Published paper

Fahmy, M., Sharples, S., Yahiya, M. (2010) *LAI based trees selection for mid latitude urban developments: A microclimatic study in Cairo, Egypt*, Building and Environment, 45 (2), pp. 345-357
http://dx.doi.org/10.1016/j.buildenv.2009.06.014

LAI based trees selection for mid latitude urban development: a microclimatic study in Cairo, Egypt.

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To study the leaf area index, *LAI*, based thermal performance in distinguishing trees for Cairo's urban developments, ENVI-met plants data base was used as platform for a foliage modeling parameter, the leaf area density, *LAD*. Two Egyptian trees; *Ficus Elastica*, and *Peltophorum Pterocarpum* were simulated in 2 urban sites with one having no trees, whilst the second is having *Ficus Nitida* trees. Trees *LAD* values were calculated using flat leaves' trees *LAI* definition to produce maximum ground solid shadow at peak time. An empirical value of 1for *LAI* is applied to numerically introduce *LAD* values for ENVI-met.

Basically, different meteorological records showed improvements for pedestrian comfort and ambient microclimate of the building using *Ficus Elastica*. About 40-50% interception of direct radiation, reductions in surfaces' fluxes around trees and in radiant temperature T_{mrt} in comparison to base cases gave preferability to *Ficus Elastica*. The lack of soil water prevented evapotranspiration to take place effectively and the reduced wind speeds concluded negligible air temperature differences from both base cases except slightly appeared with the *Ficus Elastica*. Results show that a flat leaves tree if doesn't validate *LAI* of 1, the ground shading won't fulfill about 50% direct radiation interception and this value can be used as a reference for urban trees selection.

Further simulations were held to investigate *LAI* value of maximum direct radiation interception.
Performing additional simulations, *Ficus Elastica* of *LAI* of 3 intercepted almost 84% of direct radiation and revealed implications about urban trees in practice and its actual *LAI*.

Key words: *LAI*, *LAD*, Peak time, ENVI-met.

1. Introduction:

1.1 Urban trees effects

As part of complete passive urban climate knowledge and in order to optimize urban form, urban trees as an important element of site vegetation have to lie in the core of any applied design procedure. Urban trees improve the microclimatic performance of built environment, adapt patterns to climate change and reduce energy consumptions [1-6]

Despite this is true, urban climate complexities prevented dedicating this knowledge towards supporting the decision of many interdisciplinary related fields, [5, 7, 8], such as landscape, urban planning and design which consider urban trees along with many other elements. Part of this complexity is the many mathematics, physics and models have been introduced to field to assess urban thermal interactions, but few were capable to assess human thermal comfort, all meteorological parameters and all urban surfaces and vegetation thermal interactions sufficiently [9-12]. Urban developments in Cairo were overwhelmed through the last couple of decades and didn't consider urban trees to control its hot climate[13]. In a tree microclimate, as radiant interactions critically affect comfort assessment, mean radiant temperature has been considered by many studies to give an indication about pedestrian thermal comfort [11, 14, 15]. The mean radiant temperature T_{mrt} is defined as 'uniform temperature of an imaginary enclosure in which the radiant heat transfer from the human body equals the radiant heat transfer in the actual non-uniform enclosure' [16]. For buildings interior comfort and energy demands assessment, the mean ambient air temperature, T_a is used to assess the heat transfer from outside to inside buildings through walls by conduction.

Trees microclimate is mainly due to radiation intercepted and evapotranspiration contributing to modifying the heat balance of surrounding environment. Radiation interception is owed to canopy prevention of short and long wave radiation from the upper hemisphere whereas evapotranspiration is owed to water content carrying capacity of the soil-tree-air system. Evaporation takes place from leaves surfaces to air [17], and transpiration from soil through leaves stems due to photosynthesis that circulates this system [18]. Eventually, the latent heat increases and the sensible heat decreases within a tree environment leading to lower, air temperature T_a [2]. Less heating rate for surrounding air is then achieved meaning better comfort levels outdoors as well as for indoors due to modifying ambient conditions [19]. Radiation balance that a tree modify is expressed by the total budget firstly presented by Monteith [20] and represented perfectly in literature, [21-23]. Nevertheless, urban trees have also more than the thermal benefits, Yoshida et al., [24] demonstrated that parks and vegetation have a magnificent role in increasing health quality, thermal stress reductions. Oppositely, microclimate wind speed reduction is a fairly disadvantage for urban trees specially when gathered in groups due to the drag force of plant canopies [15-17] if compared to open land wind speeds [25, 26]. Another disadvantage is the diurnal patterns of warmer nighttime temperatures and cooler daytime temperatures due to the trapped heat and humidity within urban canopy layer if also compared with the rapid nocturnal cooling of open areas [25]. Trees have a role in making visual perspective and environmental stimulation by increasing the green color in urban scene for psychological adaptation [27, 28]. Urban trees improve outdoor spaces, place making and spatial format, order, harmony, contrast, scale, proportions and variety which all can be attributed to trees urban arrangements and its geometric characteristics [29, 30]. Furthermore, trees are air filters, confidentiality elements [31] and noise reduction elements [32, 33].

1.2 Trees canopies

Selection of urban trees to accomplishing specific urban design criteria can be based on many aspects, such as its thermal performance which in turn depend on foliage characteristics as well as tree mature shape; i.e. total height and canopy geometry. In addition, botanical aspects decide selection of a tree to be planted in a specific site; i.e. type of soil to be planted in, tree deciduousness, depth and radius of roots , capability of bearing site hazards and harsh climates [29, 30].

LAD and *LAI* are conceptual environmental canopy modeling parameters in studying trees' heat exchanges with environment as they have significant role in urban heat balances [34, 35]. Based on the radiation interception concept through flat leaves trees' canopies, *LAI* is defined as a dimensionless value of the total upper leaves area of a tree divided by the tree planting ground area [34, 36]. By definition, 100% of direct solar radiation interception means that canopy shadow should equal ground planting area. In this respect, *LAI* for same tree could vary from a season to another by deciduousness, from age to another by growth, and there still the chances to propose other definitions and interpretations of *LAI* [34]. This is why trees in this study will be modeled as if they are mature. *LAD* is key parameter needed to model the radiation through a tree canopy and between a tree and its environment. It can be defined as the total leaves area in the unit volume of a tree horizontal slices along the height of a tree that can give an idea about the vertical leaves distribution [37, 38]. *LAD* modeling can be estimated by means of field measurements manually or using instrumentations along with empirical models [34]. For example, Meir et al. [37] investigated tropical trees estimations by a photographic method. Beer–Lambert law was used by Pierce and Running [39] to calculate *LAI* using the extinction coefficient and the measured light transmission. Stadt and Lieffers [40] described trees 3-D profiles, but for limited specimens and their MIXLIGHT model could be complicated in application. Lalic and Mihailovic [41] derived an empirical method to model *LAD* if the maximum *LAD*, L_m, is known which in turn is calculated in terms of *LAI*.

LAI can be measured, manually or by instruments, for example Kotzen [42] used a scanner for *LAI* measurements, whilst the Plant Canopy Analyzer (type Licor LAI-2000) and many ways are reported by others [34, 36, 40]. *LAI* investigations for trees modeling in hot regions have lacking studies either from a measurement point of view or from modeling point of view, may be Kotzen [42] study in arid regions and Shahidan et al. [36] study in hot humid region are few examples in comparison with other climate regions and forest trees studies [34, 37, 40]. In addition, urban trees modeling to assess their thermal effects in contact with buildings in hot regions are more lacking. Therefore, some questions can be raised here; how tree can be modeled without *LAI* or *LAD* sources for specific species even without measurement, how tree foliage can support its plantation preferability than another, and what is the preferred *LAI* of a tree to produce maximum shadow at peak hour of a mid latitude site?

2. Methodology:

2.1. Method:

As the main idea of this paper is to study how urban trees for specific locations can be, assessed and selected, foliage modeling is crucial. Trees' foliage thermal performance distinction in a detailed built environment and complex vegetation interactions with built environment is difficult to achieve due to the problematic and transient criteria of outdoors. Consequently, numerical simulations has been held to easily simulate such complexities using ENVI-met which helps providing design and planning decision support [9]. ENVI-met [43] is a three-dimensional numerical model that can simulate the surface-plant-air interactions of urban environments with a typical resolution of 0.5 to 10 m in space from a single building up to neighborhood provided 250 grids at maximum. ENVI-met is a non-hydrostatic prognostic model based on the fundamental laws of fluid dynamics and thermodynamics in a much improved package than only a CFD package for fluid dynamics' simulations [11]. It nearly has the complete capability to simulate built environments from microclimate scale to local climate scale at any location. This is regardless overestimations because of un-calculating soil heat storage [44] and global radiation overestimations by day and under estimations for the nocturnal cooling by night [22]. Moreover, the combination of biometeorological outputs of ENVI-met gives deep understanding of climate in the urban canopy layer, such as presented by Fahmy and Sharples [28].

ENVI-met vegetation model is formed over one-dimensional column with height z_p (z in Eq.D, E) in which the profile of a tree LAD represent the amount and the distribution of leaves [43]. The distribution of roots within the soil system is represented by the root area density, RAD, from the surface towards the root depth $-z_r$. By this way all types of vegetation can be modeled. The vegetation model is formed of four sub-models; first is the turbulent fluxes of heat and vapor sub-model that solve interactions of temperature, humidity and air movement between air and tree foliage. Second solves interactions of evaporation and transpiration of water from soil through a plant that is affected with its stomata resistance r_s. Differing from grass to tall trees, it is simply the number of stomata of a plant green leaves per unit area that describe the resistance of transpired water can face to be evaporated through leaves. Hence, stomata resistance depends on short-wave radiation and the soil water. The third sub-model is a steady state leaf energy budget depending on the foliage Albedo, a_f and light transmission factor, tr_f, that control net short-wave radiation absorbed by plant. The fourth sub-model calculates mass of water transpired from soil depending on the soil hydraulic diffusivity through its layers, so that evapotranspiration effect can take place if stomata resistance and soil water allow that. Detailed information and equations can be found in Bruce [43]. The package has its own numerical data base for some plants *LAD* profiles that is used when simulating the native environment of these plants and depends on analytical approaches that can help in obtaining the *LAD* distribution of other plants especially if the *LAI* is known [43]. This answers why ENVI-met has been decisively preferred to numerically simulate the new trees. As the foliage characteristics of hot climates' trees such as Egyptian trees investigated in this study are not represented in the plants data base of the software, the data base needed 10 *LAD* values to be distributed over the tree normalized height. Hence, the *LAD* values for 10 slices of each tree had to be generated to introduce these new trees to ENVI-met and to study their thermal performance foliage based differences.

2.2 Case studies:

Cairo, latitude of 30° 7'N and longitude of 31° 23'E, is a semi-arid mid-latitude climate zone [45]. The first case C1 is part of the Fifth community which is built in late 20th century, as one of New Cairo communities. It lies to the east of the 1st Greater Cairo's ring road.

However, the fabric surfaces of the detached housing dot pattern form mostly for single family and the lack of planned structure of vegetation increased urban canyons heat gain and thermal stress [13]. Table.2 show abbreviations used in this study. Second case C2 is part of Misr Al-Gadida which was built starting from early 20th century until 1990s to the northeast of metropolitan Cairo as multi family housing [46]. C1 is having no trees, whilst C2 is already having almost the 4m height *Ficus Nitida* trees. That is why a second case is used in this study; to compare selected trees' performances, i.e. if there will be difference in tree type to be used in each urban site upon its details. Paving in both cases under trees is cement concrete tiles of 2.5cm over sandy loam soil as described in ENVI-met finishing profiles which is in good agreement as real existing, finishing properties are mentioned in table.1.

2.3. Trees description:

Trees studied in this paper to replace the existing situation in each site are the *Peltophorum Pterocarpum* (Yellow Poinciana), T1, and *Ficus Elastica* (Indian rubber plant), T2, are Asian trees but they are planted successfully in Cairo for their shading and ornamental values. The *Ficus Elastica* also called Ficus Decora is an evergreen tree with 12-15m mature height, 6-9m corresponding height and 4-6 trunk height. The *Yellow Poinciana* is a deciduous tree can reach up to 20m height with 12-16m corresponding height and up to 6m trunk height. T2 is not dominantly used as urban street tree whereas T1 is widely used. Fig.1 demonstrates both trees [47, 48].

In C1, trees were arranged in front of F2_B2 in both cases in two positions, so that each it has two trees. On the other hand, F1_B1 facades have one tree for each to allow more air access to between buildings and generating shadows for pedestrian at low solar altitudes, refer to Fig.2. In C2 the non uniform distribution of trees planted is replaced with a linear distribution that has same trees arrangements as described formerly. It is of importance also to mention that position of trees in relation to buildings is critical as the shadow produced and wind speeds are affected in turn [49], but this is beyond the scope of this study. However, trees in this paper are allocated at the 1.5 and 4m distance away from the building plots in C1 and C2 respectively, Fig. 2 and 3.

2.4. LAD generation:

Leaf area density spatial distribution introduced for ENVI-met simulations [43] in two steps. First, the minimum *LAD* of the tree is calculated using software compiled in Fortran by authors based on the empirical *LAD* model of Lalic and Mihailovic [41]. This model was solved 10 times to produce *LAD* values at different heights of the tree using the tree height h, the maximum leaf area density L_m, and the tree canopy corresponding height z_m. In the second step, *LAD* results were added to ENVI-met plants database to represent the 3-D canopy of these trees. Consequently, these trees were introduced to the model area and simulated, regardless the many ways of field measurements of *LAI*; it was a research question to investigate modeling of a tree canopy in absence of measured value. The maximum *LAD*, L_m , needed in the *LAD* model have been derived by assuming *LAI* value.

In this respect, the ground level shape of tree shadow that depends on the light transmission profile has been suggested regarding trees plantation objective. Plantation objective mean the purpose or the aim of planting a tree, is it ornamental, functional, etc[29, 30]. In this work the objective is to produce maximum ground shadow at peak time of Cairo. Eventually, a specific thermal performance and modifications towards a tree microclimate can give it preferability from another one. With regard to the solar position, the average peak solar altitude in the typical summer hot week is 82.40˚ (between 82.80˚- 82.10˚) at 13.00LST. This was on the 7th of June of the typical summer week, despite that altitude reaches 83.3˚ in the extreme hot week (26th of Jun – 2nd of July).

However, this day conditions were simulated a typical hot summer day at the middle of the typical summer hot week (5-11 of June) based on 30 years of WMO Station no.623660 records at Cairo international airport [45]. Simulations were held for the peak solar 6h from 10.00 – 16.00 LST, attributed to only studying the microclimatic effects, neither to calculate the comfort levels for pedestrian nor to study buildings interior climate. In addition, as ENVI-met simulations are time consuming, there is no possibility at all to simulate more than a representative day for summer and a representative time for day shading.

Table.1 indicates the main meteorological daily average inputs of June used in simulations.

By definition, *LAI* can be represented as following:

$LAI = A_L/A_p$ Eq. A.

A_L is the upper leaves area.

A_p is the tree ground planting area.

At peak time if the shadow is solid, then A_p should almost equal the projected ground shadow, A_g. Thus Eq. A. can be converted to:

$LAI = A_L/A_g$ Eq. B.

A_g is the maximum projected ground shadow of the tree at maximum solar altitude, (13.00 LST)

In other words, the least value for LAI to produce a solid ground shadow at maximum solar altitude of nearly 90˚ (peak time), is when the upper leaves area equal that shadow area, i.e. if the tree modeled, it will produce solid shadow with minimum amount of leaves; or

$LAI = A_L/A_g = A_L/A_p = 1$ Eq. C.

In relation to the site investigated, this means a good approximation of applying this LAI value when the altitude is 82.40˚ of the simulated day, the 7th of June, Fig. 4.

Hence L_m of the minimum LAI of maximum shading effect can be calculated from the model equation as following;

$$LAI = \int_0^h L_m \left({}^{h-z_m}\!/_{h-z} \right)^n . \exp\left[n\left(1 - {}^{h-z_m}\!/_{h-z} \right) \right] . dz \qquad \text{Eq. D.}$$

Substituting L_m in the following equation, so that LAD can be calculated for any z;

$$LAD = L_m . \left({}^{h-z_m}\!/_{h-z} \right)^n . \exp\left[n\left(1 - {}^{h-z_m}\!/_{h-z} \right) \right] \qquad \text{Eq. E.}$$

h ; is the total height of the tree.

z_m ; is the canopy height at which LAD is the maximum (L_m).

z ; is the height of LAD slice.

$$n = 6 \text{ if } 0 \geq z \geq z_m \text{, and } 0.5 \text{ if } z_m \geq z \geq h$$

The compiled software solved equations D and E to automatically record *LAD* values needed for ENVI-met database.

Moreover, for any tree, if h, L_m, and z_m do not ensure that *LAI* = 1, this means that the ground shading will be filtered rather than dense or solid, the tree will transmit larger amount of radiation. Thus, *LAI* = 1 can be used as a benchmarking reference value for urban trees of Semiarid Mid Latitude region in which Egypt lies, where solar height angle is close to 90˚ and the shadow area will be almost equal to the planting area.

Other foliage parameters in the original database, inputs regarding foliage characteristics, materials and soil types for both cases are fixed, table.1 to allow only a comparison of thermal performance based on the differentiated *LAD* values and sites details.

2.5. Parameterization:

In order to study *LAI* of 1 trees base performance on the selected fabric as an example of urban developments, snapshots were placed in three groups around. Each of them has eight snapshots except the third is composed of only one point under trees outside the plot limit, Fig.2/c, d, e, f. First and second groups consist of four points for best interpreting each parameter average from the four records. Rear façades' snapshots were only used for wind speed comparison with its corresponding front façade, whereas all outputs around buildings were averaged near only F1_B1 and F2_B2 in both cases for the rest of meteorological records.

First and second snapshot groups' distances were placed 0.5m from the front and rear facades that are directly in contact with trees to assess effect on meteorology of near wall as ambient conditions (which are needed for building interior design as if we are going to do it). The third group is used to assess the effect of the tree from a pedestrian point of view. Distance from wall is due to the resolution used in the model area is 1 for x and y. The efficient radiant interactions that affect the near wall air temperature couldn't have been recorded unless the snapshots were placed closest to facades. Outputs were recorded at 4.5m a.g.l. around building facades for the first and second snapshot groups whilst at 1.5m a.g.l. under tree canopy for T_{mrt} and at zero height for surface heat budget investigation. Justification for the 4.5m is made as the buildings examined are all ground and two floors of total height 9m, so 4.5m height can be approximately representing the height at which the first floor gains heat from walls having trees' shadows. Yet there will be no indoor climate study in this paper, but in real practice ,heat gain from all walls due to ambient conditions should be accurately investigated for which is affected by specific foliage. The 1.5m height under trees is used to represent a pedestrian comfort point of view following Pearlmutter et al. [10]. Nevertheless, the thermally affected height of a pedestrian from 1.2-1.75m a.g.l. is acceptable, the 1.2m a.g.l. was used by Ali-Toudert and Mayer [6] and at 1.4m a.g.l. used for measurements in Freiberg also by Ali-Toudert and Mayer [14].

Parameters assessed around buildings in both cases are the near wall air temperature T_a, wind speed V and the relative humidity RH. T_{mrt} as a pedestrian comfort indication is recorded under trees' canopies, regardless the ground finishing material which is fixed in all simulations to avoid different emissivity, table. 1. T_{mrt} is affected by all types of radiation from the six directions of both hemi spheres; i.e. from direct and diffuse short wave radiations, all long wave radiations from sky, from surrounding built environment, trapped by trees canopies as well as emitted from ground that are why ground material is crucial with soil underneath.

For better understanding shadow effects and in turn which tree thermal performance is the best, radiation components at ground surface recorded from under trees' snapshots. Direct and diffuse short-wave radiations $S_{w.dir}$ and $S_{w.dif}$ are compared with that of free horizontal surface radiations recorded at Cairo International Airport weather station. Moreover, the air-surface long-wave radiation fluxes downward from sky $L_s\downarrow$, downward from trees canopies $L_t\downarrow$, from surrounding walls $L_w\leftrightarrow$ (either from F1_B1 towards the far north snapshot or from F2_B2 towards the far south snapshot in both case), upwards emitted from ground $L_g\uparrow$, and surface total heat budget $L_p\updownarrow$ (as total budget at a time could mean delivering or absorbing heat upwards or downwards), are compared with those of base cases in each site.

3. Results:

3.1 Building ambient conditions:

Fig. 5 is a plot of T_a, *V* and *RH* at F1_B1 and F2_B2 in both sites together with plotting of the hourly data also from 10.00-16.00 LST at airport for only *RH*. Theoretically, it could be possible to compare ENVI-met results for T_a, *V* and *RH* in a mid-latitude location [22]with measurements if meteorology at boundary conditions were adjustable, height of simulated records within urban canopy layer equals its corresponding measured and if these heights assure blending between the roughness sub-layer and the urban canopy layer in both sites [50]. ENVI-met calculates T_a, *V* and *RH* from the initial inputs which are kept constant. Future development of the software could consider forced daily measurements, but limitations still exist. It was worth-plotting results of *RH* from simulations with that of airport station as they were found to have nearly the same profile and ranges as if the trees were not exist in the model at all. It has been recognized that evapotranspiration didn't take place effectively because there wasn't enough water content in soil under trees. The water content after all simulations for all receptors ranges only from 0.08-0.14 m^3/m^3 at different depths due to the soil reduced humidity input, i.e. almost no water has been applied for trees and hence the fixation of water content at 1.75m depth by ENVI-met didn't affect. This clarifies why humidity environment of trees was close to the measured at airport although it has increased by usage of T2 compared with T1 with minor difference of 1-3% between them. This lack prevented increase of latent heat and allowed increase of sensible to balance the foliage irradiative budget concluding with no valuable difference in T_a. Despite values differences didn't exceed a negligible value of 0.1-0.3 K, the 0.3 K was assigned to using T2 which has the denser canopy than T1 due to higher *LAD* values. Wind speeds also didn't help reducing T_a. It is generally in both sites are about 1.1-1.5 m/s at F1_B1 that face prevailing wind from north and reduce to about 0.1 m/s at F2_B2. Wind records ranged from 0.1-0.3 m/s in between rear facades. Overall wind speeds recorded were reduced about 60-95% from the initial simulation input of 3.5 m/s due to trees and the urban form wind blocking even in cases without trees. The usage of T1, which has the smaller *LAD* values, reduced wind speeds in both sites rather than the usage of T2 because of its height. In C2 the slight rotation from E-W helped increased speeds due to the angel of attack from prevailing wind across the buildings block that increased speeds at F2_B2 to double that of F2_B2_C1 for T0, T1 and T2.

After all, canopy proportions and foliage characteristics of T2 showed better T_a reduction from base cases, blocked wind speeds less and introduced more humidity to its microclimate regardless the lack in soil water content.

3.2 Under trees:

3.2.1 Radiant temperature:

Because of the dependency of T_{mrt} on radiation interactions, it is of importance to know how ENVI-met calculates short and long wave radiation as they conclude the T_{mrt} value. The heat budget at any point on the ground surface or in the model atmosphere is generally calculated by modifications to the radiation sources due to buildings and plants using SVF and the vegetation foliage transmission factor[43]. It is a place to mention that work held in this paper revealed issuing new BETA version of ENVI-met because of the trees transmission factor [51], that hasn't operate effectively as if the trees doesn't exist in the model and simulations had to be repeated twice.

However, as described formerly there is no influence from the model boundary conditions. Hence, unlike comparing T_a, V and RH of simulations with airport measurements, radiation can be compared in order to address the different masking effect of different trees' foliage at specific height a.g.l., regardless some gases' effects (carbon dioxide, etc) are not included.

Fig.6/a, b represents T_{mrt} of both sites. T_{mrt} as a biometeorological representation of all wave radiations influencing pedestrian comfort under trees canopies is attributed to solar movement. The southern snapshots recorded lower values at early and late simulated time rather than the northern one in comparison to base case of each site. For example, in C1 at 10-11.00 LST values for F2_B2 were 346.4˚/T0, 329.6˚/T1 and 324.0˚/T2 K, C2 values were 345.3˚/T3, 331.5˚/T1and 328.5˚/T2.

At early simulated time, higher values of $S_{w.dir}$ were recorded rather than at peak hours of 12.00-14.00 LST because of the combined effect of trees and buildings. But at peak time, T2 performed better in both sites with about 3 K difference in C1 and 7 K in C2. At early evening L_g↑ start to be emitted and increase T_{mrt} which recorded about 6 K less by using T2 than T1 at C1 and 11 K less by using T2 than T1 at C2. Further T_{mrt} drop at 14.00-16.00 LST in both cases is attributed to site orientation where direct radiation is blocked by buildings and with tremendous drop in C2 because of the more deviation from N-S orientation of facades.

3.2.2 Short-wave fluxes:

In comparison with the airport free horizon measurements, all urban situations of both cases had overestimations of short-wave radiation that can be owed to the large time steps used to save time in simulations especially when sun at high altitude (15min for surface data update, 20min for radiation and shadow update and 25 min for plant data update). Also it has to be mentioned that the adjustment factor used for short wave radiation is 1, whereas for example Ali-Toudert [22] used 0.84 which mean that overestimations for the radiation should be intercepted by trees are included. The much difference came when sun at low altitude due to obstacles from environment. This later reason particularly made the diffuse (include diffusely reflected) radiation output from ENVI-met for BC1 and BC2 much less than measured in Airport. Fig.7/ a, b, c, d illustrates $Sw._{dir}$ and $S_{w.dif}$ for both sites.

In C1, at peak time $S_{w.dir}$ values for T0 in front of both facades were equal and almost as the free horizon. By usage of T1 records were 768/F1_B1 and 597/F2_B2 w/m^2 (about 40% of direct radiation incident on the tree) and for T2 recording 547/F1_B1 and 522/F2_B2 w/m^2 (about 50%). About 100 w/m^2 of intercepted direct radiation were recorded by the foliage of *Ficus Elastica* rather than the *Yellow Poinciana* in both sites.

In C2 almost same discipline has been noticed for $S_{w.dir}$, although orientation and the base case details made more discrepancies from the free horizon measurements. Values at peak time were 600 w/m^2 for both under trees' snapshots of T1 and 525 w/m^2 for both under trees' snapshots of T2 respectively whilst snapshots of T3_BC2 generated almost same as Airport. This was due to position of snapshot that wasn't exactly under trees, besides the buildings examined in C2 almost wasn't having trees near facades, which approved the need for additional simulations. Nevertheless, records give an initial indication that T2 in both cases made environment perform better than T1 subject to investigate all T1, T2 and T3. The reduced records of $S_{w.dif}$ in both sites are attributed to built environment and trees that blocked much of airport measurements values 900 w/m^2 to reach not more than about 90 w/m^2 in situ.

3.2.3 Long-wave fluxes:

Understanding results of all long-wave radiation components under trees is better to be related at first to the *LAD* values of both T1 and T2 canopies foliage characteristics. The integration of *LAI* of 1 actually has distributed same amount of leaves over the different canopy height of both T1 and T2. Consequently, the one of them that has more canopy height will be less foliage density and more transmitting for $S_{w.dir}$ and $L_s\downarrow$ which mean initial preference of T2 than T1.

Fig.8 illustrate long wave radiations from sky, from environment, from trees, emitted from ground and the total budget of pavement surface are presented in both sites. Amounts of heat trapped by canopies are attributed to $L_t\downarrow$ (either due to $L_s\downarrow$ or due to $Sw._{dir}$) or as part of the emitted $L_g\uparrow$. These amounts heat microclimate environments, and have to be considered in assessing effects of specific canopy profile.

Basically, by means of $Sw._{dir}$, $L_w\leftrightarrow$ and $L_s\downarrow$, the ground initially receives radiation then heat stored in pavement tiles under trees. Pavement has an Albedo of 0.4 and an emissivity factor of 0.9 and the deep soil contained not more than 30% of *RH* which mean high rate of sensible heat will take place. The pavement material can play a role to giving chance for more dense trees. As emissvity increases more trapped heat by dense canopies will increase and vice versa.

The most effect of trees was on the radiation from sky, trees intercepted about 120-150 w/m^2 by T1 and T2 more than T0 or T3 respectively. In both cases usage of T2 reduced $L_s\downarrow$ by about 20-30 w/m^2 at F1_B1 and F2_B2 more than usage of T1 due to T2 *LAD*. The orientation of buildings also in both sites affected all amounts of radiation received at both receptors. At 13.00 LST the southern trees' row receptor in C1 most of the time received $L_s\downarrow$ with only 2-4 w/m^2 less than the northern receptor due to the increased number of trees and rose to about 10 w/m^2 between trees receptors of C2 because of the tilt angle of form from E-W axes. T2 intercepted 20-25 w/m^2 less than T1 at all facades of both cases.

Lw↔ from environment towards receptor points was all time more from F2_B2 in C1 and C2 than F1_B1 in C1 and C2 due to the more trapped heat by trees arrangements at southern buildings' facades in comparison with northern facades rather than by tree foliage itself. In addition, F2_B2 is receiving more Ls↓ and Sw.dir all day time. But in comparison with T1, T2 trapped the less heat from walls with a slight difference of no more than 5 w/m^2.

Due to Ls↓ *and* Lw↔ the emitted Lg↑ is effective and reached about 540 w/m^2 which is about half of the direct radiation value at airport at 13.00 LST. In this respect, T2 recording about 10 w/m^2 less than T1 in C1 and C2, but with almost no difference between F1_B1 and F2_B2 in each site. The disadvantage of T2 than T1 appears here as Lt↓ from T2 is ranging 20-30 w/m^2 more than T1 in C1 for both facades whereas in C2 with only 7-10 w/m^2 more than T1.

By evening, amounts of all long-wave radiations increase until 16.00 LST at which a decrease begin to take place especially with T2. As a conclusion, T2 performed better than T1 in C1 and than T1 and T3 in C2 except Lt↓ which is a disadvantage of the higher *LAD* values of T2 than T1.

3.3 *LAI* values comparison:

With reference to about 40-50% interception of short wave direct radiation, a partial proof for the concept of *LAI* equal one upon the used *LAI* definition can be interpreted. But *LAD* distribution was expected to prevent more than 50% of coming radiation as realized from *LAI* definition of flat leaves (theoretically there is no tree can intercept 100% of coming radiation [21]). As trees of this study were introduced numerically by integrating their structural proportions ($h,\ z_m$) over height, it could have needed more *LAD* to achieve solid shadow. From this standing point, in main simulations of BC2, T3 intercepted less than expected, even in comparison with T1 and T2. This could be due to snapshot positioning that wasn't exactly under T3 canopies because canopies almost were growing outside the pedestrian pavement of BC2.

For all of these reasons, further simulations using *LAI* of 2 and 3 have been performed for same trees for only the peak hour. Only one snapshot receptor is placed at centre under each tree (ENVI-met doesn't simulate trees' trunks) to investigate which *LAI* value can contribute to nearly 100% interception along with assuring T3 performance. *LAD* model used in this paper integrated only *LAI* of 1 over the whole trees height. Which means the more height of tree, the less *LAD* at any of the canopy slices. This could explain why almost only about 40-50% of direct radiation has been intercepted by T1 and T2 respectively in both cases. But doesn't explain why T3 didn't intercept more than T1 and T2. It is not only the integration of *LAI* that decide the distribution of *LAD*, but also the relation between z_m and h with respect to Eq. D and E which can close performance of different trees to each other provided closer of their foliage proportion to each other. $S_{w.dir}$ at ground surface under trees comparisons showed that T2 still performing better even than T3, not only because of the slight difference of intercepted $S_{w.dir}$ but also because T2 is 15m height, i.e. more shadows will be generated specially at higher values of *LAI* rather than T3. Additional simulations show about 84% by T2 and T3, and 73% by T1 interception of free horizon direct radiation has been achieved. In a related note, if *LAI* calculation is basically by dividing leaves area over the shadow area, then an actual definition of *LAI* shouldn't be only 1 as interpreted in section 2.4 in order to achieve more solidity of shadow than the 50%. An actual definition of *LAI* for flat leaves shade production trees should be related to its proportions and its solid shadow area. For example, for a 15m height *Ficus Elastica* tree to produce solid shadow, actual *LAI* shouldn't be less than 3 times its ground solid shadow area at peak time. Fig. 9 indicates values comparison.

4. Discussion and Conclusion:

Basically, the purpose of this paper is to study how to choose a tree to be planted in urban spaces to improve microclimate in two urban sites either for pedestrians or for indoor inhabitants and how to model a tree for assessing these microclimatic effects without having source data for its foliage characteristics. A key parameter of tree foliage is the leaf area index which has many definitions. The flat leaves' trees used in this paper oriented the study to initially suggest empirical value of 1 for *LAI* upon its definition to generate solid shadow. In order to check such *LAI* based trees' performances, numerical simulations using ENVI-met took place for the cases' environments with these trees. The canopies' *LAD* profiles have been generated to be used within ENVI-met plants database. Main simulations in completion with additional ones indicated that, when selecting a tree, the more height the more need to increase leafs to conclude more density for more interception but with caution to long wave radiation trapped by canopies. Optimization between ground surface physical properties and the amount of heat trapped by a tree could help increasing *LAI* value of a specific tree so that more direct and sky radiations can be intercepted. In this study, the *Ficus Elastica* performed better than the *Yellow Poinciana*. Although air temperature records showed about 0.1-0.3 K reductions from both base cases due to the reduced wind speeds and lack in soil water that prevented evapotranspiration effects it performed generally better. Humidity rates were close to using the *Yellow Poinciana* or the base cases. Wind speeds were reduced by about 60% from the model input value at northern facades and about 95% at southern facades in both cases. Realizing the most effect of *Ficus Elastica* came from studying surface heat budget under canopies; heating under canopies less. The radiant temperature reductions reached 5-15 K in Misr Al-Gadida and up to about 40 K in the Fifth community (that wasn't using trees at all) in comparison with each one base case. This is in addition to intercepted direct radiation of more than $100\, w/m^2$ with the *Ficus Elastica* rather than the *Yellow Poinciana* in both cases. But regardless the *Ficus Elastica* trees performed meteorologically better than the *Yellow Poinciana* and the base cases situations, non of the two trees introduced even the shorter one exist in the second case, have intercepted more than 50% of direct short-wave radiation of free horizon measurements at airport. This could be owed to an overestimation of the software and integrations of Eq. D and E, it is expected that the smaller the height the more dense its shadow. Despite *LAI* of 1 can be considered the least value to intercept about half of short wave direct radiation by using up to a 20m height flat leaves tree (such as the *Yellow Poinciana*), more *LAI* values could have intercepted more coming radiation. Results suggest an actual definition of *LAI* for flat leaves shadow production trees to be in terms of height regardless its type and in terms of the peak time solid shadow rather than the changeable upper leaves area, i.e. specific definition for each trees range of h and z_m. For a 15m height tree for example; it is three times its ground solid shadow area at peak time. Hence, if the *Yellow Poinciana* examined in this paper is to be used for a housing height up to 20m, may be not less than *LAI* of 4 should be this tree to intercept about 100% of coming radiation. This way can solve the discrepancies of *LAI* definitions reported by Jonckheere et al. [34]. The study also indicated that, to interpret an actual *LAI* value for a shadow production flat leaves tree with a specific foliage proportions, methodologically, first; test the empirical value *LAI* of 1 to model the tree. At a semi-arid mid-latitude regions starting from 30˚ like Egypt and towards low-latitude sites, any tree of h, L_m, and z_m if doesn't validate *LAI* of 1, the ground shading won't fulfill at least 50% interception and this value can be used as a benchmarking reference for urban trees selection. For other climate regions the empirical start for *LAI* will be 0.5. Second, simulate this tree environment and calculate its corresponding climate effects to initially find the preferable tree among others. Third, estimate its approximate 100% interception *LAI* value then search the market for such tree.

Finally, it worth to say that despite work presented is a trial to ease trees' modeling complexity as part of the bigger complex picture of urban climate to be linked with applied urban planning and design, more complication might be added to urban planning and design practice itself as trees modeling and *LAI* based thermal performance assessment has to be included in such practice.

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Fig.1/a, b: The Ficus Elastica (Indian Rubber Tree) to the left, the Peltophorum Pterocarpum (Yellow Poinciana not in mature height) to the right.

Fig.2/a, b: 0.6m resolution Quick bird 2008 satellite images indicate location of sites in the study.

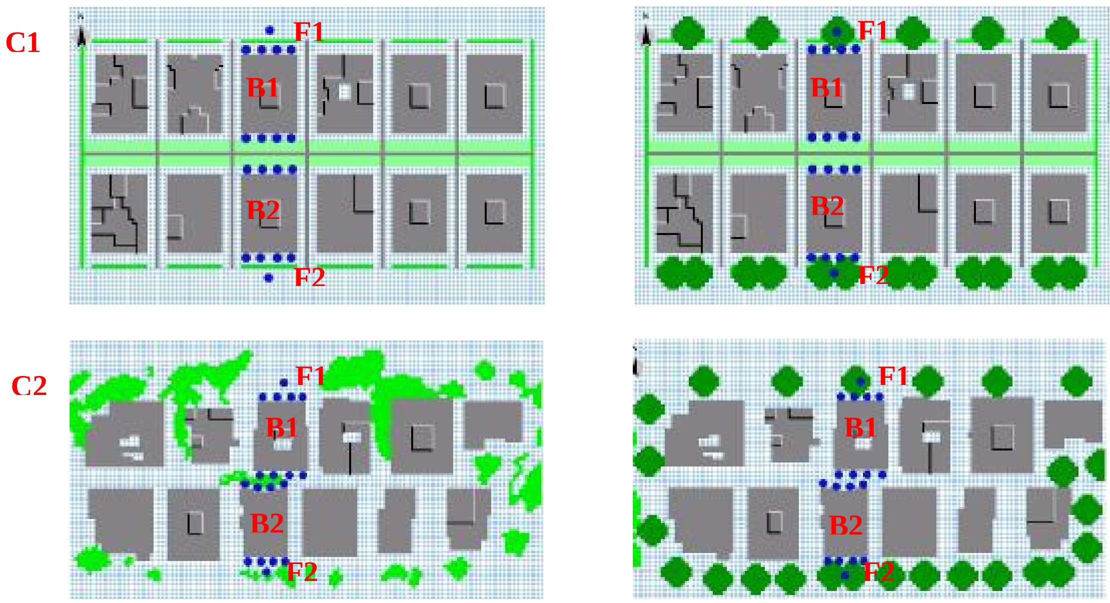


Fig.2/c, d, e, f: Illustration of sites before and after trees modifications with buildings and facades examined surrounded by snapshot receptor points; C1 is top and C2 is bottom.

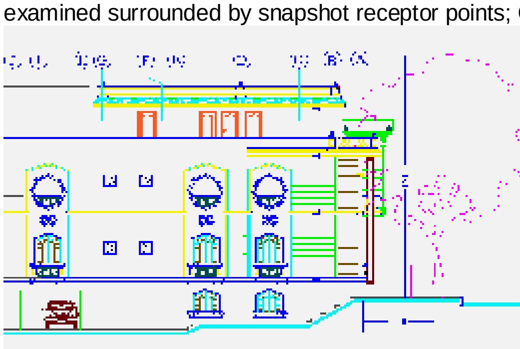


Fig.3: Side façade CAD illustration for the building-tree relation that could affect on the walls shadow, example is a design for the first author in C1.

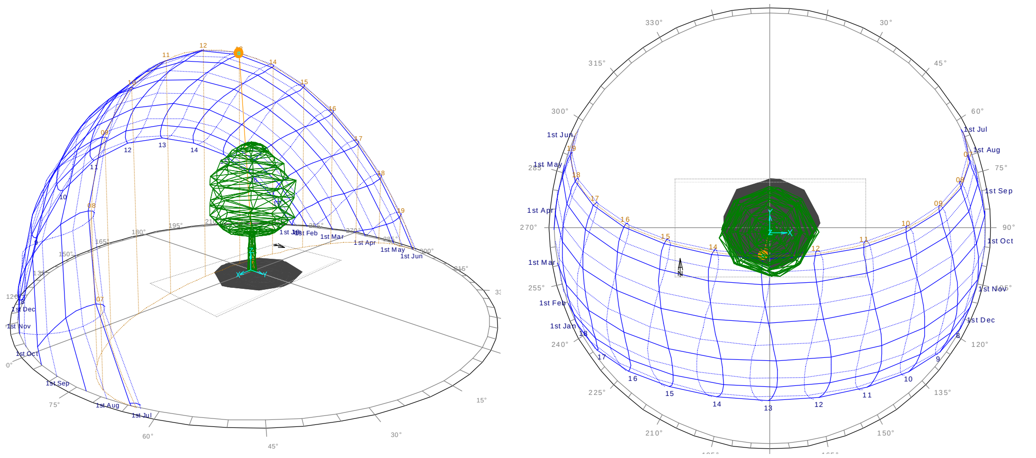


Fig.4: Schematic model by ECOTECT 5.6 for the Yellow Poinciana (following Shahidan et al., [36]) to indicate shadow of solar altitude of 82.40˚ on the simulated day, the 7th of June at peak time of 13.00 LST, which is almost equal plantation ground area; i.e. the least LAI should be 1.

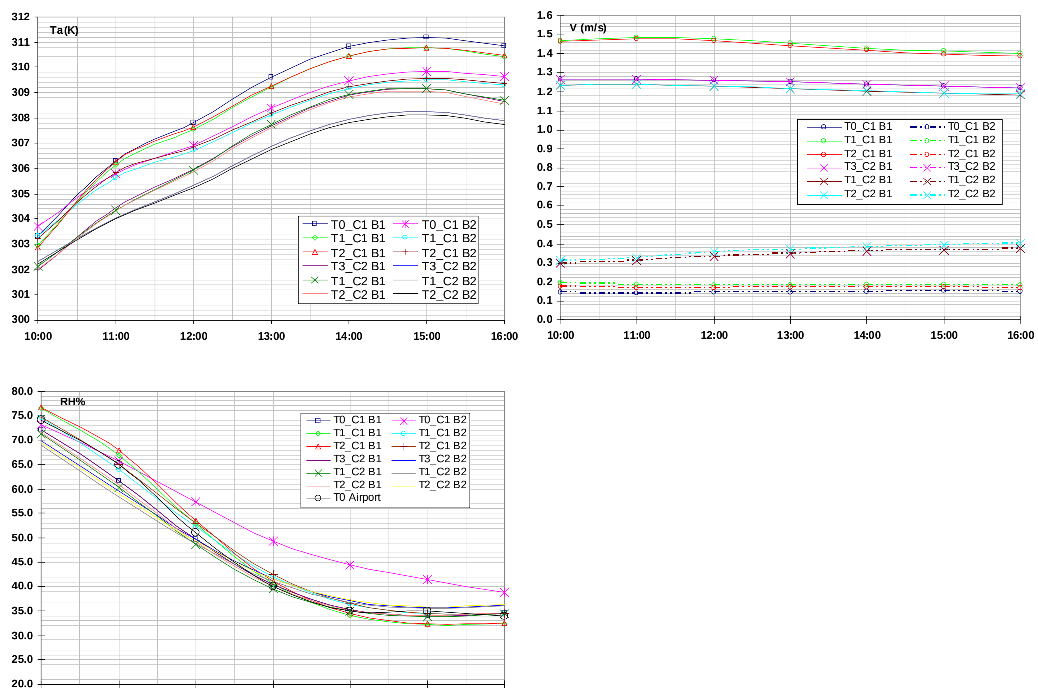


Fig.5: Comparison of Ta, V, and RH at F1_B1 and F2_B2 in both sites, respectively.

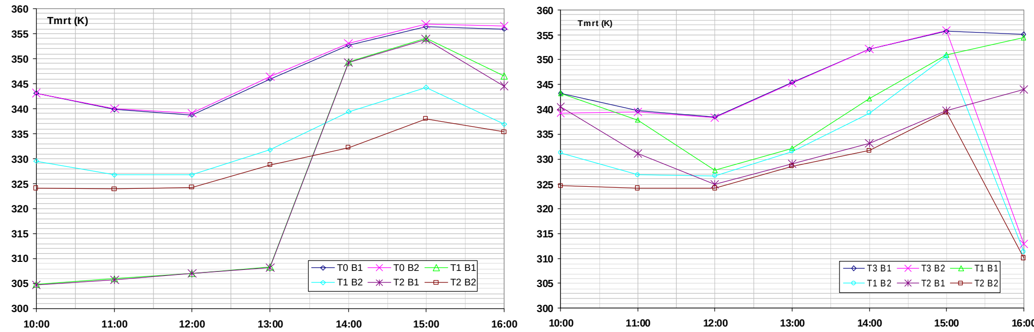


Fig.6: *T*mrt at F1_B1 and F2_B2; left is C1 and right is C2.

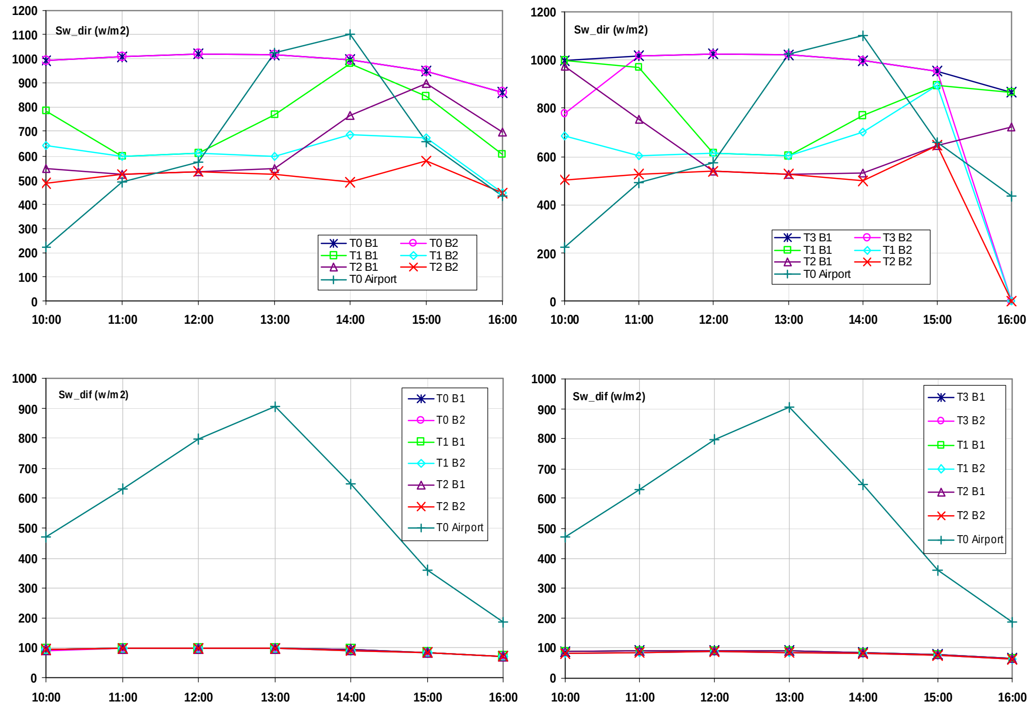
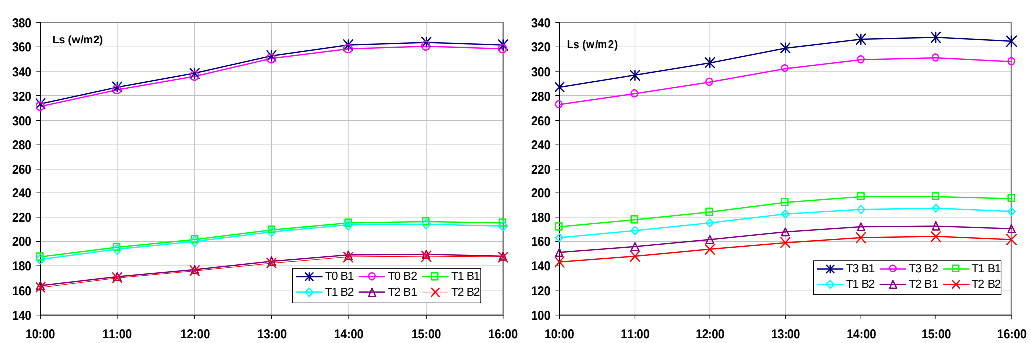


Fig.7/a, b, c, d: *S*w.dir and *S*w.dif at F1_B1 and F2_B2; left is C1 and right is C2.



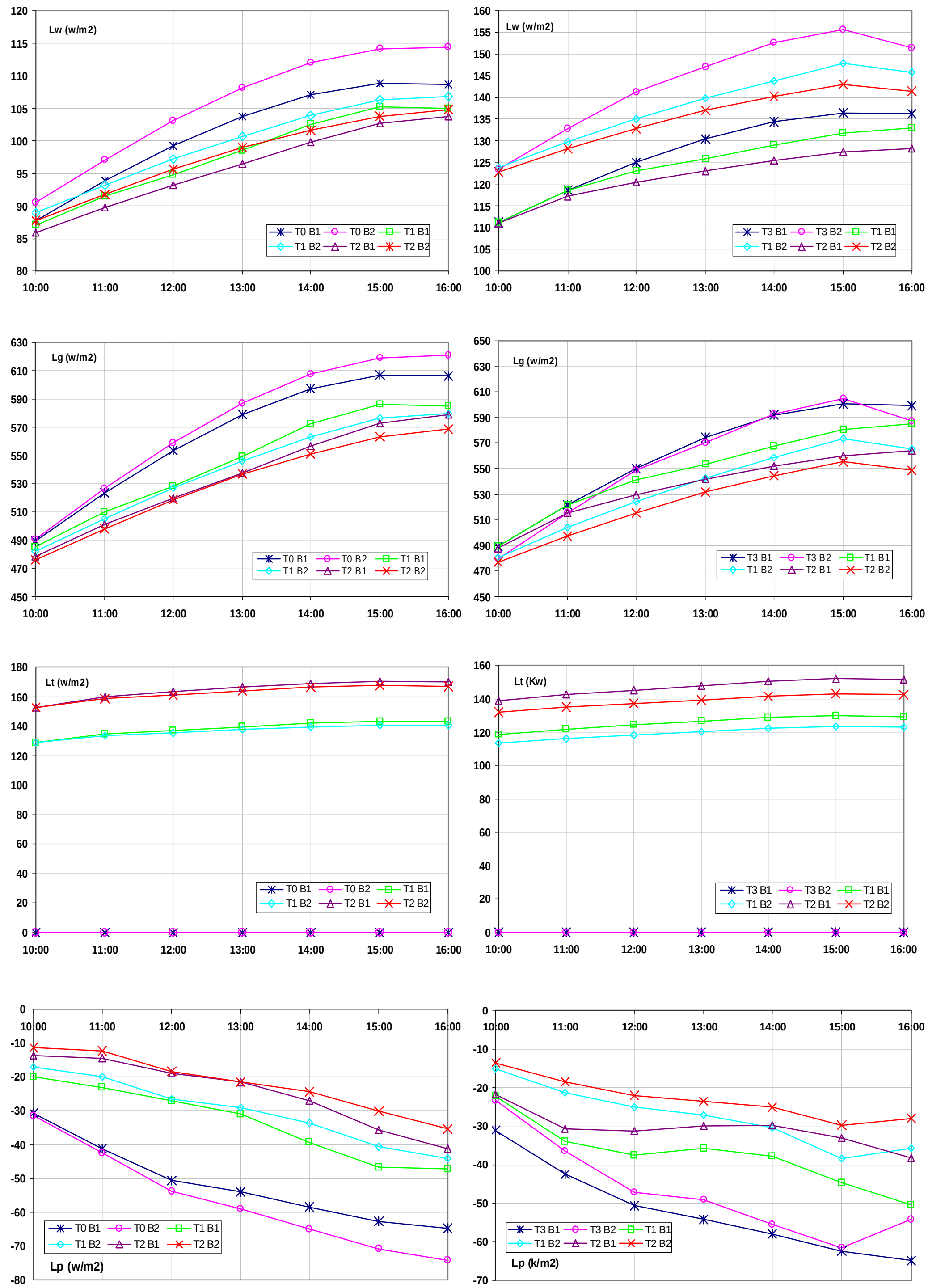


Fig.8/a, b, c, d, e, f, g, h, I, j: *L*s↓, *L*w↔, *L*g↑ and *L*t↓ *L*p↕ for both sites; left is C1 and right is C2, values of *L*t↓/T3 are zero due to receptor position away from trees.

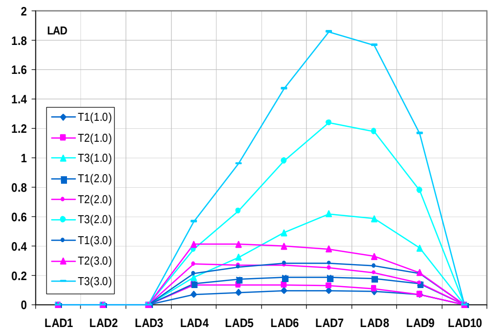


Fig.9/a: LAD values of T1, T2 and T3 upon 1, 2 and 3 LAI.

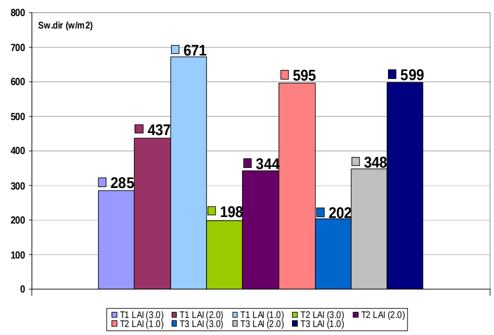


Fig.9/b. Short and long wave radiations recorded under trees upon different LAI values at 13.00 LST.

Table.1: Meteorology inputs used in simulations for the 7th of June.

No.	Parameter	Value
1	T_a	300.55˚ K
2	*RH*	51%
3	*V*	3.5 m/s at 10m height
4	Ground temperature	299.25˚ K from 0-0.5m and 297.15˚ K from 0.5-2m
5	Ground humidity	20% from 0-0.5m and 30% from 0.5-2m
6	U value Walls	1.7
7	U value Roofs	2.2
8	Albedo Walls	0.25
9	Albedo Roofs	0.15
10	Albedo Pavement	0.40
11	Pavement Emissivity	0.90
12	Stomata resistance	400
13	Root area density, RAD	0.1
14	Albedo leafs	0.20

Table.2: Abbreviations used in the study.

Symbol	Meaning
C1	Site case no.1; Fifth Community
C2	Site case no.2; Misr Al-Gadida
B1	Northern Building in each case
B2	Southern Building in each case
F1	Northern façade in each building
F2	Southern façade in each building
BC1	Base case one of the 5th community
BC2	Base case two of Misr Al-Gadida.
T0	No Trees; the base case situation of site one
T1	Peltophorum Pterocarpum (Yellow Poinciana).
T2	Ficus Elastica (Indian rubber plant).
T3	Ficus Nitida; the base case tree of site two.