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Hot and humid climate: prospect for thermal comfort in residential building

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Abstract

Human body response intelligently to different climate conditions by acclimatization and adaptation. The different thermal comfort behavior of human need for people in different climate condition and also for different season clearly shows that the design strategy for building must comply with the locality of the building. Intelligent system may be used for the purpose of compliance to thermal comfort. This paper describes typical strategies to naturally improve comfort in a climate which is hot and humid without air conditioning. Hot and humid countries like Malaysia usually require air conditioning but for residential buildings, the dependence for thermal comfort through air conditioning may be minimized. The prospect for not using air conditioning in rural area is relatively high when good design was adopted.

Keywords: Thermal comfort; Hot climate; Residential building

1. Introduction

Hot and humid climate will develop a condition of thermal discomfort in a building. Perhaps, air conditioning will be an answer to this problem of uncomfortable condition but the process of air conditioning requires energy which most of the people in the developing countries have limited affordability. The challenge to the related researchers is to come out with effective strategies to overcome the state of discomfort with minimum energy utilization.

A building is an enclosure for the benefit of human habitation, work or recreation. The energy demand scenario in buildings can be understood from the experience of developed nation. Malaysia which is on the track towards a developed nation must understand and proactively be prepared for the potential implication. In 1998, the residential and commercial building sectors account for 35% of all U.S. energy-related carbon emission, more than either the industrial or the transportation sectors and since 1990, 48% of the increase in U.S. carbon emissions can be attributed to increasing emissions from

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the building sector [1]. U.S. has only 5% of the world population but used 25% of the world energy. Japan used 6% of the world energy while having only 2% of the world population [2].

Usually the degree of development of a nation is reflected from the total energy per capita consumed. Of the total energy consumption, energy used to provide air-conditioning in commercial buildings accounts for up to 45% of the total electricity consumption in Hong Kong [3]. This situation is expected to be quite similar to other countries with similar climate condition.

One important aspect of energy utilization in building is the thermal behavior. The development of heat transfer analysis for the prediction of the thermal behavior of structural walls is a problem of a fundamental concern in a broad range of engineering applications such as HVAC, estimation of heating and cooling loads in buildings as well as in passive solar design [4].

Considering the average temperature for typical towns in Malaysia (Subang 1998–2002) is about 30.1°C with a standard deviation of $\pm 2.6^{\circ}\text{C}$ during the office hours (8 am–5 pm) while the average temperature after office hours is $26.1^{\circ}\text{C} \pm 1.7^{\circ}\text{C}$ (Table 2), it seems that air conditioning during office hours is a must if people living in the hot and humid climate like Malaysia want a thermal comfort in the building space during the day. Nevertheless, wherever possible if air conditioning can be avoided in the residential houses, without compromising thermal comfort, that possibility must be explored.

The purpose of correct sizing for an air conditioning system is to avoid wastage. It was observed that guidelines developed were based on studies and experiences from some specific places like US. Malaysian Government issued a guide or energy code of practice for buildings to encourage energy efficiency in building design [5] and there is a need for continuous improvement through more extensive studies.

The awareness among Malaysian also drive the establishment of Malaysia's National Energy

policy in 1979 [6], aims to have an efficient, secure and environmentally sustainable supply of energy in the future as well as to have an efficient and clean utilization of energy. Thus the need for energy research and efficiency improvement in buildings is not an option but a must.

Most of the developing nation like Malaysia intends to develop in a sustainable manner. Sustainable development is defined as the development that meets the needs of the present without compromising the ability of future generations to meet their own needs [7]. The task for those who share the intension of sustainable development is to use energy efficiently, intelligently, and wisely. Through the knowledge of thermal comfort behavior of human and energy utilization behavior of buildings, the best strategy can be adopted.

The main objective of this study is to explore the possible means and ways of improving and increasing the effectiveness of energy efficiency strategies of buildings in Malaysia.

This paper will report certain climate behavior that will assist building architects and engineers to design energy efficient buildings.

2. Methodology

Climate data will be analyzed and typical thermal behavior of buildings was evaluated. The analysis will be compared with the state of thermal comfort for people living in Malaysia. From here, it will be established whether thermal comfort can be achieved without air conditioning and if air conditioning is still required, to what extend the air conditioning be designed without overcooling the building space. Overcooling means that extra energy being used and wasted.

The evaluation will include the behavior of human thermal comfort, thermal behavior of building envelope, and Malaysian climate scenario.

Typical result from a house away from the intense urbanization influence will also be analyzed.

2.1. Human and thermal comfort

The adaptive behavior of human body to climate condition shows that human body has the intelligent behavior, able to learn through acclimatization and adaptation process.

Human thermal regulation base on the need to dissipate heat because of metabolism rate demonstrated the learning and adaptive behavior. Efficiency of human body to regulate the heat transfer is limited. Insufficient heat loss leads to overheating and is termed as hyperthermia while excess heat loss results in body cooling called hypothermia. Skin temperature $>45^{\circ}\text{C}$ or $<18^{\circ}\text{C}$ causes pain. Skin temperature associated with comfort at sedentary activities is $33\text{--}34^{\circ}\text{C}$ and decrease with increasing activity [8].

Energy efficiency in buildings refers to the ability of a building to operate and function with minimum energy consumption. If comfort is a pre-requisite for functioning effectively then comfort must not be compromised when adopting strategies to conserve energy.

2.2. Building envelope thermal behavior

Knowledge on the thermal behavior of a building envelop is vital to control the amount of heat that goes into a building space. Experimental and theoretical investigation of effects of wall's thermophysical properties on time lag and decrement factor demonstrates the thermal inertia of the internal space and wall system [9]. Transient heat transfer through insulated walls behave differently if the insulation is on the outside surface or the inside surface [10]. Heat flow estimate using the system of transfer coefficient provide a good indicator [11, 12].

Rate of heat extracted must be just the amount required to maintain the comfort temperature, accordingly, to the total amount of heat generated and dissipated from solar radiation.

Fig. 1 shows the simulated time lag between the instantaneous solar radiations falling from

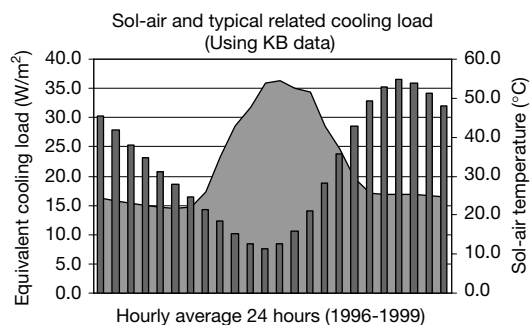


Fig. 1. Time lag between external sol-air temperature and peak cooling load required in a building space.

the sky as compared to the heat that enter the building space [13].

2.3. Malaysian climate scenario

A hot and humid country like Malaysia will experience thermal discomfort if not enough and effective strategy adopted to reduce the extra heat going into a building. Strategy to flush out the extra heat which will improve thermal comfort consumes energy. Since air conditioning consumes a lot of energy and money, not many Malaysian can afford to install air conditioning system in their house.

A typical location in a Malaysian town tends to receive solar radiation of more than 5.0 kWhm^{-2} per day. Thus the total amount of solar energy that has the potential to transform into heat for a normal house of 100 m^2 is 500 kWh (equivalent to RM100.00 @ 20 cent per kWh for Malaysia) per day. Since at present, this energy cannot be explored efficiently, it creates discomfort and becomes a problem that needs to be extracted from the building space. This conditioning process needs energy and if through proper building design strategies, perhaps this discomfort can be reduced or eradicated and more people can live in a more comfortable house.

Fig. 2 shows a typical solar radiation falling onto a horizontal surface in UiTM Shah Alam.

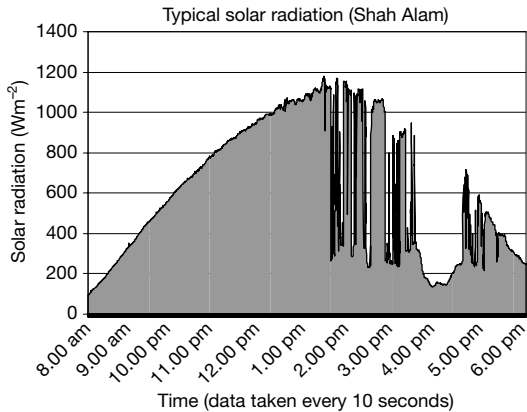


Fig. 2. Solar radiation of 6.05 kWh/m² for a typical day in UiTM Shah Alam (5th May 2003).

Managing and controlling this heat is very important to improve thermal comfort.

Measurement is usually required to response and to control certain phenomena, and thus to achieve a desired objective. Knowing the solar radiation behavior and building envelop characteristics will enable the necessary measures to control and manage the heat effectively. While energy is not wasted, comfort is not compromised (Figs. 3–5).

It has been claimed that a temperature of as high as 30°C in Malaysia can give a relatively comfortable condition [14]. If this claim is true,

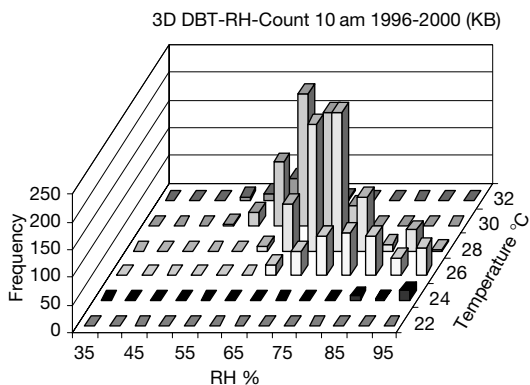


Fig. 3. A 3-D graphical view of frequency distribution for relative humidity and dry bulb temperature.

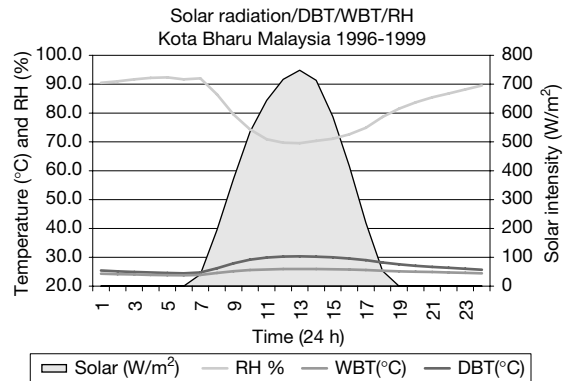


Fig. 4. A typical variation of solar radiation/DBT/RH for a town in Malaysia.

then energy can be saved without compromising thermal comfort, especially beyond office hours. Simulation work shown in Fig. 1 indicates that the maximum heat that goes into a building space is after 4.00 pm due to the heat capacity or thermal mass of a building (Table 1).

The relatively high solar radiation and ambient temperature give rise to a high sol-air temperature. The high sol-air temperature will then increase the temperature difference between external state and internal state. This drive more heat to flow into the building space and higher air condition cooling power is required.

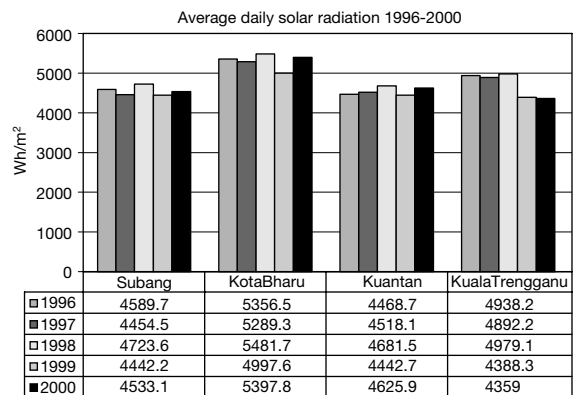


Fig. 5. The average solar radiation of typical town in Malaysia.

Table 1

The average dry bulb temperature, wet bulb temperature, relative humidity and solar radiation for a period of five from 1996 to 2000 years for Subang, Malaysia

Time	DBT (°C)	WBT (°C)	RH (%)	Sol (W/m ²)	Time	DBT (°C)	WBT (°C)	RH (%)	Sol (W/m ²)
1	25	24	90	0	13	30	26	70	749
2	25	24	91	0	14	30	26	70	714
3	25	24	92	0	15	30	26	71	587
4	25	24	92	0	16	30	26	73	416
5	25	24	92	0	17	29	26	75	220
6	24	24	92	0	18	28	25	79	53
7	25	24	92	41	19	28	25	82	0
8	26	25	86	195	20	27	25	84	0
9	28	25	80	372	21	27	25	85	0
10	29	26	74	535	22	26	25	87	0
11	30	26	71	644	23	26	25	88	0
12	30	26	70	717	24	26	24	90	0

It can be observed from Table 2 that the state of temperature and relative humidity is quite far from the thermal comfort of 26°C and relative humidity of 70% from the guideline given by Malaysian Energy Efficient Guideline, thus very hard to achieve thermal comfort during office hours from natural ventilation. The situation is different for the period of outside office hours.

2.4. Air flow and effective temperature

Factors that have influence on thermal comfort to human include dry bulb temperature, relative humidity and air flow. Increase in relative humidity from 50% will increase the effective or

apparent temperature while air flow will reduce the effective temperature. Higher mean temperature will lower the offset temperature require to acquire thermal comfort.

Survey of human thermal response in South East Asia produce the following equation for estimating thermal neutrality T_n base on the mean monthly dry bulb temperature T_m :

$$T_n = 17.6 + 0.31 T_m, \quad (1)$$

For 90% acceptability for thermal comfort suggested is $T_n \pm 2.5$ K and 80% acceptable for comfort suggested $T_n \pm 3.5$ K [15].

Table 2

Design parameters for building design in a typical Malaysian town

Subang	Office hours (0800–1700)		Outside off hours (1800–0700)	
	Temp (°C)	RH (%)	Temp (°C)	RH (%)
1996–2000				
Maximum	37.0	98.0	33.7	99.0
Percentile (99.8%)	35.9	96.0	32.2	97.0
Average	30.1	67.8	26.1	86.8
Percentile (0.2%)	23.5	39.0	22.5	54.0
Minimum	22.5	32.0	21.8	44.0
Standard deviation	2.6	12.4	1.7	8.0

The average dry bulb temperature for Kota Bharu (a town in Malaysia) from 1996 to 2000 is 27.30°C, thus the thermal neutrality will be

$$\begin{aligned} T_n &= 17.6 + 0.31 \times T_m, \\ &= 17.6 + 0.31 \times 27.3, \\ &= 26.19^\circ\text{C}. \end{aligned} \quad (2)$$

Comfort zone for 80% acceptable, then temperature must not be more than

$$\begin{aligned} &= 26.19^\circ\text{C} + 2.50^\circ\text{C}, \\ &= 28.69^\circ\text{C}. \end{aligned} \quad (3)$$

For 90% acceptability, minimum temperature range for comfort will be 26.19°C + 3.50°C = 29.19°C.

The air flow to off set the excess temperature is given by

$$V = (\text{excess temperature}/3.67) + 0.2 \text{ m/s} \quad (4)$$

Let say, the excess temperature is 2.1°C, then the air flow required = 0.7 m/s for the upper limit.

To compensate for the temperature of thermal neutrality, the air flow required is 1.5 m/s. High humidity and high temperature (above 32°C) makes heat more harmful because it slows the evaporation of perspiration—the body's natural cooler.

The effective temperature ET is the temperature of an environment at 50% relative humidity that results in the same total heat loss from the skin as in the actual environment. It combines temperature and humidity into a single index so that two environments with the same effective temperature should produce the same thermal response even though the temperatures and the humidities may not be the same [16].

3. Thermal evaluation

A house with various thermal comfort strategies was identified and temperature for a period of four days, every 5 min were taken for various location of the house.

The three design strategies were adopted for thermal comfort in the building are

(i). Cross ventilation in the attic: Heat trapped in the attic will transfer into the upper floor. When cross ventilation allows free flow of air from outside to the attic, heat generated in the attic will also be flushed out. The graph in Fig. 2 shows that there is a significant temperature drop in the attic.

(ii). Facilitate air flow: Facilitating air flow from the lower floor to the upper floor and vice versa within the building space improves comfort. The interior house design and furniture must also be place to facilitate the air flow. This will reduce thermal stress within the building space.

(iii). Insulated wall: While the wall constructed pre-cast and insulated within using polystyrene, the wall repel most of the heat. The external wall may be hotter but the inner wall was found to be cooler.

4. Results and discussion

Temperature measurements were made at various location of a terrace house, adopting various strategies to facilitate air flow. What was observed is that if there is no air flow, only 44.0% occurrences is below 28.69°C but an air flow of 0.7 m/s will improve the occurrence of thermal comfort to 100%.

The outside average temperature is quite close to the inside average temperature. The outside variation has limited influence on the inside variation where the variation is much less, compared to the outside. Fig. 6 also indicates that the building is able to protect from the intense heat from outside.

Table 3
Hypothetical influence of air flow

	DBT less than	Air flow (m/s) %		
		0	0.7	1.5
T_n	26.19	0%	0%	100%
$T_n \pm 2.5$	28.69	44.0%	100%	100%
$T_n \pm 3.5$	29.69	100%	100%	100%

Table 3 shows that without air flow, there is no count of temperature below the neutral temperature while only 44% occurrence below 28.69°C.

An air flow of 0.7 m/s will give rise to comfort while if the air flow is more than 1.5 m/s, the space will be comfortable throughout.

An air flow if less than 0.2 m/s would not be effective while more than 2.0 m/s will create other related problem, e.g., paper flying from the desk.

Table 4 shows that the building space, whether upper floor or lower floor, the temperature is still below 30°C which is consider relatively comfortable if an air flow of at least 1.0 m/s¹ is created. Relative humidity measured for the same period is less than 80%. For that reason, an air flow through ventilation can add up and improve comfort.

5. Conclusion

A hot and humid country like Malaysia will experience thermal discomfort if not enough and

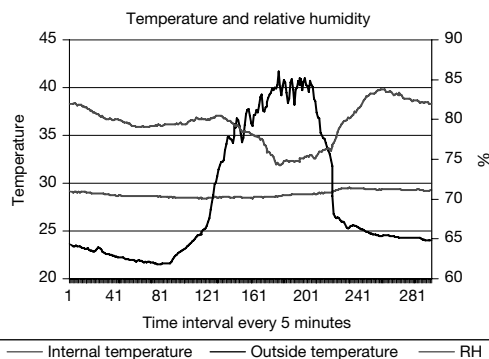


Fig. 6. The variation of temperature for the inside of the evaluated house.

effective strategy adopted to reduce the extra heat going into a building. Strategy to flush out the extra heat which will improve thermal comfort consumes energy. Since air conditioning consumes a lot of energy and money, not many Malaysian can afford to install air conditioning system in their house.

Knowing the solar radiation behavior and building envelop characteristics will enable the necessary measures to control and manage the heat effectively. While energy can be conserved, comfort is not compromised.

The prospect for limited thermal comfort through passive cooling is limited to the rural areas. For urban areas, thermal comfort can be improved through enough microclimate strategies within the surrounding areas of the building. Else, thermal comfort cannot be achieved through natural ventilation.

Table 4
The average temperature profile of the evaluated house

	Maximum	90% less than	80% less than	Minimum
Roof top	42.16	38.18	36.19	22.36
Attic	31.90	31.41	30.31	24.40
Upper floor	29.50	29.10	28.70	25.95
Ground floor	29.10	28.70	28.30	26.34

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