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THE EFFECT OF LEAF AREA INDEX AND LEAF AREA DENSITY ON URBAN MICROCLIMATE

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ABSTRACT

The canopy of urban trees has a major impact on microclimatic conditions. Leaf area index "*LAI"* and leaf area density "LAD_z" of any tree are two major parameters that allow us to predict the tree's climatic impact. Hence, urban planners and designers need to calculate *LAI* and LAD_z for use in urban climatic studies. Unfortunately, despite the clear need for urban trees in an arid climate such as that of Egypt, very little data is available for these two parameters. Therefore, to study the microclimate changes that a tree canopy can cause within its urban built environment, a guideline for estimating *LAI* and LAD_z values for the trees was created to generate a database that can be used as an input data for outdoor thermal simulation programs. A developed method that mixes between direct and indirect measurements used to calculate *LAI* values for the most common urban trees in Cairo "*Ficus nitida, Delonix regia and Morus alba*", which also allowed us to find LAD_z values that are necessary for running ENVI-met simulations. After studying these trees' canopy parameters and determining their respective *LAI* and LAD_z values, we concluded that *Delonix reiga* has the highest *LAI* and LAD_z values compared to the other two trees. Afterwards, simulating four different scenarios by using these trees to prove the effect of tree canopy; the more *LAI* and *LAD* values tree generate "more dense trees canopies", the more impact on microclimate.

KEYWORDS: Leaf area index, Leaf area density, microclimate, urban trees, ENVI-met, Ecotect.

1. INTRODUCTION

Using trees in outdoor urban areas assists in reaching the optimal outdoor thermal comfort [1]. Tree canopy helps in reducing urban heat island effect which provides positive environmental effects and community comfort [2, 3]. Moreover, the cooling effect of the green area is remarkable not only located in vegetated areas but it can also be extended to the surrounding built up area environment [4].

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The climatic effect of tree canopy is characterized through several variables, including Leaf Area Index "*LAI*", Leaf area density "LAD_z", tree canopy radiation rate and evapotranspiration rate. *LAI* is defined as the tree canopy area per the ground shadow of the canopy. *LAD* is the determination of the tree canopy outline. Tree canopy radiation is manifested through the canopy preventation of short and long wave radiation coming from the upper hemisphere, whereas evapotranspiration is determind according to water content carrying capacity of the soil-tree-air system. Evaporation takes place from tree leaves surfaces to air [5], and transpiration from soil through leaves due to photosynthesis process [6]. These variables signify the canopy profile and its impact on the surrounding atmosphere [7, 8].

Few studies have investigated the role of *LAI* and LAD_z values on the tree canopy and its impact on the surrounding microclimate in Egypt [1, 8]. Therefore, the main objective of this study is to present a simple method for estimating *LAI* and LAD_z value for any tree canopy and simulate its impact on microclimate by using ENVI-met program. A hybrid method was applied through combining direct and indirect methods. Direct methods utilize field measurements and relationship between leaf area and the dimensions of canopy components. On the other hand, indirect methods involve camera photos for the tree canopy. Thus, a city near Cairo called Kerdasa, Egypt is where the survey took place to select the trees, as it is characterized by the variety of plantation area with different trees species. The secondary objective, is to generate *LAI* and LAD_z data for urban trees that are commonly used in Egypt and to simulate these trees to illustrate the relation between *LAI* and LAD_z values and its impact on microclimate through using four different scenarios.

2. LITERATURE REVIEW

2.1 The Effect of Trees on Microclimate

Several studies emphasized the significance of trees and their impact on microclimate [1, 8-10]. Furthermore, the significant benefits were illustrated of tree canopy on microclimate through computer simulations of urban outdoor areas that include trees [11, 12]. It was found that when the trees were used at the simulation, the T_a "Air Temperature" has decreased 0.04 K, on the other hand, it was found that Ta was decreased by 0.6 k, T_{mrt} "Mean Radiant Temperature" was decreased by 6.6 K and PET "Physiologic Equivalent Temperature" was decreased by 3 K [11, 12].

Moreover, the permanent shaded surface due to using large quantities of trees lead to the reduction of surface temperature up to 20°C in the summer at Manchester [10]. Also, it was found that trees' shade reduced mean radiant temperatures by an average of 4°C, though neither tree species nor *LAI* had a significant effect. Trees' shade reduced surface temperatures by an average of 12°C, and the tree species and LAI both had significant effects [13]. Furthermore, after numerous simulations in Sacramento and Phoenix that through increasing the trees by 25% temperature in summer could be reduced by 3.3°C - 5.6°C [14]. Additionally, a single layer of leaf on the tree canopy could reduce visible and infrared radiation by 50%, while reflecting 30% and transmitting the other 20%, while all trees can decrease 80 - 90% of solar radiation, depending on their leaf alignment and density of the canopy. Moreover, when comparing two types of tropical trees, it was found that heat infiltration of *Hura crepitans* is 86% and *Messua ferrea* is 97 %. This difference in percentage is due to the different canopy shape and outline. Hence, the tree canopy shape and outline profile are two major parameters in changing the microclimate [15].

2.2 Methods of Obtaining *LAI* and LAD_z

LAI and LAD_z values represent the canopy's profile, species and characteristics [16]. The canopy profile is the main controling element in changing the air temperature, wind direction and speed in the surrounding area [17].

2.2.1 Direct *LAI* measurements

Direct methods can generate accurate measurements. However, they consume a lot of time. Therefore, they are marginally used when it comes to large scale implementations [18].

For example, previous study substituted the *LAI* value equal 1 resembling a solid shade on the ground during peak time and used the default value of albedo from

ENVI-met program database. Thus, enabling them to generate the LAD_z without the need of measuring *LAI* [8] as shown in Fig. 1.

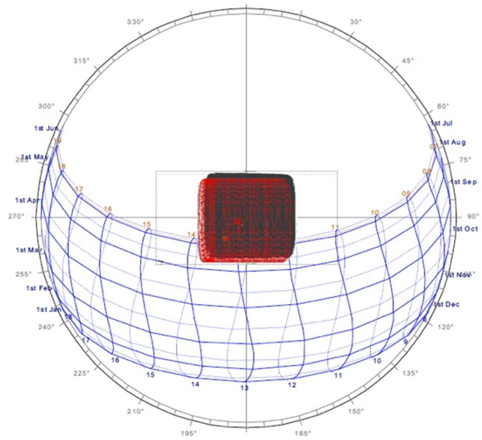

Fig. 1. A model by Ecotect program for Delonix regia at 12:00 of solar altitude 82.40º to show that the ground shadow area of the tree is almost equal to the canopy area

2.2.2 Indirect *LAI* measurements

Indirect methods for estimating *LAI* values involve site observation. They are generally faster and allow for obtaining large samples. Moreover, they are divided into two types: indirect contact *LAI* measurements and indirect non-contact measurements [18].

Previous study observed the tree canopy through talking two or four camera photos. The camera was located perpendicular on the tree and length measurements was used for obtaining the canopy outline. An object with known size was placed in the photograph in order to facilitate length measurements. Therefore, *LAI* and LAD_z value can be generated for the selected tree canopy [8].

In order to specify the behavior of a tree canopy in the ENVI-met program, *LAI* and LAD_z values are necessary. In order to start calculating *LAI* value for any tree, the upper leaves area "*AL*" for the canopy should be measured and calculated, then, Ecotect program is used for simulating the tree ground shadow area "Ag". Afterwards, *AL* and *Ag* value are substituted in Eq. (1) for calculating *LAI* value [8].

$$LAI = AL / Ag \quad (1)$$

Where: - "*AL*" is the upper leaves area. - "*Ag*" is the tree ground shadow area.

2.2.3 Calculation process for estimating LAD_z value

After *LAI* value was calculated, LAD_m value is ready to be calculated by subsisting its value in Eq. (2). This equation provided comparable results to the field measurements [9].

$$LAI = \int_0^{z_p} LAD(z)\,dz = \int_0^{z_p} LAD_m \left(\frac{z_p - z_m}{z_p - z}\right)^n exp\left[n\left(1 - \frac{z_p - z_m}{z_p - z}\right)\right] dz \tag{2}$$

- "LAD_m" is the maximum value of the "Leaf Area Density" at a height "z_m".
- "z_m" is the height of max *LAD* value.
- "z_p" is the total height of the plant taken into consideration.

Once the LAD_m is determined from Eq. (2), it is substituted in Eq. (3) for calculating LAD_z values at different heights "z". Thus, the tree is divided into 10 slices, each slice equals 1/10 of the total height as shown in Fig. 2, according to the input requirements of ENVI-met program for defining any tree canopy [9].

$$LAD(z) = LAD_m \left(\frac{z_p - z_m}{z_p - z}\right)^n exp\left[n\left(1 - \frac{z_p - z_m}{z_p - z}\right)\right] \tag{3}$$

- "z" is the height whose value is used to determine the LAD_z.
- "n" is 6 for z values included between 0 and z_m, and 0.5 for those z values included between z_m and z_p.

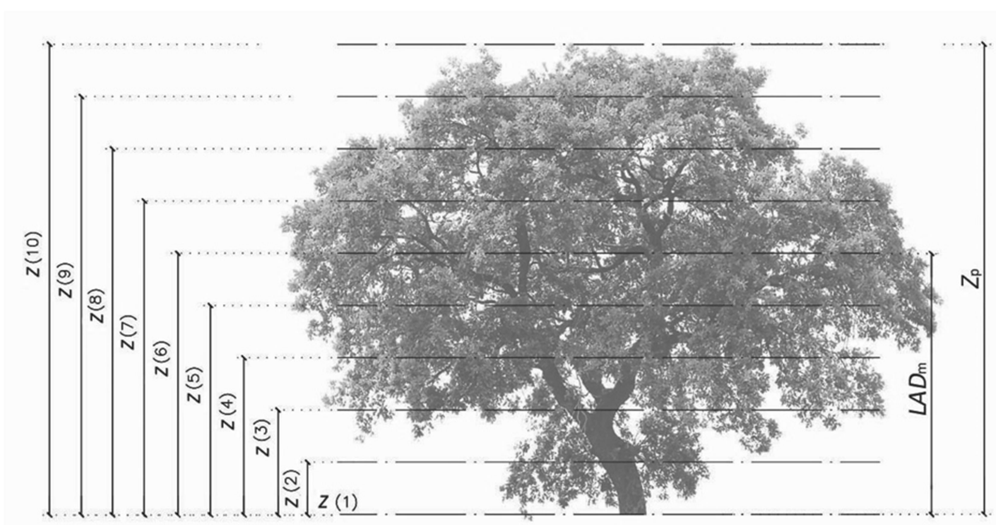

Fig. 2. Diagram illustrates the variables used in Eqs. (2, 3).

The LAD_z results were added to ENVI-met plants database, as a 10 *LAD* input value to represent the tree canopy. Consequently, its ready for simulation [8].

2.3 Environmental Simulation Using *LAI* and LAD_z Values

In order to deal with microclimatic simulation to evaluate urban climate conditions "e.g.: T_a, Mean Radiant Temperature, Wind Speed and Wind Direction" ENVI-met v4.0 program was used. This program is commonly used in many studies for climate evaluation in terms of bio meteorological conditions [19]. On the other hand, previous study pointed out the major influence of vegetation on the mitigation of urban heat island in Toulouse "France" [20]. Moreover, a park was simulated using ENVI-met with reference to São Paulo "Brazil", this park located in the middle of the site, small parks characterizing the urban texture and trees on the edge of the street also it affects microclimate [21].

3. METHODOLOGY

3.1 Estimation Process for *LAI* and LAD_z Values

The estimation process for *LAI* and LAD_z value was based on a systematic plan to achieve the desired result; an accurate *LAI* and LAD_z database for tree canopy. This study's methodology was divided into three consequential phases as follows as shown in Fig. 3:

Phase 1: Tree selection.

Phase 2: Tree measurement and photography.

Phase 3: Calculations of *LAI* and LAD_z.

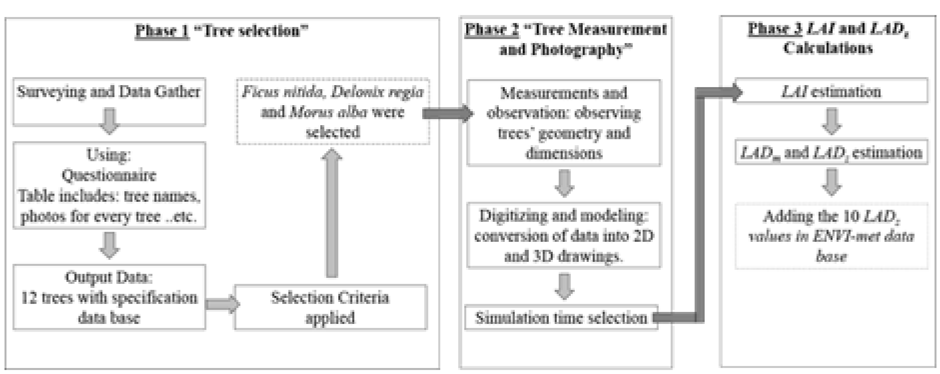

Fig. 3. Flow chart illustrate the three phases process for estimating the *LAI* and LAD_z values the used tool, the output data.

3.1.1 Phase 1- tree selection

This phase started by selecting an appropriate location that can provide generous data about the commonly used trees in Cairo. A survey took place among twenty "20" plant nurseries nearby Cairo. Each plant nursery of the 20 nurseries asked the same question "Which shade tree is the most commonly used in Cairo streets?", afterwards, the data that were obtained from the survey were transformed into points; the highest tree scored points is the more used and the lowest in points is less commonly used. Trees specifications such as leaves shapes, blooming seasons "evergreen or deciduous tree", canopy height, canopy form, canopy width and landscape use were gathered and considered during the survey. In order to narrow down the number of trees to 3 that can be studied in detail, the following criteria was applied:

a) Prevalence: the most commonly used trees for landscaping purposes.
b) Variety: different assortment of tree canopy shape and blooming season, this diversity leads to an accurate data and helps illustrating the different effects of each species.

The survey data highlighted that *Ficus nitida* scored "20 points", *Delonix regia* scored "19 points" and *Morus alba* scored "14 pints" are the most used in urban landscape according to nurseries visit. On the other hand, the least used trees are *Ficus decora* scored "6 points" and Salix babylonica scored "4 points" as shown in Table 1.

Based on the above, *Ficus nitida*, *Delonix regia* and *Morus alba* were selected to be studied as shown in Fig. 4.

3.1.2 Phase 2- tree measurement and photography

In this phase shape parameters of the selected trees were collected and outlined through three steps:

1) Measurements and observation: observing trees' geometry and dimensions.
2) Digitizing and modeling: conversion of data into 2D and 3D drawings.
3) Simulation time selection: generating the ground shadow of tree canopy by using Ecotect and Climate consultant program.

Table 1. The obtained data for the tree's selection through the surveying.

Plant Nurseries	Tree Types											
	Morus alba	*Cinnamomum camphora*	*Delonix regia*	*Salix babylonica*	*Ficus nitida*	*Ficus benjamina*	*Ficus nitida*	*Ficus decora*	*Mangifera indica*	*Citrus sinesis*	*Tecoma stans*	*Cassia nodosa*
Plantation (1)	●	●	●		●	●	●	●	●	●		●
Plantation (2)	●		●		●					●		
Plantation (3)	●		●		●	●				●	●	
Plantation (4)	●				●	●	●		●			●
Plantation (5)			●		●						●	●
Plantation (6)	●		●	●	●	●						●
Plantation (7)		●	●		●			●	●			
Plantation (8)	●		●		●	●					●	
Plantation (9)	●	●	●		●					●	●	●
Plantation (10)	●		●		●	●	●		●			●
Plantation (11)		●	●		●				●	●	●	●
Plantation (12)	●		●		●	●	●		●	●		
Plantation (13)	●		●	●	●	●		●	●			●
Plantation (14)	●	●	●		●					●	●	●
Plantation (15)	●	●	●		●	●	●		●			
Plantation (16)			●	●	●			●		●	●	
Plantation (17)	●	●	●		●	●	●		●	●		
Plantation (18)			●		●			●				●
Plantation (19)	●	●	●	●	●	●	●		●	●	●	●
Plantation (20)			●		●		●	●	●		●	
TOTAL	**14**	**8**	**19**	**4**	**20**	**11**	**8**	**6**	**11**	**10**	**9**	**11**

GRAPH

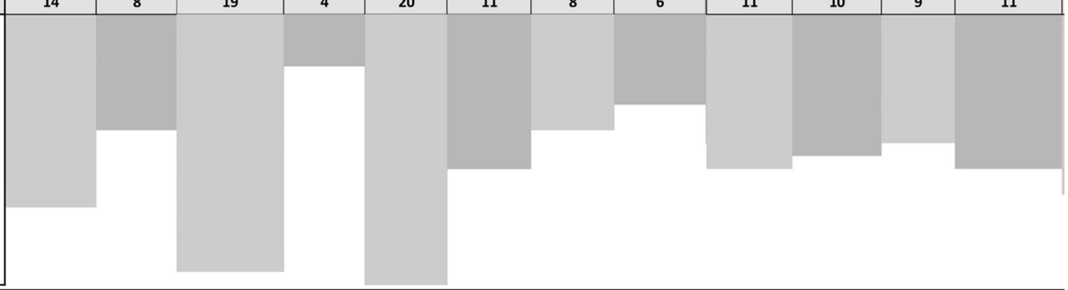

Fig. 4. Photos of the trees that will be studied.

1) Measurements and observation

Field measurements and photographs were the first step of data gathering to generate *LAI* and LAD_z value for each tree. Tree parameters "e.g., tree height, canopy height and canopy width" were gathered utilizing a camera and a tape measurement tool. Each tree was photographed from two different locations perpendicular to each other, for scaling propose a known measured object was located beside the trees.

These photographs are used for obtaining the tree height "z_p", the height of maximum *LAD* value "LAD_m" and *LAD* slices height "z". Such parameters are required to reach LAD_z values of the different slices of the tree canopy. While the tree canopy area is required to reach *LAI* value.

2) Digitizing and modeling

The measurements and data that were obtained from the first step above were converted into 2D drawings by using AutoCAD program through tracing the taken photos of each tree as shown in Fig. 5. Afterwards, the trees canopy was converted into 3D model for determining its area and to be able to determine its ground shadow area.

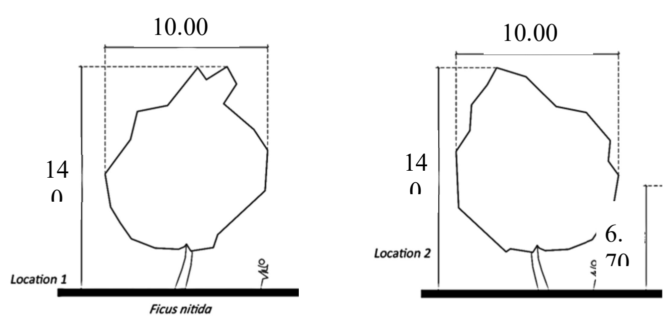

Fig. 5. A sample of 2D elevation canopy drawings for one of the selected trees (*Ficus nitida*) after tracing the tree canopy outline.

3) Simulation time selection

Simulation time for the selected trees has been obtained by using Climate consultant and Ecotect programs. These programs assist in identifying the climate characteristics of any location at any time throughout the world and generate climate database by using EnergyPlus Weather Data File "EPW" [22].

To select the months during which the study will be applied, EPW file for year 2020 was used in Climate consultant program and it was found that June, July and

August have the highest mean temperature throughout the year with 29°C. Selecting the highest 3 months in mean temperature will help in illustrating the trees' canopy impact on microclimate.

Afterwards, Ecotect program was used to select the hottest days and hours of the selected months. Consequently, it was found that 5th June, 1st July and 15th August of 2020 at 12:00, 14:00, 15:00 are the hottest times throughout the 3 months. Therefore, those are the selected simulation times that will be used in calculating the *LAI* and LAD_z values. Afterwards it will be used in ENVI-met simulation for illustrating the trees' impact.

3.1.3 Phase 3- *LAI* and LAD_z calculations

This section describes the three steps required to generate *LAI* and LAD_z value of the selected trees through equations and ecotect program.

a) *LAI* estimation

For calculating LAI value for any tree, the tree canopy area "AL" and its ground shadow area "Ag" must be estimated. Therefore, Ecotect program was used as shown in Fig. 6, while "AL" value was already calculated from the measurements that was obtained from the site "as mentioned in section 3.1.2". Consequently, after obtaining the AL and Ag, the LAI value can be now easily calculated by substituting AL and Ag value in equation (a) "as mentioned in section 2.2.2".

b) LAD_m and LAD_z estimation

In estimating and calculating LAD_m value, MATLAB program was used. It is a high-level language and interactive environment that enables the user to preform computationally intensive tasks faster than traditional programming languages [23]. The program's input data for estimating the value of LAD_m according to equation (b) are the following known variables: z_p, z_m, n, *LAI* and z.

Afterwards, LAD_m was substituted in equation (c) for calculating 10 LAD_z value. Each LAD_z value with different height. Thereafter, each selected tree has 10 LAD_z values, *LAI* value and LAD_m in selected time. This was the final step for creating the data for every tree to be ready for simulating in ENVI-met program.

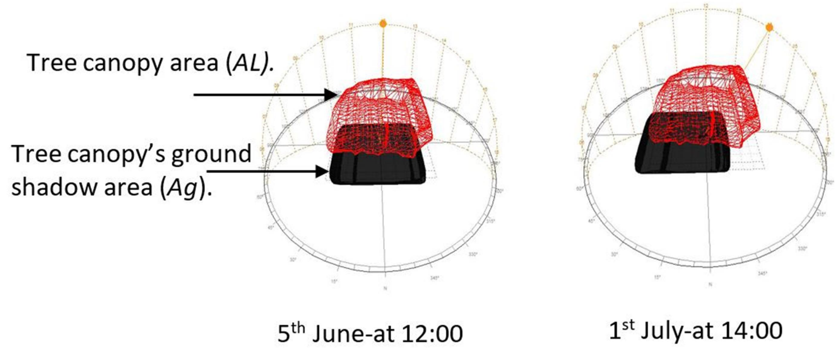

Fig. 6. Diagram illustrate how the tree canopy ground shadow is generated by using solar path in Ecotect program through the selected year, month and hour.

3.2 Site Description and ENVI-met Simulations

The selected site was a pilot site in Egypt, Cairo, latitude of 30°08΄N, longitude of 31°24΄E, elevation: 74 meters and Köppen classification: tropical and subtropical desert climate [24]. The pilot site is a small-scale, short-term experiment that will help in identifying how a large-scale project might work in practice. The selected site included streets, buildings "6m, 9m and 12m height" and trees as a typical urban form of residential neighborhood zone with 32400 m^2. In order to assess the influence of different *LAI* and LAD_z values of the tree on its thermal impact on microclimate, there are four different scenarios for the simulation, first scenario is the as built map but removing all the trees "C1", second scenario only *Ficus nitida* was added "C2", third scenario only *Delonix regia* was add "C3" and finally the fourth scenario was simulated using only *Morus alba* tree "C4". Moreover, adding receptor point for analyzing one point inside the model area as receptor allows to monitor the selected point in detail as shown in Fig. 7. The air temperature "Ta" and Predicted mean vote "PMV" were the measuring parameters in all the simulations for clarifying the tree's impact as mentioned before.

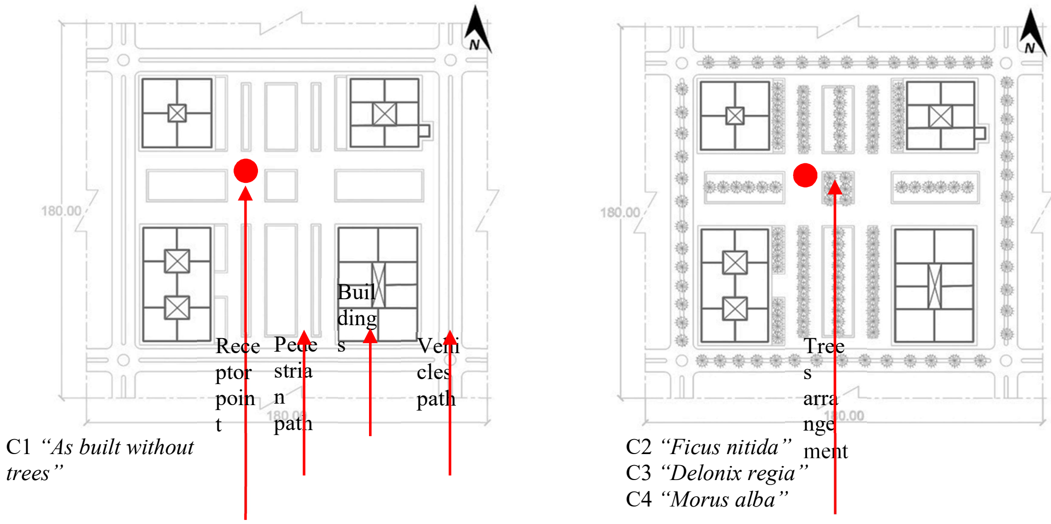

Fig. 7. On the left-hand side diagram “C1”, illustrate and shows the site attributes and the receptor point location. On the right-hand side diagram “C2-C3-C4”, shows the tree location and arrangement.

4. RESULTS

4.1 *LAI* and LAD_z Values

For each of the three selected trees “*Ficus nitida - Delonix regia – Morus alba*” we generated and calculated canopy parameters in two phases; the first phase includes the *LAI* value and the second phase includes LAD_z value.

The *LAI* value for each tree was calculated according to the selected month and hours; 1st July at “12:00, 14:00 and 15:00”, 5th June at “12:00, 14:00 and 15:00” and 15th August at “12:00, 14:00 and 15:00”. It was found that *Delonix regia* generates the highest *LAI* value reaching 1.08. This is due to the spreading canopy that generates the largest shadow area on the ground. On the other hand, *Ficus nitida’s LAI* value reaches 1 and *Morus alba* has the lowest *LAI* value with 0.92 as shown in Table 2.

Table 2. *LAI* values for each selected tree on the selected month and hour.

	Selected Days	1st July, 2020			5th June, 2020			15th August, 2020			Avg.
	Selected Hours	12:00	14:00	15:00	12:00	14:00	15:00	12:00	14:00	15:00	
Selected Trees	Ficus nitida, h = 14m	0.93	1	0.96	0.86	0.86	0.83	0.7	0.69	0.68	0.85
	Delonix regia, h = 6.7 m	1.03	1.07	1.08	1.05	1.04	1.03	0.98	1.02	1.01	1.04
	Morus alba, h = 12 m	0.92	0.88	0.78	0.9	0.87	0.78	0.84	0.78	0.72	0.83

After taking the average of *LAI* results for each tree, it was found that *Delonix regia* performed and generated 1.04 which is the highest *LAI* value compared to the other trees. On the other hand, *Ficus nitida* generated 0.85 and *Morus alba* 0.83 as shown in Fig. 8. It is known that *Delonix regia* has a canopy that spreads horizontally, which generates a large amount of shadow on the ground that produces the highest *LAI* value. On the other hand, *Ficus nitida* generated *LAI* value higher than *Morus alba*, because its evergreen canopy "leaves stay on the tree throughout the year" but *Morus alba* is a deciduous tree whose canopy leaves drop 3 or 4 months every year. Moreover, *Ficus nitida* is higher in the total tree height "14 m according to our measurements" than *Morus alba* "12 m". Clearly, the more height the tree gains, the more *LAI* value is generated.

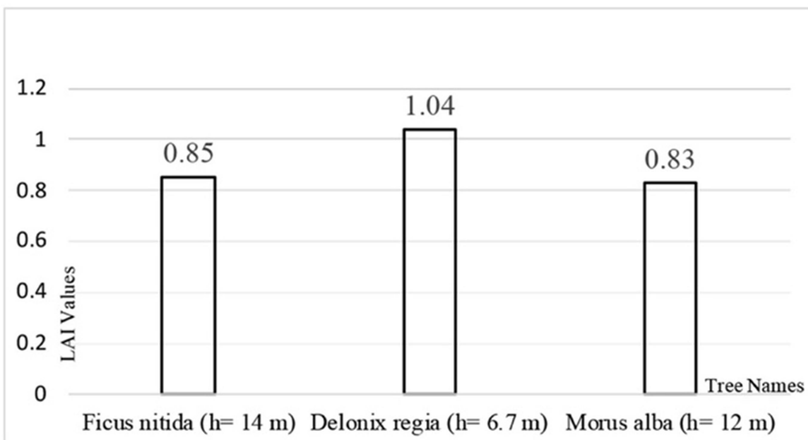

Fig. 8. Comparing *LAI* average values of the 3 selected trees.

The second phase that produces the LAD_z values for the tree canopy is divided into two steps:

- Step 1: the 10 LAD_z slices of each tree were calculated according to the hottest 3 hours in the hottest 3 days throughout year 2020 as shown in Table 3.
- Step 2: the average value of *LADz* results of each selected tree through the selected simulation time, was gathered to generate only ten slices for each tree canopy "as shown in Table 4". These *LADz* values can be added to the ENVI-met plant database for simulating the climatic effect of those trees canopies.

Table 3. Output sample for *LADz* values for each selected tree at 12:00.

SELECTED TREE		*Ficus nitida*			*Delonix regia*			*Morus alba*	
Selected Hour	AT 12:00								
MONTH/YEAR: 5th June (2020)	10 LAD Slices	*Ficus nitida* (h= 14 m) (5th June) At 12:00 LAI= 1		10 LAD Slices	*Delonix regia* (h=6.7 m) (5th June) At 12:00 LAI= 1.05		10 LAD Slices	*Morus alba* (h= 12 m) (5th June) At 12:00 LAI= 0.9	
		LAD Slice hight	LAD Value		LAD Slice hight	LAD Value		LAD Slice hight	LAD Value
	1	1.4 (m)	0.45	1	0.67 (m)	0.7	1	1.2 (m)	0.46
	2	2.8 (m)	0.2	2	1.34 (m)	0.5	2	2.4 (m)	0.23
	3	4.2 (m)	0.1	3	2.01 (m)	0.3	3	3.6 (m)	0.12
	4	5.6 (m)	0.05	4	2.68 (m)	0.21	4	4.8 (m)	0.06
	5	7 (m)	0.02	5	3.35 (m)	0.13	5	6 (m)	0.03
	6	8.4 (m)	0.01	6	4.02 (m)	0.08	6	7.2 (m)	0.0144
	7	9.8 (m)	0.04	7	4.69 (m)	0.05	7	8.4 (m)	0.0066
	8	11.2 (m)	0.002	8	5.36 (m)	0.023	8	9.6 (m)	0.0027
	9	12.6 (m)	0	9	6.03 (m)	0.0024	9	10.8 (m)	0
	10	14 (m)	0	10	6.7 (m)	0	10	12 (m)	0
MONTH/YEAR: 1st July (2020)	10 LAD Slices	*Ficus nitida* (h= 14 m) (1st July) At 12:00 LAI= 0.93		10 LAD Slices	*Delonix regia* (h=6.7 m) (1st July) At 12:00 LAI= 1.03		10 LAD Slices	*Morus alba* (h= 12 m) (1st July) At 12:00 LAI= 0.92	
		LAD Slice hight	LAD Value		LAD Slice hight	LAD Value		LAD Slice hight	LAD Value
	1	1.4 (m)	0.4167	1	0.67 (m)	0.69	1	1.2 (m)	0.46
	2	2.8 (m)	0.1942	2	1.34 (m)	0.462	2	2.4 (m)	0.23
	3	4.2 (m)	0.0897	3	2.01 (m)	0.306	3	3.6 (m)	0.12
	4	5.6 (m)	0.0409	4	2.68 (m)	0.2	4	4.8 (m)	0.06
	5	7 (m)	0.0183	5	3.35 (m)	0.128	5	6 (m)	0.03
	6	8.4 (m)	0.008	6	4.02 (m)	0.079	6	7.2 (m)	0.0144
	7	9.8 (m)	0.0033	7	4.69 (m)	0.046	7	8.4 (m)	0.0066
	8	11.2 (m)	0.0013	8	5.36 (m)	0.0236	8	9.6 (m)	0.0027
	9	12.6 (m)	0	9	6.03 (m)	0.0024	9	10.8 (m)	0
	10	14 (m)	0	10	6.7 (m)	0	10	12 (m)	0
MONTH/YEAR: 15th August (2020)	10 LAD Slices	*Ficus nitida* (h= 14 m) (15th August) At 12:00 LAI= 0.96		10 LAD Slices	*Delonix regia* (h=6.7 m) (15th August) At 12:00 LAI= 0.98		10 LAD Slices	*Morus alba* (h= 12 m) (5th June) At 12:00 LAI= 0.84	
		LAD Slice hight	LAD Value		LAD Slice hight	LAD Value		LAD Slice hight	LAD Value
	1	1.4 (m)	0.43	1	0.67 (m)	0.65	1	1.2 (m)	0.41
	2	2.8 (m)	0.2	2	1.34 (m)	0.4	2	2.4 (m)	0.21
	3	4.2 (m)	0.093	3	2.01 (m)	0.3	3	3.6 (m)	0.1
	4	5.6 (m)	0.043	4	2.68 (m)	0.2	4	4.8 (m)	0.05
	5	7 (m)	0.02	5	3.35 (m)	0.12	5	6 (m)	0.02
	6	8.4 (m)	0.0083	6	4.02 (m)	0.07	6	7.2 (m)	0.013
	7	9.8 (m)	0.0035	7	4.69 (m)	0.04	7	8.4 (m)	0.005
	8	11.2 (m)	0.0013	8	5.36 (m)	0.0236	8	9.6 (m)	0.0024
	9	12.6 (m)	0	9	6.03 (m)	0.0024	9	10.8 (m)	0
	10	14 (m)	0	10	6.7 (m)	0	10	12 (m)	0

Table 4. *LADz* values for the three trees.

	LAD Slices	1	2	3	4	5	6	7	8	9	10
Selected Trees	Ficus nitida, h = 14m	0.38	0.175	0.175	0.038	0.017	0.0074	0.003	0.0011	0.0002	0
	Delonix regia, h = 6.7 m	0.67	0.46	0.33	0.2	0.124	0.0078	0.05	0.023	0.002	0
	Morus alba, h = 12 m	0.42	0.215	0.1	0.052	0.026	0.012	0.006	0.0024	0	0

Finally, by comparing the LAD_z values, it was found that *Ficus nitida* and *Morus alba* are quite similar, while *Delonix regia* had much higher LAD_z values as shown in Fig. 9. The main reason for this difference in LAD_z values as mentioned before in *LAI* results section; the trees' parameter effect on *LAI* and LAD_z results. Thus, the more *LAI* value tree gains the more LAD_z value is generated.

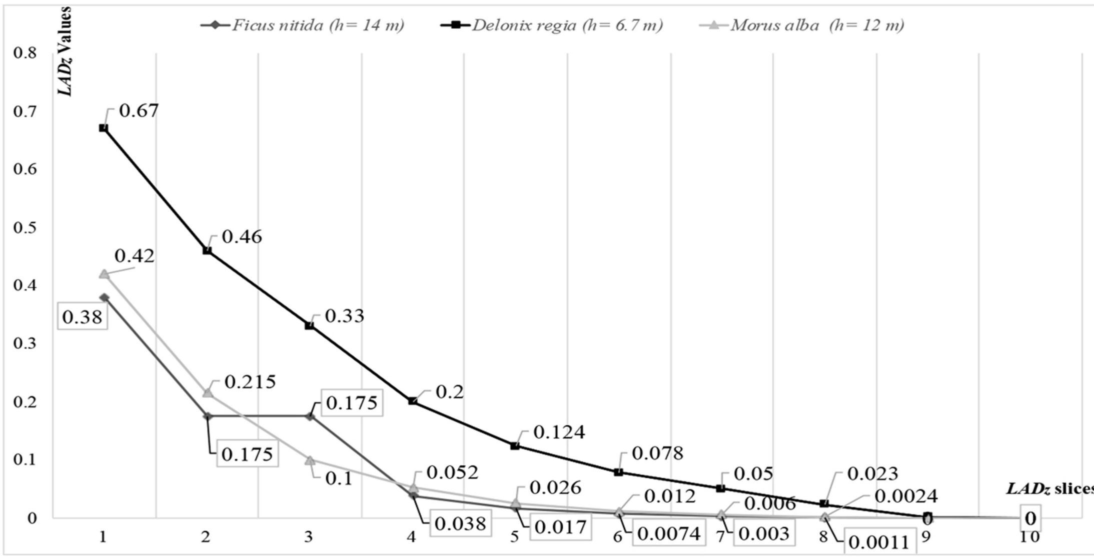

Fig. 9. Comparison between the 10 *LADz* value of the three selected trees.

4.2 ENVI-met Program Simulation Process

Output data that was obtained were taken at 2m above ground level "agl" at which pedestrian is affected by the microclimate of an urban canyon [25]. The input data for the simulation were added according to site area, location and the simulation time as shown in Table 5. The obtained output data are air temperature "Ta" and predicted mean vote "PMV". Afterwards, the output data will be displayed through map script of Leonardo2014 which is tool within ENVI-met V4.0 that allows to visualize the obtained data into monochrome schematic map and in a graph to explain the selected point in the map "receptor" output data as shown in Fig. 10.

Table 5. ENVI-met input data for the simulations.

No.	Parameter	Value
1	X-Y&Z grids	X=160, Y=160&Z=30
2	Nesting grid around	3
3	Selected soil type	Sandy soil
4	Grid size	X=3, Y=3&Z=1
5	Simulation time	1-7-2020, at 12;00, 14:00&15:00
6	Wind speed	1 m/s
7	Wind direction	355° from North
8	Initial temperature of atmosphere	27.78°C
9	Initial specific humidity of atmosphere	13.511
10	Initial relative humidity of atmosphere	67%

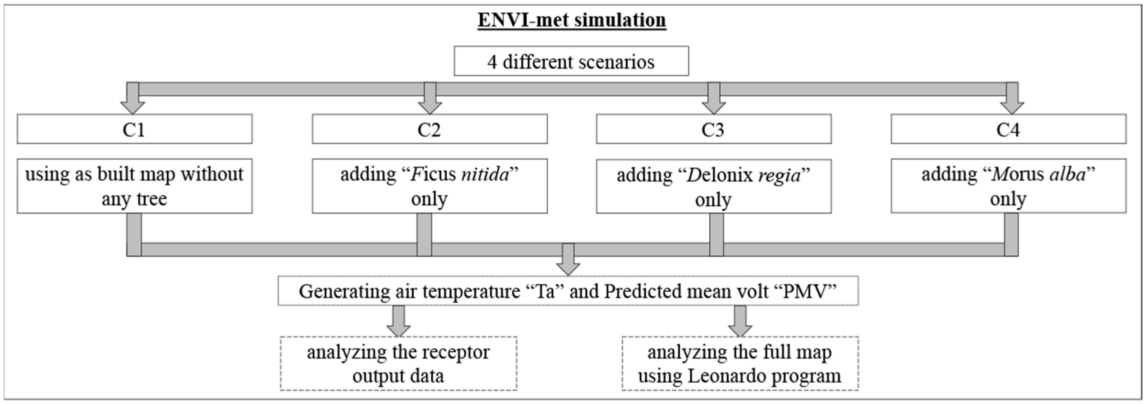

Fig. 10. Flow chart illustrate the simulation process "the used tool, the output data and its analyzing way".

The extracted receptor output data shows that in C3 the minimum Ta value was 38°C and the maximum was 41.3°C, in C2 was 38.3°C and 41.7°C, in C4 was 39°C and 42°C and finally in C1was 42°C and 43°C. Therefore, using trees in urban forms helps in decreasing Ta value. Thus, when the trees were used in C2, C3 and C4, the Ta values were decreased by 1°C to 4°C from C1. Moreover, the PMV is an average predicted index for the thermal comfort of the human body at outdoor area, on a scale range from 1 (cold) to 7 (hot) [26, 27]. It was found that in C3 the values ranged from 3.5 to 5, C2 from 4 to 5.5, C4 from 5 to 5.7 and C1 from 6.5 to 6.9.

Leonardo program used in illustrating the differences of the four scenarios "C1, C2, C3 and C4" in diagrammatical way. It was found that the values of Ta and PMV increases gradually from early morning to noon and start to decrease gradually till night as shown in Fig. 11.

5. DISSCUSION

Our findings show that using trees in outdoor urban areas helps in improving the outdoor temperature and thermal comfort. Moreover, this study emphasized and illustrated the impact of using trees in outdoor urban areas. Through simulating a case study with four different scenarios "C1, C2, C3 and C4". It was found that C2, C3 and C4 that includes tree in the simulation, generated lower output parameters "T_a and PMV" than the other case study C1. Since the T_a value decreased up to 4°C in C3 compared to C1, in C2 T_a value reduced up to 3.5°C from C1 and in C4 T_a decreased up to 3°C from C1. On the other hand, it was found that PMV value decreased up to 3 in C3 compared to C1, in C2 PMV value reduced up to 2.3 from C1 and in C4 PMV decreased by 1.2 from C1.

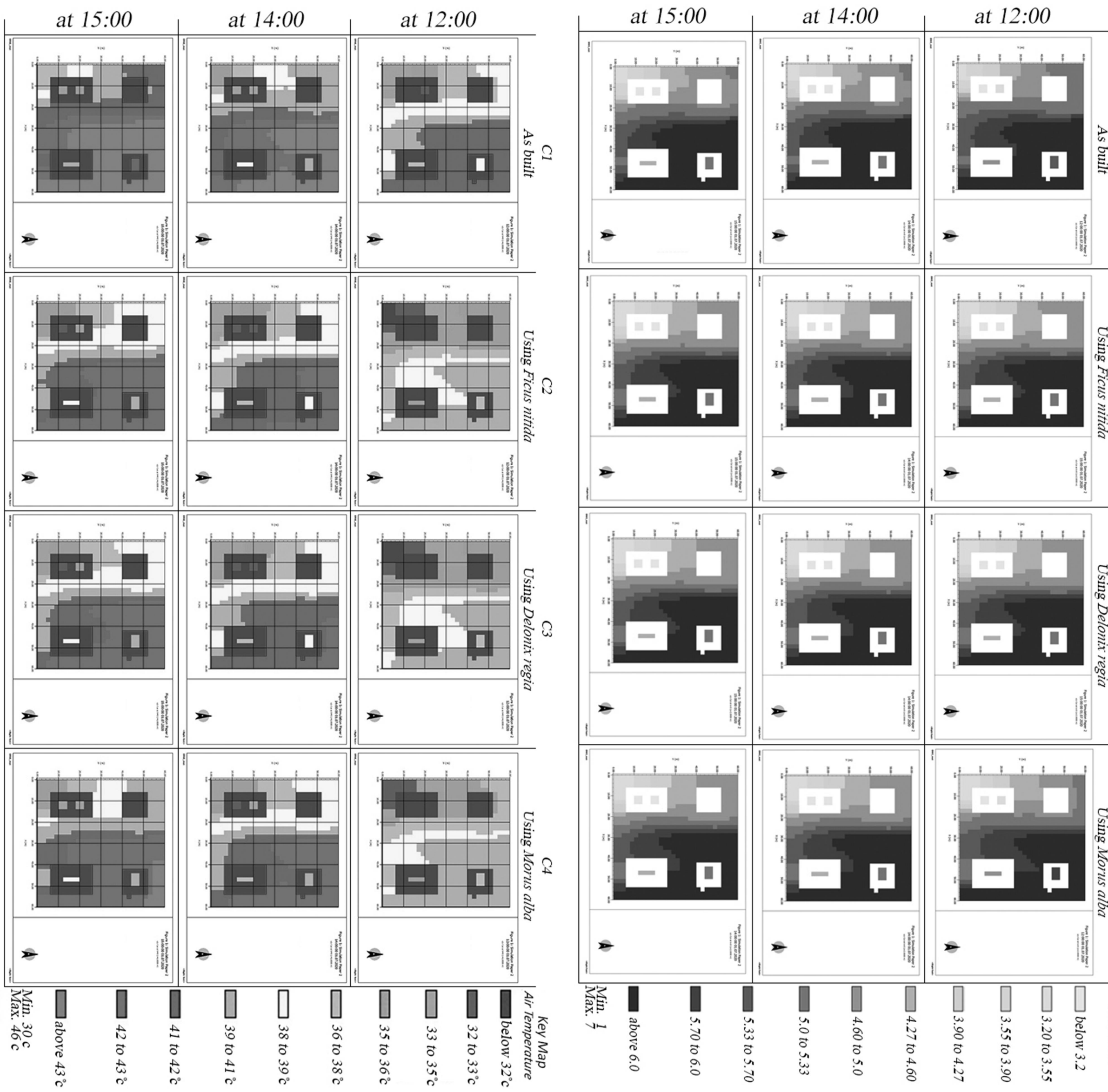

Fig. 11. The extracted maps for the four scenarios by ENVI-met, *"PMV"* located on the right-hand side and "*Ta*" located left-hand side.

It was also found the output data "T_a and PMV" from C3 were the lowest values compared to the other two case studies that includes tree in simulation, on the other hand, C2 output data were lower than C4. According to these findings the papers' hypothesis; the more *LAI* and LAD_z values tree generate, the more impact on microclimate was affirmed. Since, *Delonix regia* that was used in C3 its *LAI* value 1.04, *Ficus nitida* was used in C2 with *LAI* value 0.85 and *Morus alba* that was used in C4 its *LAI* value 0.83. Thus, it was found that this paper findings are quite similar to the previous findings [10-13, 15].

6. CONCLUSION

In this study we suggested a simple method for calculating *LAI* and LAD_z values for any tree. In order to examine the tree canopy impact on microclimate. We compared the impact of three trees through simulating four different scenarios. After the calculations and simulations, our quantitative analysis concluded that the higher *LAI* and LAD_z tree canopy generate the higher impact on microclimate. Although previous findings indicated that there is a direct relation between *LAI* and LAD_z of tree canopy and its impact on microclimate. It is possible that outcome would vary if tree canopy parameters and simulation time are different from this study.

Future researchers should consider the rest of tree canopy parameters such as CO_2 emission, albedo measurement, root zone depth, root area density "*RAD*" and the trees' season. In order to represent a full picture of tree canopy impact on the surrounding microclimate. Furthermore, our results data needed for urban designers in order to improve the outdoor microclimate and thermal comfort.

DECLARATION OF CONFLICT OF INTERESTS

The authors have declared no conflict of interests.

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تأثير مساحة وكثافة ظل الشجرة على متغيرات المناخ المحيط بها في النطاق الحضري

إن مظلة الأشجار لها تأثير كبير على الظروف المناخية، حيث أن مؤشر مساحة الأوراق "*LAI*" وكثافة ورقة الشجر "*LADz*" لأي شجرة هما خاصيتان متغيران للتنبؤ بتأثير الشجرة على المناخ ومن ثم فإنه يجب على المخططين والمصممين في المناطق الحضرية حساب قيمه *LAI* و*LADz* لاستخدامها في تحسين المناخ ورغم الحاجة الواضحة للأشجار في المناخ الحار مثل مناخ مصر، فإن هذه البيانات متوفرة بقدر ضئيل. ولذلك يجب دراسة التغيرات المناخية التي يمكن أن تسببها الأشجار داخل بيئتها العمرانية. لهذا السبب تم تكوين طريقه لحساب قيم ال *LAI* وLADz للأشجار لإنشاء قاعدة بيانات يمكن إستخدامها كبيانات للمساعدة في إستخدام البرامج التي تحسب الحرارة الخارجية. فهي طريقة متطورة تمزج بين القياسات المباشرة والغير مباشره المستخدمة لحساب قيم *LAI* للأشجار الأكثر شيوعاً في القاهرة مثل "شجره الفيكس نتدا، شجره بونسيانا وشجره التوت"، والتي سمحت لنا أيضاً بإيجاد قيم *LADz* الضرورية لتشغيل برنامج ال ENVI-met. بعد دراسة الأشجار وتحديد قيم ال *LAI* و*LADz*، توصلنا إلى أن "شجره البونسيانا" لديها أعلى قيم لل *LAI* و*LADz* مقارنة مع الشجرتين الآخرين. بعد ذلك، تم تجربه أربعة سيناريوهات مختلفة باستخدام هذه الأشجار فيما يخص تأثيرهم على المناخ.