Sustainable air-conditioning for the tropical buildings

Asrul Mahjuddin Ressang Aminuddin and S. P. Rao

Centre for Equatorial Sustainable Development
Faculty of Built Environment
University of Malaya

Abstract

Tropical climates are thermally uncomfortable and are mostly unhealthy to the occupants of the modern skyscrapers. The temperatures are usually on the hot side coupled with high relative humidity. The population living in the tropics, especially in Malaysia, is getting affluent and can afford air-conditioning their residences and offices. This leads to increased electricity consumption in the buildings. However, switching off the air-conditioning is not an option for the modern buildings as it would affect the health of the people and their productivity. This paper proposes innovative indoor units that will contribute to energy conservation by utilising principles of partial air-conditioning. The outdoor units could be utilised for clothes drying or for providing hot water to the occupants of the building. This will successfully address the issues on sustainable building technologies and techniques. It will lead to considerable savings in energy consumption in buildings in the tropical climate.

Keywords: Sustainable buildings, partial air-conditioning, total energy systems

Introduction

In the humid tropical climate of Malaysia, the differences between indoor and outdoor air temperatures are marginal. Sun is the single most important natural element to be considered in the building design. It affects virtually every design decision and has a direct impact on the energy budget of the building. Thermal Comfort analysis may be used to assess a given environment and is important in determining an energy management strategy in buildings. The human body temperature regulation determines the physiological thermal comfort of the occupant of a room, as the human body exchanges heat with the environment. Heat is exchanged by radiation, convection and evaporation. The heat is primarily produced by metabolism. During normal rest and exercise, this results in an average temperature of the vital organs of near 37 °C.

Climate of Malaysia

Table 1 is a summary of 30-year average of dry bulb temperatures, relative humidities and mean wind velocities for various months in Kuala Lumpur, Malaysia. Malaysia experiences high relative humidities, varying from 67% to 96 % with an average value of around 80%. The outdoor air temperature varies from 24 °C. to a maximum of 33 °C. There is no dominant wind direction.

Thermal comfort

Man has always striven to create a thermally comfortable environment. This is reflected in building traditions around the world – from the ancient to the present day. Creating a thermally comfortable

		Number of the years	JAN.	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual
TEMP.	MEAN	30 years	26.9	27.2	27.5	27.6	27.7	27.8	27.3	27.3	27.1	27	26.6	26.6	**27.23**
	MEAN OF MAX.	30 years	32.5	33.3	33.5	33.5	33.3	33.1	32.6	32.7	32.5	32.5	32.1	31.9	**32.79**
	MEAN OF MIN.	30 years	23.1	23.4	23.8	24.2	24.3	24.1	23.7	23.7	23.6	23.7	23.6	23.3	**23.71**
Relative Humidity (RH)		30 years	78.4	78.2	79.3	81.5	80.6	78.9	78.9	78.9	80.6	81.6	83.6	81.9	**80.20**
The Mean of Wind Speed(m/s)		30 years	1.02	1.10	1.06	1.00	1.00	1.07	1.17	1.15	1.03	1.16	0.97	0.90	**1.05**

Table 1 : Monthly Means of Outdoor Air Temperatures, Relative Humidities and Wind Speeds at Kuala Lumpur, Malaysia

environment is one of the most important parameters to be considered when designing buildings. Thermal comfort has been defined as the condition of mind that expresses satisfaction with the thermal environment. The reference to mind emphasizes that comfort is a psychological phenomena too.

Thermal comfort and discomfort

There is a wide variation in thermal requirements and in thermal sensitivity between individuals in a given group. The aim should be to create conditions for optimal thermal comfort to satisfy the highest possible percent of the group. Probably at best only 80% of the occupants would be comfortable at any one time under the best possible conditions. The individual differences in preferred temperatures would arise in part from the differences in the clothing, activity and acclimatisation to the local climate. Hence results of comfort studies made elsewhere may not necessarily be applicable to the Malaysian conditions.

Criteria for thermal comfort in the tropics

The factors, which affect indoor thermal comfort, are the air dry bulb temperature, humidity, air movement and radiation if the Sun penetrates into the building and causes re-radiation. In order to combine the effect of these factors several thermal comfort indices have been proposed. These indices attempt to combine the effect of two or more variables into a single variable on humans. Several such indices have been developed by researchers.

Thermal comfort studies in Singapore

The thermal comfort studies conducted locally are the Equatorial Comfort Index by Webb (1959) and comfort surveys by E.P. Ellis (1953). From the results of observation by 14 people Webb (1959) suggests first a "Singapore index" which includes DBT, WBT and air movement. Secondly Webb (1959) builds up the "Equatorial Comfort Index" with a nomogram from which neutral conditions could be found. From observations made by 152 residents in two separate studies, Ellis (1953) gives separate effective temperatures to British and Asian male and female residents in Singapore. Humphreys (1975) after examining more than 30 field studies of thermal comfort proposes a method of estimating the temperature of thermal neutrality as given in equation 1,

$$T_n = 2.56 + (0.831 \cdot T_m) \qquad (1)$$

Where,

T_n = temperature for thermal neutrality and

T_m = mean air temperature.

The same thermal comfort scale used in different places may yield different results, possibly due to the clothing, work habits and acclimatisation. In order to assess the thermal environment an appropriate scale and neutral zone should be determined first.

As mentioned above, the work done by Webb (1959) and Ellis (1953) are better known for the evaluation of thermal comfort in Singapore. Webb (1959) developed the "Singapore Index" as expressed by equation 2,

$$\Theta = 0.5 \cdot (t + t_w) - 0.25 \cdot V^{1/2} \qquad (2)$$

Where,

Θ = Singapore Index in °F

t = Dry bulb temperature °F

t_w = Wet bulb temperature °F

and

V = Velocity of air m/s

Θ was fixed by Webb at 78.7 ± 0.75 °F (25.94 ± 0.42 °C) when the subjects felt neither warm nor cold. Later Webb combined his work with others and developed the "Equatorial Comfort Index Nomogram".

Rao and Ho (1979) conducted experiments in six single storey buildings without sidewall enclosures (hawker stalls). The designs of the buildings were fairly uniform. However the environment inside had been made warm by the radiant heat from the cooking stoves as well as by the solar radiation absorbed and reradiated by the roof. The subjects came from all walks of life. They were asked to evaluate the environment for thermal comfort. A total of 435 comfort survey opinions were collected. The assessment percentages were compared with the corrected ECI (which was corrected for radiation). The results are summarised in Figure 3. The optimum neutral temperature was 25°C (77°F), when corrected for radiation, whereby 59% of the subjects felt neither warm nor cool. "Predicted Mean Vote" has been proposed by Fanger (1972) by formulating a thermal comfort equation which allows the prediction of the thermal sensation of a group of persons in an arbitrary, but static, climate. The basis of this equation was obtained from experiments, in which the thermal sensation vote indicated the personally experienced deviation to the heat balance -3 {cold} to +3 {hot}; seven point scale, where 0 = neutral (optimum)). Applying this PMV-equation, the thermal sensation for a large group of persons can be determined as a function of the activity, clothing, air temperature, mean radiant temperature, relative air velocity and air humidity. The PMV values as measured indicated 25°C as the mid-range temperature. There was good agreement between the opinion survey and the PMV data when Webb's CECI was used.

Lim and Rao (1977) conducted studies in some junior colleges and secondary schools. The number of people in the rooms was almost the same though might not be equal. Windows were on both sides of the room even though the actual site configurations may slightly vary. The age grouping and the type of work done were similar. Some 160 teenagers and young adults were asked to evaluate their environments and a total of 1319 recordings were made at 1/2 hourly interval during a normal day for each location using Fanger's comfort meter, anemometer, psychrometer and solarimeter. The results are summarised in Figure 4. The survey at schools gives similar results as the hawker centres. There was no need to correct for radiation and air temperature was used for the computations. The neutral temperature according to ECI was 25.2°C and is almost identical to the figure obtained earlier. Similarly the PMV value of the comfort meter was recorded at 25.1°C. It may be concluded that the ECI is still applicable with the amendment of the neutral condition to 25°C instead of 26°C as originally proposed by Webb.

Thermal comfort studies in Malaysia

For comparison purposes, the results of the criteria from several sources are summarized in Table 2. For example, the temperature range obtained from Zain (2000) is between 24.5-28.0 deg C, which is lower than Abdulmalik (1993) but higher than the range suggested by the Ministry of Energy, Telecoms and Posts. This table comprises eight thermal comfort studies, four of which have been carried out on Malaysians either in climate chambers or as field studies. The outcomes of the studies differ slightly due to different test procedures. However, most of the studies seem to agree on a Malaysian comfort zone of around 25 deg C air temperature.

Air-conditioning

Air-conditioning is defined as a process that heats, cools, cleans and circulates air and controls its moisture content. Ideally, it does all these simultaneously and on a year round basis. Thus air conditioning makes it possible to change the condition of the air in an enclosed area. Since modern man spends most of his life in enclosed spaces, air conditioning is actually more important in the present day context. Figure 1 shows a simple air-conditioning system.

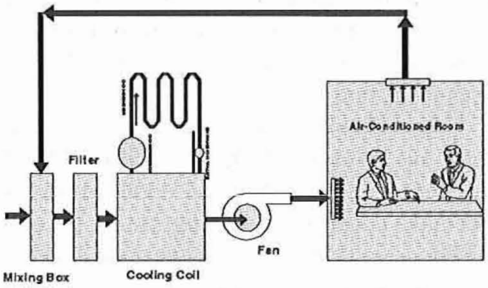

Figure 1 : Simple Single zone air-conditioning system

Air-conditioning of residences in the hot-humid tropical climate

Almost all of the split system air-conditioning units utilise the mechanical vapour compression refrigeration cycle shown in Figure 2. The split unit system contains two major elements: one is the indoor unit that blows the cool air, called fan-coil unit, second is the outdoor unit as shown in Figure 2, called a condenser

Table 2 Thermal Comfort Studies in Malaysia

Study	Comfort Zone (°C)	Type of Study	Humidity range (%)	Air Velocity (m/s)
Zain Ahmed (2000)	24.5-28.0	Field Study	72-74	0.3
Abdulmalik (1993)	25.5-29.5	Climate Chamber	45-90	-
Davis (Mohamed Ali, 2004)	24-28	Field Study	-	-
Ministry of Energy, Telecom and Posts, Malaysia (Mohamed Ali, 2004)	22.0-26.0	Field Study	-	-
Abdul Rahman (Mohamed Ali, 2004)	27.4	Climate Chamber	54 -76	0.1

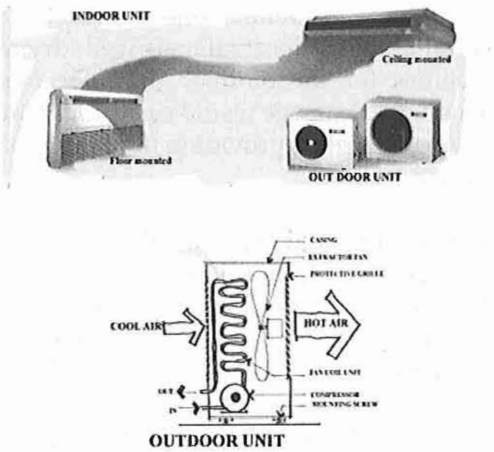

Figure 2: Components of a typical split-system air-conditioning

unit. These two are linked with copper piping that carries the refrigerant gas. The out door unit work as chillers, where the refrigerant is compressed and pumped back to the indoor unit. The outdoor unit contains an electric motor to blow away the heat as a result of the mechanical vapour compression of refrigerant. It is worthwhile to study the various potential of this reusable energy, as it has significant impact on the architectural design and environment such as in Malaysia.

Using the waste heat from the condenser (outdoor unit)

Currently the out door unit are usually installed at the discretion of installer. The maximum length of the refrigerant copper pipes governs the limit of furthest distance. Usually there are no big problems in selecting the location for the outdoor unit for the detached houses (bungalows) as there are many walls to choose from. Therefore it is easy to gather outdoor units together to collect the hot air from it. In comparison to the apartment unit, the designer usually would allocate a drying yard near the kitchen for laundry or general cleaning facilities. Outdoor units could be placed in the drying yard and if the waste heat is channelled properly to help speed up drying the laundry. Our test showed that temperature of the waste heat is about 40 ° C with the humidity about 38 %. Placing the outdoor units in the yard also will help in reducing the number out door unit arbitrarily installed on the building facades. The average size of out door unit for 3 TR air-conditioning split unit systems is 1030x850x 400mm. It can be seen from quite far away distance especially when they are installed high up.Individual units of drying facilities can be placed in the drying yards to

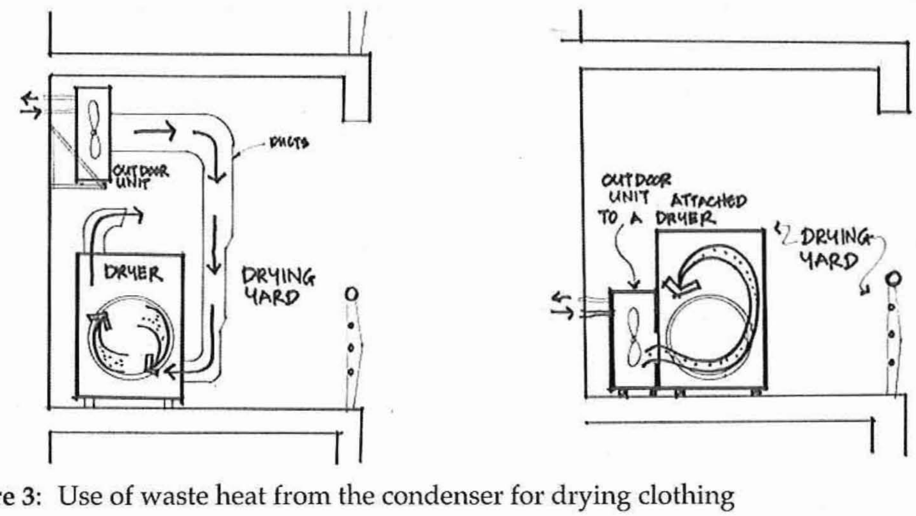

Figure 3: Use of waste heat from the condenser for drying clothing

reduce unsightly of direct sun drying at the balconies. These unpleasant views are more frequently occurs at the medium or low-income apartments. Reusing the waste heat can help to reduce the overall temperature around the drying yard as they are usually design in a clusters and it would make the unit run efficiently. Re-channelling by capturing the hot air could reduce to muffle the noise created by the units. One unit of 1 hp outdoor unit could produce a noise level of about 60dB. The out -door unit will get noisier as the number of them and the size of the unit is increased.

There are two basic ways to channel the waste heat can be utilized.: One method is to use it directly where the heat from one outdoor unit would be channeled and directed to the clothes drying lines, refer to Figure 3. The low humidity air and the air flow from the outdoor unit will evaporate the wet laundries faster than direct sunlight. In fact, prolong direct sunlight exposure will fade the cloth. Second method is to control the method of exhausting the heat using a simple ducting system to a tumble dryer as shown in Figure 3. The conventional dryer can be used here minus the heating element and fan as the waste heat is hot and airflow speed is sufficient to dry the cloth. The air speed of the wasted heat is about 1 meter per second. In the early stage of designing a high-rise residential unit, the architect could plan and locate the air-well/drying facilities for the outdoor units location. This hot air passage would run through the drying yard thus providing the communal drying facilities.

Use of the indoor fan-coil unit as a personal air-conditioning system (Concept of partial air-conditioning)

It is proposed to utilise the concept of partial air-conditioning as shown in Figure 4 for energy conservation in buildings. It is well known that a slight air movement can lead to a better sensation of thermal comfort as it increases evaporative cooling. Figure 5 shows the effect of air motion on the predicted mean votes for thermal comfort. As the air velocity is increased incrementally, there is a marked improvement in thermal comfort. Too high a velocity is uncomfortable to work with. A velocity of about 0.15 m/sec can be generated by the use a ceiling fan and this can give the same thermal comfort as full air-conditioning, without the additional energy cost.

Conclusions

This paper proposes innovative indoor units that will contribute to energy conservation by utilizing the principles of partial air-conditioning. The outdoor units could be utilised for clothes drying.

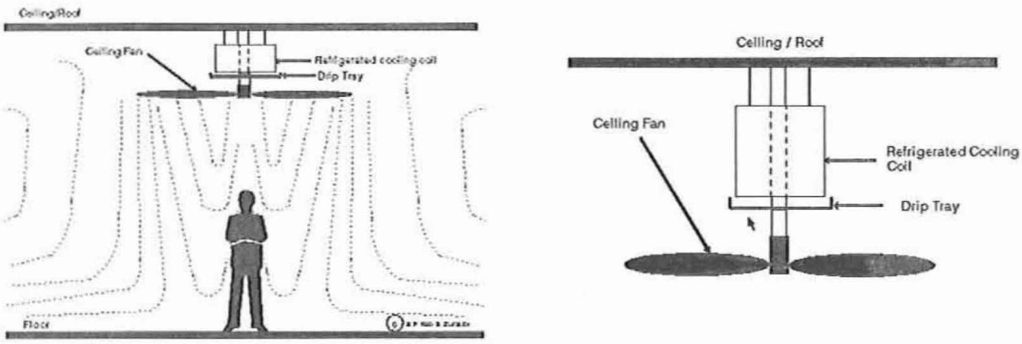

Figure 4 : Concept of Partial air-conditioning for the tropics

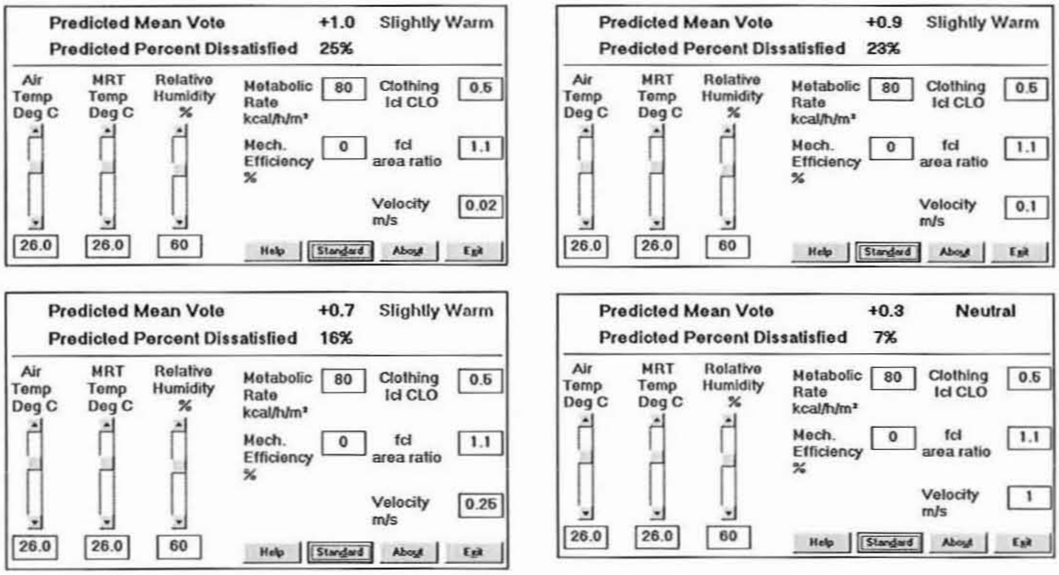

Figure 5 : Concept of Partial air-conditioning and thermal comfort

This will successfully address the issues on sustainable building technologies and techniques. It will also lead to considerable savings in energy consumption in buildings in the tropical climate.

References

Abdulmalik, A. and Young, A. (1993). Thermal comfort study as an aid to determine energy savings in building in Malaysia, Proc.Energex 93,Vol.II, Seoul.

Ellis, E.P. (1953). "Thermal comfort in warm and humid atmospheres", J of Hygiene, v 51.

Fanger,P.O. (1972). "Thermal Comfort: analysis and applications in environmental Engineering". New York: McGraw-Hill Book Co.

Humphreys, M.A. (1975). " Field studies of thermal comfort compared and applied" , BRE Current paper CP 76/75, August.

Malaysian Meteorological Station Office in Petaling Jaya, Klang Valley, Selangor, Malaysia (2006).

Mohamed Ali (2004). "Dynamic Thermal Performance Of The Living Room In The Terraced House In The Klang Valley, Malaysia", Ph.D thesis, University of Malaya.

Rao, K.R and Ho, J.C. (1979). " Thermal comfort in hawker stalls in Singapore", Applied research corporation, Singapore.

Lim, B.P. and Rao, K.R. (1977). " Thermal comfort studies in some Singapore schools", J. Singapore National Academy of Sciences, v 6.

Rao, S P, (1993). "Heat and glare problems and ameliorating measures in an office building in Singapore". In CLIMA 2000, edited by Dr David Arnold, compiled by CIBSE, UK, pp. 1-10.United Kingdom: CIBSE, 1-3 November.

Webb, C. G. (1959). " An analysis of some observations on thermal comfort in an equatorial climate", British J of Ind. Medicine, v16, pp 297-310.

Zain Ahmed, A. (2000). "Daylighting and shading for thermal comfort in Malaysian buildings", Ph.D thesis, Universiti Technologi MARA and Universiti Kebangsaan Malaysia, Malaysia