THE ECOLOGICAL ROLE OF TREES AND THEIR INTERACTIONS IN FORMING THE MICROCLIMATE AMENITY OF ENVIRONMENT

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Abstract

Plants, especially species of trees, have an important role in modifying the microclimate, particularly temperature and humidity. This study was aimed to evaluate the effectiveness of trees in modifying the temperature and humidity and their interaction in forming the microclimate amenities. There are two methods in the study, first by comparing the temperature and humidity between open space free of shading and under the shade of tree canopies. Sample trees used as many as three trees which are Bunga Sapu tangan (Maniltoa schefferi), Bauhinia (Bauhinia purpurea), and Tanjung (Mimusops elengi). The second method is by making the observation grid which sized 50 x 50 meters that is divided into grids of smaller-sized grid of 10 x 10 meters, then analyzed the air temperature to make the isotherm lines. The study shows that trees can significantly lower the temperature (2.9-7.4 ^{O}C) and increase the humidity (0.1-3.9%). Nevertheless, the tree has a limited role and can't stand alone in order to form microclimate amenity in the environment (THI> 26).

Key words*: microclimate, temperature, humidity, trees, amenity.*

1. Introduction

The presence of plants in a landscape space is absolutely necessary to give the value of ecological functions. Due to characteristics of tropical regions with high temperature, the presence of plants in the landscape space can resolve the issues. Plants can make up the aesthetic value, in addition to providing results can also control soil erosion and water, reduce air pollution, lower temperature, reducing noise, waste water control, traffic control and glare, reduce light reflection, and to reduce odor (Carpenter & Walker, 1998). Morphological and plant physiological processes determine the level of ecological function in modifying the environment microclimate. Based on these potentials, plants especially trees have the ability to reduce effectively air pollutant substances which occur in urban areas. Through photosynthesis, plants convert CO_2 in the air that comes from the remnants of burning fossil fuels into the O_2 which required for survival. Plants can reduce the concentration of Pb particles that float in the air because the plants could increase air flow turbulence (Fakuara *et. al*., 1996).

Plant functions are grouped into three main functions namely structural function, environmental function, and visual function (Booth, 1989). Structural function includes the function of plants as a wall, roof, and floor in forming a space and affects the landscape and the direction of movement. Environmental function includes the role of plants in improving air quality and water quality, preventing erosion, and modifying climate. Visual function is the role of plants as a dominant point and as a liaison point of visually through its characteristics of size, shape, color, and texture. The growth of a plant is also influenced by its neighbors. They modify microclimate, tending to increase shade, shelter, and humidity, but to reduce precipitation at ground level (Carpenter & Walker, 1998; Robinson, 2004).

However, it is often in the space of built landscape, plants only planned as complement elements or substitution. Selections of plants based only on the values of beauty and forget the potential of ecological functions. This is worsened by the loss

of green open spaces, especially in urban areas. The loss of green open spaces rapidly is resulting in reduced the comfort of a city, given the green open spaces provide an excellent ecological functions in maintaining the stability of ecosystems, in addition to social functions, and other. Inside the living space or environment, the comfort can be formed through two things which are climatic comfort and visual comfort. Climatic comfort associated with the suitability of microclimate factors in influencing the skin temperature and human perception of heat and cold, i.e. solar radiation, air temperature, wind, and humidity. While the visual comfort associated with the suitability of landscapes was captured by the eye of the observer to its environment through the perceptions and preferences (Marsh, 1991). Microclimate is the condition of the solar and terrestrial radiation, wind, air temperature, humidity, and precipitation in a small outdoor space (Brown & Gillespie, 1995).

Both these forms of comfort in an environment can not be formed spontaneously, but rather an interaction between the objects in the landscape and climatic element. When formed the harmony and balance between the in-between these factors, then the comfortable environment can be created. The purpose of this study is to analyze the ability of trees in modifying the microclimate, especially in lowering temperature and increasing humidity and their interaction with the landscape elements to form an environmental amenity.

2. Materials and Methods

2.1. Time and materials

The study was conducted in September 2007 during three weeks of observations with locations in the Arboretum and Academic Event Plaza, Bogor Agricultural Institute campus. Tools and materials used in this study were Thermo-hygrometer digital, Hagameter, DBH meter, roll meter, wooden peg, millimeter block, ruler, and stationers. Hagameter was used to measure of the trees height and DBH meter used to measure the diameter of stems at breast height. The measurement methods of temperature and humidity were conducted for three weeks and the weather conditions that moment were sunny with no or very little cloudy. Thermo-hygrometer placed at breast height from the ground surface during measurement.

2.2. Methods

This study was conducted by using two methods of measurement, firstly, temperature and humidity measurements and secondly, temperature measurements in a grid method. First method was conducted to analyze the potential of ability of trees in a lowering temperature and increasing humidity and the second method was analyzed the interaction of trees and landscape elements in the form of microclimatic amenity in the environment which will be indicated with the isotherm lines. The first measurement method taken place at the Arboretum with take the measurement point of samples were on the grass field in the form of open space free of shading and under the shade of tree canopies (Figure 1).

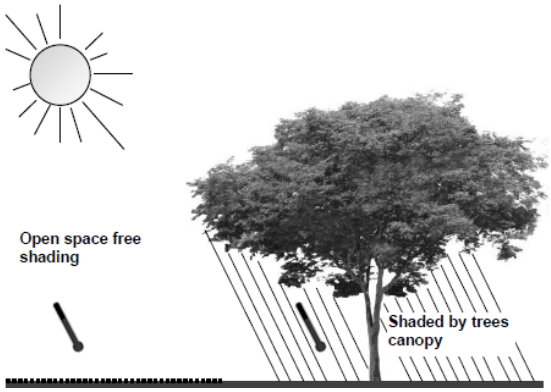


Figure 1. Layouts of temperature and humidity measurements between open space and under the trees canopy.

Table 1. The physical characteristics of sampled trees.

No.	Physical characteristics	*M. schefferi*	*B. purpurea*	*M. elengi*
1.	Height (m)	8.5	8	8.5
2.	DBH (cm)	26.5	28	22
3.	Canopy shape	Rounded	Rounded	Rounded
4.	Canopy width (m)	6.8	7.8	7.2
5.	Mass density of leaves and branches *) (qualitative value)	Dense	Dense	Dense
6.	Seasonal type	Evergreen	Deciduous	Evergreen

Source: Field data measurements.

The sampled trees were Bunga Sapu tangan (*Maniltoa schefferi*), Bauhinia (*Bauhinia purpurea*), and Tanjung (*Mimusops elengi*) and the physical characteristics of trees can be seen in Table 1. Measurements were conducted repeatedly with the measurement range for 30 minutes, which starts at 11:00 AM until 03:00 PM each day. The reasons of timing choice in this period that the atmosphere condition is climax in which maximum solar radiation and the processes of evapotranspiration are very high. So in these conditions then it can be observed the effectiveness of trees in modifying temperature and humidity of environment.

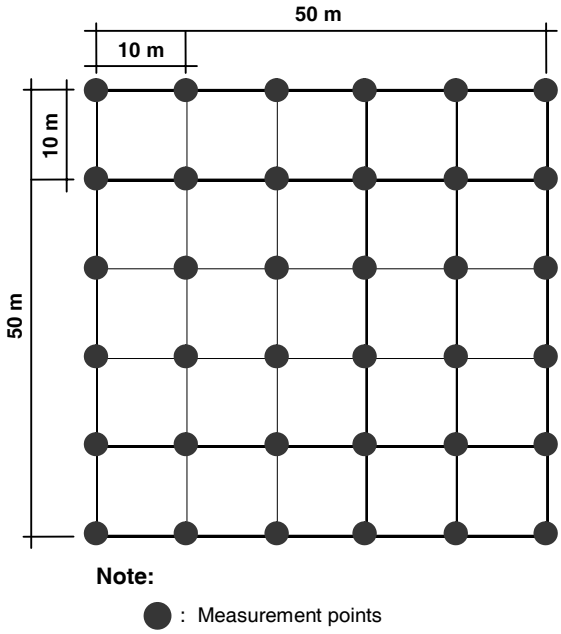


Figure 2. The size and distribution of grids of observation and measurement points of temperature for isotherm analysis.

In measurements of trees interaction with elements of landscape, it was conducted in Arboretum and Academic Event Plaza by making the grid sized of 50 x 50 meter, and the grid divided into smaller grid sized 10 x 10 meters (Figure 2). Grid was made covering several characteristics of surface and cover, which are under the canopy of trees, between tree canopies, soil or grass surface, surface of asphalt (roads), surface of paving (pedestrian), under the shelter canopy, and ceramic surfaces (plaza). This method was conducted in order to analyze the temperature dynamics on each surface cover in the site. The results of measurement at each point will be the basis of making and analyzing of isotherm lines.

In order to measure the level of environmental comfort on the microclimatic then determined the formula of Temperature Humidity Index (THI). According to Brown and Gillespie (1995), microclimate was interconnected with comfort felt, balmy temperature. Comfortness or also was referred as Temperature Humidity Index (THI), it is representing an index to specify the comfortness by quantitatively which combined of temperature and relative humidity, with formula (McGregor & Nieuwolt, 1998):

$$THI = 0.8^{*} Ta + \frac{(RH^{*} Ta)}{500} \quad (1)$$

THI = Temperature Humidity Index
Ta = Temperature (^{O}C)
RH = Relative Humidity (%)

These indices express thermal stress by indicating the temperature which, combined with a relative humidity of 100%, would create the same thermal comfort reactions (too warm, comfortable, too cool, etc.) by test persons as the existing combination of temperature and humidity (the ambient conditions). Based on standards of climatic comfort of environmental landscape, the comfortable conditions achieved at THI values between 20-26.

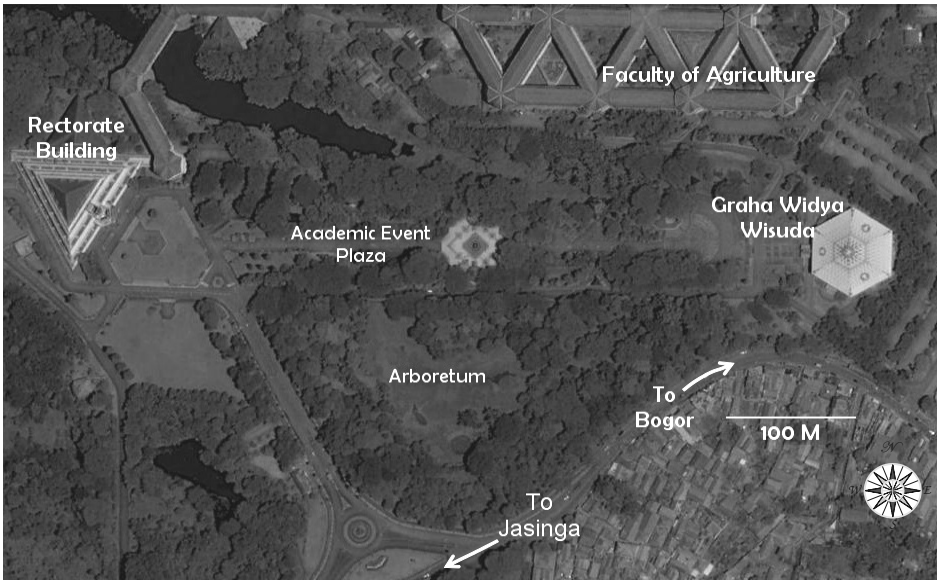
3. Results and Discussion

3.1. General conditions of the site

In generally, Academic Event Plaza and Arboretum are built landscape in the Bogor Agricultural Institute campus. This site is located on the front of the campus, so making these sites are the landmarks that is easy to be observed by all visitors (Figure 3). This condition is supported by the accessibility of roads surrounding the campus area. Viewed from the environmental aspect, the presence of site give a good impact on campus, because as an open space area, the site is able to accommodate user needs to do outdoors activities such as field practicum activities, research, and education, socializing and recreation, both by students and community surrounding the campus, and it often used for exercise activities on holidays.

The type of soil in the area is including soil type Latosol, with high levels of soil acidity. Topography of this area is quite diverse, with some degree of slope from flat to moderately steep. There are several species of birds, reptiles, and insects that can be found at the site. Arboretum and Academic Events Plaza is a built landscape that is created as a display and entrance area into the Bogor Agricultural Institute campus. As a built landscape, plants in the Academic Events Plaza were dominated by aesthetically plants. The types of plants were planted such as trees: Acacia (*Acacia auriculiformis*), Bauhinia (*Bauhinia purpurea*), Damar (*Agathis alba*), Dadap merah (*Erythrina crista-galli*), Palem raja (*Roystonea regia*), Rain tree (*Samanea saman*), and others, shrubs such as: Spider plant (*Chlorophytum comosum*), Lantana (*Lantana camara*), Heliconia (*Heliconia psittacorum*), Bougainville (*Bougainvillea spectabilis*), ground covers such as: Carpet grass (*Axonopus compresus*), Ross moss (*Portulaca grandiflora*), and vines such as: Alamanda (*Alamanda cathartica*), Monstera (*Monstera oblique expilata*), Flame of irian (*Mucuna bennetii*). These plants were maintained and managed intensively in order to form aesthetical views and to support the amenities.

Nevertheless, convenience is a major problem that occurred in the site, especially of microclimate



Source: Google™ earth, 2010 modified.

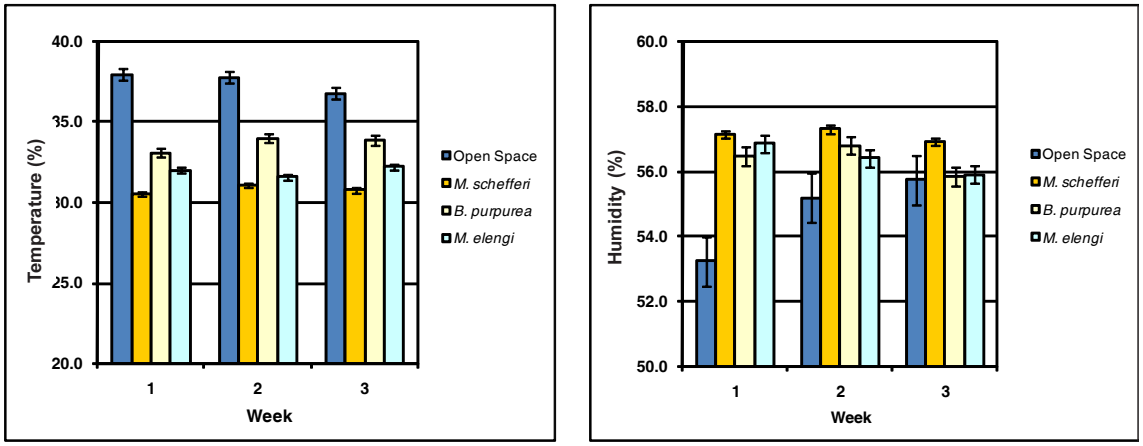
Figure 3. Academic Event Plaza and Arboretum of Bogor Agricultural Institute campus.

condition. This supported by the design of the park which is unable to accommodate user comfort for the move. The use of shrubs along the pedestrian paths lead to the path is very hot, especially during the daytime, because there is no protection from the canopy or shading. The use of some garden materials that reflect light, also increase the discomfort, such as ceramic on the surface of Academic Event Plaza. Management activities at several facilities and trees and other plants are also not optimal, so making it appear dirty, dingy, and poorly maintained. As a result, user are less appreciative with this conditions, it can be seen by how they choose another route to or not to be mobilized in this site.

While at the Arboretum, tree species more dominate the site. At this place, there are often carried out educational and research activities, especially for students. Several trees species are Tanjung (*Mimusops elengi*), Bauhinia (*Bauhinia purpurea*), Mango (*Mangifera indica*), Bunga Sapu tangan (*Maniltoa schefferi*), Casuarina (*Casuarina* spp.), Mahoni (*Swietenia mahagoni*), Flamboyan (*Delonix regia*), Rain tree (*Samanea saman*), Bungur (*Lagerstroemia loudonii*), Asam Kanji (*Diallum indum*), and others trees. Based on its roles and purposes as an arboretum, the maintenances activities were limited to plants treatments and extensively maintenances.

3.2. The trees ability to reduce temperature and to increase humidity

Based on field measurements, air temperature difference under the shading of trees canopy is lower by 2.9-7.4 ^{O}C than air temperature of environment without shading and humidity of between 0.1-3.9% higher (Figure 4). Sampled tree of *M. schefferi* has the highest capability both in lowering the temperature (difference 4.8-7.4 ^{O}C than open space), and increasing the humidity (difference 3.2-3.9% than open space). On the other hand, *M. elengi* has the lowest capability in lowering the temperature (difference 2.9-6.0 ^{O}C than open space) and increasing the humidity (difference 0.1-1.2% than open space). The effectiveness of *M. schefferi* in lowering temperature and increasing humidity may be resulted from its morphological characters. This tree has the highest density of leaves and branches than other trees (based on field observation). The densities were resulted a massive canopy and blocked sun radiation straight into ground surface. It was also resulted the effectiveness of green leaves to absorb the radiation which used by the tree in photosynthesis processes. These processes are producing more oxygen (O_2) that can be lowering the temperature, especially under tree canopy. Other process is transpiration mechanism which producing water vapor into air, with the wind blows, the steam can increase water degree in the air and than increasing humidity surrounding tree.



(a) **(b)**

Figure 4. (a) Trees ability to reduce temperature; (b) trees ability to increase humidity.

According to Panagopoulos (2007) studying different colour soils in mine areas, surface soil temperature under shadow was on average 19.5 ^{O}C lower than bare soil temperature of the same area, same time, and type of soil. Also studying the effect of olive trees shadow on soil temperature it was found that during summer period soil can be 11 ^{O}C cooler under olive shadow and during winter 4 ^{O}C warmer. Trees, shrubs, and grasses freshen up the air temperature in the environment through the control of radiation. Foliage accepts, reflects, absorbs, and transmits radiation. Its effectiveness depends on the density and shape of leaves, and branching pattern.

Trees and other vegetation also serve to give comfort through the process of evapotranspiration. The shading effect under an aged tree canopy clearly shows a reduction of the absorbed radiation by users, generating energy budget very close to comfort even with a high air temperature (Picot, 2004). Theoretical thermoregulatory models developed for the indoor environment are not viewed as adequate for describing the thermal comfort conditions outdoors, due to the great complexity of the outdoor environment, and variability temporally and spatially (Nikolopoulou & Lykoudis, 2006). Urban vegetation, however, moderates surrounding micro climates through increased latent heat exchange, shading, and lack of heat from combustion sources (Jonsson, 2004).

There is strong public interest in the quality of open urban spaces that they can contribute to the quality of life within cities. However, there is a significant lack of information on comfort conditions in outdoor spaces, which in effect will assist the design and planning of such spaces (Nikolopoulou & Lykoudis, 2006). In this context, microclimatic conditions have begun being viewed as integral to the success of an open space. Responses to microclimate are unconscious, but they often result in a different use of open space in different climatic conditions.

Consistent with these opinions, when further analysis, despite trees in this study was significantly could reduce the temperature and tend to be significant in increasing the humidity. However, in the context of microclimatic amenities, the conditions formed under the shade were not quite comfort. Based on the temperature and humidity component under the shade on each tree, then the THI values have exceeded the limit of climatic comfort (THI> 26) (Figure 5). Generally, a THI of around 21 ^{O}C is associated with most people feeling comfortable; at values around 24 ^{O}C about half of a population experience some form of thermal stress; and when the THI reaches 26 ^{O}C almost all feel uncomfortable (McGregor & Nieuwolt, 1998). At the time of the THI values exceed of 26, then the microclimate conditions of the environment become uncomfortable for humans because it became too warm or hot. Similarly, when THI values less than 20, then the conditions become too cold.

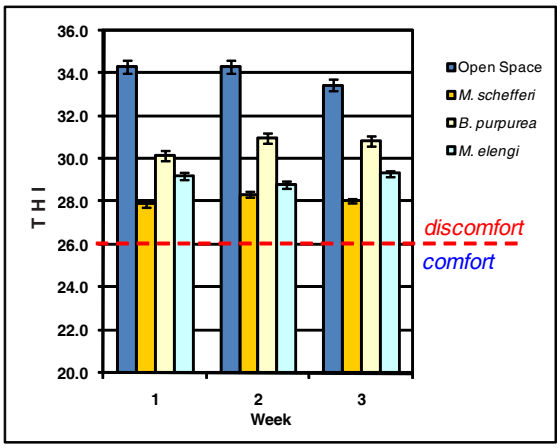


Figure 5. The value of THI that formed in open space and under the trees shading.

As previously explained, plants especially trees have high ecological functions in a landscape. Nevertheless, its ability is limited and can not stand alone without being supported other factors or elements. Other climatic factors such as wind and solar radiation intensity and hard elements within a landscape are contributed to the formation of environmental micro-climate. These interactions have a major role in the formation of microclimate amenities. Physical and physiological characteristics of trees also have a major role in lowering the temperature and increasing the humidity. Trees characteristics with broad canopy and a solid of leaves and branches mass are effective types on modifying the temperature and humidity. The density of leaves mass is not only determined by the number of leaves per unit of volume, but also the physical characteristics of leaves, because leaves with wide, thick, and hairy characteristic are more effective than other types. In addition, trees with the ability to effectively producing O_2 and water vapor from the

transpiration process results can increase the humidity. In the tropical region where gain the solar radiation for along a year, and then needed the selection of the types of evergreen trees in order to provide optimal protection.

3.3. Interaction of trees and landscape elements in forming the microclimatic amenities

Climate that going into effect at one particular area is interacted with the objects in the landscape creates microclimate. This interaction is affected to air temperature, wind speed, sun radiation, relative humidity, and other. Location of object in the landscape has consequence which significantly affect to microclimate. Microclimate is strongly alterable influence thermal amenities of human in the landscape and affect to energy budget. The changes of surfaces characteristic (such as development of buildings and structures and loss of trees) and the height of atmosphere particles at built environment are causing a higher temperature of the surfaces than it absorption of radiation so that heat blown by wind become quicker.

The interaction of trees and landscape elements in forming microclimate can be seen in Figure 6. Isotherm lines formed by these interactions indicate a role of trees in modifying the microclimate. It seen that the values of isotherm lines formed under and between the canopies are lower than other types of surfaces or covers. Isotherm lines formed under and between canopies ranged from 31 ^{O}C to 35 ^{O}C. While the types of covers and other surfaces have a higher isotherm lines ranged from 34 ^{O}C to 40 ^{O}C. Opened surfaces with pavement characteristics (asphalt, pedestrian, and academic plaza) have a high isotherm lines. This can be explained that the solar radiation coming directly toward to the surfaces without a barrier, then the radiation directly reflected back and heating the surfaces by convection. So the pavement surfaces temperature become high, it also can cause glare and discomfort.

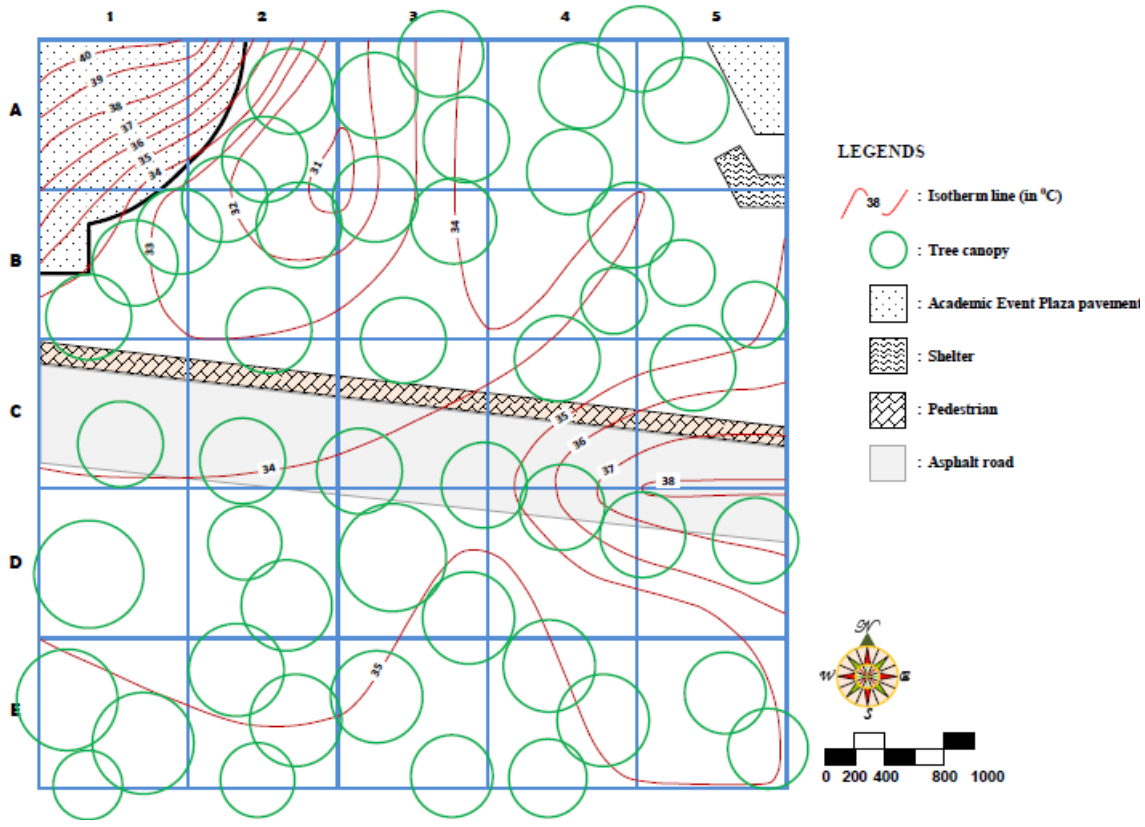


Figure 6. Covering of tree canopies, types of landscape elements, and isotherm lines.

On Grid A1 (Figure 6) has the highest degree of isotherm lines, the surfaces characters are dominated by pavement of ceramic. This material can not absorb solar radiation and tend to reflect it, and causing the heat on its surface. Other hard surfaces such as asphalts are also causing heat (grids C5 and D5), as likely other hard materials, this also can't absorb solar radiation. Therefore, planning and selection of the structure materials and substances at a landscape are playing an important role in creating microclimate amenities. If have to place or build hard structures, then it has also needed to plan the softening elements, which are with plants (trees). Except, if the structure desired to be a focal point, the plants element can join it or as a complementary element, nevertheless, materials and substances consideration remain to be important part of planning.

Another fact that can be analyzed is trees canopies can reduce air temperature than the surface of pavement. The lowest isotherm line is located around the trees configuration that indicates the shady room and sheltered from the sun (the meet of Grid A2, A3, B2, and B3). Nevertheless, the tree has a limited capability in modifying the microclimate. Interactions between the elements that create microclimate are not solely influenced by the role of the tree itself. This can be observed that despite being among or below the canopy, isotherm lines show the temperature still above 30 ^{O}C. For example in Grid E (E1 to E5), although the grids were located under and between tree canopies, isotherm line show the high temperature (35 ^{O}C). This further strengthens the fact that plants (in configuration) have a limited ability to modify the temperature of environment. It needed not only planting plants in modifying the temperature (microclimate) on a landscape, but also it has to be interacting with other landscape elements (hard elements).

In a landscape, this interaction becomes an important consideration in creating a comfortable microclimate. Beside establish a planning of hard elements and structures, materials and design, plant selection becomes an important part. In urban scale, the increasing of non vegetation area and decrease of vegetation area affect in changes of climate and environment that were indicated by air temperature and THI (Tursilowati, 2007[a]; 2007[b]). The character of hard elements that reflect the radiation and increase the surface temperature in order to create a comfortable microclimate, the selection of plants (especially trees) is focused on high trees with width canopy, mass of leaves and branches are dense and massive, and evergreen. Other characteristics include the ability to produce oxygen (O_2) effectively is another consideration in the selection of plants. Another matter needs to consider is the nativity of these plants in the area to be planned, since this attribute play a role in ensuring the survival of plants and its association with other plants and their environment. The strong relationship between microclimatic and comfort conditions demonstrate that careful design can allow for the use of open spaces, balancing exposure and protection to the different climatic elements (Nikolopoulou *et. al*., 2001).

4. Conclusion

Plants have the ability in modifying the microclimate, especially temperature and humidity factors. However, this ability is limited in the context of creating a comfortable microclimate on the environment. Because the microclimate created in an environment is the result of interaction between plants with other landscape elements. Therefore, in addition considering the materials and design of hard elements in a landscape, plant selection is a very important factor. The appropriate of plants selection with considering those aspects of ecological function and not simply a function of aesthetics alone will be able to create microclimate amenities which in turn can create an amenity of landscape space.

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