Residential Space-Cooling Energy Use

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Abstract

This study's purpose is to evaluate air-conditioning energy consumption by conducting interviews and recording data from 50 single-family houses. All study houses applying similar styles of tropical architecture and methods of building construction, with the U-values for building materials having moderate levels of thermal resistance. The finding reveals that the majority of households spends more than 37% of their energy costs on cooling during the raining season and estimating to increase by the drought seasons. The greater use of air-conditioners have resulted in an increased purchasing power of the population.

Keywords: Single-family house, thermal performance, landscape design, evapotranspiration

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1.0 Introduction

Energy costs and environmental concerns have made it more important than ever to find ways to reduce energy consumption. As human consumption of energy continues to increase, it is important to improve the energy efficiency of our built environment. There are many ways to improve the energy efficiency of the built environment. Envelope technologies, such as wall, floor, and roof insulation, high-performance windows and doors, and air infiltration, have a priority role in producing a comfortable interior. However, buildings in hot and humid climates still frequently depend on energy use for cooling. The amount of energy used is dependent on some variables, such as climate, a building's orientation, and the structure and materials used in the construction of the building envelope. This study will evaluate the cooling energy use in hot and humid tropical environment by conducting interviews and recording data of building construction, and human factors from 50 single-family houses.

2.0 Literature Review

The four physical climate parameters are air temperature, mean radiant temperature, air velocity, and humidity (Alread & Leslie, 2007; Fanger, 1973; Lechner, 2000; Moffat & Schiler, 1981). According to Givoni's (1969), the comfort zone is supposed to be between 20 and 27°C in temperature, and relative humidity (RH) between 20 and 80%. The air velocity indoors that normally occur in a small room is about 0–0.5m/s. Due to the differences between day and night temperatures, it is important to raise the comfort level at night. Physical strength and mental activity of all people are improved within a comfort zone (Furuta, 1978).

The building envelope is the interface between the exterior of the building and the interior environment. One of the most important factors affecting building envelope design is the climate (Misni, 2013). The different components of the envelope, such as foundation, walls, beams, connectors and roofing materials, can create paths for the transfer of thermal energy, which conduct heat in or out of the envelope (Hartweg, 2007). The core purpose of the building envelope is to improve the comfort level for occupants by protecting them from moisture, temperature and weather elements (Alread & Leslie, 2007). Krigger and Dorsi (2004) stated that glass transmits between 20–84% of the sun's heat. Windows must be shaded from direct solar radiation (Lechner, 2000) and hence modifies the heat flow to the interior (Givoni, 1969). The use of light coloured surfaces of buildings is practiced in areas which have a large amount of sunshine. Taha (1997) suggested that reasonable increases in urban albedo can achieve a decrease of up to 2°C in air temperature.

Electrical energy is an essential energy source that has been drastically increasing in cost. In Malaysia, demand for electrical energy is increasing each year, at an average rate of 11.2% per annum (Nasution & Hassan, 2009). The consumption of electricity includes the application air conditioning systems for cooling. Growth in the use of air conditioning has increased in residential buildings in Malaysia about 253,399 units in 1991 (Mahlia, Masjuki, & Choudhury, 2002). This figure is predicted to reach about 1,511,276 units in the year 2020. However, the source of energy continues to decrease; it is important to improve the energy efficiency of our built environment.

3.0 Methodology

3.1 House study

Data collection and interviews were carried out on 50 single-family houses in Putrajaya and Shah Alam, Selangor, Malaysia. The houses were randomly chosen from both cities. In general, most of the houses represented a conventional style of tropical architecture. They are laid out in a grid-iron manner, and the house construction includes plastered masonry infill walls to a reinforced concrete structural frame. The common typology is single-family houses with medium sized fenestration, and hipped-gable timber roofs that are covered with clay or concrete tiles.

3.2 Fieldwork period and analysis

The data collection sheets for building construction and cooling energy use, and interviews of the occupants were completed throughout the Shah Alam and Putrajaya areas over 3 months from January to March 2010. Weather data were obtained from the Malaysian Meteorology Department (2008-2009). The time for data collection and interviews for the houses is averaged 2 houses per day. The results of the influences on the amount of cooling energy used have been divided into two parts: building construction, and human factors. These variables will be calculated and evaluated by statistical analyses using origin version 8 software.

4.0 Results and Discussions

4.1 Weather

The weather data showed typical patterns of data, with Shah Alam experiencing slightly higher temperatures than Putrajaya. During the rainy seasons, from November to March, the mean temperature in these cities was relatively stable, ranging between 24 and 33°C. In contrast, during the dry season from May to September, the temperature was up to 2°C higher than usual temperatures, with less rainfall. May was the hottest month, with mean temperatures ranging from 25.5 to 34.4°C. According to Olgyay (1963), Givoni (1969) and Montgomery (1987), the best temperature range for human comfort is 20–27°C.

The RH levels for each of the study areas were slightly different. RH between 40–70% does not have a major impact on thermal comfort (Oughton & Hodkinson, 2002). On average, the RH in the study areas was between 70–88%, which represents uncomfortable levels. Olgyay (1963) suggests that the wind is particularly important for comfort when temperatures are above 29°C and the relative humidity above 50%. Both areas of the study received moderate wind with similar speeds (38–41% of the time), with slight differences in a calm atmosphere (7% of the time). This moderate wind speed can increase heat loss through convection, which decreases the air temperature and humidity levels. Solar radiation was abundant. The ranged of solar radiation in both cities are from 16.3–18.3MJ.m^{-2} with 6.9–7 Okta of the cloud cover.

4.2 Building construction

4.2.1 Construction type and materials

The results found that in the four stages of construction, similar construction methods and materials were used for each of the houses.

Table 1. An average floor and roof surfaces

Building			Average building area (m^2)				
Age of const.	No.	%	Ground floor	Upper floor	Total floor	Roof	Car Porch
0–9	17	34	234.1	220.0	454.1	264.4	27.9
10–19	3	6	245.0	245.0	490.0	283.3	40.0
20–29	23	46	206.9	201.5	411.9	254.5	30.9
30–40	7	14	171.4	171.4	342.9	218.6	30.0
All	50	100	213.5	206.2	421.3	254.6	30.3

Table 1 shows that the main structures were all reinforced concrete column and beam. The materials used for the building envelopes were floored building from reinforced concrete, brick walls with cement plaster and pitched roof structures that were built from preserved hard woods. Approximately 76% of the houses had concrete tiles on the roof, and 26% used clay tiles in various colours.

Table 2. Construction types and U-value

Const. type	Characteristics	Frequency	Percentage	U-value*
Column & beam	Reinf. Concrete	50	100	3.46
Floor	Reinf. Concrete	50	100	4.20
Wall	Bricks	50	100	4.37
Roof type	Pitch	50	100	-
Roof structure	Wood	50	100	-
Roof material	Concrete tiles	37	74	3.46
(Insulation under)	Clay tiles	13	26	3.46

* U-value unit = W/m^2·°C

The U-value is the coefficient of heat transmission used to express the amount of heat that is transferred through materials. The lower the U-value, the greater a product's resistance to heat flow, and the better its insulating value (Darling, 2011). The U-value for each material provided moderate thermal resistance for the houses, which also helped to delay and reduce heat gain to the buildings.

4.2.2 Building orientation

For the majority of the houses, the main facades were orientated to face the access roads in the northwest-southeast or north-south configurations. Orientation in these directions meant the houses were mainly only exposed to indirect solar radiation, which minimised heat gain. Glazed windows and exterior doors with shading devices were found on all front elevations and back elevations, which were exposed to direct and indirect solar radiation.

4.2.3 Interior and semi open spaces, and ceiling height

The living and dining rooms were connected to the main garden area, while the kitchens were directed to edible landscape gardens. Most of the master bedrooms also had a veranda, which served similar functions. The houses also had an open car porch located at the front of the house, which was connected to the entrance area and provided shade to the entrance doors and windows that faced them.

Similar to the exterior walls, all interior walls and ceilings were painted light colours, as well as floors finished. Light colours can reflect light and, therefore, reduce heat gain in interior spaces. Ceiling heights of the houses were around 2.8–3.0m, which it helps to circulate air. The ceiling also acted to delay the heat gain from the roof space at the upper level of the house. Each house had a well-insulated roof, a layer of aluminium foil underneath the roof cover. These insulation layers reflected and reduced the heat gain from the roof surfaces, which helped to produce a cool and comfortable interior environment.

4.2.4 Building envelopes

In this study area, the main building envelopes were brick walls. All houses had a square or a rectangular layout with similar total areas of walls in all directions ($84.1m^2$). Glazed surfaces should be shaded properly to reduce heat gain in a building. On average, houses in the study area had a glazed opening of approximately 13% of the floor area. The locations of openings were spread on all sides of the house, with an average of 13.5m2 per side.

All houses in the study areas had gables or hip roof shading devices that were between 0.75–3m wide. As well as providing shade, these helped to protect the glass surfaces from direct and diffused solar radiation during the peak time of the day in the late morning until afternoon (11.00–15.00 hours), particularly on the east and west sides. The reinforced concrete of ground floors, with their beams and foundations, was the lowest building envelope surfaces that were not directly exposed to solar radiation. However, this surrounding area needs shade to ensure the floor maintains a low temperature, which helps to provide a cool interior environment.

Table 3. The average wall and roof colour, and albedo values

Building age (year)	Wall colour*	Roof colour*	Albedo (wall and roof)
0–9	2.1	6.4	0.21
10–19	3.0	11.0	0.23
20–29	2.1	11.0	0.23
30–40	1.7	10.4	0.21
All	2.1	9.4	0.22

*1	*White/light grey*	*6*	*Light green*	*11*	*Dark brown*
2	*Creme*	*7*	*Light orange*	*12*	*Dark green*
3	*Peach*	*8*	*Light blue*	*13*	*Dark red*
4	*Light Yellow*	*9*	*Light red*	*14*	*Other dark colour*
5	*Light brown*	*10*	*Dark blue*		

In a tropical region, the solar reflectance ratio on the surfaces of the walls and roof is very important. This is expressed by the albedo value. The colour of the external envelope surfaces has a tremendous effect on the impact of the sun on the building and the indoor temperatures. An increase in the surface of albedo has a direct impact on the energy balance of the building (Misni & Allan, 2010). The average albedo values of the building envelopes were 0.22 as shown in Table 3, with the majority of houses having cream coloured walls and light red roof tiles. This value was sufficient to reflect sunlight from the building envelopes.

4.3 Energy uses

The discussions for cooling energy use were closely related to the number of occupants (users) and their lifestyles related to using air-conditioning systems for each house.

4.3.1 Number of occupants

The average number of permanent occupants of the 50 single-family houses in the study areas was five people per house (4 adults and one child or adolescent). The occupants regularly used air-conditioning systems for cooling. The quantitative results show that the cooling energy use in the two study areas had similar patterns.

4.3.2 Air conditioning systems

The use of air-conditioning differed at each house and was according to the occupant's needs. Air-conditioning use during the day and evening was mainly in living and dining rooms while in the bedrooms the air-conditioning was only used during the night.

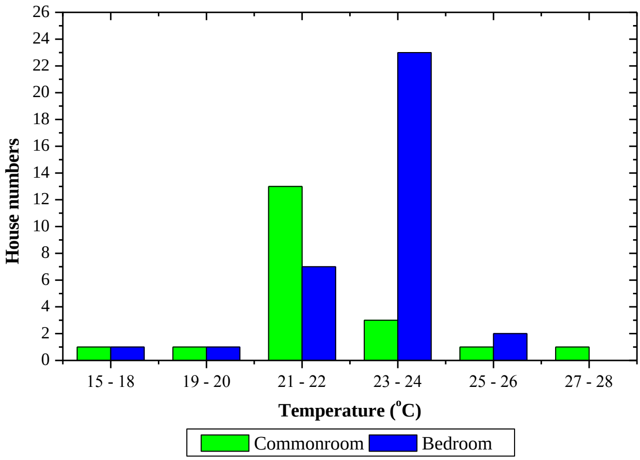

Figure 1. Air temperature settings for the common room and bedrooms

Figure 1 shows that the temperature setting was lower for common rooms because the size of the spaces was bigger. Also, these areas were used by all the family together and for a relatively short time. Use in the bedrooms was longer and at a higher temperature than in the public areas to help provide a comfortable environment for the occupants sleep in. The results showed that active cooling systems were a basic daily need to help achieve a comfortable environment in the interior spaces of houses.

4.3.3 Cooling energy use

During the rainy season, the average amount of energy used for cooling was around 36.7% Overall, the average spending on energy for cooling was up to one-third of the total cost of energy used in each house. However, throughout the year there are differences in air-conditioning use. During the dry season, air-conditioning is often used for longer periods, and energy use increases to around 48.2%. The average difference in energy consumption between the rainy and dry seasons was 11.5% per month. This is because the occupants' living habits and life styles change to adapt to high temperatures (approximately 2.5ºC higher) and humidity levels (20% higher). The difference between energy used from the rainy to dry season was 75,458kWh, at a cost of MYR18,540 per year, which represented a 22.3% difference.

Table 4. Cooling cost in the rainy season and dry seasons

Cooling cost						
House		Rainy season		Dry season		Diff. (%)
Age of const. (year)	No.	kWh	Cooling (%)	kWh	Cooling (%)	

0– 9	17	8135.9	37.0	14098.5	50.5	13.5
10–19	3	1718.4	46.9	2227.1	53.4	6.5
20–29	23	8325.6	34.4	12802.6	44.6	10.2
30–40	7	2549.5	38.5	4177.5	50.7	12.2
Total per month	50	20729.3	36.7	33305.7	48.2	11.5
Total per year	50	124376.1	36.7	199833.9	48.2	11.5

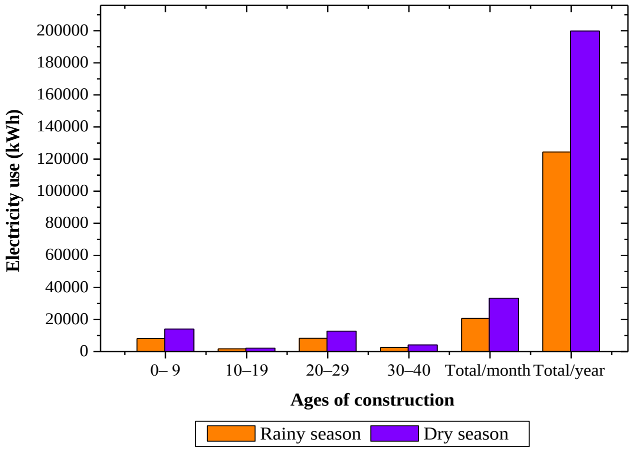

Figure 2. Cooling energy use (per month) in the rainy and dry seasons

5.0 Conclusion

In the study areas, the houses applied similar styles of tropical architecture and methods of building construction, with the U-values for building materials having moderate levels of thermal resistance. Every house had a medium amount and average size of glazed openings, which covered an area of approximately 13% of the floor area. They also had well-insulated roofs. The overall albedo value of the building envelopes was sufficient to reflect solar radiation. During the rainy season, air-conditioning was accounted for an average of 36.7%, while during the dry season, air-conditioning is often used for longer periods, estimated to increase to 48.2%. This is because the living habits and lifestyles of the occupants change adapt to higher temperatures. Strategic planning around houses could reduce the use of air-conditioning because it helps to create cool outdoor ambient air, and indirectly can reduce cooling energy and save costs.

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