Architectural Design towards Energy Optimization: A Case of Residential Buildings in Bangkok

Nuchnapang Keonil* and Nopadon Sahachaisaeree

Faculty of Architecture, King Mongkut’s Institute of Technology Ladkrabang, Chalongkrung Road, Ladkrabang, Bangkok, 10520, Thailand

Abstract

This paper investigates the thermal perceptual aspect from daily activities. The research uses the cases of small detached houses in Bangkok to examine the best manipulation of architectural elements to optimally provide thermal comfort in the Thai living context applying a multi-facet research methodology. Test result indicates that the various combinations of voids and interior configurations are responding to wind directions, which could obtain the interior air velocity up to 1.5 m/s. The effective range of summer day-time temperature for passive cooling in Bangkok is limited to only 30 - 33°C.

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1. Introduction

The current global energy crisis has called for local actions involving the reduction of energy consumption. The “think globally act locally” (Moberg, 2005) notion brought about awareness and cooperation from the design discipline, where energy-efficient design has become among the crucial...
design elements taken into consideration by architects and designers. In the past, architects had designed interior environment with respect to its local climate and living context. However, the Western designs and ideologies have recently created a huge influence on interior design by aiming to meet residents’ use values and ways of lives. As a result, most of the modern designers have adopted the technological aspects from the West to maximize the living comfort and paid little attention to the use of interior environmental management in creating the thermal comfort from passive energy. The principles and techniques of Eastern interior designs are greatly different from the Western perspectives. In the West, the living comfort is induced by the design strategy that creates warm and comfort living ambiance. Meanwhile, in the tropical climate, designing for comfort living environment can be created by decreasing indoor temperature, for instance producing the ventilation through the manipulation of architectural elements and the treatment of interior spatial arrangements.

Each of the remedial choices for energy-efficient design has its pros and cons and they could interact with each other when applied simultaneously. Applicability of combined remedial actions depends much upon the most efficient interaction effect providing the occupants an optimal living thermal comfort. Utilizing the small detached house in Bangkok as a case study, the research endeavours to examine the best manipulation of architectural elements which can optimally serve to provide a thermal comfort in the Thai living context. And finally, the study attempts to derive an interior environmental management model for the optimization of thermal comfort design.

2. Theoretical background

Derived from the literature review, theoretical basis as a foundation of the research framework comprises principles of tropical architectural designs, outdoor thermal conditions, physical requirements for passive designs, human thermal perception and comfort zone, and spatial behavioral pattern of residential usage. The passive means of heating, cooling, and lighting are closely related to building forms. The passive means are the most important energy uses in a building and creating a strong influence on its form. These effects should be known and taken into consideration in the design process (Brown, 1985). The following section presents four lines of thoughts on which the study is based.

2.1. Tropical Architectural Designs & Outdoor Thermal Conditions

In order to create thermal comfort to the interior environment, studies on architectural design need to take into account some crucial elements of outdoor conditions and should also truly understand the particular climatic conditions in that region. Architectural design in the Tropics is typically required to take a serious consideration on its local hot and humid climate, particularly in the coastal zones of South-East Asia. Designing the traditional architecture in the region has been experiencing difficulty from local climatic conditions including high humidity, little naturally air movement in a building, and constantly high temperature during a day and at night. As a result, these local factors have been influencing the varieties of design features adapted to the local climate, especially passive cooling techniques. (Lauber, 2005) The architectural design in the tropical region is usually aimed to reduce the temperature in the interior environment. Three major design techniques that could bring down the indoor temperature include (1) minimizing exposure to direct sunlight, (2) increasing cooling rate during the afternoon, and (3) introducing passive cooling elements to the building.

2.2. Physical Requirement for Passive Design
The appropriate architectural elements could create the natural ventilation to the building. Those elements include window orientation, window size, cross-ventilation, window positions, opening techniques and positions, and a sub-division of internal space (Givoni, 1981). Moreover, the pattern of air movement in a room can be influenced by two important parameters—surrounding atmospheric pressure outside the building and the inertia of moving air.

2.3. Human Thermal Perception and Comfort Zone

Besides the physical environment factors, human comfort is considered to be associated with a number of factors including a human body itself. The body condition is one of the major factors influencing people comfort perception. Body heat, as we all know, is naturally generated as a by-product of metabolic system. The aim of creating human thermal comfort is, therefore, to eliminate the heat generated from inside the human’s body. The changes of body temperatures can be explained by the transfer of “sensible heat” from human body to the surrounding environment. To manipulate thermal comfort, one needs to understand these key factors: air temperature, air movement, amount of clothing worn, and activity level. (Randall, 2006) In addition, the amount of heat generated from human body also depends on gender, age, and other factors. (Brown, 1985)

It was reported that thermal comfort perceived by Thai people has been proved to be 4 degrees higher than the index suggested by The American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHREA), since dwellers in the tropical areas are more tolerable to heat than those in the higher altitude. (Daghigh & Sopian, 2009) With appropriate amount of ventilation and wind speed, the upper limit of thermal comfort for dwellers in the tropical zone could be as high as 31 degrees Celsius. High temperature could usually be compensated by higher wind speed, namely, the individual could perceive a drop of temperature of 1.1, 1.9, and 3.3 degrees Celsius when wind speed increases 0.2, 0.4 and 1.0 meters per second respectively. Wind speed over 1.0 meter per second would cause irritating sensation for dwellers, however. (Tantasasdi, 2002) Appropriate ventilation air velocity generated by electric fan in the Thai context has been suggested between the ranges of 0.2 to 3 meters per second, with room temperature between 26-36.3 degrees Celsius, and relative humidity 50-80%. The suggestion is in accordance with the aforementioned Chalermwat’s (2002) findings (Tantasasdi, 2002), whereby, Bangkokians are tolerable to temperature higher than the ASHREA and ISO 7730 suggested and still feel comfortable with increasing wind speed. (Khedari et al., 2000)

The thermal acceptability is a few degrees Celsius beyond the thermal comfort zone defined by ASHREA and ISO 7730 for the warm boundary of summer comfort. When air velocity increases, human can feel comfortable at higher temperature level than the standard of thermal comfort.

According to the literature review, it summarizes that natural thermal comfort, in the Thai context, consists of comfort conditions—temperature between 26-31 degrees Celsius, relative humidity level between 50-80%, and maximum air velocity within 1.0 meter per second. Besides, personal factors are influence sense of thermal comfort. This research thus applies this condition as the targeted threshold to be reached by the optimal passive strategy, namely, room temperature between 26-31 degrees Celsius, 50-80% relative humidity and wind velocity up to 1.0 meter per second. Clothing and activities of dwellers are treated as controlled variable and are held constant.

3. Research framework

Derived from the literature review, the background presented in the previous section attempts to explain the relationship among variables which link interior environmental design elements and optimal degree of comfort, see Fig. 1. The research bases its framework on two lines of thoughts: theories
regarding physical environment and theories of comfort zone. (Givoni, 1981; 1998) The research initially hypothesized that the interior environment and management can be effectively designed to benefit energy conservation purposes and simultaneously serve to provide a thermal comfort living conditions.

4. Research methodology

Applying a set of 150-200 square-meter detached houses in villa-estates of Bangkok Metropolis as testing models, the research investigates two interdependent aspects of design manipulation. First, it examines the treatment of interior spatial arrangements, which is usually a constraint to cross ventilations and air-conditioning. Second, the manipulation of the building envelope will optimize the best thermal comfort in accordance with the Thai daily activities.

An integration of multi-facet research methodologies are applied towards the modelling of the optimization of comfort design. Firstly, information regarding microclimate of the Bangkok Metropolis is retrieved from the meteorology office to be compiled to derive the average outdoor ambient temperature and humidity as an input in the Bio-Climatic Chart. A perceptual comfort zone in the Thai context is then derived by the literature review. The second stage involves the classification of physical settings vis-à-vis the level of perceived comfort to be used as input in the modelling computer programming. In the testing state of research tools, typical dwelling units of villa houses could be classified into four categories in accordance with the location of building core (stair well and baht)—centre front, centre back, side of buildings, and inner center of dwelling unit. This study chose the most popular front centered stair-well type with first floor bath located adjacent to the stair as case study, see Fig. 2. The research found that among the eight orientations of building under investigation, there are only four directional groupings which needed separate testing with two seasonal wind directions of Bangkok in accordance with the micro climatic wind charts.
In Fig. 2, a number of architectural features are manipulated utilizing the trade-off approach. [9] Researcher manipulates the indoor ventilation and wind speed to exceed the outdoor ventilation flow by means of intake and out flow opening size and interior enclosure arrangement. Researcher puts the set conditions into the computer program to test the responsive indoor ambient environment. The third stage derived from the results of stage two—in terms of temperature, humidity, and air movement—to obtain the final model of comfort optimization strategy. The diagram in Fig. 3 summarizes the detail of research procedure.

5. Result and discussion

5.1. Result

As the research inspiration, it attempts to acquire the set of critical environmental features and local factors that provides the optimal degree of thermal comfort. In the first phase, the research found that, basically, Thailand thermal pattern can categorize into two patterns: From December to January: Low temperature, high humidity, and the highest comfort level. From February to November: High temperature, high humidity which requires ventilation for comfort thermal in the day time. However, it requires air condition if temperature is over 33 degrees Celsius.

For the second phase, it was found that interior wind speed could be enhanced with different types of interior opening manipulations with the constant exterior average wind velocity of 0.83 meter/second. The best type of opening responding to the 90° wind direction is creating large openings with the intake side smaller than the outflow side, which configuration is able to increase the interior wind speed up to 1.05 m/s, see Fig. 4a. The optimal type of opening for diagonal wind direction is the medium size.
openings with zigzag interior void. It results in increasing interior wind velocity up to 1.5 m/s, see Fig. 4b.

Research examines thermal comfort of internal building with the variance temperature from 20 to 40 degrees Celsius of external building by increasing every one degree Celsius. Various patterns are observed. Researcher categorized the patterns into three groups by utilizing the manipulated external temperature as the conditions. First: from 20 to 29 degrees Celsius, it is the thermal comfort, in the Thai context, without architectural feature management. This thermal condition is the average temperature for winter season in Thailand—from November to February. Second: from 30 to 33 degrees Celsius, it is the range that architect can manipulate thermal comfort by increasing air velocity (Air Movement Effect) into internal building. The research found that increasing the velocity of air movement does not either decrease temperature or expand comfort zone in the building but evaporate human’s sweat. Third: from 34 to 40 degrees Celsius, this temperature range occurs during the daytime of summer season in Thailand—from March to June. This range requires convectional air conditioning to create thermal comfort. The research, also found that the sensation of feeling hot or cold is not only just dependent on air temperature. Relative humidity, air velocity and human activities are also influencing sense of thermal comfort. The second condition represents the period when particular portion of the day is still within the comfort zone of 30-33°C; and the research hypothesizes that, with the manipulation of opening, wind speed could be increased to compensate the relatively high temperature beyond the comfort conditions. Test result from the modeling shows that with opening of the villa house facing the 90° wind direction and with larger intake openings than the outflow side, the building settings could increase the interior wind speed up to 1.05 m/s to compensate a large portion of high temperature areas. This condition also covers a larger portion of the day time living period, which makes passive cooling possible with little compromise on the thermal comfort. The last condition represents the ambient temperature of summer period, which is exceeding 33°C, whereby, passive cooling would not be applicable, and one must resort to the conventional air conditioning instead.

5.2. Discussion

The modeling is able to show the exact temperature contour and velocity of wind speed with both positive and negative pressures. The research suggests that functional settings in negative pressure areas
should be reduced or assigned to some particular types such as kitchen, and bath which are prone to odor emission. These areas should be assisted by active measures such as electric fan to enhance thermal comfort during daytime activities. However, thermal comfort could be achieved by means of airflow to reduce body temperature when ambient temperature is still slightly above the comfort zone. Test results also verify the fact that increasing wind speed does not reduce room temperature apart from its convective effect on body heat. Thus manipulation of ventilation alone can hardly lower the room temperature in the high humidity condition, as such; it makes passive cooling more complicated during the high temperature of summer period.

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