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# Microclimate Modeling Approach with in-situ Validation: Case of a University Campus in a Tropical Climate

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***Abstract*– The lack of urban planning and high temperatures are problems that negatively impact people's comfort. Thermal dissatisfaction in a humid tropical climate such as Panama City is a problem that we face every day, that many have in the background and deal with it without paying due attention to it, looking for palliative and expensive solutions. In this research, through modeling and simulation using the ENVI-met software and the validation of variables that affect thermal comfort, we want to have the best approximation of the level of thermal sensation in the selected area and identify the critical points of thermal discomfort in it. This area of study is the Víctor Levi Sasso Campus of the Technological University of Panama. The simulation provided us with concrete information to identify critical values of thermal nonconformity at the main transit points. After this, we take those transit points and other points with high temperature values and evaluate different factors that affect comfort in them. By means of in situ measurements, we validate the results of the simulations, giving us temperature values very similar to the simulations.***

***Keywords*—thermal comfort, outdoor, humid tropical, ENVI-met, thermal discomfort, microclimate modeling, simulation, measurements.***

## I. INTRODUCTION

The environment in which we carry out our daily activities should present optimal conditions to carry them out as well as possible. Ideal conditions could be enclosed in one term: "comfort"; Thermal comfort is the parameter to control and improve what? The thermal sensation? This is defined as the condition of the mind that expresses satisfaction with the thermal environment and is subjectively evaluated [1]. The World Health Organization (WHO) defines health as a state of complete physical, mental, and social well-being, and not merely the absence of illnesses or diseases. Therefore, we can make an assumption that part of having good health entails being in an environment where we are physically comfortable, in an environment with good thermal ergonomics, a pleasant sensation since improving the environment where we develop not only impacts our daily activities, but also our health [2].

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High temperatures are linked to different conditions that deteriorate human health due to heat stress. Not being in thermal comfort negatively impacts ergonomics and therefore the efficiency of any work done, e.g., in office work, things as simple as the appearance of sweating or the feeling of cold decreases this efficiency [3], [4]. To reach the conditions of thermal comfort, in indoor spaces, in humid tropical climate, air conditioning equipment is needed to keep the temperature and humidity constant and pleasant for the user. In outdoor spaces, you do not have this possibility, the person is at the mercy of the weather conditions of the moment.

### *A. Possible levels of approach to modeling*

Models using ENVI-met are quite common in simulations of microclimates and macroclimates, mostly to look for comfort strategies and evaluate heat island effects. For example, in the case of the study that was done in Tehran, Iran, at the University of Science and Technology using ENVI-met, they demonstrated how vegetation affected thermal indices in the summer, concluding that in the scenario where trees were planted, the equivalent psychological temperature was 0.7 °C less on average than the current temperature and the maximum decrease was about 2.7 °C occurred at 10:00 am incidence of the sun's rays. In this study, important characteristics of the environment and actors that affect the climate were described. The type of building and pavement materials, to the type of paint of the building, the type of vegetation and how they interact with each other to improve its benefits, are some of the characteristics mentioned [5]. These characteristics vary depending on the study being done. In some cases, characteristics such as the amount of solar radiation or what the study area is used for are described in greater depth. This is an important feature if you are talking about comfort and want to study and improve areas of public use such as parks. The level of description can go as far as specifying the year, month, and day that was used for the study [6].

Another example of how the level of detail of simulations can vary is the study that was done at the Beijing University of Civil Engineering and Architecture. Also, using ENVI-met, they made simulations of the effect that bodies of water have on the environment. To model their study area, they used a variable control method in which they set a green space with a cover rate of 30% around the water body. And they varied the proportion of the body of water. In this research, it was important to describe albedo levels [8], a common feature in studies involving the benefits of nature in the environment [7], [6].

Other characteristics that describe the study area, quite important are the geographical location and type of climate, within the type of climate can be described the average temperatures, wind speed, wind direction, the percentage of humidity and precipitation [6], [8].

### *B. Validation of modeling approaches*

To validate the results of the simulations in ENVI-met or in any software, there are different methodologies, such as the measurement of the same variables at the study site, "in situ". This provides data for comparison with simulations. In the same study from the University of Science and Technology in Tehran, they found that the correlation between the on-site measurements and the simulations at ENVI-met had a value of $R^2 = 0.826$, concluding that the simulations are reliable [5].

Many studies validate their results by basing data on multiple sources at once. They use weather data from the software, data from previous studies, data from weather centers, surveys, and even satellite images [9]. These are the most solid studies in terms of validating the results of a base scenario of a simulation or the validation of a problem that people experience daily. This is because they make sure the data backs up their theory or simulations and therefore your solutions are as real and accurate as possible [5], [10]. Other authors base their results entirely on software data [7].

### *C. Thermal comfort assessment*

To assess the effect of vegetation and other techniques on comfort, some studies use the correlation between air temperature, surface temperature, wind speed, the Sky view factor, the PET index (Physiological Equivalent Temperature) [5], [9] or another index such as the PMV (Average Predicted Vote), which also connects these factors. But add the type of clothing of the people. All these indicators are estimated by means of software [6], [8].

There are several bioclimatic techniques that alone manage to contribute to the goal of reducing the problem of external thermal dissatisfaction. The purpose of this experimentation is to couple techniques that complement each other to enhance this contribution to the reduction of temperatures, techniques such as tree planting, cooling by sprinklers, bodies of water, and other similar methods, and the combination between them. The motivation of the study is mainly to improve outdoor comfort using these combinations; strengthening this factor is where the true potential and innovation of this study lies. Not enough literature has been found on these combinations, considering the humid tropical climate of the country (Panama), which, despite having studied using the techniques in isolation in countries with similar climates, the solutions are not optimal for the country's context.

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## II. METHODOLOGY

In this section, we will explain the methodology of experimentation, the steps followed, and their development. In Fig.1, we can see the schematics of the methodology.

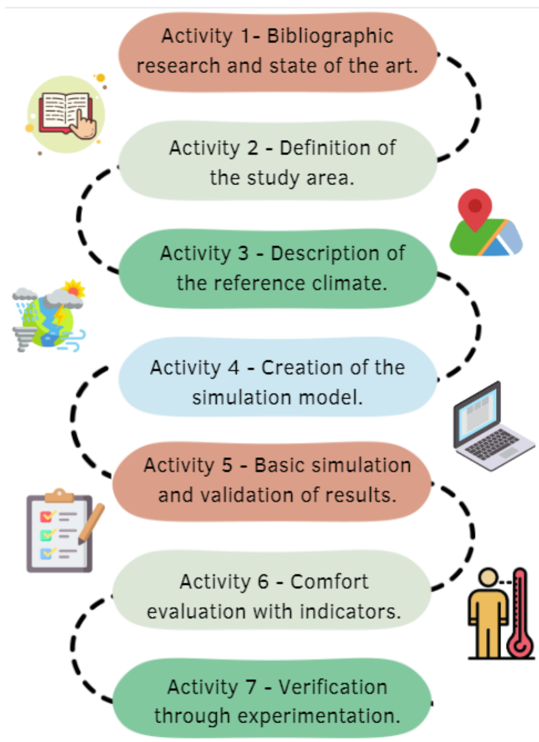



Fig. 1 Methodology Outline

### *A. Description of the case study*

In this research, the study area is the Victor Levi Sasso campus of the Technological University of Panama (UTP), located at coordinates 9°1′22.8" N, 79°31′51.6" W [11]. Specifically, an area of approximately 100 percent was chosen to study the microclimatic phenomena of pedestrians around campus because it encompasses the busiest areas on foot and by car (Fig. 2). Panama is in the intertropical zone near the Earth's equator and has a climate, one rainy season and one dry season. The first begins in May and lasts approximately until November, with the months of October and November being the rainiest (approximately). The dry season or months with little rainfall is notorious between the months of December and April, except for the Caribbean slope, where it rains almost all year round. The large ocean masses of the Atlantic and Pacific are the main sources of the high moisture content in our environment and due to the narrowness of the strip that separates these oceans, the climate reflects a great maritime influence. This ocean-atmosphere interaction largely determines the heat and moisture properties of the air masses circulating over the oceans. Ocean currents are closely linked to the rotation of the earth and winds. Tags. $269\,667.27 m^2$ [12].

In Panama, the hot season has average maximum temperatures of 32 °C and minimum temperatures of 25 °C, while the cool season has average maximum temperatures of 30 °C and minimum temperatures of 24 °C, even in the cool season, temperatures remain high, and humidity remains at the limit (between 50% and 70%) [13]. These data highlight that we are outside the thermal comfort zone that ranges between 18 °C to 26 °C and between 40% to 70% relative humidity, according to the ASHRAE 55 [14].

Fig. 2 Study area, Campus Victor Levi Sasso

*B. Simulation model*

The modeling of this research consists of recreating the study area, the Víctor Levi Sasso Campus, in a macro way. Using the Google Earth tool, which gives us a satellite view, we raise the model using the ENVI-met software in, which it has an option that, using these satellite images, the elements can be added on top of them. This software is a 3D urban climate modeling tool, to simulate the microclimatic effects of buildings, vegetation, and other objects in the fields of urban design and planning and real estate development [15].

Now that we have the base scenario defined, both its location and its characteristics, we will proceed to recreate the model in the selected microclimate simulation tool, the ENVI-met software. This software allows satellite images to recreate the study area. Depending on the degree of detail used in the simulations, these data must be obtained beforehand, such as: the height of the buildings, the materials of the buildings, the material of the pavement, the number of trees, type of trees, among others, depending on the detail that you want to give it. In Figs. 3 and Fig. 4 we can see how the Víctor Levi Sasso campus looks after recreating it at ENVI-met.

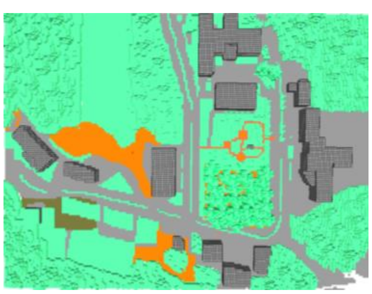


Fig. 3 Victor Levi Sasso Campus top view

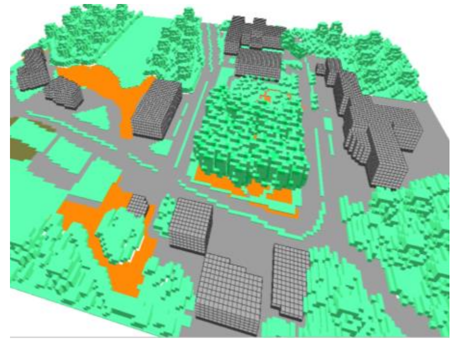


Fig. 4 Campus Victor Levi Sasso relief view

Since we have the complete simulation scenario, with all the buildings, green areas, trees, streets, materials, and specifications of each one. We will proceed with the simulation of the selected microclimate. The simulations will give us the necessary data to know which techniques to apply, where and when. They will show us the critical points and regions of temperature and at what time they occur. They will also show us other data such as: wind speed, wind direction, potential air temperature (not to be confused with the actual air temperature), average radiant temperature, specific humidity, and CO2 concentration in the air. Table 1, Table 2, Table 3, and Table 4 present the characteristics of the materials and vegetation used in the simulation at ENVI-met.

TABLE I
BUILDINGS MATERIALS CHARACTERISTICS

| **Wall/Roof Materials** | **Default Thickness** | **Absorption** | **Reflection** |
|---|---|---|---|
| Concrete | 0.01 m | 0.7 Tailcoat | 0.3 Tailcoat |
| **Emissivity** | **Specific Heat** | **Thermal Conductivity** | **Density** |
| 0.94 Frac | 850 J/(Kg*K) | 1.6 W/(m*K) | 2220 kg/m^3 |

TABLE II
SOIL MATERIALS CHARACTERISTICS

| **Code** | **Material** | **Roughness Length** | **Albedo** | **Emissivity** |
|---|---|---|---|---|
| 0200PG | Concrete Pavement Gray | 0.01 m | 0.25 Tailcoat | 0.90 Frac |
| 020KK | Brick road | 0.01 m | 0.3 Tailcoat | 0.90 Frac |
| 0200LO | Loamy Soil | 0.015 | 0 | 0.9 |
| 0200SL | Sandy Loam | 0.015 | 0.2 | 0.9 |

TABLE III
SIMPLE PLANTS CHARACTERISTICS

| **Code** | **Leaf Type** | **CO2 FixationType** | **Albedo** | **Emissivity** |
|---|---|---|---|---|
| 0200XX | Gras | C3 | 0.2 | 0.97 |
| **Transmittance** | **Plant height** | **Root Zone Depth** | **Leaf Area Profile** | **Season Profile** |
| 0.3 | 0.25 m | 0.2 m | 0.3 | 1 |

TABLE IV
3D PLANTS CHARACTERISTICS

| **Code** | **Canopy** | **Shape** | **Dimension** | **Trunk** | **Height** | **Leaf Type** |
|---|---|---|---|---|---|---|
| 02HMSS | Sparse | Cylindric | Small | Medium | 5 m | Deciduous |
| 02HMSM | Sparse | Heart-shaped | Medium | Medium | 15 m | |
| 02OLDS | Turn | Cylindric | Small | Large | 5m | |
| 02OMDL | Turn | Cylindric | Large | Medium | 25m | |
| 02HLSS | Sparse | Heart-shaped | Small | Large | 5m | |

## C. *Validation*

As we explained earlier in the introduction, the forms of validation for an experiment of this type can consist of using only the data from the software, meteorological data from meteorological centers, data from previous studies, data taken in situ, and satellite images. Here we will use the data from the software, data that by setting the polar coordinates of the site automatically makes the setting of the required values, together with data from in situ measurements of the study area.

For these site measurements, we will be measuring factors like wind speed, relative humidity (RH%), air temperature, concrete temperature, albedo temperature, dry albedo temperature and albedo temperature under shade.

The instrumentation we will use consists of a thermal imaging camera to measure the apparent surface temperature of the materials, an anemometer to measure wind speed, and an air quality meter with which we will measure the relative humidity and temperature of the air.

The HT-18 thermal imaging camera, from the HTI brand, is a device that integrates surface temperature measurements and thermal images by taking the temperature of the objects that can be captured on the screen, the camera is set to an emissivity value of 0.95 by default which means that the camera assumes that objects in the viewing area reflect 5% of the thermal radiation it receives and emit 95%.

The unidirectional digital anemometer, model GM8091 of the BENETECH brand, is used to measure wind speed to make specific evaluations and we will use the average speed at an interval of five minutes.

To measure the temperature of the air and the relative humidity of the air we will use the carbon dioxide meter model 7755, from the PCE-Iberia brand, an ideal instrument for the diagnosis of air quality that measures the air temperature, the dew point, the wet bulb temperature, and the humidity. This meter uses non-dispersive infrared (NDIR) technology to ensure long-term reliability and stability.

In Fig. 5 we can see the schematics of what heights, what angles and with what instruments the different measurements were taken. With the unidirectional digital anemometer, model GM8091, the averages are taken at a head height of approximately 1.78m. With the HT-18 thermal imaging camera, measurements are taken at an angle of 35° at about 1.25m, pointing towards the floor. With the model 7755 carbon dioxide meter, measurements are also taken at a height of about 1.25m, although this height does not vary the measurements in a great way.

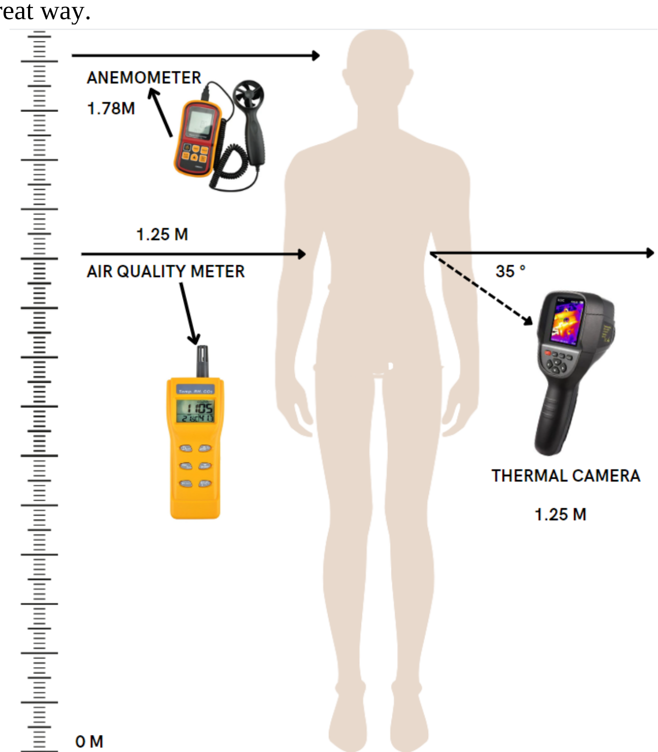


Fig. 5 Scheme of the forms of measurements

## III. RESULTS ANALYSIS AND DISCUSSION

In the methodology, we explain what simulations and validation would consist of. In this section, we present the results of these tests. The results of the simulations for 12:00 p.m. are presented in Fig. 6 for radiant temperature, in which we can observe temperatures in a range of 25.05 °C to 55 °C. Based on these results, we chose four critical points based on temperature and human flow levels to make the on-site measurements to validate the simulation results.

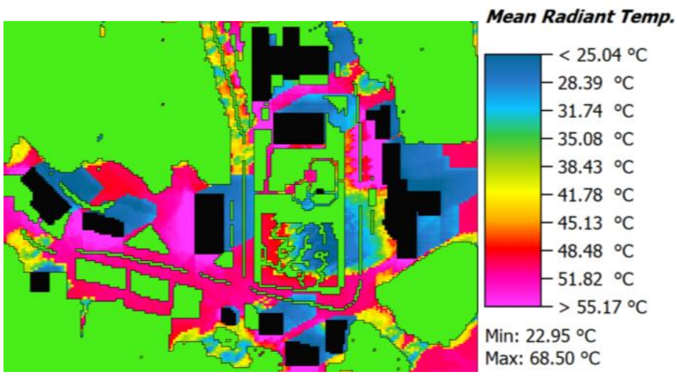



Fig. 6 Mean Radiant Temperature.

The in-situ measurements were also made at 12:00 p.m. as in the simulations, since this was the time when the radiant temperature was highest. Since we can't be at all four points at once, the measurements were made as close to 12:00 p.m. as possible. In a range between 11:45 a.m. and 12:15 p.m. The measurements consisted of being at the measurement point and measuring values such as air temperature, relative humidity of the air, mean wind speed, concrete temperature, and albedo temperature, dry albedo temperature and albedo temperature under shade, all giving different from each other. In Fig. 7 we mark these points where the temperature was critical and where people pass most often.

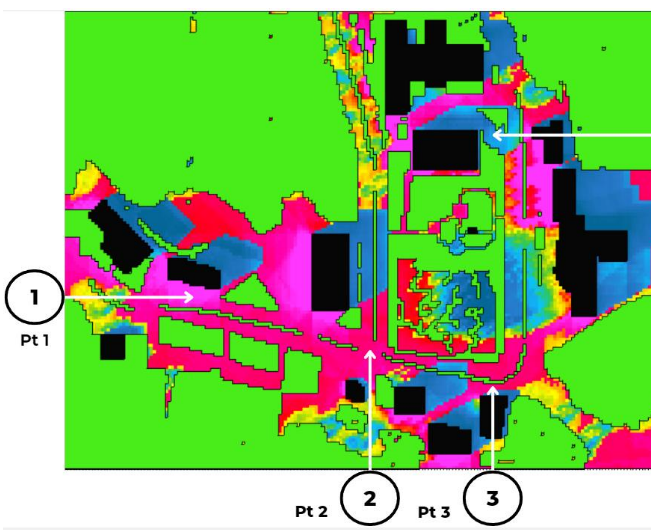



Fig. 7 Critical Thermal Points.

Point 1 is located in front of the Research and Innovation Laboratories building. This point lacks any type of vegetation or any bioclimatic technique to mitigate high temperatures or seek the comfort of people. Fig. 8 (a),(b),(c) shows the images of this measurement point taken with the HT-18 thermal imaging camera and in the same figure (d), (e), (f) the images of this same site but taken with a normal camera are shown, for comparison and orientation.

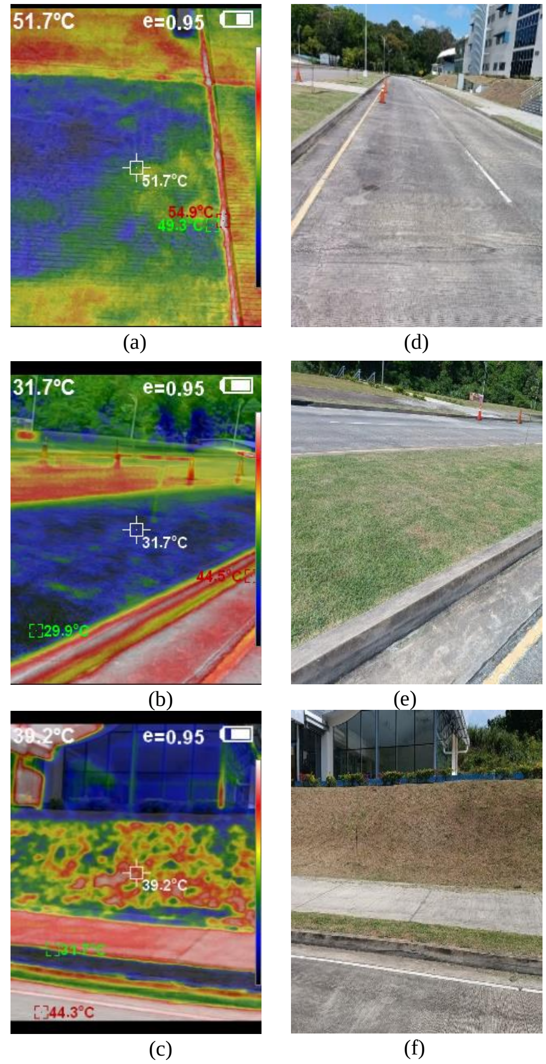
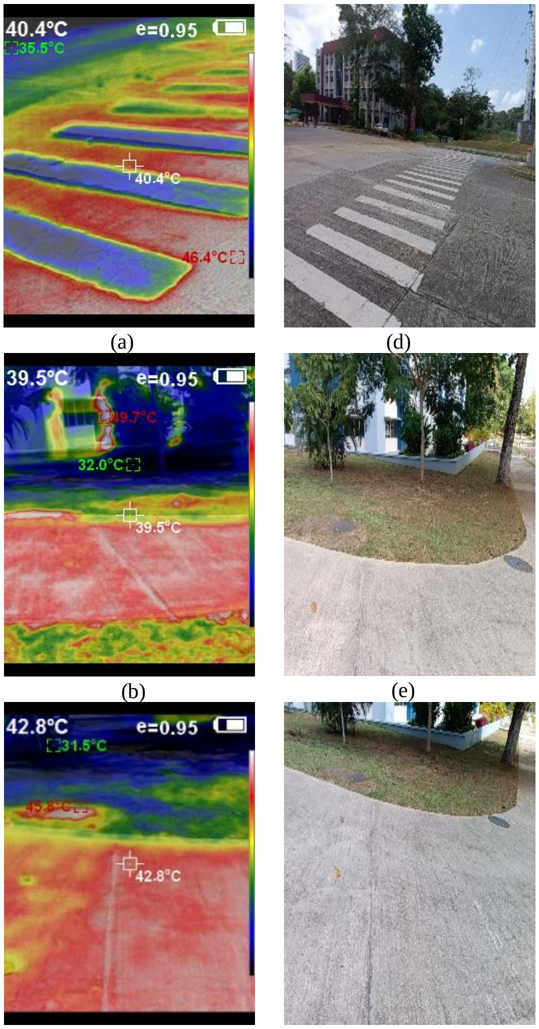



Fig. 8 Point one of measurements with thermal imaging camera (a), (b), (c); with normal camera in situ (d), (e), (f). Saturday, January 6, 2024. Measurement time 11:45 am. Clear sky.

Point 2 is located next to the intersection of the Vice-Rectory for Research, Postgraduate and Extension (VIPE) building and the Classrooms building No. 4. A point that does not have any bioclimatic technique to mitigate high temperatures or seek the comfort of people. Fig. 9 (a),(b),(c) shows the images of this measurement point taken with the thermal imaging camera and in the same figure (d), (e), (f) the images of this same site are shown with a normal camera, for comparison and orientation.

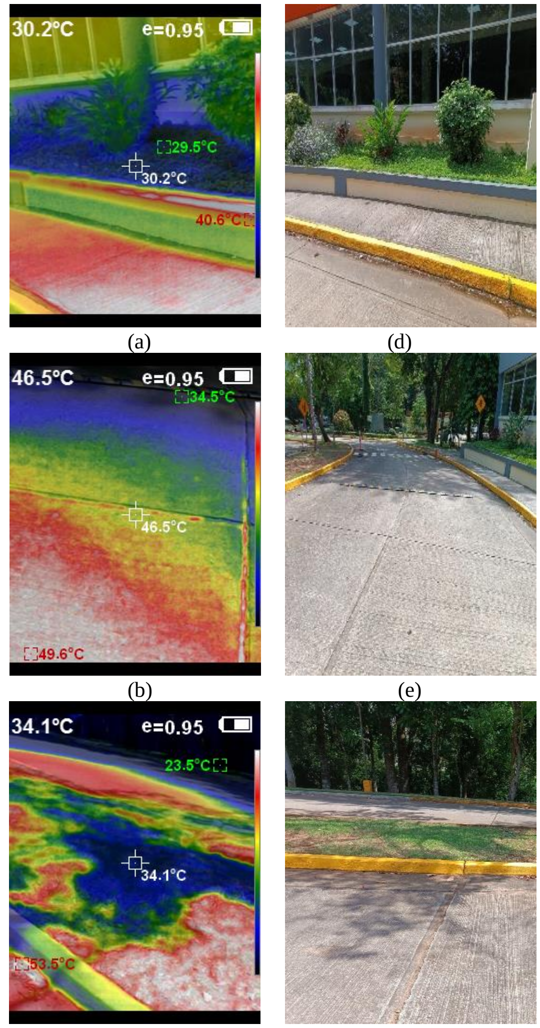



(a) (d)

(b) (e)

(c) (f)

Fig. 9 Point two of measurements. With thermal imaging camera (a). (b), (c); With normal camera in situ (d), (e), (f). Saturday, January 6, 2024. Measurement time 12:00 am. Clear sky.




(a) (d)

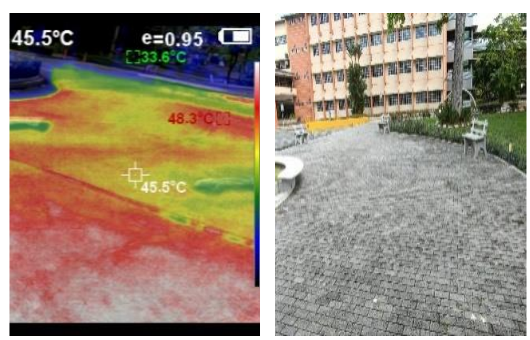
(b) (e)

(c) (f)

Fig. 10 Point three of measurements. With thermal imaging camera (a). (b), (c); With normal camera in situ (d), (e), (f). Saturday, January 6, 2024. Measurement time 12:15 pm. Clear sky.

At point 3 it is located in front of the central cafeteria, it has some vegetation, but the conditions are out of comfort at certain times of the day. Fig. 10 (a),(b),(c) shows the images of this measurement point taken with the thermal imaging camera and in the same figure (d), (e), (f) are shown the images of this same site, but taken with a normal photographic camera, for comparison and orientation.

Point 4 is located next to the new flagpole area, where a paved path has been made for people to transit. Fig. 11 (a),(b),(c) shows the images of this measurement point taken with a thermal imaging camera and in the same figure (d), (e), (f) are shown the images of this same site, but taken with a normal photographic camera, for comparison and orientation.




(a) (d)

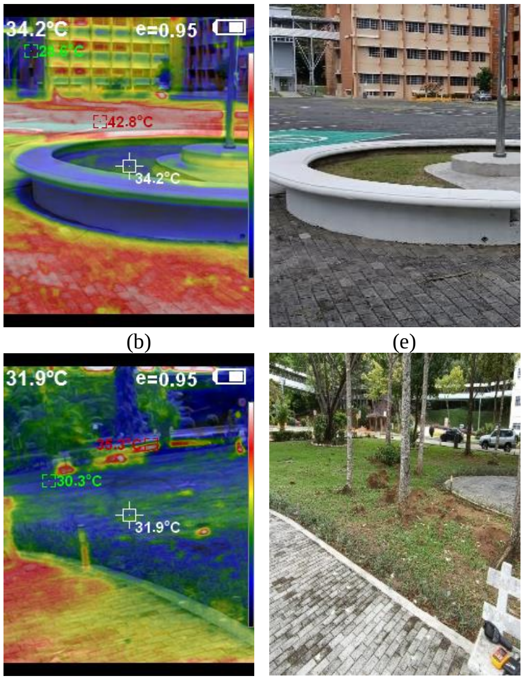



Fig. 11 Point four of measurements. With thermal imaging camera (a). (b), (c); With normal camera in situ (d), (e), (f). Saturday, January 6, 2024. Measurement time 12:30 pm. Clear sky.

In Table 5, Table 6, Table 7, and Table 8, the results of the different days of measurements made in situ are presented, for validation of the model.

TABLE V
DAY ONE OF MEASUREMENTS

| Day 1 of measurements | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Average Air Velocity(m/s) | Air Temp(°C) | Air Humidity (%) | Concrete Temp(°C) | Albedo Temp(°C) | Albedo (in shadow) Temp(°C) | Dry Albedo Temp(°C) |
| Pt1 | 2.9 | 36.5 | 44 | 46.8 | 30.1 | NA | 39.2 |
| Pt2 | 2.8 | 35.1 | 44 | 45.2 | 38.8 | 32.5 | NA |
| Pt3 | 1.7 | 34.8 | 42.9 | 42.1 | 29 | 27.6 | 30.6 |
| Pt4 | 1.8 | 33.1 | 48 | 36.3 | 33.3 | 31.4 | 32 |

TABLE VI
DAY TWO OF MEASUREMENTS

| Day 2 of measurements | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Average Air Velocity(m/s) | Air Temp(°C) | Air Humidity (%) | Concrete Temp(°C) | Albedo Temp(°C) | Albedo (in shadow) Temp(°C) | Dry Albedo Temp(°C) |
| Pt1 | 1.5 | 33 | 52 | 45.9 | 36.1 | NA | 40.3 |
| Pt2 | 2.2 | 33 | 52 | 40 | 36.9 | 31.6 | NA |
| Pt3 | 1.4 | 36.9 | 41.5 | 46.5 | 30.8 | 29.7 | 45.9 |
| Pt4 | 1.7 | 34.1 | 45.4 | 39.3 | 31.9 | 31.4 | 34.2 |

TABLE VII
DAY THREE OF MEASUREMENTS

| Day 3 of measurements | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Average Air Velocity(m/s) | Air Temp(°C) | Air Humidity (%) | Concrete Temp(°C) | Albedo Temp(°C) | Albedo (in shadow) Temp(°C) | Dry Albedo Temp(°C) |
| Pt1 | 2.7 | 39.7 | 42 | 55 | 39.3 | NA | 44.9 |
| Pt2 | 1.8 | 39.6 | 38.8 | 48.6 | 43.3 | 36 | NA |
| Pt3 | 1.1 | 37.3 | 38.5 | 49.5 | 30.9 | 37.9 | 39.4 |
| Pt4 | 1.8 | 40.5 | 34 | 54.9 | 44.3 | 32.7 | 47.2 |

TABLE VIII
DAY FOUR OF MEASUREMENTS

| Day 4 of measurements | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Average Air Velocity(m/s) | Air Temp(°C) | Air Humidity (%) | Concrete Temp(°C) | Albedo Temp(°C) | Albedo (in shadow) Temp(°C) | Dry Albedo Temp(°C) |
| Pt1 | 3.2 | 35 | 37.4 | 54.4 | 39.7 | NA | 45 |
| Pt2 | 2.9 | 35 | 34.4 | 52.1 | 47.9 | 34.5 | 50.9 |
| Pt3 | 0.5 | 36.2 | 30 | 59.4 | 41.6 | 33.9 | 52 |
| Pt4 | 4.9 | 32.7 | 39.7 | 51.1 | 39.3 | 32.9 | 49.5 |

For greater contrast of these tables, we will use the temperature values of the cement and the temperature values of the shaded albedo, which are the values most distant from each other. This is also to highlight the usefulness of the greenery between the trees and the albedo, thanks to the shade. Figure Fig. 12 shows a graph showing the temperatures of four days of in-situ measurements, at the four critical measurement points and in these results, we can see the similarity between the temperatures of the simulations made in ENVI-met, which correspond to the last columns on the right labeled as "Simulation" and the in-situ measurements.

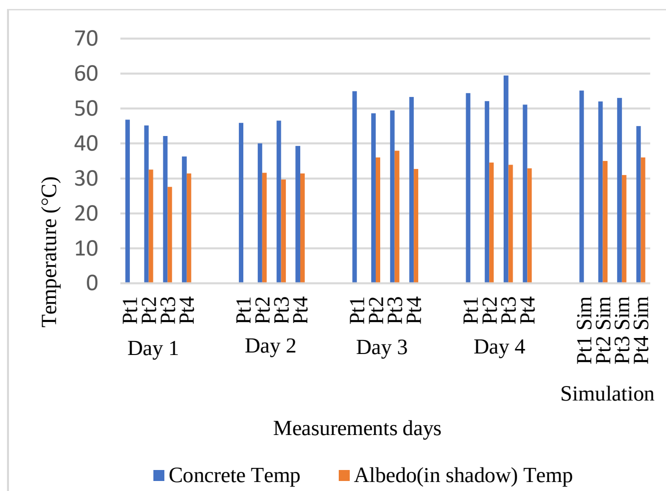



Fig. 12 Results of Temperature Measurements in-situ and temperature obtains in ENVI-met.

In this figure we can see how the measurements of the ENVI-met program Fig. 12 have results close to the in-situ measurements. With a difference of 0.37°C in the maximum temperature measurement on day 3 Fig. 8 (a). Temperature differences similar to the literature found where the variations range from 1.2°C to 2.6°C [5].

## Conclusion

The use of different methodologies to carry out a microclimatic study helps to validate the data obtained in any of the forms of measurement. But it shows that the use of software could be unique as it allows large amounts of meteorological data to be processed at once, efficiently, providing accurate and detailed results. They facilitate the application of changes in that environment to improve its characteristics, giving a preview of whether the change is beneficial or the opposite. All this only at the cost of the software, much less than the cost of making that change and not having it work. In addition to also facilitating the visualization of weather patterns for correct urban planning [16].

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