AMELIORATION OF BUILDING MICROCLIMATES THROUGH LANDSCAPE DESIGN APPROACHING HOT-HUMID CLIMATE

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Abstract - Saving energy in buildings has become a more important issue in various countries. One strategy that can reduce the cooling load in buildings is landscaping and environmental design. However, it is difficult to estimate the amount of influence of landscape, environment and their elements on ambient temperature. Therefore, the purpose of this study is to examine the relationship between landscape elements and outdoor temperature. The arrangement in relation to temperature reduction is also determined. From the study, it was found that the first important factors that helped to reduce the ambient temperature were water elements, followed by mature trees and groundcover areas. In addition, the outdoor area should be minimally open ground and a hard surface area. The proper placement of each element should be considered specifically the water area should be placed on the south or south-west. The groundcover should be placed next to the building and trees should be placed on the south, east and west sides. The width of canopy of mature trees should be at least 4.5 meters, and evergreen trees should be at least 6 meters of height and dense. Besides these, there are many other variables, such as building layout, building shapes and building materials that may have some effects on the ambient temperature, and they will be studied later.

Index Terms - Ambient temperature, building, hot-humid climate, landscape design, passive design

I. INTRODUCTION

The building sector is responsible for about 30-45% of the total energy consumption of the global energy demand [1]. Buildings consume energy indirectly and directly in all phases of their life cycle right from the cradle to the grave. The operating energy during occupancy phase has a major share (80–90%) in the life cycle energy use of buildings [1, 2]. It is required for maintaining comfort conditions that are usually the energy for ventilation and cooling systems for buildings in the regions having a hot and humid climate [2] such as Thailand. Therefore, the building sector has become the focus on energy reduction initiatives to achieve more sustainable development in various countries [3, 4]. Long term energy savings can be fulfilled by improving the building design and building technology as well as conserving energy during the operation phase [5] and energy optimization of HVAC systems is particularly important [6]. Therefore, advances in technology are increasing to achieve the desired reduction in energy consumption goals but this does not necessarily lead to an overall reduction [7].

One of the green design approaches to cooling buildings by natural means is the passive cooling strategy. This strategy involves a controller that limits the total effect of the heat gain to provide an indoor temperature lower than that of the natural surroundings [7]. Energy-efficient building design can be made by orientation and size of windows or transparent building elements, building forms, shading, thermal insulation material selection, using natural ventilation, etc. [8]. In addition, the environmental design around the building to reduce the air temperature before entering the building is also important, because it can help to reduce the cooling load in the building as well [9, 10]. Landscaping has always played an important role in modifying the building environment. In addition, it becomes a strategy to offer protection from the most severe conditions imaginable and reducing surrounding temperature through shade trees and the process of soil evaporation and plant transpiration. Plants are able to absorb heat energy by releasing water vapor [9]. However, landscape design guidelines will be recommended in terms of tree positioning and choosing the sizes and shapes of the trees. Therefore, it is difficult to estimate the numbers of trees to be planted and the amount of influence of landscape and its elements on ambient temperature [11]. This study aims to examine the importance and relationship of landscape elements with outdoor temperatures and their arrangement in relation to the temperature reduction.

II. METHODOLOGY

This study was a preliminary stage of a research study to determine the landscaping ability to reduce surrounding temperature and associated energy consumption in buildings. The study results were from a summary and collation of secondary data sources. The sources included previous research reports, magazines and journals as well as government and private company statistics that involved landscaping designs to reduce ambient temperature.

III. RESULTS

A. Landscape elements and land cover proportion

Elements of general landscaping include the hard landscape(hardscape), such as paths, walls, water

features, sitting areas and decking, and soft landscape (softscape) elements, known as plants, pattern of plantations, flowers and others. Usually, hardscape refers to hard surface elements such as concrete, wood and rocks, while, softscape is the living elements on landscape designs [10, 12]. In the aspect of the influence of landscape design for reducing outdoor thermal comfort, studied by Bonan [13] and Yu [14], it was found that softscape and water are the important elements of landscape design. This aspect usually applies to various plants such as matured trees, shrubs and grass, and water elements which have potential to improve the outdoor thermal comfort due to their shade and humidity [15]. According to Dimoudi and Nikolopoulou, it was found that, of all the landscape design elements, vegetation is the most effective factor and plays a role in surface and air temperature modification [16]. In other studies such as Bonan, Givoni, Pearlmutter and co-workers, they found that grass or mulching area and water element increase humidity around the building and then have an effect on cooling temperature [17, 13, 8]. Therefore, the combination of shade trees, groundcover areas and water elements was predictably found to be the most effective landscape strategy. Although water is an artificial facility, a shallow pond, a small waterfall, and a spray fountain can create an air temperature decline area on the leeward side [8]. Shashua and co-workers [18] found that efficient landscape design can reduce air temperature more than 3oC before entering the building and it can reduce cooling costs by about 30% [16]. Small waterfalls or spray fountains scattered at various points around the building can reduce the temperature before entering the building by 33.33% [14]. In addition, Tominaga et al. found that evaporative cooling can reduce pavement surface temperature near the building by approximately 2oC [19]. Various previous studies found that the pavement surface characteristics around the building affect the temperature. For example, if the ambient temperature is about 40oC, asphalts pavement surface would have a temperature of about 42oC and the concrete surface temperature would be about 45oC [15]. According to a study by Xiaoshan Yang and Lihua Zhao [20], it was found that the surface temperatures of the concrete and granite slab pavements are significantly higher than those of softscape and water surfaces throughout the daytime period. Surfaces of lawn soil and the grass leaves are hotter than that of the pond during the daytime. Therefore, when the wind blows over the concrete surface, it would be about 5oC higher temperature than the ambient temperature in the building. However, if the wind blows over the grass surface, the temperature of the air flow is about 1 to 2ºC cooler than that of the over bordering areas. Misting the grass with a fine spray of water to raise humidity around a lawn, would decrease its surface temperature about 8oC lower than that of a dry grass surface temperature. In addition, in high shade areas of a wet lawn, the surface temperature would be about 2oC cooler than that of an open wet lawn during the maximum temperature of the day.

From a study by Wanpen [21], she established a few multiple regression models providing a possible solution to reduce urban temperature by means of determining the proper proportion of land covering urban areas. The results show a significant positive correlation between the build-up area and temperature and a negative correlation between vegetation and water-covered land and temperature. A model was calibrated with some existing data and the answers were similar to the others. Therefore, the model can be applied in landscaping design process for reducing ambient temperature as shown in equation (1). The model demonstrates that for every percent, if increased by land covered by trees, water areas (1.5 meters deep), and lawn areas could result in a 0.028^{o}C, 0.053^{o}C and 0.009^{o}C decrease in temperature. The temperature would rise by 0.022^{o}C and 0.016^{o}C if the building area or hardscape and ground are increased in every 1 percent of the surrounding area. Therefore, if the building has 100 square meters of space, the outside temperature would be 40°C. The 10 square meter grassy area of a total 50 square meter area would reduce the temperature to about 38.7^{o}C.

$$T_2 = T_1 + 0.022*X_1 + 0.016* X_2 - 0.028* X_3 - 0.053* X_4 - 0.009* X_5$$

Where,

T_2 = modified temperature (^{o}C)
T_1 = ambient temperature (^{o}C)
X_1= percent of hard surface pavement areas to surrounding areas
X_2= percent of brown areas to surrounding areas
X_3 = percent of tree areas to surrounding areas
X_4 = percent of water areas to surrounding areas
X_5 = percent of lawn areas to surrounding areas

B. Plants selection

The focus vegetation for reducing the temperature around the building consists of 2 groups, namely, trees and mulching plants such as grass or bean sprouts. The characteristics of the trees selected for this purpose include genetic variability, foliage color and density, overall form, growth rate (both fast and slow growing plants may be desired) and ability to grow and survive under a hot-humid climate [22]. For a hot-humid climate area, shading from the trees is very important. The most suitable trees characteristically have spreading crowns, dense foliage and provide excellent shade. Therefore, the canopy diameter of mature trees should be at least 4.5 meters and the height should be over 6 meters. In addition, they should be evergreen trees and dense at the top of the trees, but the lower part should be airy to allow the wind to blow through. The dense canopy trees should block out over 70-90% of the sunlight [23].The ability to withstand drought is a factor that must be considered when landscaping in the summertime. In addition, invasive alien species and exotic pest plants should not be used. There are

many examples of temperate trees for this purpose as shown in Table 1.

Plants	Height (m.)	Canopy Width (m.)	Growth Rate			Image	Plants	Height (m.)	Canopy Width (m.)	Growth Rate			Image
			Fast	Moderate	Slow					Fast	Moderate	Slow	
Ylang-ylang (Cananga odorata)	20	8	✓				Marian plum (Bouea oppositifolia)	15-20	4-7		✓		
Eagle wood	30	4	✓				Diospyros glandulosa (Lace)	10-15	8	✓			
Alstonia macrophylla	20	6-10	✓				Longan (Dimocarpus longan lour)	30	5-8	✓			
Cordbretum	15-20	5	✓				Neglkassar (Mammea siamensis kosterm)	15	4			✓	
Yellow saraca (Saraca thaipingensis)	10-15	7			✓		Cinnamon	15-20	5			✓	
Magnolia (Michelia rajaniana craib)	25	5	✓				Banyan (Ficus altissima)	30	4-6	✓			

Table 1 Some temperate trees used in landscaping in hot-humid area

C. Function and Position of Landscaping Design Elements

The layout for the modification of temperature in different climate zones needs different designs. This study focuses on the hot-humid climate where Tucson [24] and Attia's study [25] found plantings on the west and south sides of homes tend to provide the most cooling in summer, while plantings on the north side actually increase the heat load, perhaps by blocking winds. In the second category of Thai's Rating of Energy and Environmental Sustainability (TREES) which is cited, the landscape category requires planting mature trees on 3 sides of the building i.e. east, west and south, and the gap between the canopy of mature trees should be less than 1 meter apart for effective shading.

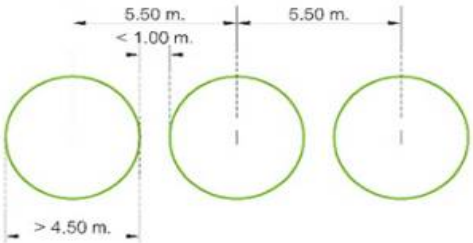

Figure 1 Mature tree placement in landscape design for shading

The trees at 3-5 meters from the building provide shade on the roof and trees 6-10 meters from the building provide shade on the wall. However, the trees should be planted far enough away from the building so that when they are mature, their root systems do not damage the building's foundation and branches do not damage its roof. Shrub plants (1.00-1.50 m. high) help to shade on the west and south walls which face to low-angle sunlight to warm the building and to control wind direction by obstruction, guidance, deflections, and filtration though the windows or voids. Figure 2 shows the placing impact of height differences of large bushes or rows of shrubs with differing distances from the windward wall of a building with window openings. The low shrubs at the building causes airflow to drop inside the building. This conditions provide positive natural ventilation and air mixing characteristics inside buildings. In addition, the placing distances generate secondary eddies; when shrub-hedges are placed some distance from the windward side of the building, lee eddies of relatively calm air are created. Groundcover plants (0.30-0.90 m. high) can also shade the ground and pavement. They should cover the pavement or ground around the building on the east, west and south sides. Water areas, such as a shallow pond, a small waterfall, and a spray fountain should be placed under trees and in front of windows and voids of the building i.e. in the south and south-west.

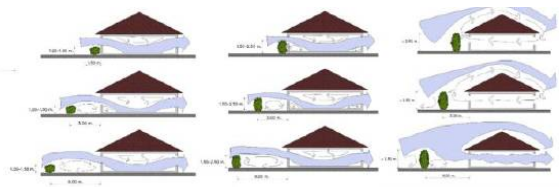

Figure 2 The impacts of shrub's height and placing distance on wind direction and eddies

DISCUSSION AND CONCLUSION

The result of this paper demonstrates that landscape design helps to improve the microclimate surrounding a building. The landscape design elements such as the quadripartite layout, water, vegetation and walls should be all integrated in the building landscape as a way of passive cooling. Important factors that help to reduce the ambient temperature for tropical areas such as Thailand should include water elements, wet areas, trees, and groundcover areas. The objectives are for increasing humidity and shading, and reducing heat reflections from hard cover and open ground area around the building. It was found that humidity from

water elements has the most potential to decrease ambient temperature. The water elements can be a natural pond, an artificial pond, a small waterfall, or a spray fountain. In addition, the proper position of these water elements should be included in the design. The proper placement of the each element should be; specifically the water area should be placed on the south or south-west. The groundcover should be placed next to the building and trees should be placed on the south, east and west sides. The trees should be at least 4.5 m in canopy diameter and higher than 6 m. They should be evergreen trees and dense at the top. However, the reduction in ambient temperature also depends on many other variables, such as building layout, building shape and building materials. These variables will be studied later.

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