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Overall Thermal Transfer Value of Residential Buildings in Malaysia

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Abstract: This study presents the Overall Thermal Transfer Value (OTTV) and the energy consumption of room air conditioners of the residential buildings in Malaysia. A survey has been conducted to investigate the OTTV and the energy consumption of room air conditioners of the residential buildings in Malaysia. OTTV calculation, energy consumption and effect of the building parameters on energy consumption have been investigated. It is found that OTTV of the residential buildings in Malaysia varied from 35 to 65 W m^{-2} with a mean value of 41.7 W m^{-2}. The sensitivities of several parameters such as window to wall ratio (WWR), Shading Coefficient (SC), U-value for wall (U_w) and solar absorption (α) are provided to design and optimize the thermal performance of residential buildings. It is found that U and α influence more on OTTV compared to other parameters. The analysis shows that about 14, 10 and 5% of residential building air conditioners have annual electricity consumption in the ranges 500 to 1000 kWh, 1000 to 2000 kWh and 7500 to 10000 kWh, respectively. The maximum, minimum and average annual electricity consumption of the air conditioner of residential buildings is 22055.5, 136.1 and 3708.8 kWh, respectively.

Key words: Energy consumption, air conditioner, wall conduction, residential building

INTRODUCTION

In recent years, Malaysia is maintaining a high economic growth and therefore, its energy consumption is increased dramatically. Mahlia *et al.* (2004) conducted survey on energy consumption and estimated that electricity consumption has increased from 326 GWh in 1970 to 9,471 GWh in 2000 in the residential sector in Malaysia. Varman *et al.* (2005) predicted that residential electricity consumption would be increased in 35,360 GWh in 2020. Rahman and Lee (2006) investigated that the energy demand increased almost 20% within the last 3 years (1999 to 2002). The energy demand is further expected to increase almost 60% within 8 years (2002 to 2010). Mahlia *et al.* (2001) investigated that room air conditioners were 253,399 units in 1991 to 726,540 units in 2005 and expected will be 956,155 units in 2010. In Malaysia, air conditioners accounted about 42% of total electricity consumption for commercial building and 30% of residential building. Figure 1 shows that the electricity increasing year by year from year 1998 which is 53.4 to 68.4 billion kWh in 2002. The usage of domestic electricity in Malaysia has increased rapidly due to the enhancement in the standard of living of the household. The American Society of Heating, Refrigerating and Air conditioning Engineers (ASHRAE) had originated the Overall Thermal Transfer Value (OTTV) as a thermal performance index for the envelope of air-conditioned buildings in 1975.

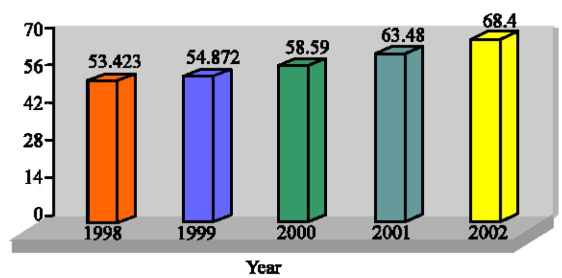

Fig. 1: Electricity consumption in Malaysia (Source: CIA World factbook unless otherwise noted, information in this page is accurate as of January 1, 2005)

OTTV is considered a better performance index than thermal transmittance (U-value) because it takes into account the impact of direct solar energy on the envelope of mechanically cooled buildings. Lam *et al.* (2005) completed a survey and investigated the OTTV of 144 buildings in the month of June during 1992-2001 in Hong Kong. The OTTV was varied from 27 to 44 W m^{-2} with a mean value of 37.7 W m^{-2}.

In the survey, OTTV for the residential buildings in Malaysia is studied. The effects on OTTV by varying the building envelope design parameters are considered as well. Tenaga Nasional Berhad (TNB) has carried out a series of survey and educational program to study the consumption pattern and raise the level of awareness

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among consumers on the importance on energy savings. One of the ways to reduce the energy wastage is mainly from reducing the wastage of electricity. Household appliances such as air conditioner, computer, television and refrigerator are some of the area of interest as these appliances are used by consumer in a daily basis.

The energy efficiency of room air conditioners has increased substantially around the world. In the US, the average EER (Energy efficiency ratio, kW kW^{-1}) has increased from 5.98 in year 1972 to 9.08 in year 1996. By the year of 2001 this average is likely to climb above 10.0, driven by new room air conditioner minimum efficiency standards that take effect in the year 2001 cooling season (Mahlia *et al*., 2001). In Malaysia, it is recommended that a minimum EER for all room air conditioners irrespective of size, which will be allowed to enter the Malaysian market in the year 2002, should be 10. The program seems to be beneficial to be implemented in this country in order to reduce future electricity demand in the residential sector as well as reducing the environmental impact caused by burning fossil fuels. Some method of comparing energy use which is energy index is explained. The index selected would depend on the intended application of the index and the normalizing factor. Among Architects the normalizing factor for comparing buildings is the gross floor area. The most commonly used index for comparing energy use in buildings is the Annual Area Energy Use Index (AEUI). This is usually expressed as kWh/m^2/year which measures the total energy used in a building for one year in kilowatts hours divided by the gross floor area of the building in square meters.

Among the Asian countries, Singapore is the first country to develop Building Energy Standards (BES) which was implemented in 1979 for commercial buildings through the Building Control (Space, Light and Ventilation) Regulations. Malaysia also adopted in 1987 OTTV as a building envelope thermal performance index in its energy standard for new commercial buildings. Having found that the solar absorption of external wall surfaces would affect the chiller load by 8-9%, wall surface absorption was included as a multiplicative factor in the term for heat conduction through opaque walls and roofs in the OTTV equation. All of them adopted the basic OTTV concept on the building envelopes, but their OTTV methods have been refined to reflect local conditions and simplify compliance. The provisions for lighting, HVAC systems and electric power are similar in nature and follow the principles of the ASHRAE Standard 90 series.

The aim of the study is to investigate the OTTV and the effect of the building design parameters on the OTTV in the residential buildings in Malaysia.

MATERIALS AND METHODS

This research data has been collected using questionnaire survey. The survey was conducted by Mechanical Engineering Department, University of Malaya in 2007.

OTTV concepts: Energy is one of the indispensable factors for continuous development and economic growth. Energy consumption increased rapidly. Residential energy consumption is one of the major energy consumption sectors. Overall Thermal Transfer Value (OTTV) is meant to measure the envelope thermal performance of air conditioning buildings that is followed an energy efficiency standard. Yik and Wan (2005) stated that the OTTV is an appropriate building envelope energy performance index for use in regulatory control. Based of the climatic parameters, OTTV is calculated for residential building envelope designs in Malaysia. To standardize the residential energy consumption, the researchers researched about many parameters. The American Society of Heating, Refrigerating and Air-Conditioning Engineers was introduced the Overall Thermal Transfer Value (OTTV). The OTTV is measured the heat transfer from outside to inside the building. Lam (2000) stated that there are three components of heat transfer from outside to inside the building such as conduction through the opaque surface, conduction through the glass and solar radiation through the glass that is shown in Fig. 2.

OTTV for the walls: The surfaces of an opaque wall, solar and thermal radiation together with convection heat transfer causes a net conduction heat flow into the wall material. Hui (1997) stated that as walls at different orientations receive different amounts of solar radiation, the general procedure is to calculate the OTTV of individual walls with the same orientation and

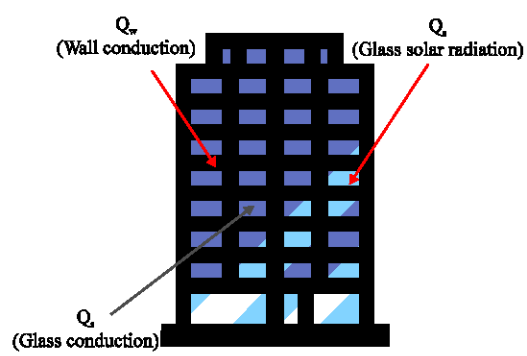

Fig. 2: Heat conduction through opaque wall, window glass and solar radiation through window glass in a building

then given by the weighted average of these values. The general form of OTTV equation for buildings:

$$OTTV_w = \frac{Q_w + Q_g + Q_s}{A_i}$$
$$= \frac{(A_w \times U_w \times TD_{eq}) + (A_f \times U_f \times DT) + (A_f \times SC \times SF)}{A_i}$$
$$= (1 - WWR) \times U_w \times TD_{eq} + WWR \times U_f \times DT + WWR \times SC \times SF \quad (1)$$

Where:

$OTTV_w$ = OTTV of a wall (W m^{-2})
WWR = The ratio of window area to gross wall area
U_w and U_f = U-value of the opaque part of the wall and fenestration, respectively
A_w, A_f and A_S = Area of the opaque part of a wall, a fenestration and a skylight, respectively
TD_{eq} = Equivalent temperature difference for the opaque part of a wall (°C)
SC = Shading coefficient of a fenestration or a skylight
SF = Solar factor (W m^{-2})
DT = Temperature difference between exterior and interior design conditions (°C)

Lam *et al.* (2005) stated that WWR is the percentage of results from dividing the total glass area of the building by the total wall area:

$$\text{Total gross area of wall, } A_i = 2 \times H \times L + 2 \times H \times D \quad (2)$$

Where:

H = Height of the wall
L = Length of the wall
D = Width of the wall

$$\text{Window to wall ratio, } WWR = \frac{A_f}{A_i} \quad (3)$$

Where:

A_i = Total gross area of the wall
A_f = Total gross area of the window

OTTV for the roof: The roof is almost similar to the wall. The calculation of the OTTV for the roof is similar to the calculation of the wall. Lam *et al.* (2005) stated that the calculations for the roof are often simpler because the roof usually does not contain a large amount of glazing, except for skylights over an atrium and similar to the walls. Yik and Wan (2005) considered the compliance criterion for the OTTV of roofs and investigated that OTTV is a constant value of 26.8 W m^{-2}.

Table 1: Mean outdoor temperatures of Kuala Lumpur in Malaysia

	Mean temperature (°C)	
Month	Daily minimum	Daily maximum
January	22.5	32.1
February	22.8	32.9
March	23.2	33.2
April	23.7	33.1
May	23.9	32.9
June	23.6	32.7
July	23.2	32.3
August	23.1	32.3
September	23.2	32.1
October	23.2	32.1
November	23.2	31.6
December	22.9	31.5

Climatologically information is based on monthly averages for the 30 years period from 1971 to 2000 (Source: World weather information service, Malaysia)

Determination of the OTTV parameters: Three parameters: indoor and outdoor temperature difference (DT), Solar Factor (SF) and equivalent temperature difference (TD_{eq}) are related to the outdoor ambient temperature and the solar radiation. The outdoor temperature of Kuala Lumpur is shown in Table 1. Their values depend on the weather conditions and the period over which the measured temperature and solar radiation data are averaged. A darker surface would absorb more solar heat.

Solar Factor (SF) of a glass wall is the ratio of the total solar energy flux entering the premises through the glazing to the total incident solar energy radiation. The lower the solar factor, the better the performance of the product. Equivalent temperature difference considers both the conduction heat gain due to the temperature difference between the indoor and the outdoor environment and the effect of solar radiation on opaque surfaces. Surapong (2006) developed countries experience OTTV equation with building energy code and energy efficiency in the existing buildings of Thailand, Malaysia, Singapore, Indonesia and Philippines. The OTTV standard equation for Malaysia is:

$$OTTV = 19.1\alpha \times (1\text{-}WWR) \times U_w + 194 \times WWR \times SC \quad (4)$$

where, α (solar absorption coefficient) is the degree to which a substance (wall) will absorb solar energy.

Shading coefficient of fenestration (SC) is the ratio of solar heat gain through a particular glass type compared to the solar heat gain through a 3 mm clear float glass. It measures the ability of window to reduce solar heat gain. The shading coefficient is expressed as a number between 0 and 1. The lower the shading coefficient, the less solar heat it transmits and the greater its shading capability. Typical values of different parameters of building in

Table 2: Typical values of different parameters to calculate OTTV in Malaysia

Name	Value of α	Value for use	Typical values of U (W m^{-2} K)
Normal glass window with coating	0.74		
Without coating	0.89	0.76	
Tinted glass window with coating	0.64		
Without coating	0.75		
Single glazed windows with coatings			4.20
Without coating			5.70
Double glazed windows with coatings			2.20
Without coating			3.80
Wooden walls			3.05
Brick concrete walls			2.15
Well-insulated floors			0.20
Poorly-insulated floors			1.00

Table 3: No. and types of residential building in the survey

Residential buildings types	No. of houses
Single story terrace	25
Double story terrace	27
Flat house	13
Traditional house	13
Condominium	11
Bungalow	7
Others	4
Total surveyed houses	100

Table 4: No. and window glass types of residential building in the survey

Window glass types	No. of houses
Normal glass	33
Normal glass with coatings	31
Black glass	4
Black glass with coatings	32
Total surveyed houses	100

Malaysia are shown in Table 2. For example a window with shading coefficient 0.4 will prevent about 60% of solar heat gain.

Data collection: A survey is conducted on residential buildings from different areas in Kuala Lumpur and its nearby areas for the purpose of calculating OTTV in Malaysia. A survey questionnaire is prepared to get the information for OTTV and energy consumption of air conditioner of the residential buildings. In the survey the information includes residential types (such as flat house, single storey terrace, double storey terrace, bungalow, traditional house, condominium), the length, width and height of the walls and the windows, grass types of the windows (such as normal glass, normal glass with coatings, black glass, black glass with coatings) and energy consumption of the residential buildings are collected that are shown in Table 3 and 4. The respondent has filled in the questionnaire form concerning the above characteristics of the residential buildings. Residential building and window glass types and number of houses are shown below in Table 3 and 4. The survey is conducted on 100 residential buildings with 16806 m^2 of walls area and 924 m^2 of windows area.

After the data has been collected, data is being analyzed and presented in the chart or graphic using SPSS and Microsoft Office Excel. A statistical analysis computer program SPSS version 12.0 is used to analyze the surveyed data. The effects of varied residential parameters, such as WWR, SC, wall U-value and wall absorption on OTTV were carried out.

RESULTS AND DISCUSSION

OTTV of the residential building: The OTTV of the residential buildings in Malaysia has been calculated and shown in the Fig. 3. The OTTV varied from 35 to 65 W m^{-2} with a distinct peak at 37-40 W m^{-2}, which accounted above one-third of the residential in the survey. The mean of the OTTV is 41.7 W m^{-2}. In the survey, about 90% of residential building OTTV ranges from 35 to 49 W m^{-2}. From the Fig. 3, about 80% of the residential building has OTTV below 45 W m^{-2}. That means, if legislative control of building envelope design is to be introduced for residential building in Malaysia and set at 45 W m^{-2}, 80% of the building in Malaysia are meet the requirement. There are about 10% of residential buildings OTTV over 50 W m^{-2}. There are 03 traditional houses with OTTV above 60 W m^{-2}. The mean OTTV is 41.7 W m^{-2} and still meet the requirements which the OTTV limit for wall in Malaysia is 45 W m^{-2}.

The mean OTTV is 41.7 W m^{-2} and still meet the requirements which the OTTV limit for wall in Malaysia is 45 W m^{-2}. Whereas the maximum OTTV is 65.2 W m^{-2} which is very high compared with the OTTV limit. Table 5 shows maximum, minimum and mean value of WWR, wall conduction, window solar radiation and OTTV of the residential buildings in Malaysia. The mean window solar radiation is 8.9 W m^{-2} and the mean wall heat conduction is 32.9 W m^{-2} which is 4 times mean window solar radiation. Hence, it concludes that OTTV for residential mostly from heat conduction through wall and only 20% through window solar radiation. This is due to WWR for residential which ranges from 0.01 to 0.18, that means only 1.05 to 18.16% of window glass area compared to total gross area of wall. Hence, the major thermal transfer value is contributed from heat conduction through opaque wall.

Effect of building parameters on OTTV: Many building design parameters are taken into consideration during the design of the building. In the survey, the four main residential building parameters are considered that are window to wall ratio, Shading Coefficient (SC), U-value for wall (U_w) and solar absorption (α). The mean OTTV from

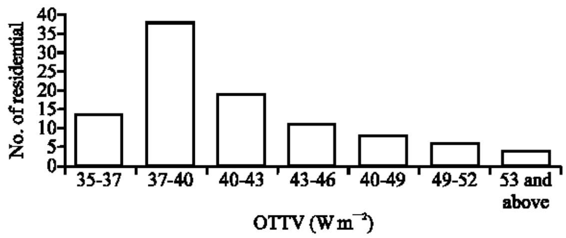

Fig. 3: Distribution of OTTV among the 100 residential

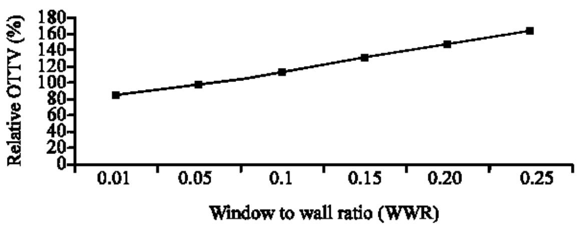

Fig. 4: Effect of WWR on OTTV

Table 5: Maximum, minimum and mean value of WWR, wall conduction, window solar radiation and OTTV of residential buildings in Malaysia

Parameters	Maximum value	Minimum value	Mean value
Wall Window Ratio (WWR)	0.18	0.01	0.06
Wall heat conduction (W m^{-2})	40.57	29.45	32.86
Window solar radiation (W m^{-2})	31.36	1.81	8.85
OTTV (W m^{-2})	65.22	35.57	41.71

the results is taken as the base value which is 41.7 W m^{-2}. The mean OTTV from the result is taken to be 100% and used as a reference. For all the cases with change in the varied parameter, the OTTV is expressed as a percentage of the amount of the base case called relative OTTV.

Effect of window to wall ratio on OTTV: The value of the WWR is found from 0.01 to 0.18. All other parameters such as SC, wall U-value and wall absorption are kept constant and the relative OTTV against the varied WWR is plotted and shown in Fig. 4. It is found that lower WWR value affects the OTTV to reduce, but the WWR for residential is already very low where the mean WWR value is 0.06 (only 6% of total wall gross area). So, the WWR does not affect the OTTV significantly for residential and it does not reduce the WWR.

Effect of shading coefficient on OTTV: The Shading Coefficient (SC) is varied from 0.3 to 0.9 but all other parameters are kept on the base value from survey. Figure 5 shows that the effect of shading coefficient is a large impact on the OTTV. With shading coefficient 0.3 only reduce nearly around 15% of OTTV. It should be noted that the window shading coefficient can be reduced by applying a coating on window glass.

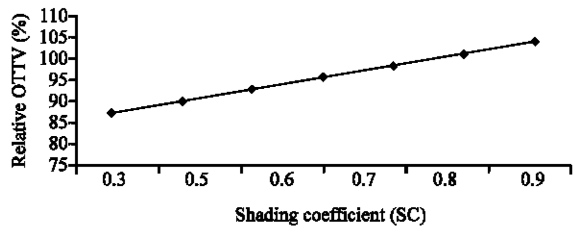

Fig. 5: Effect of shading coefficient on OTTV

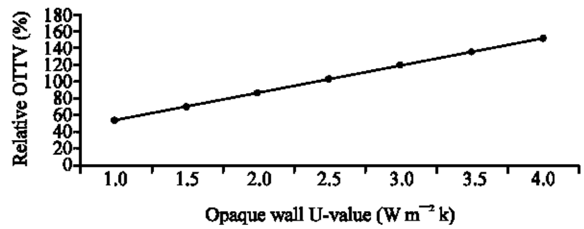

Fig. 6: Effect of opaque wall U-value on OTTV

Effect of opaque wall U-value on OTTV: Figure 6 shows the relative OTTV (%) against varied U-value. By changing the SC back to original value from survey and all the other parameters to be same as survey values. U-value of the opaque wall is varied from 1.0 to 4.0 W m^{-2}K. Lowering the wall U-value can reduce the heat conduction through wall. By reducing the U-value to 1.0 W m^{-2}K for opaque wall; the OTTV can be reduced up to 50%.

Effect of wall surface absorption on OTTV: The wall absorption is also varied from 0.3 to 0.9. Its effect on the OTTV is plotted that is shown in Fig. 7. With lower the wall absorption, the lower is OTTV. When wall absorption is 0.3 it is reduced around 50% of OTTV.

Overall effect on OTTV: OTTV is measured from the average heat gain into a building through its envelope. It is measured in W m^{-2}. An air-conditioned building with a higher OTTV imposes a greater load on the air conditioning system, which would have to expend more electrical energy in removing it. All air conditioned buildings must be designed to have an OTTV of not more than 45 W m^{-2}. This is aimed at achieving adequately designed building envelopes to cut down external heat gains and hence reduce the cooling load of air conditioning systems.

Figure 7 are shown that the wall U-value and wall absorption have much larger impacts on the OTTV than other parameters. That means the OTTV for residential in Malaysia mostly affects by wall heat conduction compared to solar radiation for window. Heat loss on solar radiation is not critical due to low WWR for residential.

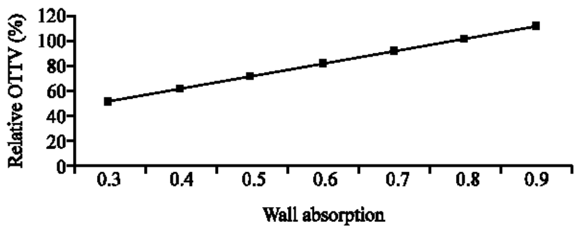

Fig. 7: Effect of wall absorption α on OTTV

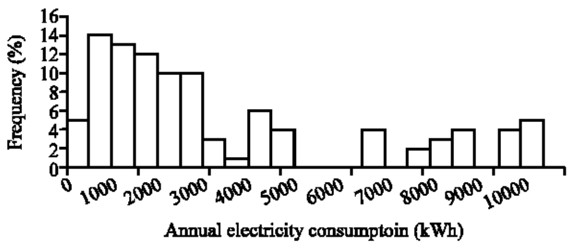

Fig. 8: Annual electricity consumption of air conditioner

Table 6: Max, min and average energy consumption of residential buildings in Malaysia

Maximum energy consumption (kWh year^{-1})	Minimum energy consumption (kWh year^{-1})	Average energy consumption (kWh year^{-1})
22055.5	136.1	3708.8

So, the OTTV can be reduced by using lower wall U-value and lower wall absorption. Wall U-value and wall absorption can be reduced by thermal insulation the concrete brick for wall and using the light colour of wall external surface finish. Moreover introducing shades and coating on glass can reduce solar heat gain. With choice of windows with a low thermal transmittance characteristic will also minimize solar heat gain.

Energy consumption for air conditioner: The annual electricity consumption of air conditioners of residential buildings in Malaysia is shown in the Fig. 8. Figure 8 shows that about 14, 10 and 5% residential building air conditioners annual electricity consumption are in between 500 to 1000 kWh, 1000 to 2000 kWh and 7500 to 10000 kWh, respectively. This is considered very high electricity consumption for the residential buildings. From the survey, this high electricity consumption of air conditioner of residential buildings is in urban and high income family. The maximum, minimum and average annual electricity consumption of the air conditioner of residential buildings is 22055.5, 136.1 and 3708.8 kWh, respectively (Table 6).

The air conditioner ownerships are expected that the living status and life style will be standardized according to economic growth in the near future. Due to the increase of the living status and life style, it is predicted that the ownership of air conditioner will increase. So energy consumption will increase. As a result, all these socio-economic factors should be considered in reflecting the energy consumption of air conditioners. It is essential to enhance the public awareness towards global environment in order to achieve energy saving objectives in cities.

CONCLUSION

In Malaysia, it is found that the OTTV varied from 35 to 65 W m^{-2} with a mean value of 41.7 W m^{-2}. The OTTV for residential in Malaysia mostly from wall conduction compared to window solar radiation, this is due to low WWR for residential. An air conditioned building with a higher OTTV imposes more cooling load on the air conditioning system. The OTTV of the air conditioned residential building should be designed not more than 45 W m^{-2}. The maximum, minimum and average annual electricity consumption of the air conditioner of residential buildings is 22055.5, 136.1 and 3708.8 kWh, respectively. The four important residential parameters are window to wall ratio, shading coefficient, U-value for wall and solar absorption. The sensitivities of these parameters have provided the guideline to design and optimize the thermal performance of residential buildings. It is found that there are greater effect on OTTV for the wall U-value and wall absorption compared to other parameters.

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