal stress conditions.
  - The absence of vegetation or moisture retention mechanisms creates unbearable outdoor environments.
  - It serves as the worst-case scenario for urban thermal stress.

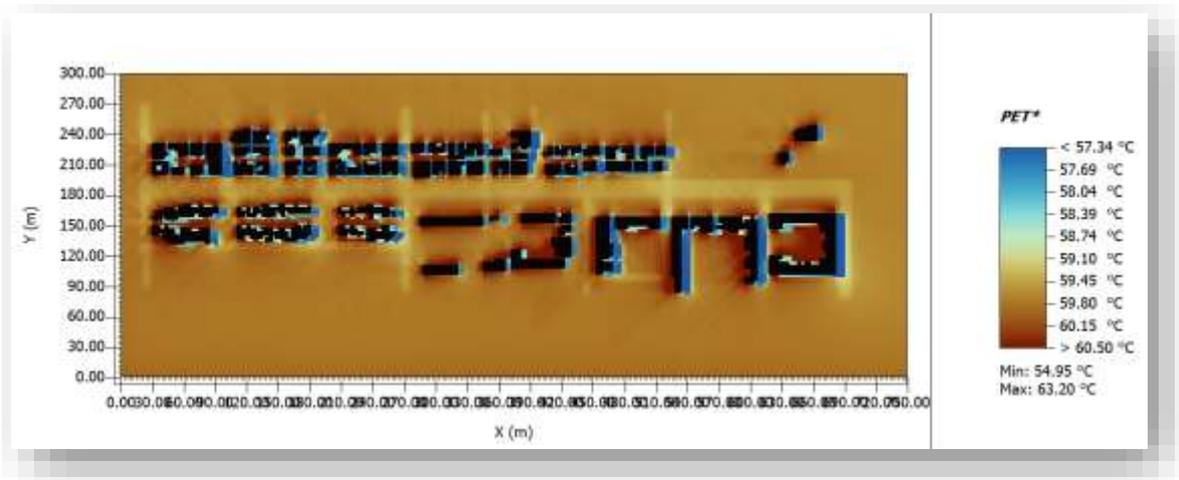


Fig 11 Scenario 1 – PET Baseline: No vegetation, no water system  
 Source: Authors, 2025

**Scenario 2 – Vegetative Cover (10-meter spacing, no irrigation):**

- **PET Range:** 54.38°C to 60.99°C
- **Observations:**
  - A slight reduction in PET values is recorded compared to Scenario 1, particularly in the vicinity of tree canopies.
  - However, most values still exceed 58°C, placing them in the "extreme heat stress" category.
- **Interpretation:**
  - The *Ficus nitida* trees contribute to localized shading, which leads to minor reductions in the PET index.
  - Nonetheless, the 10-meter spacing between trees does not allow for continuous or efficient cooling effects.
  - As a result, PET values remain high in pedestrian and roadway zones, maintaining an overall uncomfortable thermal sensation.

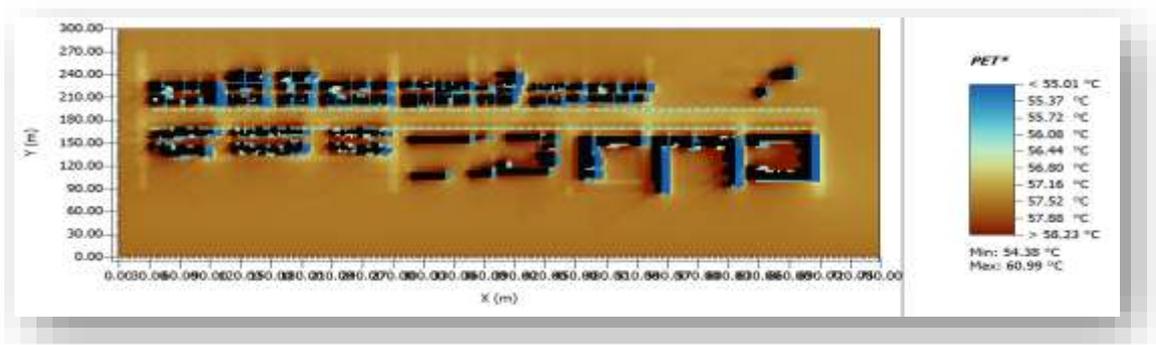


Fig 12 Scenario 2 – PET Vegetation (10 m spacing, no irrigation)  
 Source: Authors, 2025

**Scenario 3 – Optimized Tree Distribution (6-meter spacing) + Irrigation System:**

- **PET Range:** 49.06°C to 61.84°C
- **Observations:**
  - A noticeable reduction in PET values is observed, with several areas dropping below 55°C.
  - Zones benefiting from continuous tree shading and soil moisture show significant improvement in thermal sensation.

These results highlight the strong positive impact of combining dense tree planting with an irrigation system. This integrated approach effectively reduces thermal stress and significantly enhances outdoor thermal comfort in urban spaces—particularly in arid cities like Béchar.

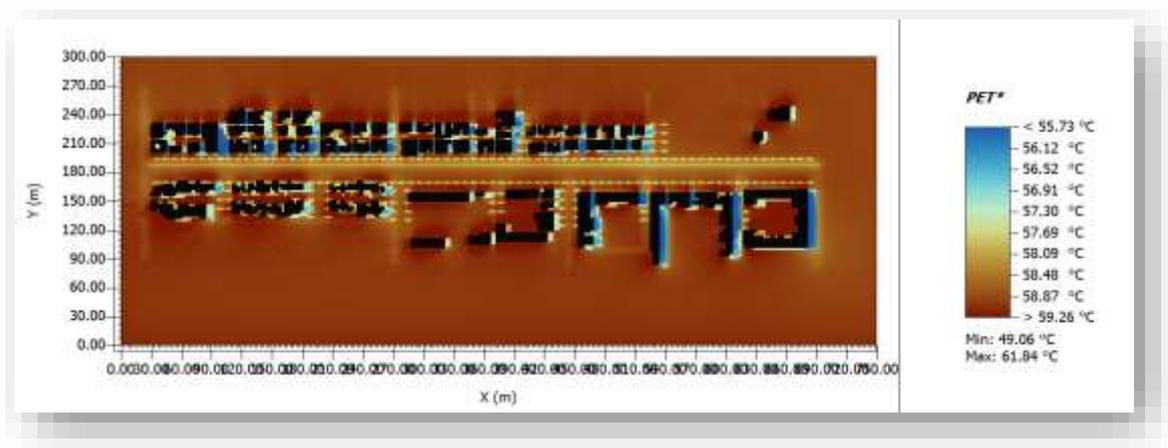


Fig 13 Scenario 3 – PET Optimized trees (6 m spacing) + irrigation system  
 Source: Authors, 2025

**Interpretation:**

- The combination of closely spaced trees and soil irrigation enhances the effectiveness of cooling through both evapotranspiration and the overlapping shade produced by the tree canopies.
- This scenario demonstrates the best thermal performance, reducing PET values by approximately 5 to 7°C compared to the baseline (Scenario 1), particularly in primary pedestrian zones.

Despite the PET values remaining high due to the region’s harsh desert climate, this configuration proves to be the **most practical and efficient solution** for mitigating thermal stress in such urban contexts. (Thomas et al., 2023)

Property	Scenario 3	Scenario 2	Scenario 1
Minimum PET (°C)	49.06	54.38	54.95

Property	Scenario 3	Scenario 2	Scenario 1
Maximum PET (°C)	61.84	60.99	63.20
Areas shaded under 57°C	Clearly present	Slight improvement	Very limited
Tree spacing	6 meters	10 meters	None
Irrigation system	Yes	No	No
Heat stress mitigation	Significant	Limited	–

Tab 3 Summary Table – PET Comparison  
 Source: Authors, 2025

### ANALYTICAL CONCLUSION:

The results of the Physiological Equivalent Temperature (PET) index confirm that **Scenario 3**, which combines **dense vegetation cover with an irrigation system**, is the most effective configuration for mitigating heat stress along Toumi Tayeb Street. While all three scenarios operate under harsh climatic conditions, Scenario 3 succeeds in reducing PET values by **5 to 7°C**, significantly enhancing outdoor thermal comfort and making the environment more suitable for pedestrian activity. (Thomas et al., 2023)

### VERTICAL AIR PROFILE ANALYSIS

To complement the horizontal thermal comfort assessment, vertical cross-sectional analyses were produced using **ENVI-met** for each of the three scenarios. These vertical profiles offer deeper insight into:

- The **thermal layering** of the air column,
- The **heat accumulation** near the ground surface,
- The **airflow patterns** between and above urban structures.

This approach helps elucidate the **three-dimensional thermal structure** of the urban space and highlights how different urban design configurations affect **air movement** and **heat retention**. (Johansson & Emmanuel, 2006 ; Qin & Zhou, 2025)

#### Scenario 1 – No Vegetation and No Irrigation

- **Potential Air Temperature (X-Z Section)**
  - **Range:** 42.01 °C to 45.22 °C
  - **Observation:** Elevated air temperatures persist from the ground level up to nearly 2 meters. Thermal stratification is weak, indicating a stagnant heat layer close to pedestrian height.
- **Pressure Disturbance**
  - **Range:** -1.08 to +0.44 decipascal

- **Observation:** Low pressure differentials reflect minimal air movement between built masses, confirming thermal stagnation and lack of natural ventilation.

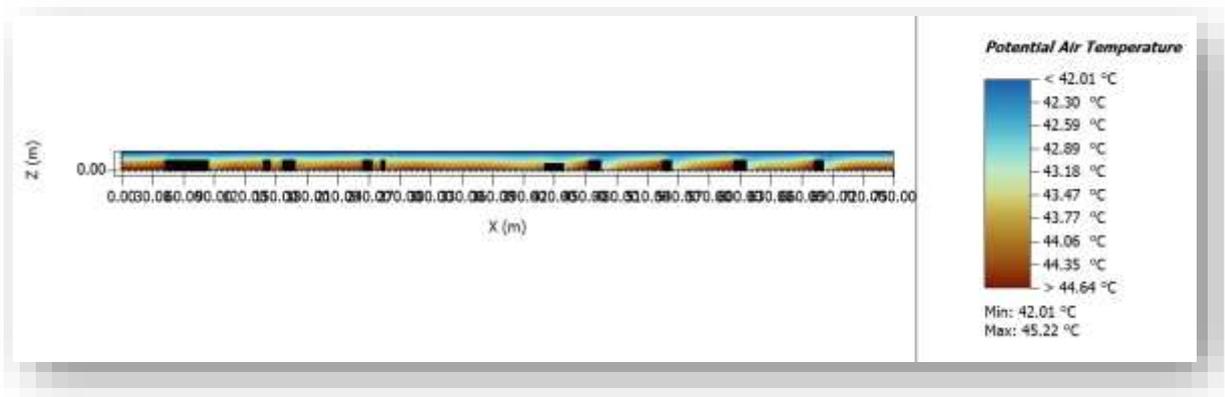


Fig 14 Scenario 1 – Potential Air Temperature (horizontal cut X-Z) No vegetation, no irrigation  
 Source: Authors, 2025

- **Interpretation (Scenario 1):**

- This configuration leads to **heat accumulation near the ground surface and between building facades**, which increases the risk of **urban heat islands** and intensifies **thermal stress at pedestrian level**.
- **Ventilation is weak** due to the absence of vegetation and shading elements, resulting in **stagnant air and limited thermal relief**.

**Scenario 2 – Trees Spaced 10 Meters Apart, No Irrigation**

- **Potential Air Temperature (Y-Z Cross-Section):**

- **Range:** 41.95 °C to 45.13 °C
- **Observation:** Slight cooling is observed near the tree locations, especially in the lower air layers up to 1.5 meters. However, **vertical air mixing remains limited**, and the thermal gradient is weak.

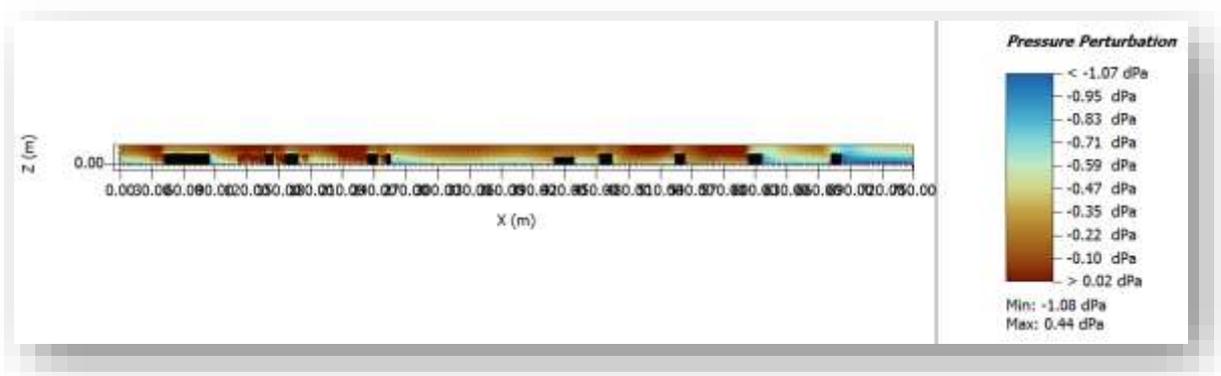


Fig 15 Scenario 2 – Potential Air Temperature (horizontal cut X-Z) Trees (10 m spacing), no irrigation  
Source : Auteurs 2025

**Interpretation:**

- The trees in this scenario contribute to **localized microclimate modification**, but their wide spacing **does not allow for continuous shaded zones** or effective support for **upward airflow circulation**.
- As a result, the improvement in thermal conditions remains **localized and inconsistent**, particularly at **pedestrian height**.

**Scenario 3 – Trees Spaced 6 Meters Apart + Irrigation System**

- **Potential Air Temperature:**
  - **Lowest recorded values across all sections** reach **41.95 °C** in shaded zones.
  - **Improved thermal stratification:** Cooler air layers remain **closer to the ground**, reducing **heat load on pedestrians** and enhancing comfort.

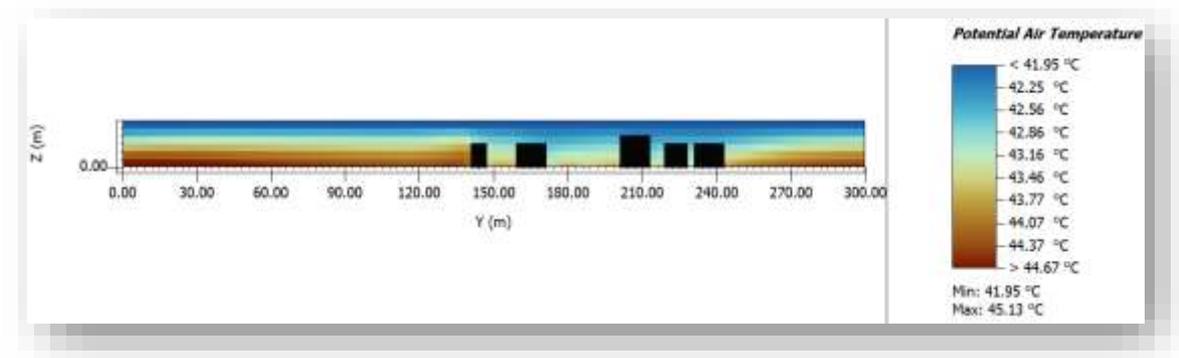


Fig 16 Scenario 3 – Potential Air Temperature (horizontal cut X-Z) Trees (6 m spacing) + irrigation  
Source: Authors, 2025

**Interpretation:**

- The combination of **dense vegetation** and **soil moisture** in Scenario 3 significantly contributes to **cooling the lower air layers**, especially between **0.5 and 2 meters**, which aligns with human exposure height.
- Trees also create **micro-turbulence** in the air, promoting **upward airflow** and **enhancing convective cooling** above the canopy level.
- This leads to a **more efficient thermal regulation** within the urban canyon, improving pedestrian-level comfort in a hot, arid context.

**Comparative Summary – Vertical Thermal Environment**

Properties	Scenario 3	Scenario 2	Scenario 1
Minimum Air Temperature	41.95 °C	41.95 °C	42.01 °C
Maximum Air Temperature	< 45.13 °C	45.13 °C	45.22 °C
Pressure Disturbance Range	Similar	Similar	-1.08 to +0.44 dPa
Thermal Stratification	Improved	Moderate	Weak
Pedestrian-level Cooling	Clear	Slight	Absent
Airflow Enhancement	Strong (vegetation-supported)	Limited	Weak

Tab 5 Comparative Summary – Vertical Thermal Environment  
Source: Authors, 2025

#### ANALYTICAL CONCLUSION:

The vertical sections confirm the previous findings: **Scenario 3** offers the most favorable outdoor microclimatic conditions, not only at surface level but also within the **first two meters** of the urban canyon—the critical height range for human exposure. This scenario demonstrates that **enhancing vegetation structure** and implementing an **efficient irrigation system** increase shading, **stimulate vertical airflow**, and **reduce heat accumulation** between facades, thereby improving thermal comfort conditions. (Johansson & Emmanuel, 2006 ; Qin & Zhou, 2025)

#### VERTICAL RELATIVE HUMIDITY ANALYSIS – COMPARATIVE STUDY

This section presents **X-Z** and **Y-Z** sectional analyses of **relative humidity distribution** in the air across the three scenarios. The goal is to understand how **vegetation density** and the presence of an **irrigation system** influence vertical moisture distribution, especially within the **0–2 meter layer**, which plays a vital role in perceived comfort in dry climates. Salata, F., Golasi, I., de Lieto Vollaro, A., & de Lieto Vollaro, R. (2017).

##### Scenario 1 – Baseline: No Vegetation or Irrigation

- **Relative Humidity Range:** 35.44% to 41.90%
- **Observations:**
  - The air remains **dry near ground level** and around building facades.
  - Slight increases in humidity are observed **just above rooftops**, but the effect is limited.

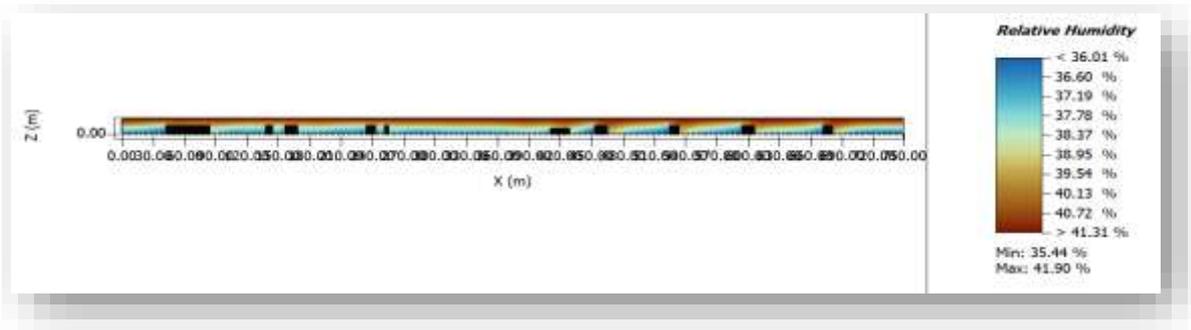


Fig 17 Scenario 1 – Baseline: No vegetation, no irrigation  
 Source: Authors, 2025

**Interpretation:**

- The absence of vegetation or soil moisture results in an almost entirely dry local microclimate.
- The lowest level of evaporation is recorded, which significantly weakens thermal mitigation across all height levels.

**Scenario 2 – Vegetation Cover (10-Meter Spacing), Without Irrigation**

- **Relative Humidity Range: 35.45% to 41.91%**
- **Observation:**
  - A slight increase in humidity was observed at the canopy level of the trees, but the effect remains superficial and inconsistent.
  - The influence does not extend beyond the areas immediately adjacent to the trees.

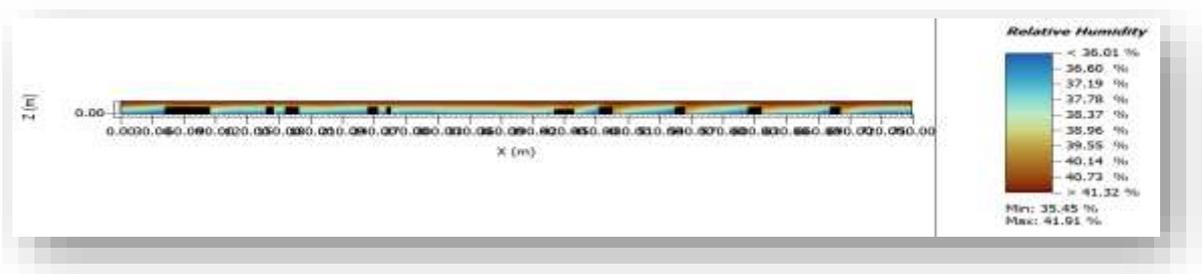


Fig 18 Scenario 2 – Vegetation (10 m spacing), no irrigation  
 Source: Authors, 2025

**INTERPRETATION:**

- Ficus nitida trees provide a limited localized climatic benefit; however, the 10-meter spacing reduces the overlap of humidity zones. (Johansson & Emmanuel, 2006)
- The absence of an irrigation system restricts transpiration from the root level, which in turn weakens the moisture effect in the surrounding environment.

**Scenario 3 – Dense Vegetation Cover (6-Meter Spacing) with Irrigation System**

- **Relative Humidity Range:** 36.38% to 41.94%
- **Observation:**
  - Humidity levels rise significantly at pedestrian height and within the tree canopy layer.
  - A clear vertical extension of the humid zone is observed, particularly at heights ranging from 0 to 2.5 meters.

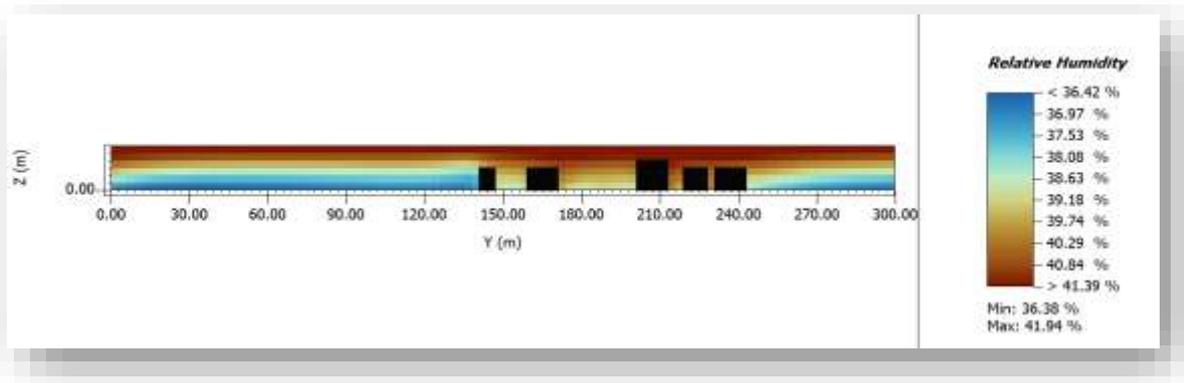


Fig 19 Scenario 3 – Dense vegetation (6 m) with irrigation  
 Source: Authors, 2025

**INTERPRETATION:**

- The combination of dense vegetation and an irrigation system enhances the effectiveness of soil evaporation and plant transpiration, thereby increasing humidity levels near ground level.
- This results in a noticeable improvement in hydrothermal comfort, particularly in shaded pedestrian areas.

**Table 6 – Summary Table: Vertical Relative Humidity**

Characteristics	Scenario 1	Scenario 2	Scenario 3
Lowest Relative Humidity (%)	35.44	35.45	36.38
Highest Relative Humidity (%)	41.90	41.91	41.94
Air Humidity Near the Ground	Dry	Slightly Improved	Noticeably Improved
Irrigation System	No	No	Yes
Vertical Humidity Gradient	Weak	Localized	Clearly Extended

Characteristics	Scenario 1	Scenario 2	Scenario 3
Hydrothermal Comfort Improvement	Weak	Limited	Strong

Tab 6 Summary Table – Vertical Relative Humidity  
 Source: Authors, 2025

### ANALYTICAL CONCLUSION:

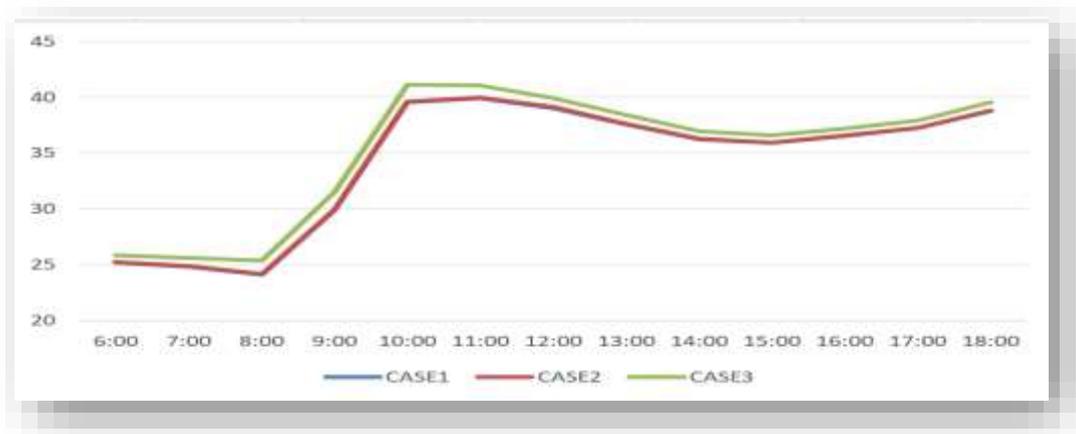
Vertical humidity profiles confirm that only **Scenario 3** results in a substantial increase in air moisture at heights relevant to human experience. Through the strategic distribution of vegetation and active soil moistening, this scenario enhances evaporative cooling and improves perceived humidity—an essential factor in reducing heat stress in dry, sun-exposed urban environments.

### SIMULATION RESULTS ANALYSIS

#### Interpretation of the Mean Humidity Curve (from 06:00 to 18:00):

The dataset compares the evolution of average humidity throughout the day across three different urban configurations:

- **Case 1:** Baseline scenario (no vegetation or irrigation system)
- **Case 2:** Planting *Ficus nitida* trees with 10-meter spacing
- **Case 3:** Improved setup with *Ficus nitida* spaced 6 meters apart, supported by a basic irrigation system



the Average Humidity Curve (06:00–18:00)  
 Source: Authors, 2025

### KEY OBSERVATIONS

#### 1. Morning Period (06:00–09:00):

- All three cases show relatively similar humidity values, generally below 30%.
- **Case 3** consistently records slightly higher humidity levels, indicating early benefits from vegetation cover and soil moisture.

## 2. Midday Peak (10:00–14:00):

- All cases experience a sharp increase in humidity, but **Case 3** demonstrates a clear advantage.
- For example, at 12:00, humidity in Cases 1 and 2 hovers around 44%, whereas **Case 3** exceeds 46%.
- This is attributed to stronger evapotranspiration resulting from denser vegetation and more effective shading.

## 3. Afternoon Period (15:00–18:00):

- Humidity levels begin to decrease in all scenarios after 14:00.
- Nevertheless, **Case 3** maintains the highest humidity levels, staying ahead by approximately 1 to 1.5 percentage points compared to the other two cases.
- This reflects better moisture retention and continued transpiration in the improved scenario.

## ANALYTICAL CONCLUSION:

**Case 3** proves to be the most effective solution for improving local climatic conditions in urban outdoor spaces. The combination of dense vegetation and irrigation significantly enhances relative humidity levels during the hottest periods of the day, contributing to improved thermal comfort and reduced physiological heat stress in arid urban environments such as Béchar.

### Interpretation of the Average Thermal Comfort Curve (PET) – 06:00 to 18:00

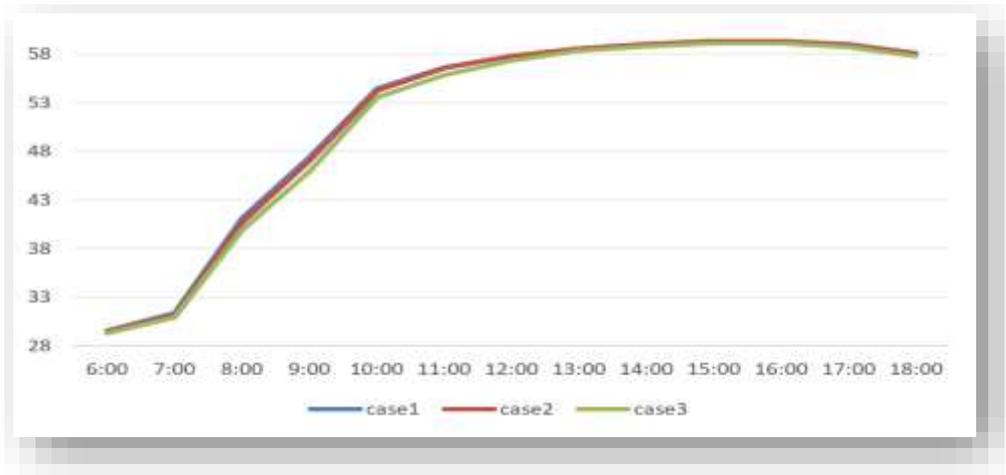
This graph illustrates the diurnal variation of the **Physiological Equivalent Temperature (PET)** index for the three urban scenarios:

- **Case 1:** No vegetation, no irrigation
- **Case 2:** Ficus nitida trees spaced 10 meters apart, no irrigation
- **Case 3:** Improved vegetation cover (6-meter spacing) with irrigation

The **PET index** is a reliable indicator of human thermal perception, as it integrates multiple environmental factors, including:

- Air temperature
- Relative humidity
- Solar radiation
- Wind speed

As such, PET offers a precise representation of the physiological thermal stress experienced by individuals in urban spaces—particularly in hot, arid environments like the city of Béchar.



Average Thermal Comfort Curve (PET) - 06:00 to 18:00  
Source: Authors, 2025

## KEY INTERPRETATIONS OF THE THERMAL COMFORT CURVE (PET)

### 1. Early Morning (06:00–08:00):

- PET values are relatively moderate across all cases, ranging between 29°C and 41°C.
- **Case 3** shows slightly improved thermal comfort (i.e., lower PET values), indicating the early influence of shade and soil moisture.

### 2. Late Morning to Early Afternoon (09:00–14:00):

- PET values rise rapidly, exceeding 60°C in **Case 1** around midday.
- **Case 3** demonstrates a consistent reduction in PET, ranging between 1.5°C and 2.5°C, particularly during critical hours.
- For instance, at 13:00, PET in **Case 1** reaches 62.9°C, compared to 61.2°C in **Case 3**.
- This reduction is significant in mitigating thermal stress for pedestrians.

### 3. Afternoon Period (15:00–18:00):

- PET values gradually decline in all scenarios as solar radiation diminishes.
- **Case 3** consistently maintains the highest level of thermal comfort throughout the afternoon, reflecting the cumulative impact of the improved tree layout and irrigation system.

## ANALYTICAL CONCLUSION:

The improved scenario (**Case 3**) clearly outperforms the others in delivering thermal comfort throughout the day. The reduction of PET by up to 3°C during the most thermally stressful hours confirms the critical role of strategic greening and climate-responsive design in urban planning for hot regions such as Béchar.

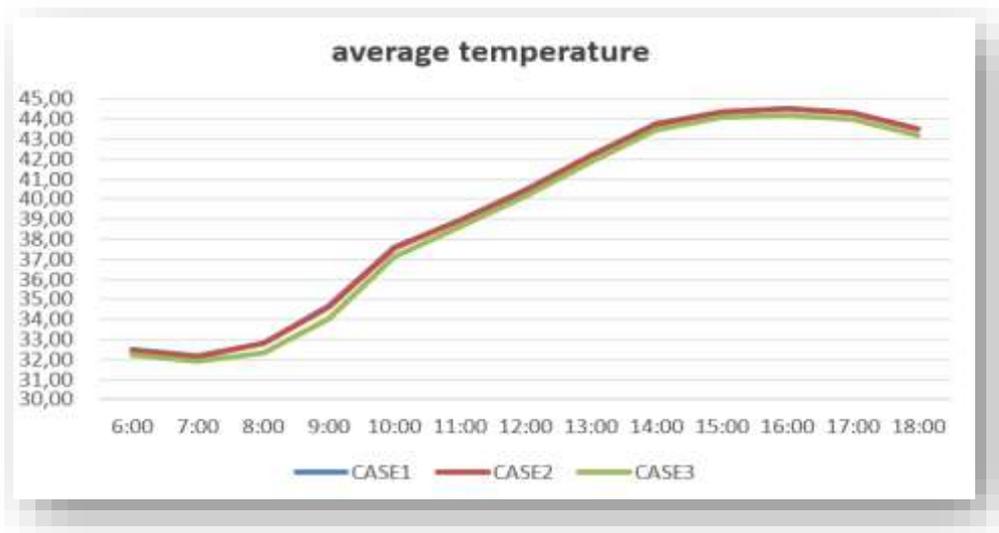
The results demonstrate that planting trees at an optimal density, combined with a basic irrigation system, can significantly alleviate heat stress and enhance the usability of outdoor urban spaces—especially during harsh summer conditions.

#### Interpretation of the Mean Air Temperature Curve – 06:00 to 18:00

This graph illustrates the evolution of mean air temperature throughout the day under three different urban configurations:

- **Case 1:** No vegetation or irrigation; fully paved surfaces (asphalt and concrete)
- **Case 2:** Ficus nitida trees spaced every 10 meters, without irrigation
- **Case 3:** Ficus nitida trees spaced every 6 meters, supported by a basic irrigation system

This curve provides insights into the cumulative effect of each configuration on urban air temperature and highlights the importance of vegetation cover and soil moisture in mitigating daytime heat levels—especially in hot climates like that of Béchar.



Average Air Temperature Curve – 06:00 to 18:00

Source: Authors, 2025

#### KEY INTERPRETATIONS OF THE MEAN AIR TEMPERATURE CURVE (06:00–18:00)

##### 1. Morning Period (06:00–09:00):

- Air temperatures remain relatively stable across all cases, with slight variations ranging between 32°C and 34°C.
- **Case 3** exhibits slightly cooler temperatures compared to Cases 1 and 2, reflecting the early influence of dense vegetation cover and soil moisture.

##### 2. Midday Peak (10:00–14:00):

- All scenarios show a rapid rise in air temperatures.

- **Case 1** (the scenario with no vegetation) peaks at approximately 41.3°C, whereas **Case 3** reaches around 40.1°C.
- The temperature difference of 1 to 1.5°C between the improved and non-vegetated scenarios highlights the effectiveness of tree shading and evapotranspiration in cooling the air.

### 3. Afternoon Period (15:00–18:00):

- Air temperatures begin to gradually decline after 15:00 in all scenarios.
- **Case 3** continues to maintain the lowest temperatures, with the difference becoming more pronounced around 17:00 and 18:00.

### ANALYTICAL CONCLUSION:

**Case 3** demonstrates superior performance in reducing heat accumulation throughout the day, achieving a reduction exceeding 2.2°C compared to the baseline scenario (**Case 1**). These results underscore the importance of dense, irrigated tree planting in enhancing outdoor thermal comfort in arid cities such as Béchar. They further support the adoption of sustainable urban cooling strategies in response to harsh climatic conditions.

### OVERALL CONCLUSION

This study presents a detailed climatic analysis of Tomi El Tayeb Street in the city of Béchar, evaluating the impact of three different design scenarios using the ENVI-met environmental simulation tool. The simulation results revealed the critical role played by vegetation density and moisture availability through irrigation systems in improving outdoor thermal comfort, particularly in hot, arid climates characterized by high temperatures and low humidity.

**Scenario 3**, which involved *Ficus nitida* trees planted at 6-meter intervals supported by a basic irrigation system, outperformed the other configurations. This scenario demonstrated:

- A noticeable decrease in air temperature by approximately 2°C compared to the reference case (with no vegetation),
- An increase in relative humidity by about 10 percentage points,
- A reduction in the PET index ranging from 5 to 7°C, reflecting a significant improvement in pedestrians' thermal perception, especially during peak heat periods.

These findings clearly highlight the effectiveness of plant-based climatic strategies—centered on shading and humidity enhancement—as practical and context-sensitive solutions for arid urban environments. They affirm that integrating environmental considerations into the design of outdoor spaces should not be treated as optional, but rather as a **core element** of urban adaptation policies to climate change, particularly in light of increasing heatwaves and rapid urban expansion.

Accordingly, the study recommends the adoption of **enhanced green infrastructure** as a key tool in sustainable urban development plans. This includes the implementation of climate-sensitive solutions such as strategic tree planting, efficient irrigation systems, and bioclimatic design, all of which contribute to improving quality of life and mitigating the negative impacts of local microclimates in desert cities like Béchar.

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