

CHAPTER 2 THORIES AND HYPOTHESIS

The categories of theory and hypothesis in terms of design strategies in energy efficiency based on tropical climate substantially consist of thermal comfort and passive design that would be defined. The sources will be gathered and analyzed to implement the thermal comfort in the research and to guide further research involved to this field. Therefore, this chapter will be referred to the tropical climate in overall and Bangkok weather data for local climate to understand the weather condition in the experiments.

2.1 Tropical Climate

Climate is the characteristic condition of the atmosphere near the earth's surface at a certain place on earth. It is the long-term weather of that area (at least 30 years) including the region's general pattern of weather conditions, seasons and weather extremes like hurricanes, droughts, or rainy periods. Two of the most important factors determining an area's climate are air temperature and precipitation. The climate of a region will determine what plants will grow there and what animals will inhabit. All three components, climate, plants and animals are interwoven to create the fabric of a biomass.

The sun's rays hit the equator at a direct angle between 23°N and 23°S latitude. Radiation that reaches the atmosphere here is at its most intense. The climate system is based on the location of these hot and cold air-mass regions and the atmospheric circulation created by trade winds and westerly. Trade winds in the north of the equator blow from the northeast. Whereas that of the south of the equator, blow from the southeast. The trade winds of the two hemispheres meet near the equator, causing the air to rise. As the rising air cools, clouds and rain develop; the resulting bands of cloudy and rainy weather near the equator create tropical conditions. While the Earth rotates on its tilted axis around the sun, different parts of the Earth receive higher and lower levels of radiant energy that create seasons.

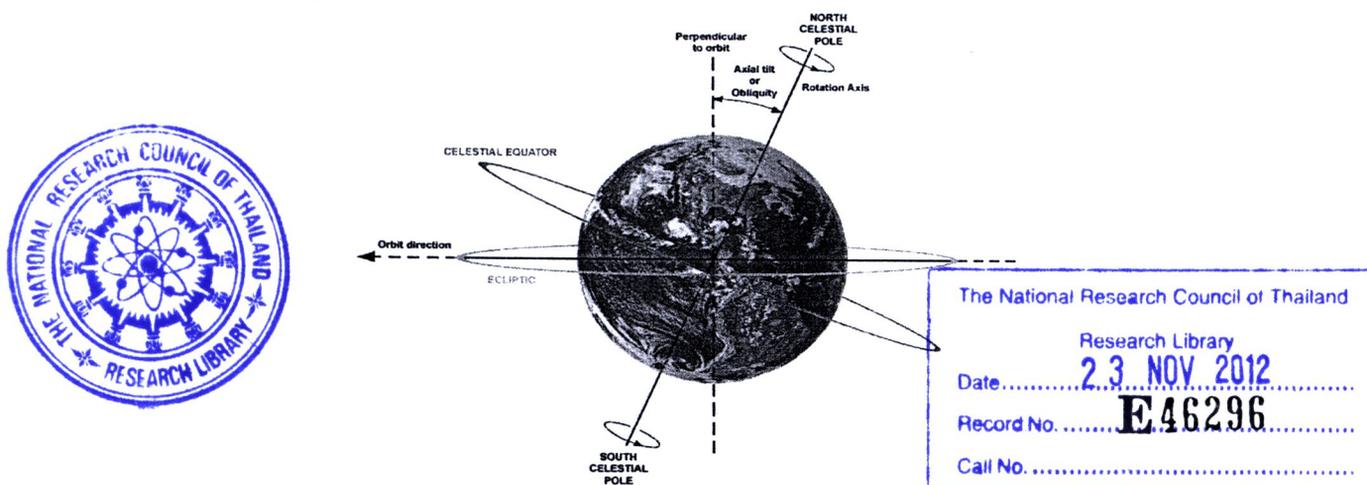


Figure 2.1 The rotation axis of the earth [Neilson, 2007].

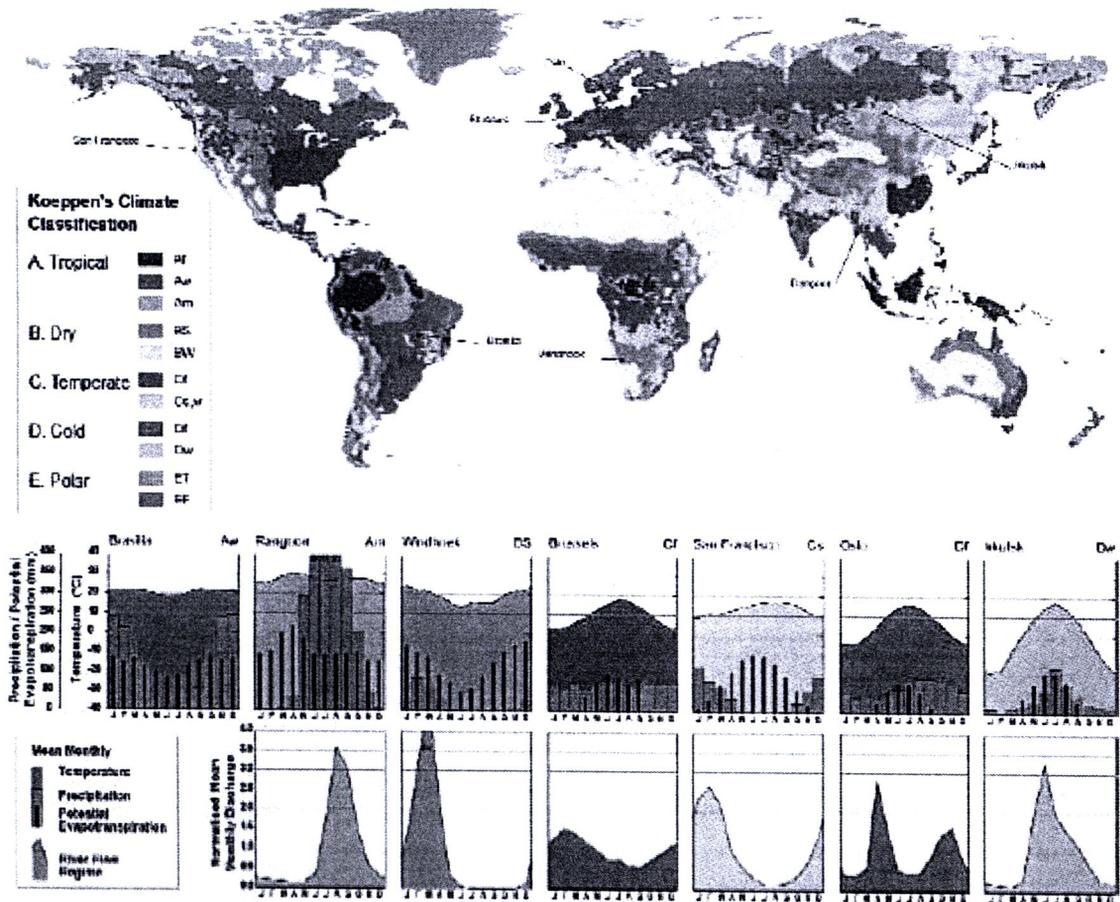


Figure 2.2 The world climate classified by Köppen [Stahl and Hisdal, 2004].

Thailand's climate is classified as low-latitude and tropical moist climate (Af) rainforest type by the Köppen Climate Classification System, the most widely used for classifying the world's climates, where "A" means Moist Tropical Climates known for their high temperatures year round and for their large amount of year round rain, and "f" means moist with adequate precipitation in all months without dry season. The rainfall is heavy all months in rainy season. The total annual rainfall in Bangkok is often more than 250 cm. (100 in.). There are seasonal differences in monthly rainfall but temperatures of 27~30°C (80~86°F) mostly stay the same and humidity is between 77 and 88%. High surface heat and humidity cause cumulus clouds to form early in the afternoons almost every day [Strahler, 1984]. The climate on eastern sides of continents is influenced by maritime tropical air masses. These air masses flow out from the moist western sides of oceanic high-pressure cells, and bring lots of summer rainfall. The summers are warm and very humid. It is also a lot of rain in the winters.

2.2 Local Weather Data

Thailand is located in tropical, hot and humid, climate, where the capital city is Bangkok. It has a tropical wet and dry climate under the Köppen climate classification system. Average temperatures in the city are approximately 2°C (3.6°F) higher than the ones shown for the Don Mueang Airport during the 1961-1990 periods. The highest

recorded maximum temperature is 40.8°C (105.4°F) in May 1983 and the lowest recorded minimum temperature is 9.9°C (49.8°F) in January 1955. The coldest temperatures were recorded in January 1924, January 1955, January 1974 and December 1999. The hottest year on record was 1997 (average yearly at Don Mueang 30.0°C) and the coldest was 1975 (average yearly at Don Mueang 26.3°C). The coldest daytime maximum temperature was 19.9°C (68°F), recorded in December 1992 [Thai Meteorology Department's data].

Bangkok Weather Data

Overall Thailand's climate is warm and humid. It is warm and dry in winter but warm and humid in summer. There is a bit annual and diurnal temperature range. Winds, being forced by influence of the monsoon, blow from southwest during summer and from northeast during winter. And the cloud dense affects the daily solar radiation gain.

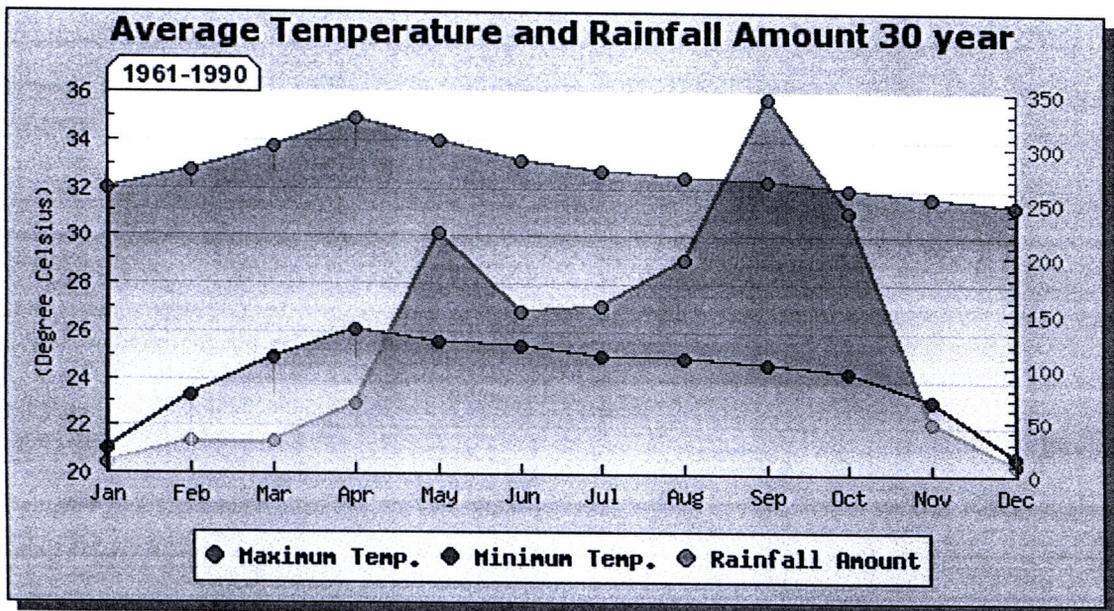


Figure 2.3 Average Temperature and Rainfall (1961-1990) at Bangkok port Klong Toey [TMD data].

2.3 Thermal Comfort

Thermal comfort is defined as the state of mind that expresses satisfaction with the surrounding environment [ASHRAE Standard 55, 1992]. Proper understanding of the parameters around thermal comfort is a crucial component of successful buildings and system design. It is special important in passive design, where buildings should be maintained thermal comfort without the aid of mechanical systems as much as possible. Thermal comfort refers specifically to thermal perception of the surroundings. The factors most commonly addressed in the conventional design process are air temperature and air humidity respectively. The effectiveness of passive design strategies

depends on the range of acceptable thermal comfort parameters set for each projects. Therefore, this chapter will be addressed thermal comfort factors, comfort zone or comfort condition especially for Thailand, thermal sensation, and control strategies of thermal comfort.

2.3.1 Thermal Comfort Factors

Thermal comfort is complex and partly subjective. It depends on several factors, of which air temperature, relative humidity, air movement, radiant temperature, and two personal factors; the metabolic rate and the level of clothing are fundamental [Fanger, 1970]. The impacts of these factors on the thermal balance of the human body are irrespective of adaptation to the local climate from the basis on theoretical comfort models/standards such as Fanger's Predicted Mean Vote (PMV) in acceptable range of $0 \sim \pm 1$ PMV. Human thermal comfort is actually maximized by establishing a heat balance between the occupant and the environment. Since the body can exchange heat energy with its environment by conduction, convection and radiation, it is required to consider the factors which affect these heat transfer processes along with the body's ability to cool itself by the evaporation of perspiration [Turner, 1942]. The factors of Thermal comfort consist of the followings;

1) Air Temperature

Air temperature is the level of climatic characteristics that can be changed every day from radiation of the sun. It effects to human's behavior adaptation and could absorb various heats depending on colors of surfaces.

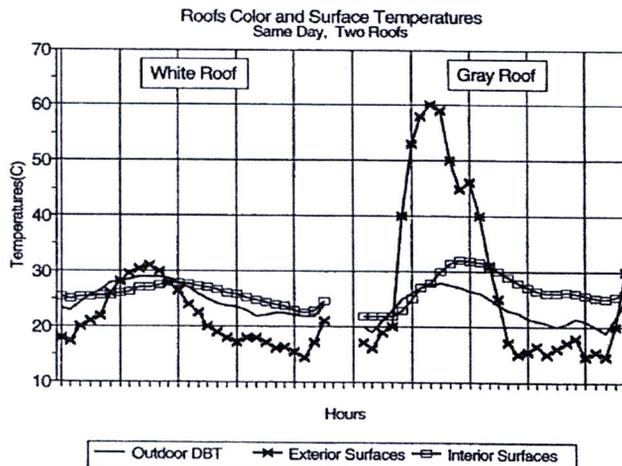


Figure 2.4 External and internal surface temperature of horizontal roof/ white and grey roof.

2) Relative Humidity

Relative Humidity (%RH) is defined as the amount of moisture contained in the air related to the total amount of moisture that the air could hold at fully saturated conditions. Relative humidity is a function of temperature; as air warms, it is capable of holding more moisture. Our body rejects heat through perspiration, and this critical

system works most effectively when relative humidity levels are lower. Perspiration does not evaporate as readily at higher relative humidity levels, to the detriment of thermal comfort. Most people are comfortable when the relative humidity is between 30 and 60 percents, though once again there are seasonal variations. It is normally expressed as a percentage and defined in the following manner:

$$RH = \frac{P(H_2O)}{P^*(H_2O)} \times 100\%$$

where; RH is the relative humidity of the mixture being considered.

$P(H_2O)$ is the partial pressure of water vapor in the mixture.

$P^*(H_2O)$ is the saturated vapor pressure of water at the temperature of the mixture.

3) Air Velocity

Air velocity is the air movement from a positive pressure on the windward side and a negative pressure to the leeward side of buildings. The speed of air effects to human perception depends on air temperature as well. The ASHRAE guide-1985 specifies an upper limit of 0.8 m/s for indoor air velocity, presumably to prevent paper flying around and/or the feeling of cold drafts from cool air flowing out of the ventilation diffusers. On the other hand, the air velocity limit can be based on its effect of comfort which depends on the temperature. The effect of air velocity on comfort depends on the environmental temperature and humidity, as well as on the clothing. At temperatures below 33°C (91.5°F), increasing air velocity reduces the heat sensation due to the higher convective heat loss from the body and the lowering of the skin temperature. At temperatures between 33~37°C (91.5~98.5°F), air velocity does not affect significantly the thermal sensation, although it might have very significant effect on discomfort from excessive skin wetness, depending on the humidity level and the type of clothing. At temperatures above 37°C (98.5°F), increased air velocity actually increases the thermal sensation of heat, although it still reduces skin wetness and might be desirable.

Table 2.1 The effects of internal air velocity in buildings [Autodesk-Ecotect, 2008].

DESCRIPTION	M/S	KM/H
Still	0.0	0.0
Not Noticeable	0.1	0.4
Barely Noticeable	0.3	1.0
Pleasant Breeze	0.5	1.8
Light Breeze	0.7	2.5
Hair and Papers Move	1.0	4.0
Noticeably Draughty	1.4	5.0
Unpleasant Breeze	1.7	6.0
Gusting Breeze	2.0+	6.5+

4) Mean Radiant Temperature

Mean Radiant Temperature (MRT) is electromagnetic radiation emitted from the surface of an object which is due to the object's temperature. For instance, the infrared radiation emitted by a common household radiator or electric heater, a person near a raging bonfire will feel the radiated heat of the fire even if the surrounding air is cold. Thermal radiation is generated when heat from the movement of charged particles within atoms is converted to electromagnetic radiation. Solar radiation heats the earth during the day, while at night the earth re-radiates some heat back into space. Thermal radiation transferred in the air, in the environments, and between environment and human's bodies. Internal human's bodies temperature will be balanced when it is 37°C, meanwhile surface temperature on human's skin is 31°C-34°C depending on environment and Mean Radian Temperature (MRT), the net exchange of radiant energy between two objects which is approximately proportional to their temperature difference multiplied by their ability to emit and absorb heat.

5) Personal Factors

Personal factors consist of metabolic activities and clothing. When measuring metabolism rates, many factors have to be taken into account. Each person has a different metabolism rate, and these rates can fluctuate when a person is performing certain activities, or under certain environmental conditions. Even people who are in the same room can feel significant temperature differences due to their metabolic rates, which makes it very hard to find an optimal temperature in a given location. While clothing with insulated layers can help keep a person warm, during cold weather. At the same time, if the person is doing a large amount of physical activity, lots of clothing layers can prevent heat loss and possibly lead to overheating. Generally, the thicker the garment is the greater insulating abilities will be. Depending on the type of material the clothing is made out of, air movement and relative humidity can decrease the insulating ability of the material.

2.3.2 Comfort Zone

The comfort zone is a behavioral state within which a person operates in an anxiety-neutral condition, using a limited set of behaviors to deliver a steady level of performance, usually without a sense of risk [White, 2008]. It takes into account that humans can adapt and tolerate different temperatures during different times of the year. Even though, several researches in the past used comfort zone data from the west, currently the young researchers who studied their researches in the tropical or the other climates use adaptive comfort zone. Because there are more different temperatures between indoors and outdoors, it is found that naturally ventilated buildings are more effective especially in harsh climates such as hot and humid climates. In Thailand, Kitchai Jitkhajornwanich established the comfort conditions by performing simple linear regressive analysis and proposed new comfort zone: the range of air temperatures was 25.6-31.5°C and of relative humidity was 62.2-90.0%, shifting to a new dimension

for thermal comfort study, especially in the contexts of tropical building design. This proposal had been proved that it fits with the central-three-category of ASHRAE votes more than the Olgyay’s Bioclimatic Chart which is 22-29°C and 20-75%RH.

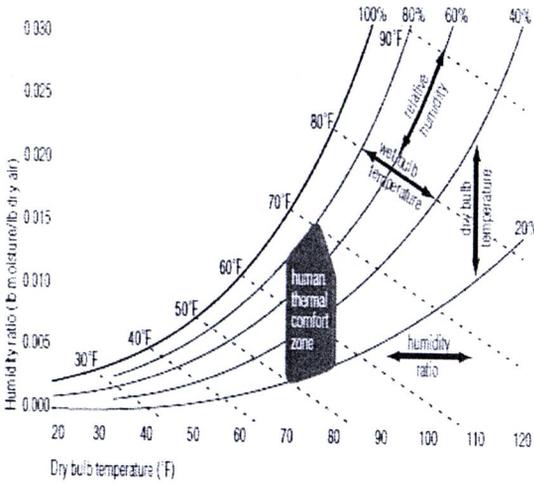


Figure 2.5 Combination of temperature and relative humidity in Olgyay’s comfort zone, [ASHARES-55, 1992]

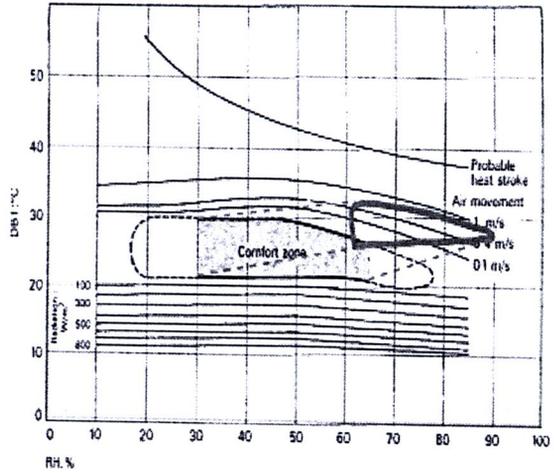


Figure 2.6 The proposed comfort zone shifting from Olgyay’s Bioclimatic chart, [Jitkhajornwanich, 2006]

Joseph Khedari et al. had also studied and purposed the comfort condition for Thailand including relationship between temperature, relative humidity and air velocity. It is indicated that human can be approached to comfort condition if air velocity is higher in proper relative humidity.

Table 2.2 The proposed comfort zone for Thailand [Khedari, 2000].

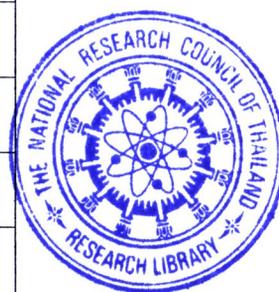
Sources	Temperature (°C)	Relative Humidity (%)	Air Velocity (m/s)
Khedari et al. (1998)	22.0-29.5	20-80	0.00-0.25
	29.5-30.7	20-80	0.25-0.50
	30.7-32.5	20-80	0.50-1.00
	32.5-34.0	20-80	1.00-1.50
	34.0-36.0	20-80	1.50-2.00
	36.0-36.5	20-80	2.00-3.00

2.3.3 Thermal Sensation

The main sensory thermal responses are the sensation of cold heat and the discomfort from perspiration. The thermal sensation over the whole range from cold to hot is often graded along a seven-point numerical scale. A scale from -3 to +3 is sometimes used to express the same sensation, with 0 stating neutral or comfortable sensation. The range from slightly cool to slightly warm can be considered as designating acceptable conditions (0~±1).

Table 2.3 Climate Conservation in Building and Urban Design [Givoni, 1998].

-3	Cold
-2	Cool
-1	Slightly cool
0	Neutral (comfortable)
+1	Slightly warm
+2	Warm
+3	Hot



2.3.4 Control Strategies of Thermal Comfort

Human being have the effort to control indoor thermal comfort which depend on their geographies and climates and have to extremely adapt when the global is changed in this present. The thermal comfort, for assessing and predicting comfort levels in indoor buildings, influences human in mental and physical environments. It demonstrates that, due to high humidity levels, high wind speeds, and acclimatization, no single universal comfort indices have been developed for human from anywhere of the world to need adjustments. Control strategies of thermal comfort will be divided into two principles, by natural method such as, natural ventilation, daylighting, and building envelope, and by mechanical method such as HVAC system.

In conclusion, the results from a large number of field studies have indicated that theoretical models which neglect the impact of acclimatization can significantly underestimate the thermal and humidity tolerance of the occupants of free-running buildings in tropical climates. For example, while ASHRAE Standard 55-1992 Addenda 1995 suggests that the summertime comfort zone ranges from approximately 23.5C at 25% relative humidity (RH) to approximately 26°C at 60% RH [ASHRAE, 1995], comfort is experienced at a temperature as high as 32°C at over 85% RH in Bangladesh [Mallick, 1996], within higher ranges of temperatures and relative humidity of 25-31.5°C at 62.2-90% RH in Thailand [Jitkhajornwanich, 2005], as well as higher range

of temperatures and relative humidity of 29.5-36.0°C at 20-80%RH for air velocity of 0.25-2.0 m/s in hot and humid climate like Thailand [Khedari, 2000]. Adaptive models, however, usually predict comfort zones which are closer to the field study results [Chenvidyakarn, 2007]. As attempts to identify the appropriate comfort zones for different local conditions continue, the impact of humans' acclimatization to global warming on their thermal tolerance and preference should perhaps be taken into consideration.

2.4 Passive Design for Tropical Climate

Passive design, known as “bioclimatic design” or “climate responsive design”, is an approach to building design that uses the buildings to minimize energy consumption and improve the thermal comfort. The building form and thermal performance of building elements, including architectural, structural, envelope and passive mechanical, are carefully considered and optimized for interaction with the local microclimate. The ultimate vision of passive design is to fully eliminate requirements for active mechanical systems and to maintain occupant comfort at all times. Inherently flexible passive design principles typically accrue energy benefits with low maintenance risks over the life of the building. Building shape, orientation and composition can improve occupant comfort by harnessing desirable site specific energy forms and offering protection from undesirable forms of energy. Through properly applied passive design principles, building energy requirements could be greatly reduced before consideration of mechanical systems. To beneficially implement the passive design approach, acceptable thermal comfort criteria and related air velocity regarding the proposed comfort zone studied by Khedari should be defined with related air velocity, the local climate data should be analyzed and measurable and reliable energy performance targets should be established clearly.

2.4.1 Building Orientation

Building orientation is the placement of a structure on the property with certain environmental and physical factors taken into consideration [Jifferis, and Madsen, 2005]. It is one of the preliminary factors that the architect determines at the beginning of the design process. Obtaining a proper building orientation contributes greatly to the performance of the system. In the tropical regions the provision of effective cross ventilation under the local wind direction is the major factor that might affect the building orientation. Orientation for ventilation does not imply that building should be perpendicular to the wind direction [Autodesk-Ecotect, 2008]. For Bangkok, oblique winds at angles between 30 and 120 degrees to the wall can provide effective cross ventilation if opening is provided in the windward and leeward walls. However, the wind must be able to flow inside the building from the inlet to the outlet openings.

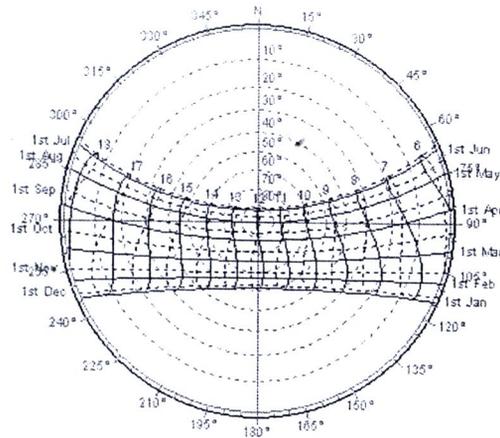


Figure 2.7 Sun path diagram for Thailand at latitude $15^{\circ}\hat{A}$ [Autodesk-Ecotect, 2008].

The most important characteristic of solar position is its seasonal variation. During summer in the northern and southern hemisphere the sun rises slightly of east and sets slightly of west. In winter it rises slightly north of east and sets slightly north of west. In both hemispheres the sun rises earlier and sets later in summer than in winter. The greater the degree of this effect is, the closer the site is to either pole.

2.4.2 Natural Ventilation

Natural ventilation: Unlike fan-forced ventilation, uses the natural forces of wind and buoyancy to deliver fresh air into buildings. Fresh air is required in buildings to alleviate odors, to provide oxygen for respiration, and to increase thermal comfort. At interior air velocities of 160 fpm or 0.8 m/s, the perceived interior temperature can be reduced by as many as 5°F or 2.78°C [Walker, 2008]. However, unlike true air-conditioning, natural ventilation is ineffective at reducing the humidity of incoming air. This places a limit on the application of natural ventilation in humid climates.

Cross ventilation: Wind causes a positive pressure on the windward side and a negative pressure on the leeward side of buildings. In summer, wind is used to supply as much fresh air as possible, while in winter ventilation is normally reduced to levels sufficient to remove excess moisture and pollutants. Wind causes a positive pressure on the windward side and a negative pressure on the leeward side of buildings. To equalize pressure, fresh air will enter any windward opening and be exhausted from any leeward opening. An expression for the volume of airflow induced by wind is as follows:

$$Q_{\text{wind}} = K \times A \times V$$

where; Q_{wind} = volume of airflow (m^3/h)
 A = area of smaller opening (m^2)
 V = outdoor wind speed (m/h)
 K = coefficient of effectiveness

The coefficient of effectiveness depends on the angle of the wind and the relative size of entry and exit openings. It ranges from approximately 0.4 for wind hitting an

opening at a 45° angle of incidence to 0.8 for wind hitting directly at a 90° angle [Walker, 2008].

Stack ventilation: The density of air depends on temperature and humidity (cool air is heavier than warm air at the same humidity while dry air is heavier than humid air at the same temperature). Within the cool tower itself the effect of temperature and humidity are pulling in opposite directions (temperature down, humidity up). Stack effect ventilation is an especially effective strategy in winter, when indoor/outdoor temperature difference is at its maximum. Stack effect ventilation will not work in summer (wind or humidity drivers would be preferred) because it requires the indoors to be warmer than outdoors, an undesirable situation in summer. An expression for the airflow induced by the stack effect is as follows:

$$Q_{\text{stack}} = C_d \times A \times [2gh (T_i - T_o)/T_i]^{1/2}$$

where; Q_{stack} = Volume of air flow (m³/s)

C_d = 0.65, a discharge coefficient.

A = Area of inlet opening (m²), which equals area of outlet opening.

g = 9.8 (m/s²), the acceleration due to gravity

h = vertical distance between inlet and outlet midpoints (m)

T_i = average temperature of indoor air (K), note that 27°C = 300 K.

T_o = average temperature of outdoor air (K)

Design for natural ventilation system in buildings by Whole Building Design Guide recommended that:

- Wind-induced ventilation perpendicular to the summer winds should be maximized.
- Naturally ventilated buildings should be narrow.
- Supply and exhaust openings while minimizing the obstructions to airflow should be separated.
- Window openings should be operated by the occupants.
- Outlet for both buoyancy and wind-induced ventilation should be provided.
- Clerestories or vented skylights for buoyancy ventilation strategy should be used.
- Attic ventilation to reduce heat transfer to conditioned rooms below should be provided.
- Fan-assisted cooling strategies should be used.
- Mechanical cooling in tropical regions should be used.
- Open staircases to provide stack effect ventilation should be used.

2.4.3 Daylighting

Daylighting is a design strategy that employs the available daytime exterior light to illuminate the interior of buildings. Appropriately designed daylighting brings daylight into the interior space without introducing unwanted glare and heat gain. Studies have

shown the value of incorporating daylight into spaces for improved productivity and satisfaction with the work environment. The additional advantage of daylighting spaces is the corresponding reduction in the need for electric lighting during daytime hours. Daylight sensors reduce the light output from the electric lighting system proportionally to the amount of daylight available to maintain a uniform light level throughout the day, saving a significant amount of energy consumed by the building. The amount of daylight is optimum at the time of day when the demand for electrical energy is the greatest, resulting in peak demand reduction and substantial energy savings by balancing of heat gain and loss, glare control, and variations in daylight availability. It provides the benefit for the building and operation as follows;

- Improved Life-Cycle Cost
- Increased User Productivity
- Reduced Emissions
- Reduced Operating Costs

Daylighting provides high illuminance and permits excellent color discrimination and color rendering, while abstaining from disability glare when light scatter occurs within the eye, for well visual comfort. Daylighting design strategies consist of:

- Function of systems, as daylighting system has three major functions: solar shading, protection from glare, and redirection of daylight.
- Location, as daylighting systems can be described in relation to the window pane as exterior, interior, or within the pane.
- Ability of change, as an important characteristic of daylighting systems is adaptable, because the sky condition regularly changes.
- Transparency, as daylighting systems have to provide transparency of material for a view to the outside.

Table 2.4 Daylighting Factor in appearance and energy implications [Ander, 2008].

Average DF	Appearance	Energy implications
< 2%	Room looks gloomy	Electric lighting needed most of the day
2% ~5%	Predominantly daylight appearance, but supplementary artificial lighting is needed.	Good balance between lighting and thermal aspects
> 5%	Room appears strongly daylight	Daytime electric lighting rarely needed, but potential for thermal problems due to overheating in summer and heat losses in winter

Daylight admitted into a building through the holes in external fabric such as windows, and roof lights which in adverse climates generally incorporate glass or an alternative transparent material to heat loss and/or inclement weather spaces. The amount of light received inside a building is usually only a small fraction of that required. Because of modifications imposed by the size and position of openings, it will

also constantly vary owing to the influences imposed on the whole sky, illumination level by clouds, buildings and/or other reflecting planes. Therefore, it is impracticable to express interior daylighting in terms of the illumination actually obtainable inside a building at any one time, for within a few minutes that figure is liable to change with corresponding changes in the luminance of the sky. Daylighting factor (DF) is percentage ratio of the instantaneous illumination level at a reference point inside a room to that occurring simultaneously outside in an unobstructed position. DF 2-5% is good balance between lighting and thermal aspects [Ander, 2008].

2.4.4 Building Envelope

Building envelope is the separation between the interior and the exterior environments of a building. It serves as the outer shell to protect the indoor environment as well as to facilitate climate control. Building envelope design is a specialized area of architectural and engineering practice that draws from all areas of building science and indoor climate control. The physical components of the envelope include the foundation, roof, walls, doors and windows. The dimensions, performance and compatibility of materials, fabrication process and details, their connections and interactions are the main factors that determine the effectiveness and durability of the building enclosure system, regarding protection from weather and climate, indoor air quality, durability and energy efficiency. Building envelope design to protect heat transfer includes four major performance objectives which affects building insulation greatly:

- Structural integrity
- Moisture control
- Temperature control
- Control air leakage

However, there is acoustic problem in the manufactures. Many conventional manufactures do not use roof insulation due to its large amount of insulation have been invested. It affects to the occupants' health and productivity.

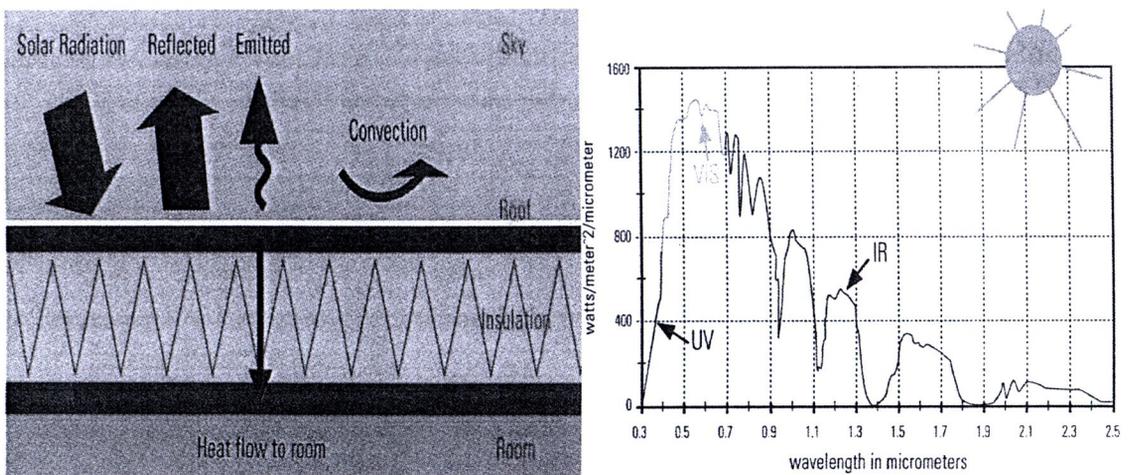


Figure 2.8 Heat transfer through the roof (left) and solar energy distribution (right) [EDR, 2008].

2.5 Minimized Active Design for Industrial Buildings

According to the nature of the natural energy in passive design such as solar energy and wind energy are uncertain, providing minimized active design possibly is essential to assist the building performances. In tropical industrial buildings, the ventilation significantly encourages the comfort condition for occupants. Therefore, photovoltaic (PV) and BIPV, and active ventilation like roof fan will be investigated:

2.5.1 Photovoltaic (PV) and BIPV

Photovoltaic (PV) system is the system constructed by assembling a number of individual collectors called modules electrically and mechanically into an array. One of the most promising renewable energy technologies is photovoltaics. Photovoltaic (PV) are truly elegant means of producing electricity on site, directly from the sun, without concern for energy supply or environmental harm. These solid-state devices simply make electricity out of sunlight, silently with no maintenance, no pollution, and no depletion of materials. There are two basic commercial PV module technologies available on the market nowadays:

- 1) Thick crystals products include solar cells made from crystalline silicon either as single or poly-crystalline wafers and deliver approximately 10-12 watts per ft² of PV array (under full sun).
- 2) Thin-film products typically incorporate very thin layers of photovoltaic active material placed on a glass superstrate or a metal substrate using vacuum-deposition manufacturing techniques similar to those employed in the coating of architectural glass. Presently, commercial thin-film materials deliver approximately 4-5 watts per ft² of PV array area (under full sun). Thin-film technologies hold out the promise of lower costs due to much lower requirements for active materials and energy in their production when compared to thick-crystal products.

Building Integrated Photovoltaic (BIPV) System is the system of integration of photovoltaic (PV) into the building envelope. The PV modules serve the dual function of building skin, replacing conventional building envelope material, and sand power generator. By avoiding the cost of conventional materials, the incremental cost of photovoltaics is reduced and its life-cycle cost is improved. That is, BIPV systems often have lower overall costs than PV systems requiring separate, dedicated, mounting systems. Its complete BIPV system includes:

- a. The PV modules (which might be thin-film or crystalline, transparent, semi-transparent, or opaque).
- b. A charge controller, to regulate the power into and out of the battery storage bank (in stand-alone systems).
- c. A power storage system that generally comprises the utility grid in utility-interactive systems or, a number of batteries in stand-alone systems.

- d. Power conversion equipment including an inverter to convert the PV modules' DC output to AC compatible with the utility grid.
- e. Backup power supplies such as diesel generators (optional-typically employed in stand-alone systems).
- f. Appropriate support and mounting hardware, wiring, and safety disconnects.

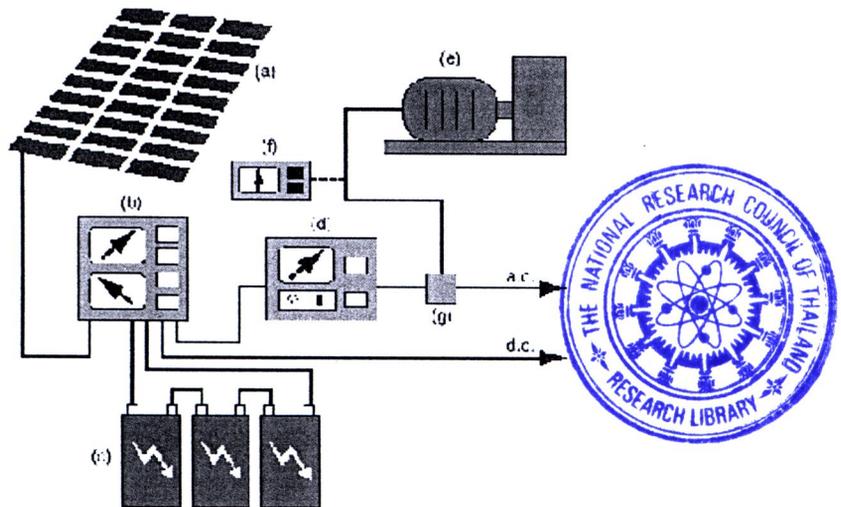


Figure 2.9 BIPV system diagram [RISE, 2007].

BIPV systems can either be interfaced with the available utility grid or they may be designed as stand-alone, off-grid systems. The benefits of power production at the point of use include savings to the utility in the losses associated with transmission and distribution (known as 'grid support'), and savings to the consumer through lower electricity because of peak shaving (matching peak production with periods of peak demand). Moreover, buildings that produce power using renewable energy sources reduce the demands on traditional utility generators, and often reduce the overall emissions of climate-change gasses.

In Thailand, Solar Map developed by DEDE (Department of Alternative Energy Development and Efficiency) and Faculty of Science at Silpakorn University, had shown that the distribution of solar radiation intensity at various places in the country for each month influenced by Northeast monsoon and Southwest monsoon. The majority of the country receives the maximum solar radiation during April and May with values ranging from 20 – 24 MJ/m²-day. Considering the daily solar radiation for an annual average, the areas with the maximum solar radiation are at the northeast covering partly of Nakorn Ratchasima, Buriram, Surin, Srisaket, Roi-et, Yasothon, Ubonratchathani, Udonthani and some parts of the central region at Suphanburi, Chainart, Ayutthaya, and Lopburi, of which the solar radiation receiving of 19 – 20 MJ/m²-day as an annual average and such these areas are accounted for 14.3 percent of an overall country. In addition, the 50.2 percent of the total area receives an annual average of solar radiation at 18 – 19 MJ/m²-day. The total daily solar radiation of an annual average in an overall country area has a value of 18.2 MJ/m²-day and this result indicated of the rather high potential of Thailand solar energy [DEDE, 1999].

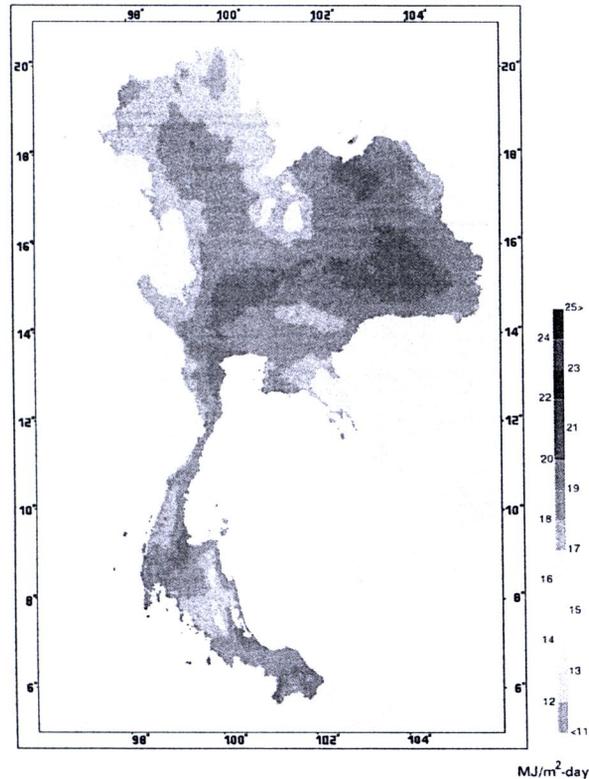


Figure 2.10 Map of Solar energy in Thailand [DEDE, 1999].

Analyzing the solar energy consumption in Thailand, DEDE had implemented the Solar Energy Project throughout the country during 1983 – 2004 for totally 677 sites with a total capacity of 2,031.606 kW classified by these following systems. For Thailand solar energy utilizations from 1983-2003, there were in public sector and educational institutes that installed the PV power generation system, PV water pumping system, including a PV communication system at total 5,763.813 kW.

2.5.2 Fan Assisted Ventilation

Ventilation is requisite for removing moisture and airborne pollutants from a building to protect the occupants' health and comfort. It is important for temperature control, particularly in summer, when the wind is halting and the temperature between inside and outside buildings is not different. Electrical roof fan, the tool of active ventilation installed on the roof, and exhaust ventilation fan installed onto the wall, are electrically powered devices employed to produce an airflow for the purpose of creating comfort (particularly in the heat), ventilation, exhaust, and cooling in minimized active system integrated to assist the passive system needed as possible. Combination of minimized active system between photovoltaic and mechanical roof fan can increase the effectiveness of the ventilation to achieve thermal comfort thoroughly occupants' working hours.

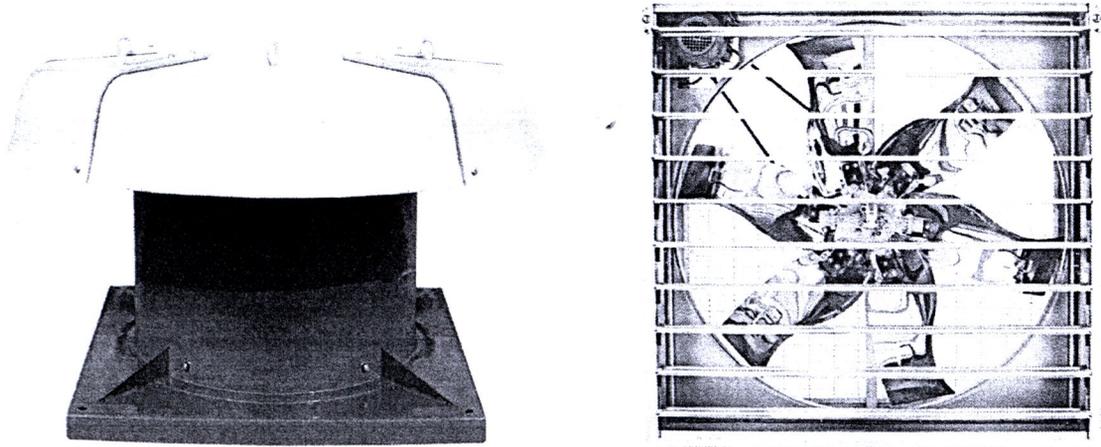


Figure 2.11 Mechanical roof fan installed the roofs (left) and exhaust fan installed on the walls (right) of industrial buildings.

2.6 Integrated Building Design

Integrated building design is a process of design in which multiple practices and seemingly unrelated aspects of design are integrated in a manner that permits synergistic benefits to be realized. The goal is to achieve high performance and benefits at a lower cost than the total of all the components combination. This process often includes integrating design strategies into conventional design criteria for building form, function, performance, and cost. It is most effective when key issues are addressed early in the facility planning and design process. Opportunities of design integration are the most easily identified through an open process of exploring how to combine low-energy-use and other design strategies to achieve the best results. The graph below suggests that the earlier design integration becomes a part of the process, the more successful the results will be. On the other hand, if a building is designed as usual and then high technologies are applied to it as an afterthought, the results will probably be poorly integrated into the overall building design objectives, and the design strategies will likely be expensive to implement the goal. However, after result of interviewing from the data acquisition, it can be used as criteria or design objective.

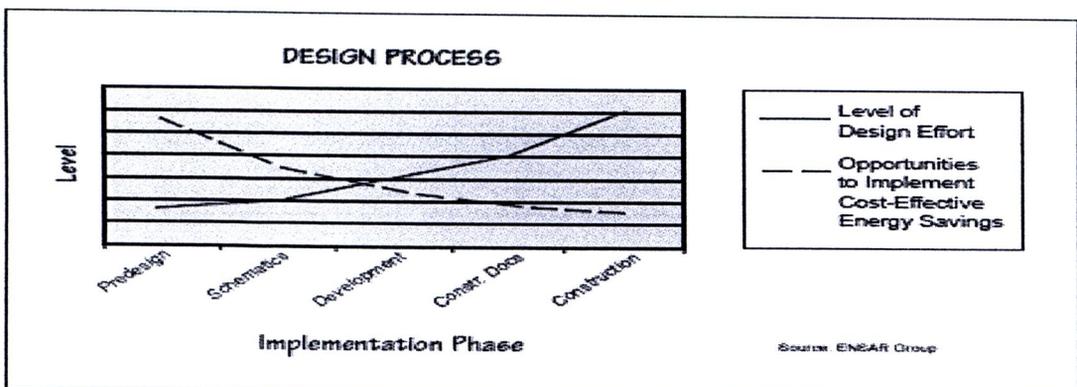


Figure 2.12 Opportunities of energy-efficiency implementation [Wilson, 2001].

The impacts of integrated design compounding upstream energy savings are showing the cascading benefits of adding measures such as extra insulation, more-efficient lighting, and high-performance glazing. The combined measures reduce the air-conditioning load by 35 to 45 percent, depending on their locations [EDR, 2008].

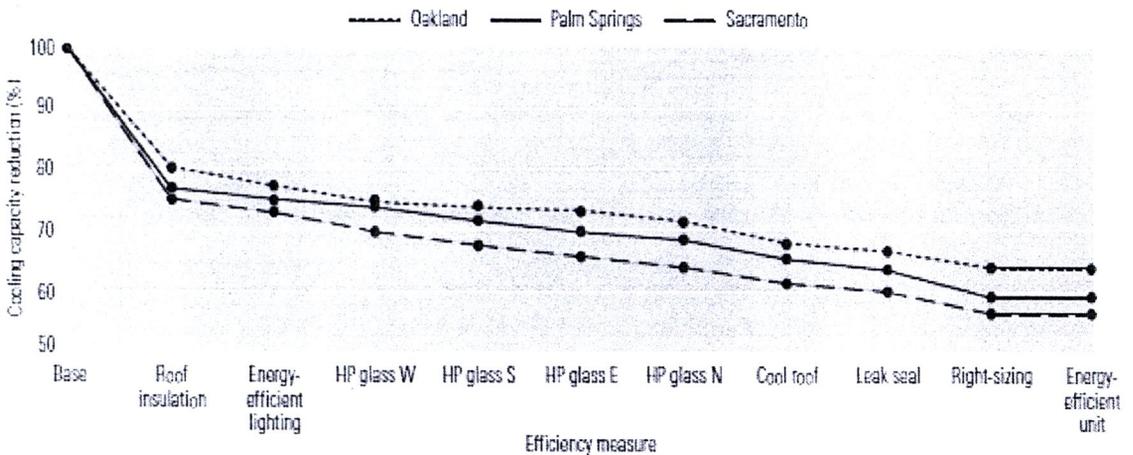


Figure 2.13 The impact of integrated design [EDR: Integrated Building Design, 2008].

To approach passively integrated building design in thermal comfort of industrial buildings in tropical climate like Thailand, the strategies should be considered to the roof material that has most impact factors especially for tropical climate. Since roof is the main area that exposed to the sun radiation.