179: Plant Canopy Design in Modifying Urban Thermal Environment: Theory and Guidelines

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Abstract

Recent growing interests in the urban heat island phenomenon originate from the consequences from improper design planning, increased urbanization and deterioration in the outdoor environment. This phenomenon invites understanding of the basic theories in modifying urban thermal environment by integrating the key microclimate components of the dynamic outdoor thermal cycle (wind velocity, humidity, temperature and radiation) in the whole design process. Such approach has been demonstrated in the use of vegetations and plant canopies in the fields of urban and landscape planning, architectural design and environmental engineering. In addition, good plant canopy arrangements and design approach had been shown to promote latent-heat evaporation and solar shading in significant way. These approaches, incorporated into the design process, could provide an equilibrium cycle in mitigating urban heat island. However, despite these and existing architectural planning and landscape design principles, many planting schemes are poorly constructed. Therefore, such schemes can be improved through understanding and implementation of effective urban thermal environment design theories and guidelines. This paper will describe the importance of investigating the impact of comprehensive relationships between plant canopy design parameter for thermal comfort and outdoor thermal environment.

Keywords: Plant Canopy Design, Outdoor Urban Microclimate Modification, Theory and Guidelines

1. Introduction

The culprits of the urban heat island phenomenon are recognised to be the consequences of improper design planning, increased urbanization and abrupt changes in the outdoor environment [1]. These man-made urbanization developments have created significant undesirable changes to the natural ecosystem and/or landscape. There are concerns about climate change worldwide and landscapes are increasingly replaced by stiff and sharp-edged roughness of building blocks with associated roads and hard surfaces. Now, rising concrete buildings have crowded out vegetation and trees [2]. On top, the variety of urban grids and buildings generates a wide range of different streets, squares, courts and open spaces that modify local climate into urban microclimates [3]. These changes posed deterioration in the urban areas, giving rise to problems with urban heat island.

Katzshner and colleagues defined *the* 'ideal' urban climate as an atmospheric situation within the Urban Canopy Layer with a high variation in time and space to develop inhomogeneous thermal conditions for man within a distance of 150 m. This should be free from air pollution and thermal stress by means of more shadow, ventilation and wind protection [4]. Combining good natural elements and effective landscape design may provide the approach to create both sustainable urban development and desirable urban climate.

The modification of the urban climate can be targeted at four key microclimate components of the dynamic outdoor thermal cycle: wind velocity, humidity, temperature and radiation. A good quality landscape, with its own characteristic can be adapted on its technical and functionality to address these microclimates in the whole design development. This approach emphasises better appreciation of the climates in the basic design principles to provide a potential solution to the urban heat island phenomenon. For instance, by creating as much outdoor shading as possible, prevent solar radiation on building and ground, and actively utilize the cooling effect of the latent heat of evaporation [5].

In this paper, we describe the use of plant canopy design that integrates the microclimate components and landscape design, utilising the principles of basic sustainable design theories and guidelines. This design approach encompasses urban and landscape planning, architectural design and environmental engineering approach that are relevant to mitigate the effect of urban heat island.

2. Importance and Relationship of Plant Canopy Design and Microclimate Components in Outdoor Thermal Environment

2.1 The Importance and Use of Plants in Outdoor Thermal Environment

Most designers place much emphasis on the aesthetic value of vegetation and other related landscape elements instead of the technical aspects. The technical aspect of a landscape element can change the surrounding ambiance to give more comfort, for both outdoor and indoor environments [5]. The capability of certain types of landscape elements can be explored by looking at the morphology of landscape entity. In this context, the use of plants has been recommended because plants can be objectively evaluated and quantified. Although not always understood, their effects on the environment tend to be desirable [6].

The functions of the plants should be the basis for their use in environmental design. The primary aim of planting design is to use plants in solving environmental problems such as urban heat island effects for both tropical climate (hot and dry) and temperate climate (during summer). The basis for this design depends on their characteristics and their use to solve functional problems and to what extent they do this. In designing plants and landscape elements, architectural, engineering and aesthetic factors are the major aspects that are considered. In contrast, for environmental design, climatic control is the key factor to optimise the use of plants. Four key microclimate components can be manipulated and controlled through planting design, namely, radiation, humidity, wind, and temperature. Ideally, the use of plants for climate control such as shades, windbreakers, precipitation and evaporation should be utilised using clear understanding of theory to form guidelines.

However, despite a sufficient body of knowledge of functional capabilities, the dissemination of such knowledge is not widely practised [6]. Therefore, given its potential to address urban heat island issues, proper interpretation of theories and guidelines for the use of plants should be promoted to be part of designing the overall outdoor environment in urban areas.

2.2 Relationship on Microclimate Components and Plant Canopy Design

In general, the microclimate consists of five main components that affect the condition of outdoor spaces. The components are solar radiation, terrestrial radiation, wind, air temperature and humidity which are the important elements in creating comfortable thermal surroundings [7]. Physically, the components can be modified by elements in landscape.

There are four main ways to modify the microclimatic environment through landscape elements, especially green structures. These include wind modification, relative humidity, incoming solar radiation and terrestrial radiation from the ground and other surfaces [7].

2.3 Radiation Control and Modification

According to Robinette (1968), one significant usage of plant in climatic control is radiation control. Trees, shrubs, ground covers and turf are among the best exterior solar radiation control devices. Deciduous plants in full leaf are the best solar radiation control devices when the sun's rays are most oppressive in temperate climates. He added in his study that in a tropical climate, evergreen trees are more suitable because of the leaf density and the leaves are alive on a year-round basis. Thus, it gives full radiation control and filtration through the whole year.

Each plant variety casts its own distinctive shadow both in shape and density. Hence, the performance of trees in giving the best shadow and filtering the radiation is according to the form and solidity of the canopy [6]. The character depends on tree canopy form and tree structure that is influenced by two major elements, namely, (i) branching and twigs; and (ii) leaf covers. These two elements may influence the overall character of tree shape and density [7, 8].

According to Brown and Gillespie (1995), a single layer of leaves will generally absorb 80% of incoming visible radiation, whilst reflecting 10% and transmitting 10%. Approximately 20% of infrared is absorbed with 50% being reflected and 30% is transmitted (Fig. 1). Therefore, the percentage for these two types of radiation absorbed is approximately about 50%; reflected 30% and only 20% is transmitted. In addition, all trees can filter approximately 80-90% depending on leaf density, arrangement and types of leafs [5]. Thus, more layers of leaves will be more efficient at reducing solar radiation under a tree.

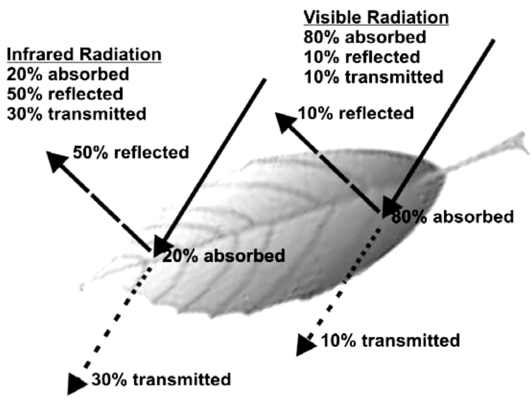

Fig 1. Leaf absorption, transmission and reflection. (Shahidan et al., 2007)

Most of the solar energy we receive, though, is in the form of visible light and solar infrared [7,9]. Approximately half of this energy is visible light and the other half is solar infrared [7]. However, this energy that reaches the ground is absorbed, transmitted or reflected by the ground. Radiation that is reflected will affect energy budgets and thermal comfort as will the absorbed radiation. The amount of absorbed energy, which is the emitted, as terrestrial radiation, is a function of the temperature of the object.

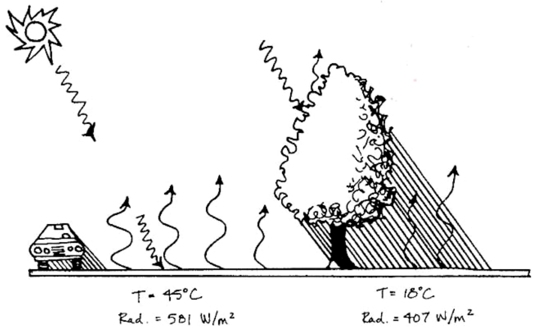

Fig 2. Shading and radiation filtration by trees reduce the surface temperature of the ground surface (Source: Brown and Gillespie, 1995)

By blocking solar radiation the branches and leaves of a tree directly reduce the energy reaching the ground, thereby reducing temperature and long-wave radiation from the ground [9].

Plants used for interception of solar radiation may completely block the sun's rays or filter them. Another aspect of radiation control is shading (Fig. 3). Each plant variety casts its own distinctive shadow both in shape and density [6]. For example, maples, oaks, and beeches cast dark, dense shadows; and trees such as honet-locust and willow-oak cast fine, light, lacy shadows. Therefore, in order to understand the capability of the trees in providing shadows according to the environmental needs, we must study the variety of shadow casting from the canopy that can be manipulated through planting design. It suggests that in having a good quality of shadows, plants with dense foliage, multiple layers, or a dense canopy are used. Filtration occurs when plants with open, loose foliage are used.

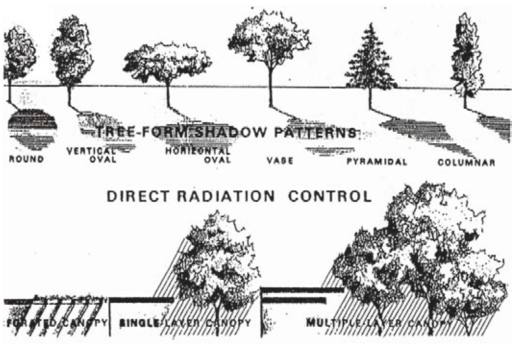

Fig 3. Types of tree-form shadow pattern (above); Direct radiation control and impact on multiple layer canopy (Source: Robinette, 1995)

A study has been made in order to calculate the filtration level based on planting design aspects such as tree density, form and branching structure. The result shows that tree density (branching, twigs and leaf covers) play an important role in filtering thermal radiation. Variations of canopy structure influenced the filtration effectiveness, quality of shade and reduction of radiant heat underneath the canopy [10].

In order to control solar radiation some aspects in planting design should be considered to provide an optimum filtration, interception, shading and temperature reduction underneath the canopy:

1. tree canopy density (branching, twigs and leaf covers)
2. height of the plant;
3. the transmissivity of the canopy in different seasons (a combination of the characteristics of the leaves, twigs, branches, dates, and size)
4. Multiple layers canopy structure

In the previous tropical climate study (Malaysia), differences in tree canopy density (measured in leaf area index - LAI) and transmissivity (percentage of light transmission) found to contribute to a significant radiation filtration underneath the canopies. The higher LAI values and lower transmissivity percentage value corresponded to the higher number of radiation filtration percentage. This implies that LAI values greater than five can approximately filter more than 90% of radiation while about 70 to 90% filtration occurs when LAI below five. Thus, it can be assumed that trees below than five (<5) LAI value can be considered as loose canopy density and those with more than five (>5) signified high density trees. On the other hand, transmissivity percentage in the range of 1-10% will be much greater in filtering radiation due to combination characteristics such as branching, twigs and leaf covers [11].

2.4 Wind Control and Modification

Wind is one microclimate indicator that can be significantly modified by landscape components and it also strongly affects human thermal comfort, energy use in buildings, and surroundings temperature in urban areas. It is a very important consideration in landscape and planting design for microclimate. Wind would carry heat away from people and buildings and strongly influences their energy budget. However, wind is extremely difficult to visualize and even more difficult to control. Basically, plants can control wind by obstruction, guidance, deflection and filtration. The differentiation is not only one of the degrees of effectiveness of plants, but of the techniques of placing plants [6]. However, it should be noted that plants as natural elements are not always absolutely predictable in their size, shape, and growth rate, and consequently in their absolute effectiveness. Obstruction with trees, as with all other barriers, reduces wind speed by increasing the resistance to wind flow. Coniferous, evergreen and deciduous trees and shrubs used individually or in combination affect air movements. Trees and shrubs can be designed in a way that they can direct, reduce and deflect wind at the required impact (Fig.6).

Trees generally reduce the wind velocity and produce a sheltered area on the leeside and to a smaller extent on the wind side of the screen. This reduction in wind velocity brings about a lowering of the rate of thermodynamic exchanges between the air layers, with the result that protection from the wind generally permits higher temperatures to prevail in the protected zone. In a different condition where there is free air movement, there is little or no difference between actual air temperatures in sun or shade. However, under tree flanked by shrubs reflecting air currents upward, there will be cooler temperatures in the shade [6]. Soft wind break barriers such as trees and shrubs are often preferable to hard barriers because they do not produce so much induced turbulence on the downstream side.

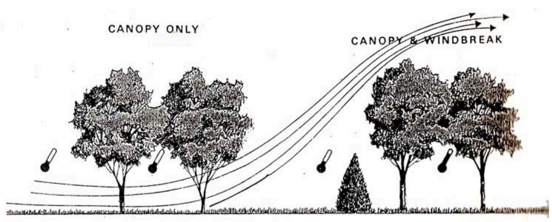

Fig 4. The impact of air layers movement influenced by tree and shrubs design (Source: Robinette, 1968)

Plants also may be used with landforms and architectural materials to alter the airflow over the landscape, around the buildings and spot areas (Fig.7). Based on theories, landforms can force wind to change direction and can increase or decrease wind speed. However, landforms have a very large effect on wind speed when used on their own. Landforms in conjunction with other elements such as trees or shrubs can enhance the effect of the vegetation (Fig. 5).

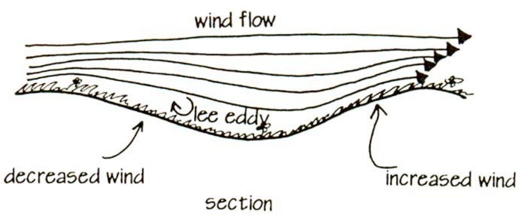

Fig 5. Landforms can increase or decrease the wind direction (Source: Brown and Gillespie, 1995)

In another aspect of planting design, some of the characteristics of plants that affect the wind are size, location, orientation, porosity, and proximity. Landscape elements that have denser (less porous) windbreak, the greater the effect on wind speed, but the smaller is the area of affected air. Conversely, the looser (more porous) a windbreak the lower the effect on wind speed, but the larger the area affected. In that case, it depends on how the designers want it to be and how it can influence the micro surrounding according to the landscape elements chosen. In urban areas, we need to create a very small, very calm area, or a very large area of slightly lower wind speed. It will offer a better quality and comfort level [12].

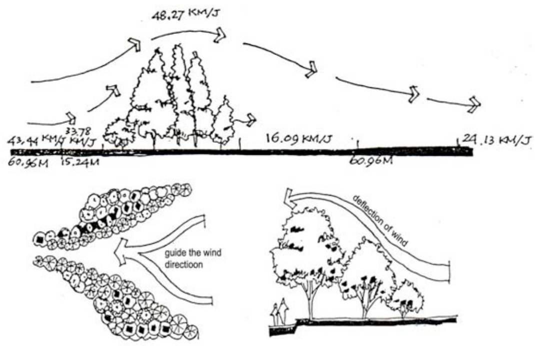

Fig 6. Function of trees and shrub in reducing, directing and deflecting wind. (Modified from: Abdul Chalim, 1998).

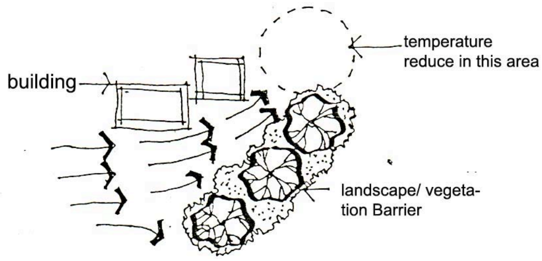

Fig 7. Landscape and building act as barrier in directing the wind towards spot area and finally reduce the temperature in that area. (Modified from: Abdul Chalim, 1998)

In addition, trees provide added cooling through the leaf transpiration process. When leaf moisture is converted to vapour there is an evaporative cooling effect as heat is absorbed from the air to convert the moisture into vapour. It will increase the humidity level through the cooling effect. In, warm, dry climates, lush green canopy design with multiple layers consists of ground covers and dense tree canopy creates cooling effect from leaf transpiration process. The cooler air can be drawn through wind effect and can expand to certain distance. This process can provide an optimum comfort when both entities work together. In order to maximize the effect of evaporative cooling, we need to increase the amount of plant cover (turf or ground covers) to their fullest potential in the landscape, as alternatives to paved surfaces such as asphalt or concrete (Fig.8).

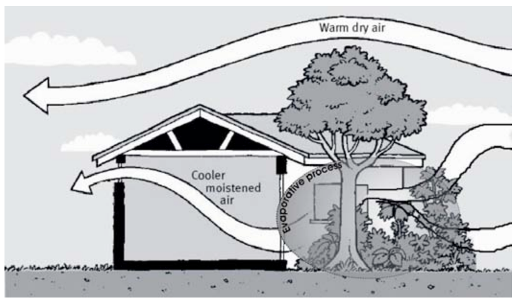

Fig 8. Example: Effect of wind on evaporative cooling

2.5 Humidity and Temperature Control and Modification

Air temperature and atmospheric humidity cannot normally be significantly modified by landscape elements and design [7] (Fig. 9). The atmosphere is such an efficient mixer that any temperature or humidity differences that may occur are normally dissipated very quickly [7].

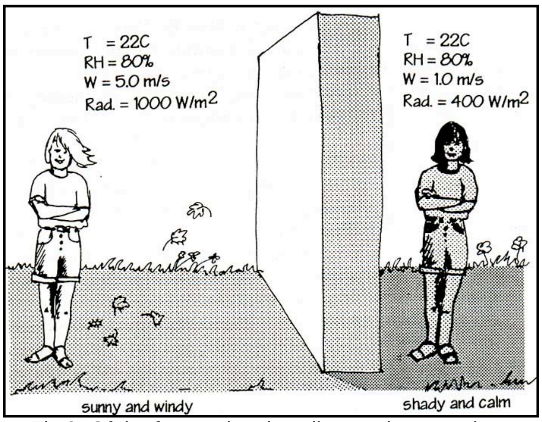

Fig 9. Of the four main microclimate elements that affect the streams of energy into and away from a person, only radiation and wind can be significantly modified by a landscape (Source: Brown and Gillespie, 1995).

However, it can be achieved through the other microclimate components such as radiation and wind modification. For example, plants block solar radiation, inhibit wind flow, transpire water into the atmosphere, and reduce evaporation from the soil, a microclimate of controlled humidity under plants; can be offered particularly in a planting design with forest-like cover of plants [6]. One significant plants process that should be highlighted in modifying humidity and temperature is evapotranspiration [13].

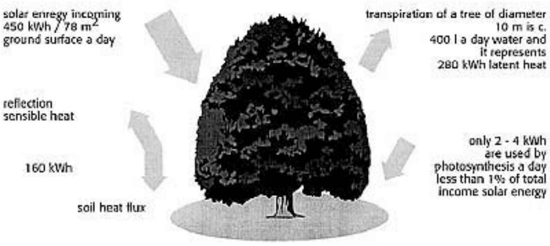

Fig 10. The cycle of transpiration process on single tree supplied with water (Source: Pokorny, 2001).

Evapotranspiration (the combination process of evaporation and transpiration) from soil-vegetation systems is another moderator and can contribute significantly to reduce urban temperature (Fig. 10) [2,14]. This is because vegetation produced more latent heat flux and it can modify the local climate. If vegetation is removed extensively and replaced by water proofed material, the latent heat will decrease and most radiation will be converted into sensible heat. As a result, the moisture content in the city will reduce and the air will be dried and become hotter (Fig. 11).

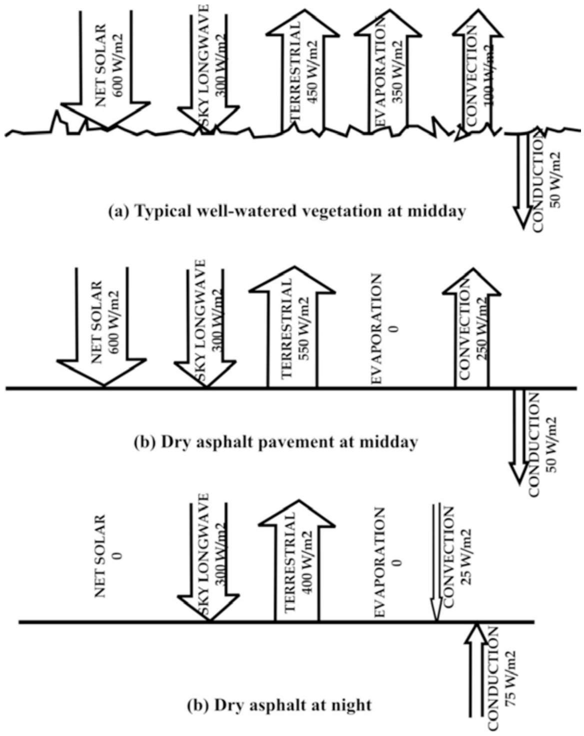

Fig 11. Typical partitioning of energy over different landscape surfaces at noon and during the evening (Source: Brown and Gillespie, 1995).

Hence, canopy layers design is introduced in order to provide high humidity and low evaporation rate that acts to stabilize temperature, keeping it lower than the surrounding air during the day and preventing it from dropping greatly at night. Three layer canopy structures (Tree canopy – shrub layer – field layer) that provide multiple layers will allow (i) moisture retention; (ii) protection from sun and wind provided by plants reduces evaporation of soil water; (iii) optimum shading effect that reduces air temperature near the ground, (iv) optimum cooling effect provided by higher evapotranspiration process from shrubs, medium plant and large tree canopies [6,15]. (Fig. 12)

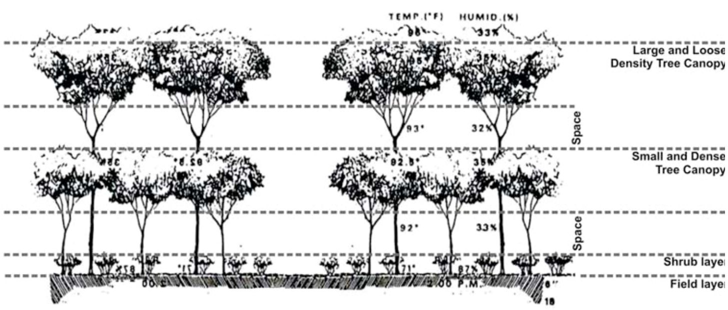

Fig 12. Concept of multiple canopy layers in modifies temperature and relative humidity in urban areas.

3. Guidelines Suggestion on Plant Canopy Design Parameter in Modifying Urban Thermal Environment

3.1 Design Guidelines

The multiple layers canopy design highlights the various microclimate modification effects that can be achieved basing on design parameters and scientific processes. This design aims to create new microclimate environment that covers the analysis and understanding of site parameters, climate conditions, plant material characteristics, and environmental design approaches. Figure 13 illustrates the proposed basic guidelines on canopy design theories to provide an effective high-quality environment in urban areas.

We introduce different planting layers (e.g. upper layer – middle layer – field layer) that can modify all the microclimate components in the overall design. The upper layer will concentrate more on radiation filtration and shade. In giving a good quality of shade and filtration, the design should provide trees with loose density (LAI index values <5) that can filter approximately more than half filtration of light and radiation. This is to make sure that the radiation is partly filtered before continued to the next layer. On the other hand, source of light is still required for photosynthesis process at the middle part of the layer. For this purpose, tall trees with loose density and broad/spreading forms characters are chosen. These special characteristics (height, density and form) could help in modifying wind component by deflecting and guiding wind gust to carry away the dry warm air at the upper part of the canopy. At this point, we could obtain approximately half of heat reduction and light filtration in achieving an ultimate quality of shade at the ground surface. This end-result at the first half of the area will allow gradual natural increase and decrease of humidity level and air temperature, respectively. A cluster design of canopy may double these effects.

In the middle layer, the dense tree canopy can provide high-quality of shade and full radiation filtration. Aside from the high density trees (LAI index values >5), <10% transmissivity value is also recommended. These characteristics can be acquired by choosing an evergreen (for tropical climate) or deciduous (for temperate climate) medium height tree species that can obstruct more light for high-quality of shade. Tree species with round/oval solid form that have multiple layers and broad leaf characters are also favourable to improve the absorption and filtering more radiation. This ambient will allow more moisture retention, reduces evaporation of soil water at ground surface and provide an optimum shading effect that can reduce more air temperature near the ground. It will naturally generate evaporative comfort cooling that could moderate surrounding temperature and humidity. In giving the optimum impact, tree canopy with high proximity (due to specific characters of medium size and high density) will deflect wind that can blow the water vapour by filling the gap on the upper and under part of the middle layer canopy. For this reason, full-shaded green plants (thick low shrubs or turf) are chosen to encourage more evaporative cooling at the field layer. This will maximize the evaporation and transpiration process, stabilize the temperature and absorb excessive thermal heat underneath the canopy.

The desired wind effect that distributes the evaporative comfort cooling to the overall surrounding requires a suitable landform design that suits the geographical and climate conditions. The suitable landforms and surface design (e.g. turfing with thin layers) can reduce surface roughness to increase the natural wind flow that can effectively blow cooler moistened air to the surrounding area. Finally, we need shrubs that can act as windbreaker in creating the impact of air layers movement to provide

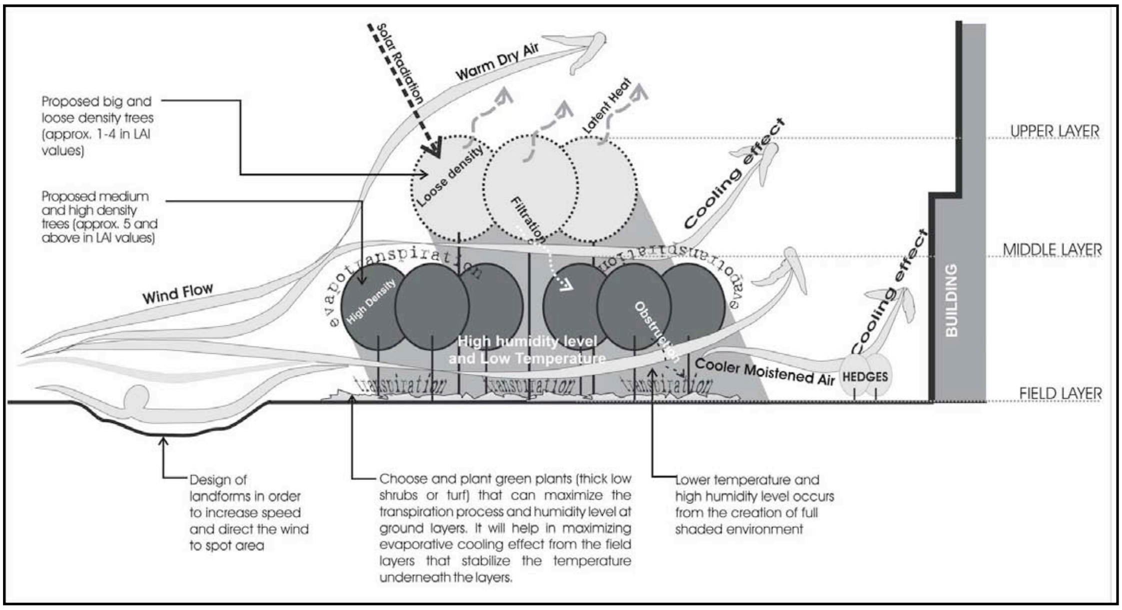

Fig 13. Schematic diagram explaining the whole process of all four microclimate components modification based on planting design theories and guidelines

optimum comfort cooling in front of the building, directing the wind towards spot area and ultimately reduces surrounding air temperature.

4. Conclusion

The introduction of multiple canopy layers is to create a new landscape design that incorporates all four microclimatic components, as identified in the design theories and scientific processes. Three layers of plant cover will create a high-quality shaded area, promote high humidity level, provide an optimum evaporative comfort cooling and reduce the overall surrounding air temperature in urban area. The variation in canopy densities will modify solar radiation and reduce transmission that can help maximize transpiration and evaporation processes. It will also help to create cooler air that can be drawn through wind effect and can expand to certain distance. The creation of landform will generate high wind speed that blow away warm dry air at the upper part of the canopy and provide a cooler moistened air underneath the canopy. Finally, the whole process will produce a significant optimum cooling effect that offers a better ambience in microclimate and the outdoor thermal comfort in the city. Therefore, the theories and proposed guidelines as elaborated in this paper highlight the importance of a clear understanding of components and processes in the whole design scheme to maximize the cooling effect in urban thermal environment.

5. References

1. Roth, M. (2002). *Effects of Cities on Local Climates.* Paper presented at the Workshop of IGES/APN Mega-City Project, Kitakyushu, Japan

2. Santamouris, M., & D N Asimakopulos, V. D. A., N Chrisomallidou, N Klitsikas, P Michel, M Santamouris, A tsangrassoulis. (2001). *Energy and Climate in the Urban Built Environment*. Greece: James & James (Science Publishers) Ltd., United Kingdom.

3. Scudo, G. (2002, October 2002). *Thermal comfort in green spaces.* Paper presented at the Green Structures and urban planning, Milan.

4. Katzshner L., Bosch U., Roettgen, M. (2004). *Thermal Comfort Mapping and Zone*, RUROS, Fitfth Frame Work Programme 1998-2000, Key Action 4 “City of Tomorrow and Cultural Heritage” from the programme “ Energy, Environment and Sustainable Development”.

5. Shahidan M. F., & Mustafa, K. M. S. (2005, 5, 6 and 7 December 2005). Tropical Microclimate Indicators for The Malaysian Urban Landscape. Paper presented at the ASEAN Postgraduate Seminar in Built Environment, University of Malaya, Malaysia.

6. Robinette, G. O. (1968). *Plants and their Environmental Functions*. Washington D.C: U.S. Department of the Interior

7. Brown, R. D., & Gillespie, T. J. (1995). Microclimate Landscape Design: Creating Thermal Comfort and Energy Efficiency. New York: John Wiley & Sons.

8. Picot, X. (2004). Thermal Comfort in Urban Spaces: Impact of Vegetation Growth Case Study: Piazza Della Scienza, Milan, Italy. *Journal Of Energy, 36*, 329-334.

9. Kotzen, B. (2003). An Investigation of Shade Under Six Different Tree Species of the Negev Desert Towards Their Potential Use for Enhancing Micro-climatic Conditions in Landscape Architectural Development. Journal of Arid Environments, 55, 231-274.

10. Shahidan M. F., Mustafa, K. M. S., Elias S. (2007). *Effects of Tree Canopies on Solar Radiation Filtration in a Tropical Microclimatic Environment*. Paper presented at the PLEA2007 Conference, Singapore.

11. Shahidan M. F (2008), Effectiveness of *Mesua ferrea L.* and *Hura crepitans L.* As Thermal Radiation Filters in Outdoor Environment, MSc Thesis, Design and Architecture Faculty, Univ. Putra Malaysia.

12. Chalim . A, (1998), *Peran Vegetasi dalam Pengendalian Mikroklimat,* Abdul Chalim, Jakarta.

13. Pokorny, J. (2001). Dissipation of solar energy in landscape – controlled by water management and vegetation. *Renewable Energy, 24*(2001), 641-645.

14. Taha, H. (1997). Urban climates and heat islands: albedo, evapotranspiration, and anthropogenic heat. *Energy and Buildings, 25*(2), 99-103.

15. Robinson N. (1992). The Planting Design Handbook. Gower Publishing Company, England.

179. Plant Canopy Planting Design in Modifying Urban Thermal Environment: Theory and Guidelines (Sustainable Urban Design/Environmental Theory and Architecture)

Reviewers Feedback (Correction)

Background Research

This seems to be a compilation of previous research, no own study? Mainly a literature review. However well presented.
Added data and result form the previous research regarding Leaf Area Index Transmissivity of plant canopy in strengthening the paper.

Reference [10] does not appear in PLEA 2007 proceedings (finally found under other last names!)
Noted and corrected.

Calculation i 2.3 Heat Transmission: "Half is visible ... and half is ... infrared" means that total visible (10% transmitted) is 3 times infrared (30% transmitted)? In that case, total transmitted energy is not (10+30)/2=20%, but (3*10+30)/2=30% ??? Please clarify or correct!
"Most of the solar energy we receive, though, is in the form of visible light and solar infrared [7,9]. Approximately half of this energy is visible light and the other half is solar infrared [7]." The underlined statement was missing in the first paper. The statement clearly explained, for total energy we received is contributed approximately 50% of visible radiation and the other 50% is solar infrared. So, the heat transmission is according to that particular percentage we received. Below are the correct calculation for the whole process:

	Visible (100%)	50%	Infrared (100%)	50%	Total 100%
Absorb	80	**40**	20	**10**	**50**
Reflect	10	**5**	50	**25**	**30**
Transmit	10	**5**	30	**15**	**20**
					100

We have already checked with the author of the book *[7] Brown, R. D., & Gillespie, T. J. (1995). Microclimate Landscape Design: Creating Thermal Comfort and Energy Efficiency. New York: John Wiley & Sons.* He agreed with the calculation and the percentage… ***"I think the calculation is correct. Different species of trees will vary depending on things like leaf area index and amount of twigs and branches, but as a general estimate 20% of the solar radiation that arrives at a tree will be transmitted through the leaves. So the human eye would see that there is not very much light under a tree and people generally believe that this means that not very much solar radiation has passed through the canopy. But you and I know that there is quite a bit of invisible (NIR) solar radiation under the tree that they eye cannot see…"***

Originality/Significance

The topic is significant and needs highlighting, but there are no original conclusions in this

paper.
Re-write according to the original guidelines and ideas. (Corrected)

Presentation

Well presented, though some comments:
Title: Consider "Plant Canopy Design"... or "Canopy Plant Design"... - also in text.
Corrected and changed to "Plant canopy Design..."

Chapter 2.3: Title should be "Radiation control and Modification"? Also includes infrared!
Corrected and changed.

Chapter 2.4: Mention also the wind's effect on evaporative comfort cooling.
Added to the manuscript.

Chapter 2.5: Reference 'Brown (1995)' should add '& Gillespie'. Why not use the [x] reference system all over?
Corrected and changed.

Chapter 4, line 3: 'guidelines' should read 'components', 'processes' or similar? Figures are small, most of them difficult to read. Especially Fig 12 is central and important to clarify.
Corrected and changed.

Comments to Author

This paper is clear and well written, but own results, conclusions and recommendations (like guidelines) are weak
Re-write results, conclusions and recommendations - arguments were strengthened according to the original ideas.