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Enhancing Users' Thermal Comfort: Implementation in Commercial Outdoor Spaces, New Cairo, Egypt

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***Abstract*— Controlling direct solar radiation and improving temperature should be the main factors in the design of urban open spaces to achieve a greater use & value for this space, especially during hot climates. One of the most important functions of urban vegetation is its impact on temperature reduction & increasing shaded areas. This paper will demonstrate how plant material affects the microclimate elements by analyzing 2 case studies in new Cairo. The research is focused on several objectives but mainly the importance of using several types of vegetation, this is reached by the selected simulation tool Envi-met, to determine the difference in temperature in presence of vegetation compared to temperature without vegetation in outdoor places, as well as the effect of tree shading on surface cooling during the day. It shows that the temperature of green areas using either grass only or trees with grass is lower than that of the non-vegetated surfaces exposed to direct solar radiation, this confirms the necessity of vegetation for urban cooling.**

Keywords—Outdoor spaces; vegetation; microclimate elements

1 INTRODUCTION

Due to rapid and wide urbanization, the characteristics of outdoor urban microclimates have changed, affecting pedestrian satisfaction, especially in hot regions. Many researchers and urban space planners are faced with the challenges of choosing suitable ways to reduce urban heat stress and, as a result, enhance the level of air temperature of outdoor space for individuals to improve their usage of outdoor space. The open outdoor spaces such as the circulation area, main pedestrian's axis, and outdoor plazas need to provide more thermal comfort for users that can be obtained by vegetation which not only reduces the exposure of pedestrians to direct sunlight; but also reduces the amount of sunlight that reaches building surfaces and pavement, **e**specially in hot summer days, thus it can help to promote activity in these places.

When understanding factors that affect the microclimate, we can achieve maximum thermal comfort by reducing sun penetration to the ground surface and enhance pedestrian comfort and activity in public outdoor spaces. This research aims to improve the quality of outdoor areas through vegetation as it is an effective method of cooling the prevalent hot air and protecting different surfaces from direct solar radiation to achieve thermal comfort for users and increase the interaction in such spaces.

The study analyses the impact of vegetation on decreasing outdoor temperature and the extent to which landscape material influences microclimate in outdoor open areas, as well as the impact of trees and shading on daytime surface cooling. The study went through two case studies that showed the impact of vegetation by using Envi-met modeling & simulation, the case studies focused on measuring thermal comfort indices & changes in microclimate elements during the design process.

Research methodology

The strategy followed in this study consists of two parts:

The first part is an analytical approach: by analyzing the input data collected for two different outdoor areas in new Cairo and evaluating how the design of its vegetation affect the sun radiation penetration and thus help decrease heat stress and improve the thermal comfort for pedestrian. The essential feature for both cases is the large outdoor area and the landscape inside its commercial area. In order to see how vegetation affects solar radiation and temperature, a number of input data were taken into account; as it requires standard weather data, vegetation types, buildings, and surface materials, to calculate the microclimate parameters.

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The second part is a deductive approach: used to state the recommendation and possibilities of applying decisions to reduce direct radiation and provide more shaded area using landscape elements in order to enhance thermal comfort for users.

Paper Structure

The paper is divided into five main sections (excluding the introduction & references) as follows:

PAPER STRUCTURE (RESEARCHER, 2022)

Section number and title	Section content
2.Microclimate thermal comfort and outdoor open space.	This section will focus on elements that influence microclimate and how vegetation affects these elements to reduce heat stress and control wind.
3.Applying the selected Envi-met simulation tool	This section will focus on how Envi-met can simulate the study area with high accuracy.
4.Case studies simulation	This section shows the effect of tree shading on reducing the surface temperature for 2 different case studies.
5.Discussion of the results	This section is discussing some main points for the simulation results
6.Conclusions and recommendations.	This section is concluding the influence of vegetation to improve microclimate conditions & seeking to introduce recommendations.

MICROCLIMATE THERMAL COMFORT AND OUTDOOR OPEN SPACE.

"Urbanization is leading to the warming of micro-climate. The effect of climate modification, especially thermal outdoor conditions, has consequences such as increased health risks, and overall quality of life in cities." [1]. The vegetation of urban public places may play a significant role in reducing the negative effects of urbanization.

Thermal sensation is mainly depending on urban planning and the layout of the surrounding area, microclimatic factors have an impact on the attractiveness and usage of open spaces. In reality, the built environment, the thermal absorption coefficient of the ground surface covering, the vegetation and its evapotranspiration process, and the shading that have made by the structure or natural trees have an impact on the outdoor thermal climate [2].

The most important factor in attracting urban residents is outdoor thermal comfort. People have been paying more attention to the urban environment in recent years as the urban climate has changed, causing researchers all over the world to focus on outdoor thermal comfort. The outdoor climate has several factors that affect thermal comfort, such as meteorological factors: air temperature, relative humidity, wind speed and direction, solar radiation, etc.—and other personal factors [3].

1.1. Microclimate elements as the basis for analyzing the climate.

Microclimate differs from macroclimate as the latter is concerned with the local atmospheric conditions as they affect the living conditions of plants and animals, and not with the mechanics of the weather itself. This brings us to the definition that [4] concluded which is that microclimate is the condition of some elements which includes solar radiation, wind velocity, air temperature, and humidity in any space. The analysis of these elements provides the basis for weather forecasting and defining the climate [5]. Air temperature is the most evident component of climate and the primary factor affecting it, and has a direct relation with solar radiation.

1.1.1. Solar radiation

The direct sun rays and energy that reach the earth from the sun are known as solar radiation. The atmosphere contains the vast majority of the radiation emitted from the surface of the Earth. Both natural and artificial surfaces absorb and reflect some of the radiation, according to [4]. The radiation's color spectrum, as well as the properties of the receiving surface, influence the absorption and reflection process [6]. By reflecting the green part of the received energy and absorbing the other visible spectrum wavelengths, plant matter, for instance, appears green. Albedo is the ratio of incident light that is reflected over the surface.

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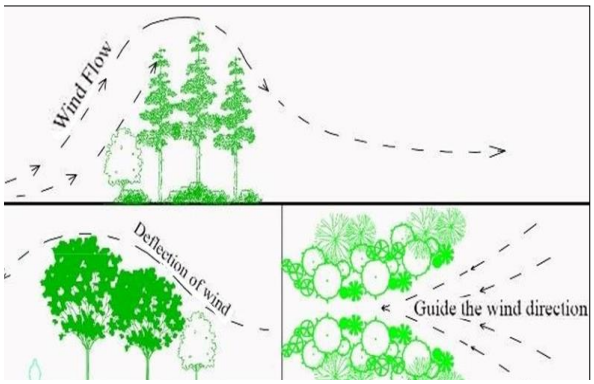
1.1.2. Air temperature

One of the most important elements in describing and evaluating weather conditions is air temperature because it affects or regulates other weather components including rainfall, humidity, and pressure [5]. A thermometer placed in the air but protected from direct sunlight, 1.5 to 2 meters above ground, is used to measure air temperature, according to another definition [7]. Seasons, cloud coverage, and time of year are the primary determinants of air temperature. Air temperature is described by [8], as the most observable aspect of climate and the most important aspect in influencing how much energy is used for heating and cooling.

2.1.3 The influence of vegetation on microclimate elements.

The vegetation influences the regional climate, and it is recognized as an essential design component for enhancing the urban microclimate and outdoor thermal comfort in urban areas [9]. Plants are influenced by climatic change due to their long lifespan and progressive genetic adaptation to environmental changes. The urban microclimate consists of four main factors: Solar radiation, temperature, wind, and humidity, the impact of plants on each of these aspects has to be considered to help support the decision-making process of which plants are capable of surviving and maintaining their function and value in each microclimatic space. According to a study undertaken in Greater Manchester, United Kingdom by [10] another approach to cool the surface was discovered to be tree shade. It has been observed that in small areas, the maximum temperature of the concrete floor may be decreased by up to 12 – 19 degrees Celsius in the park. As a result, if the grass is inefficient, tree planting will significantly reduce the amount of ground area. In a term related to solar radiation plants can either totally block or filter the sun's radiation. Each plant kind has a unique form and density to its shadow [11]. So that, we need to examine the variations of shadow projection from the canopy that may be controlled through planting design to understand the ability of trees in providing shadows according to environmental needs. Also, controlling wind may be done in a variety of ways, from selecting various plant types to arranging trees. Lowering wind velocity causes a reduction in the rate of thermal exchange in the air layers, leading to better temperatures in the protected zone as shown in figure one [12].



"Fig. 1," The effect of trees and shrubs in directing & controlling wind. Source: (Minh, et al., 2019).

2.2. Thermal comfort and vegetation

Thermal comfort is "a condition of mind which expresses satisfaction with the thermal environment" according to [13]. In a recent study by [14], the impact of thermal comfort on outdoor activities is a complicated topic that takes into account both meteorological and behavior factors. For optimizing the thermal comfort of pedestrians, the use of vegetation to minimize heat in cities is seen to be preferable to the use of high-albedo materials on the surface [15]. Vegetation affects outdoor thermal comfort through evapotranspiration, specifically it provides moisture cooling since the absorbed solar energy increases latent heat (vegetation's water evaporates into the atmosphere), which cools the leaf surfaces and the air around them [16] and [17]. Furthermore, compared to construction materials, vegetation absorbs and stores less heat, and tree shadowing reduces air and surface temperature since trees absorb solar radiation [18].
There are various thermal comfort indices for indoor and outdoor spaces. however, [19] stated just two indices that were specifically developed for outdoor comfort studies by reviewing the most popular comfort indices used in outdoor comfort research: The Physiologically Equivalent Temperature (PET) and the Universal Thermal Climate Index (UTCI) shown in table (2). (PET) is based on the four previously mentioned climatic variables, while clothes and exercise rate remain constant, however (UTCI) on the other side, is unaffected by clothes insulation (assumed to be a function of air temperature and wind speed using an adaptive clothing model with activity rate "standardized" (for a walking person at 1.1 m/s).

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TABLE I. , UTCI THERMAL COMFORT CLASSIFICATIONS (WALLS, ET AL., 2015).

Above 46°C	38°C to 46°C	32°C to 38°C	26°C to 32°C	9°C to 26°C	9°C to 0°C	0°C to -13°C	-31°C to -27°C	-27°C to -40°C	Below -40°C
Extreme Heat Stress	Very Strong Heat Stress	Strong Heat Stress	Moderate Heat Stress	No Thermal Stress	Slight Cold Stress	Moderate Cold Stress	Strong Cold Stress	Very Strong Cold Stress	Extreme Cold Stress

3. APPLYING THE SELECTED ENVI-MET SIMULATION TOOL.

Several microclimate simulation software such as; ENVI-met, Rayman, and Autodesk CFD are currently available, each with different objectives and responses to different parameters. It is found that ENVI-met is capable of predicting and simulating thermal comfort indices, meteorological parameters, and most outdoor design strategies, as well as it is the most user-friendly of all climatic software.

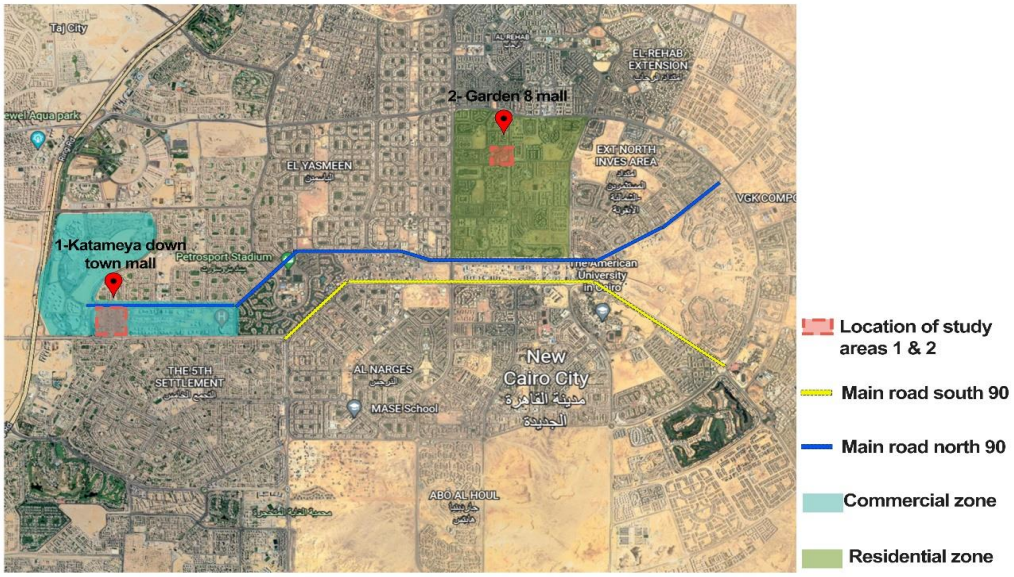
The model requires simple input parameters and calculates all essential weather data, including air temperatures, wind speed, and direction, air humidity, for comfort analyses. The first step will be to prepare the space for modeling the study inside Envi-met, this covers the dimensions of the architectural environment, surface materials, distribution, and percentage of green surfaces plus the location, type, and height of all plant materials. The second phase would be to collect information regarding the site's location as well as specific data such as the time and date to run the simulation. The output files are shown through the LEONARDO maps to see how different vegetation parameters affect the microclimate elements. Conclusions could be formed based on how the values are brought closer to thermal comfort. Finally, recommendations are presented to provide design guidelines for the use of vegetation in controlling the microclimate.

4. CASE STUDIES SIMULATION

In order to determine how vegetation impacts direct solar radiation, that in turn influences the temperature and thermal comfort of the outdoor commercial areas. Two different areas were selected and compared to each other. The two sites were chosen according to their strategic location in the center of the new Cairo city, connecting and serving multiple places. The first case study (Katameya downtown mall) is located on the main road 90 and connected to all main roads around it which make it easily accessible for users, containing several landscape spots and many buildings with different heights. On the other side the second case study (Garden 8 mall) differs from the first one as it is located inside a residential compound, and a few minutes away from different landmarks, containing large landscape unique space and one main building with an average height about 9 meters.

4.1. Simulation conditions

The simulation for two outdoor shopping malls in New Cairo city, Egypt, with co-ordinates 30.13° N, and 31.4° E, as shown in figure two, were run in the summer period 2022 on the 9th of July at a specific hot hour (1 pm), and weather input data were as follows: air temperature, relative humidity, wind speed and cloud coverage that obtained from weather file Calculated by Climate consultant 6.0 2021.



"Figure 2," Displaying the two sites' locations inside New Cairo. Source: (Google Earth, 2022), Edited by the Researcher

4.2 Case study one (Katameya downtown mall)

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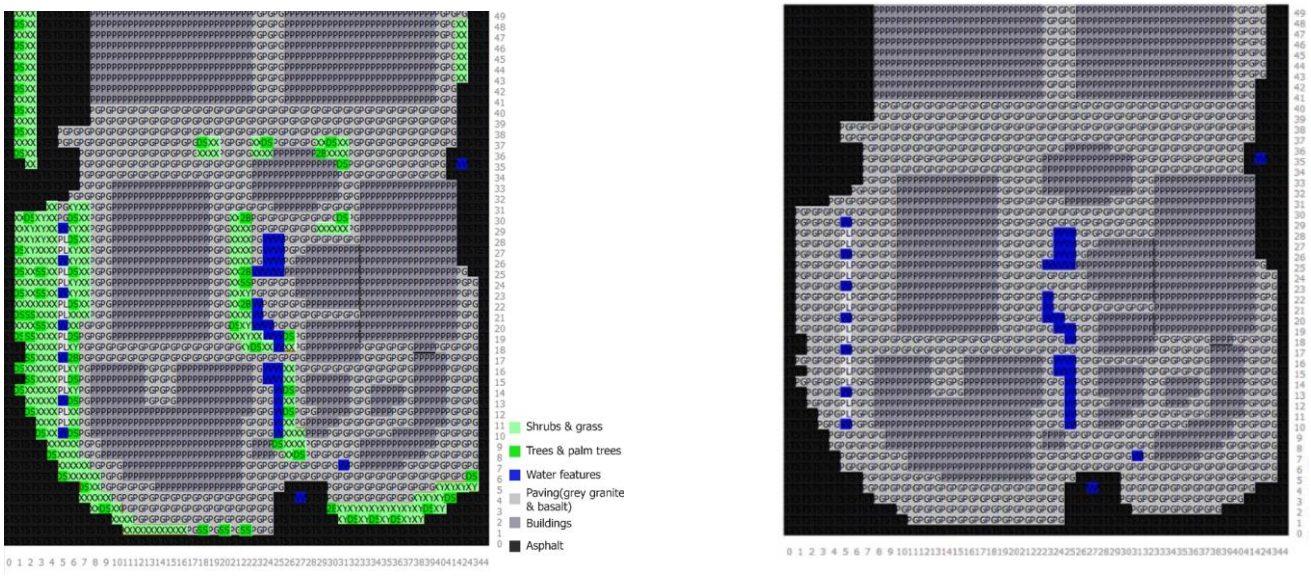
The area was modeled inside Envi-met space 45x50 cells, with a total area of about 45000 m² including 9 separate buildings with different heights ranging from 4m to 18m tall with a total buildup area of 45%. Two scenarios were modeled the first using the vegetation types existing on site including grass, shrubs, trees, and palm trees with different heights of 5m-25m representing 17% from the total area as shown in figure three (left) and the second scenario is without vegetation as shown in figure three (right).

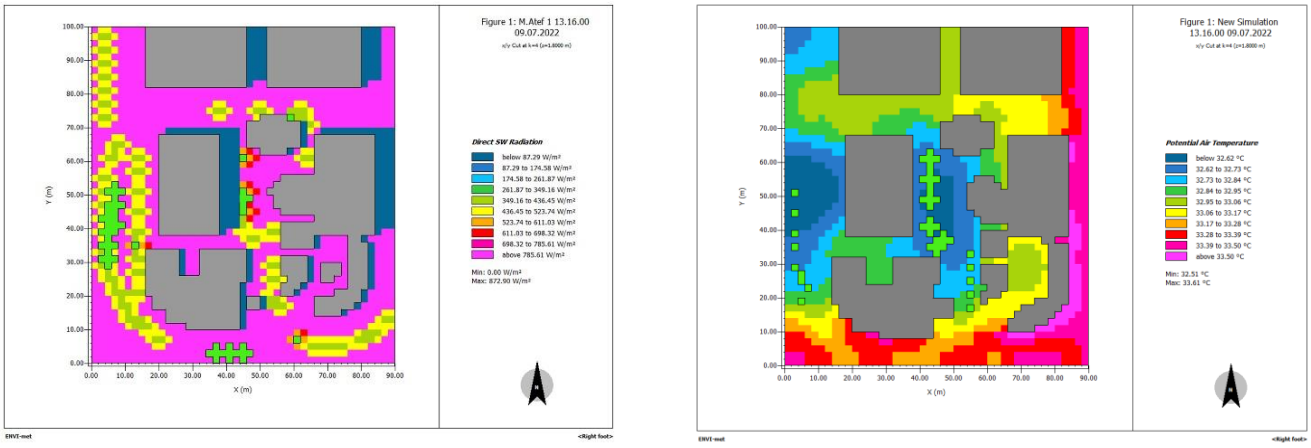


"Figure 3," Study area of the base case scenario with current vegetation types (left), Study area of same mall without vegetation types (right), modeled by Envi met. (Researcher, 2022)

The simulation was run one time with current vegetation types and location and another time without vegetation.

4.3 Results case study one (Katameya down town mall)

The following maps in figure five and six illustrates the solar radiation and air temperature values for the first case study from 9 am to 4 pm, results came at a specific hot hour from 1 pm to 2 pm, from the following Leonardo maps we can observe that the air temperature has changed from an average of 33.06°C to 34.28°C after removing the vegetation types.



"Figure 4," LEONARDO maps for the base case scenario, showing solar radiation & air temperature distribution at human height 1.8m. (Researcher, 2022)

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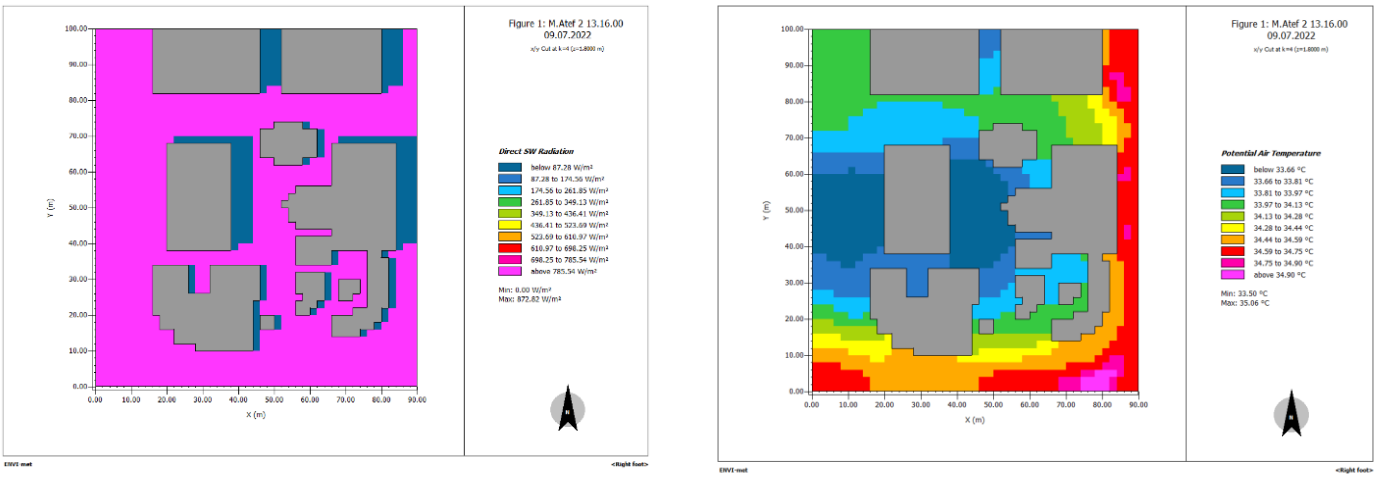
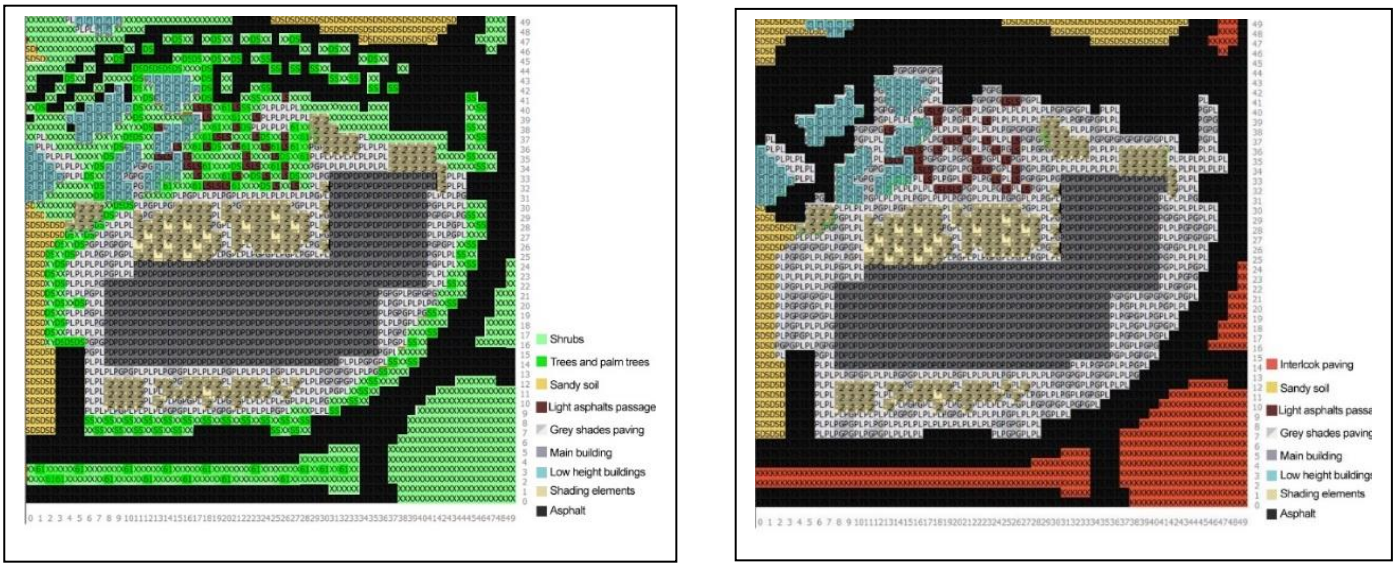


2. *Figure 5,"* LEONARDO maps for the proposed scenario without vegetation, showing solar radiation & air temperature distribution at human height 1.8m. (Researcher, 2022)

3. Tree canopy reduced the direct solar radiation that can be seen from the color variations according to the blocking ratio in the previous maps, figure (4 & 5). The percentage of the shaded area dropped from 24.5% in the base case with vegetation to 9% in the proposed scenario with no vegetation, although there was a mutual shading between buildings and trees, especially inside the core of the study area.

4.4 Case study two (Garden 8 mall)

A different architectural form is used in the second case study with a total area of around 22,000 m², which has only one main building with a height of 10m, small wooden retails or kiosks with 3 m tall representing a total area of 37% and an open outdoor space with a variety of plants covering 23%, the location is surrounded by residential compounds and close to many landmarks and main streets inside New Cairo. The simulation resembled in Envi-met model with grid 50x50 cells with the same previous date and climatic input data for the current case scenario and the proposed one without vegetation as shown in figures 6 (left & right).



"Figure 6," Current vegetation types as modelled by Envi in the study area of the base case scenario (left), proposed model for the study area of Garden 8 mall after removing vegetation (right), (Researcher, 2022)

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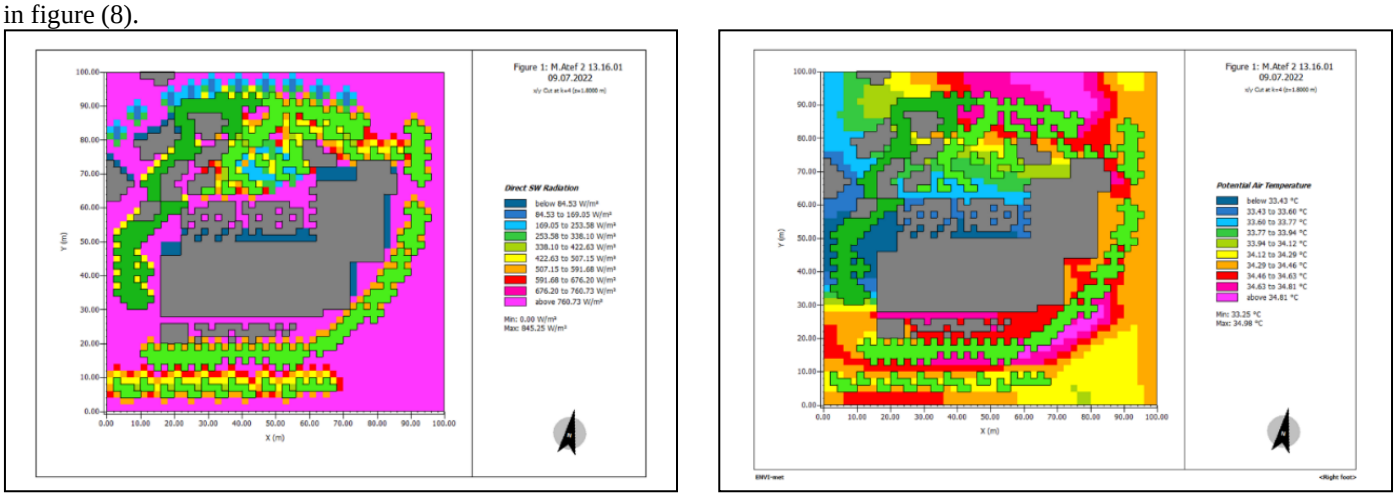
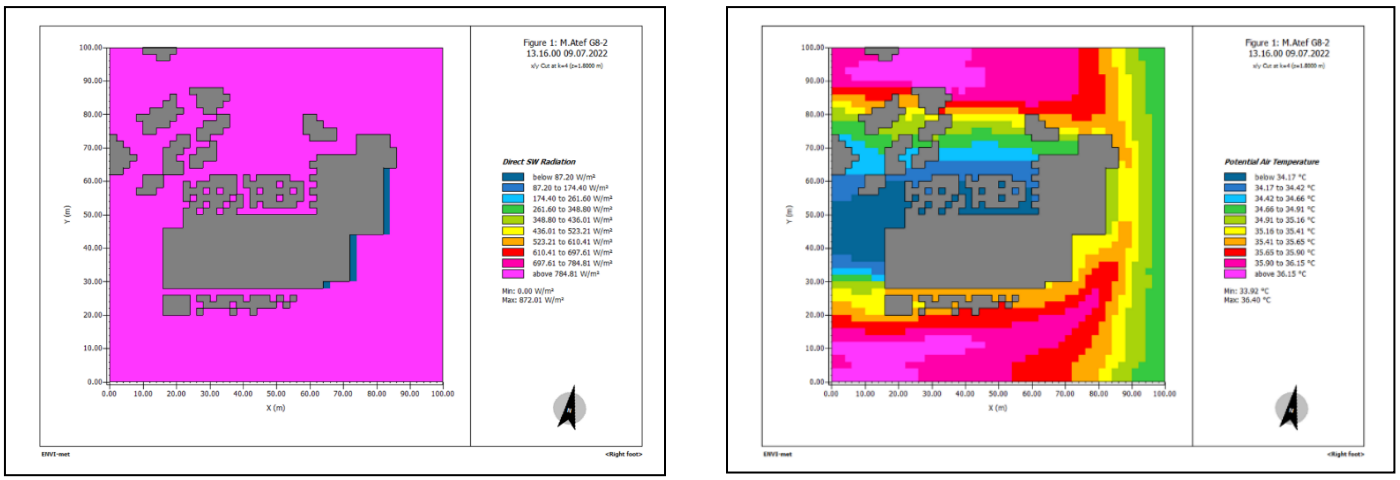
4.5 Results case study two (Garden 8 mall)

According to the analysis of the two simulations for the second case study and comparison of the two scenarios, the air temperature has changed from an average of 34.11°C to 35.16°C after removing the vegetation types as shown in figure (7), the study found that trees have a cooling effect, also the total outdoor shaded space reduced from 34% with vegetation to 7% without vegetation in figure (8).



"Figure 7," LEONARDO maps for the base case scenario, showing solar radiation & air temperature distribution at human height 1.8m for case study 2. (Researcher, 2022)



"Figure 8," For case study 2, LEONARDO maps for the mentioned scenario without vegetation demonstrate the distribution of solar radiation and air temperature at a height of 1.8 meters. (Researcher, 2022).

5. DISCUSSION OF THE RESULTS

The Leonardo maps from the above-mentioned output data showed a specific change in micro-climatic data for the two case studies with two different scenarios (current case scenario & proposed scenario without vegetation), a considerable increase in the temperature was noticed after removing the vegetation in the two case studies by around 1.22 °C for the first case study, and 1.05 °C for the second case, also the shading percentage is decreased by 15.5% and 27% for the first & second cases respectively. Trees have a relatively mild impact on the direction and speed of the air and also on the relative humidity.

6. CONCLUSION AND RECOMMENDATIONS

The objective of this research is to examine how plants can reduce direct solar radiation and improve outdoor thermal comfort. A mutual relationship between plant material and microclimate elements has been found after analyzing their relation, and this relationship needs to be taken into account. The two case studies were selected according to their location in the middle of New Cairo city, connecting and serving many of its areas. ENVI-met software, a modeling, analysis, and simulation tool; was utilized to evaluate the two examples. Based on the discussion of the two case studies, it should be noted that the second case study found that the impact of vegetation on sun penetration reduction was more effective as the tree's shade was almost entirely beneficial for the outdoor area, when compared to the first case study's finding of mutual shading between buildings and trees in a particular area. The overall average wind velocity value only improved in areas that were close to trees, and the improvement goes away after a few meters, and the humidity percentage wasn't significantly changed as it was within the comfort intervals in all cases.

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Last but not least, it is clear that vegetation has a considerable impact on microclimate, it is also clear that the importance of location and arrangement of the plant is very importance to improve the conditions of the outdoor space, which take us to recommend the following points:

A- Utilizing Envi-met software to model, evaluate, and simulate outdoor areas is recommended since it is highly accurate in forecasting thermal comfort indices, microclimate parameters, and the majority of outdoor design techniques.

B- Investigating the use of large tree canopies in outdoor open places to shade every project appropriately, especially in hot climates, to reduce direct solar radiation and enable thermal comfort performance.

C- Going to enforce specific regulations to help develop open outdoor areas, as the government should consider the selection and percentage criteria for plant material to achieve the maximum beneficial effect on users' thermal comfort and quality of life through vegetation.

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