Available online at www.elixirpublishers.com (Elixir International Journal)

Civil Engineering

Elixir Civil Engg. 68 (2014) 22342-22345

ISSN: 2229-712X

Appraisal on Roofing Materials Thermal Properties in Malaysian Climate

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ARTICLE INFO

Article history:

Received: 15 January 2014;

Received in revised form:

22 February 2014;

Accepted: 8 March 2014;

Keywords

Roof overheat,

Thermal comfort,

Thermal performance,

Humid climate,

Building envelope.

ABSTRACT

As well all know, residential buildings and houses in Malaysia are experiencing overheating of roof space problems owing to unsuitable selection of roofing materials and the systems as well. Subsequently, the indoor thermal comfort of the building is deficiently affected, particularly for low rise buildings where the roof is representing around 70% of heat gain. The thermal performance of a building is affected by the solar absorbance of roof, during a clear sky conditions up to 1kW/m^2 of radiation can be incidental on a roof surface and between 20% and 90% of this radiation is naturally absorbed. This paper is anticipated to reassess the roofing materials and roof colours employed in Malaysian building and establish whether they are appropriate for the hot humid climate zone. The study aims to review the thermal performance of roofing materials in Malaysia. Roof colors on some existing buildings and home buyers preferred roof tiles' colors have been determined. A survey was conducted among home buyers in Malaysian to determine the most preferred roofing colors. The survey results suggest that blue and brown are the most preferred ones followed by red. The study also revealed that 70% of households in Malaysia are using air-conditioning. The observation survey on some existing buildings revealed that 90% of roof tiles are red followed by 10 % black color

Introduction

Buildings in Malaysia are subject to important cooling requirements owing to elevated concentration of heat transmission from building envelope, particularly for low rise buildings where the roof is representing around 70% of heat gain (Vijaykumar et al., 2007). Accordingly, the selection of appropriate roofing materials with higher performance in solar energy rejection will be a good alternative solution to make indoor temperature more comfortable and reduce the increasing demand in air conditioning by the building sector. The results of observation survey conducted by Allen et al. (2008) revealed that concrete roof tiles are the most usually used roofing finish in Malaysia as it represents 85 % followed by clay tiles and metal deck with 10% and 5% respectively. In another observation survey performed from October 2012 to February 2013 on roof colour for residential buildings in Kuala Kangsar, Setiawan, Seri Iskandar and Shah Alam in Malaysia suggests that 90% of roof tiles in residential buildings are red followed by black colour roof tiles which correspond to around 10 %. White colour roof tiles were found to be 0% in the surveyed areas. Hence, introducing alternative roofing materials with higher Solar Reflectance Index (SRI) became a top urgent necessity in Malaysia. SRI is a composed measure that accounts for surface's solar reflectance and emittance measured on a dimensionless scale from 0 to1 (Marceau, 2007)

Background

Building Impact on the Environment

Houses and buildings impact the environment in several ways as a result of both their energy use and material consumption. The emission of greenhouse gases and the creation of heat islands in urban areas are among their major impacts. Therefore, the adoption of building design strategies and construction materials that address these issues will lead to huge difference to global warming and reductions in a building's overall environmental impact. Further, the use of mechanical ventilation and air conditioners in buildings is arising two major problems as shown in Figure 1. First, air conditioning system is consuming a lot of energy and consequently increasing the households in the utility bills. Second, the electricity generation from fossil fuels is increasing the greenhouse gases concentration in the atmosphere which affects the global warming and climate changes. This paper is intended to appraise the properties of roofing materials employed in Malaysia in terms of solar heat rejection.

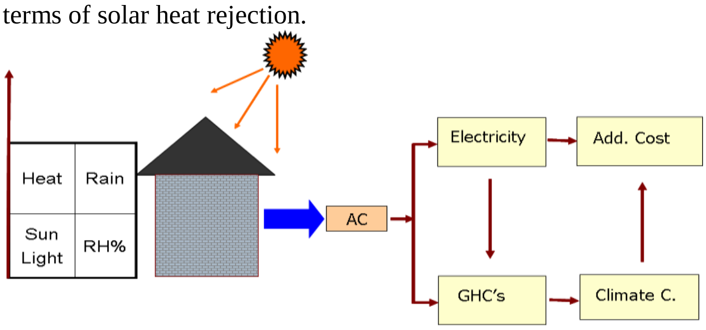

Figure 1. Cause and Effect Diagram

Building Envelope Heat Gain

The concept of using cool roof in residential, commercial and industrial buildings is growing in the last decade as one of the most cost effective solutions to mitigate the global warming issue and reduce the greenhouse gases (GHG's) emittence resulting from burning of fossil fuels in electricity generation. The thermal performance of a building is affected by the solar absorbance of roof. During a clear sky conditions up to about 1kW/m^2 of radiation can be incidental on a roof surface and between 20% and 90% of this radiation is typically absorbed (Suehrcke, H., et al., 2008). Heat entering to the houses and low

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rise building's structure is the major cause of discomfort in hot humid climate zone countries. The building roof is about 50-70% of the total heat entry of rooms as shown in Figure 2 (Vijaykumar et al., 2007). Further, In May 2009, Dr. Steven Chu Secretary of Energy " United States

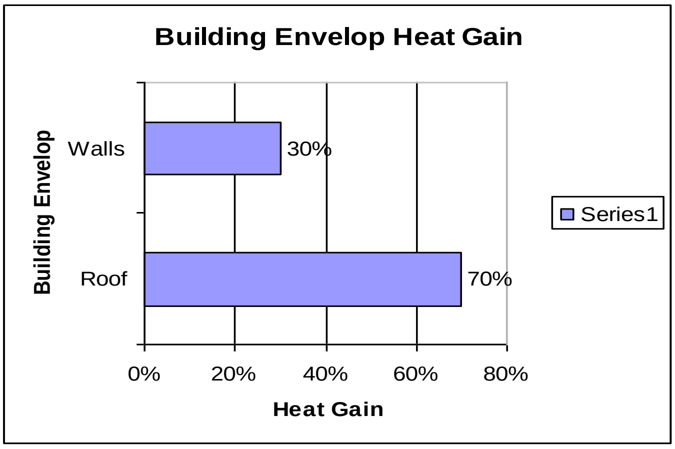

Figure 2. Low Rise Building Envelope Heat Gain

Department of Energy" advised that painting roofs white to reflect sunlight can make a huge difference to global warming (Mark, 2009). Hence, in order to meet challenges in mitigating global warming and climate change, the use of light color roofing materials with higher SRI would be highly recommended in Malaysia, as roof is the most important part of the building envelope which is exposed directly to sun light during the day. Figure 3 shows the cool roof technology which this technique optimises the roof's thermal performance by using a combination of heat reflection, ventilation and insulation products to minimise the solar gain of the roof and reduce the heat transmitted into the attic and living space.

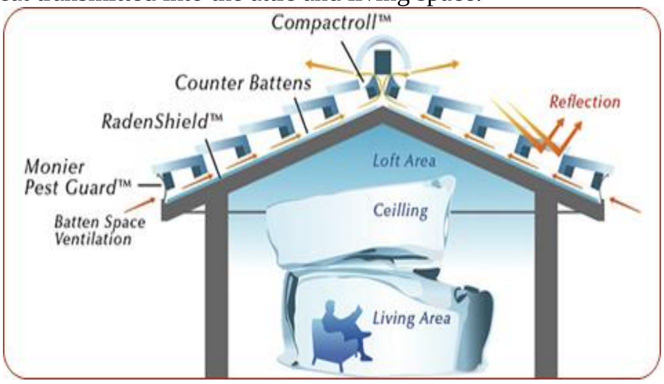

Figure 3. Cool roof technology in Malaysia

Review of Some Existing Literature

The review of some existing literature has revealed that several successful researches on solar reflectance and heat transmittance of different materials have been conducted during the last decade. For instance, a research done by Lawrence Berkeley National Laboratory in 1997 revealed that a whiter roof results in savings of $ 51 per year per 1000ft^2 roof area of air conditioned buildings (Konopacki et al., 1997). Experiments in California and Florida have produced summer direct cooling energy savings of 10-70% (Sara and Akbari, 1997). On the other hand Suehrcke *et al.*(2008) using numerical simulation and deriving equations suggested that in hot climates a significant reduction in downward heat flow can be achieved by using a light or reflective roof color instead of a dark one.

The benefits of using light color roofing materials have been noted by Jayasinghe *et al.* (2003), Levinson *et al.* (2005, 2010), Filho et al., (2010) and Bryan and Roth (2010). Furthermore, Levinson *et al.* (2007) have demonstrated in their research that non white near-infrared-reflective architectural coating can be applied in-situ to concrete or clay tile roofs to reduce temperature. The study suggests that under typical condition e.g. 1 KW/m^2 summer afternoon insolation, R-11 attic insulation, no radiant barrier, and 0.3 reduction in solar absorptance, absolute reduction of roof surface temperature, attic air temperature, and ceiling heat flux were about 12K, 6.2K and 3.7W/m^2 respectively. In the same study Levinson *et al.* (2007) reported that for a typical 139m^2 houses with R-11 attic insulation and no radiant barrier, reducing the roof absorptance by 0.3 revealed whole house peak energy saving of 230W in Fresno, 210W in San Bernardino and 210W in San Diego. Detailed explanation on how does cool roofing help is also provided in Cool Roof Design Brief (2006).

Commonly Used Roofing Materials in Malaysia

Concrete, clay, and metal sheets are the roofing material types that are available in the market and widely used in hot humid climate zone; especially in Malaysia. The decision on roofing materials are normally made according to home buyer's requirements and climatic conditions. The budget also plays an important role in selecting the type of roof tiles. However, the roof material's ability to reject solar energy is not a governing factor during the selection of roof color. This is due to lack of information on the significant influence of roof color on thermal heat gain. An observation survey was conducted by Allen et al.,(2008) from December 2006 to March 2007 on roofing systems and materials for residential buildings within the state of Selangore and Wilayah Persekutuan Kuala Lumpur in Malaysia. The study revealed that 85% of residential uildings have concrete roof tiles, followed by 10% clay and 5% metal deck sheets used mainly in bungalow building types.

Heat Transfer

a. Modes of Heat Transfer

Where there is a temperature difference between two places heat tends to flow from the higher temperature to the lower and the heat transmission can occur in three ways; (1) conduction, (2) convection, and (3) radiation (Esmond, 1999) . The following terms are normally used to rate the materials insulation performance of building envelopes.

- The thermal resistance (R) is a measure of a material's ability to resist heat transfer. It is the direct measure of its resistance to transfer energy or heat. R values are expressed using the metric units (m^2.K/W).
- Thermal conductivity (K) is defined as the ability of material to conduct heat; its unit is (W/m. K).
- U-Value is defined as a measure of the rate of heat loss or gain through a material or assembly, it is the inverse of R, therefore, $U = 1/R$ and its unit is W/(m².K)

b. Solar Reflectance Index (SRI)

The Solar Reflectance Index (SRI) is defined as the ability of material to reject solar energy; it is a composed measure that accounts for surface's solar reflectance and emittance (Marceau et al., 2007). The SRI is the fraction of the sun light that a surface reflects, sun light which is not reflected is absorbed as a heat (Bryan and Kurt, 2010). Solar reflectance is measured on a scale of 0 to 1. For example a surface that reflects 66% of sun light has a solar reflectance of 0.66. Most dark roof material reflects 5% to 20% on incoming sunlight, while light colored roof materials typically reflects 55% to 90% (Bryan and Kurt, 2010). Solar reflectance has the biggest effect on keeping roof cool in the sun (Carolyn, 2008).

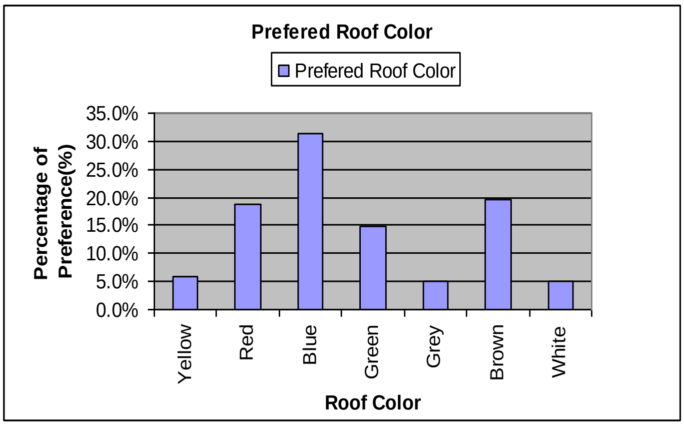

Figure 4. Preferred Roofing Colors in Malaysia

Further, another survey was conducted by the authors to determine the home buyers' most preferred roofing color in Malaysian. The survey was conducted during Malaysia Property Expo (MAPEX 2011). From 500 target population 204 participants have responded to the questionnaires survey. The preliminary analysis of study revealed that 32% of home buyers in Malaysia prefer blue color roof tiles, 20% brawn color followed by 29% red, 15% green, 7% yellow and 5% for grey and white as shown in Figure 3.

The majority of home buyers who decided to select dark colors roof tiles as their preferred color justified that this is because white color tiles are quite difficult for maintenance. As white color roof tiles tend to discoloration and fungi growth associated with monsoon and high level of humidity that characterize the Malaysian climate zone. However, this issue can be resolved by developing stainless light color roofing materials. In addition when we compare the preferred roof colors summarized in Figure 4 with some solar heating properties of roofing material, we can conclude that most of dark color roof tiles are falling within SRI value below 40. This indicates that the roofing colors used in Malaysia are not the optimum in terms of solar reflectance as most of them are dark materials. This means the solar performance of roofing materials in Malaysia are not in line with the global trends for light color roofing system implemented in USA and Europe in order to mitigate the global warming.

c. Thermal Comfort

Thermal comfort can be defined as the range of climatic condition considered comfortable and acceptable, and in accordance with ANSI/ASHRAE Standard, (2005) the thermal comfort is state of mind that expresses satisfaction with the surrounding environment. Thermal comfort is very important to many work-related factors. It can affect the distraction levels of the workers, and in turn affect their performance and productivity of their work. The thermal comfort might be affected by the (1) environmental (air and ambient) temperature, (2) humidity, (3) air speed, (4) clothing and metabolic rates. The thermal sensation of humans is mainly related to the thermal balance of the body as a whole. Thermal balance exists when the internal heat production in the body is equal to the loss of heat to the environment. PMV index (Predicted Mean Vote) and PPD index (Predicted Percentage Dissatisfied) are the most widely used indices in moderate thermal environment. Examples of recent studies in thermal comfort include Jorn (2005), Roonak et al. (2009) and Cao et al. (2010).

Energy Consumption

Electricity is a necessity factor for developing and civilization of nations, but the energy generation from fossil fuels has two major effects. On one hand, the fossil fuels reserves are depleting, for instance, in 2004, Malaysia was ranked 24th in terms of worlds oil reserves and 13th of natural gas, and in January 2007, PETRONAS reported that oil and gas reserves in Malaysia amounted to 20.18 billion barrels equivalent. In accordance with the Malaysian government estimates; at the current production rate, Malaysia will be able to produce oil and gas up to 18 years and 35 years respectively (Cha and Oh, 2010) with respect to 2004 level. On the other hand, the process of electricity generation using fossil fuels is damaging the ecosystems by producing greenhouse gases (GHG's). Further, in accordance with the International Energy Agency's CO_2 emission report published in 2010 (International Energy Agency, 2010). It is obviously evident that CO_2 emission is related directly to electricity consumption, with China being the biggest CO_2 emitter in the word with 6508.24 MT of CO_2 in 2008, followed by USA with 5595.92 MT of CO_2.

Moreover, Ong et al. (2010) found that Malaysia's energy sector is still heavily depending on non renewable fuels such as crude oil and natural gas and coal, and these non renewable fuels are gradually depleting and contribute huge amount of greenhouse gas emissions. In addition, Saidur et al. (2007) in their study on energy and associated greenhouse gas emissions from household appliances in Malaysia for estimated period of 17 years (1999-2015) suggested that refrigerator–freezer is the major energy consuming appliances followed by air conditioners. The number of air conditioner units in Malaysia was 493,082 in 1999 while the projected number of air conditioners in 2015 is expected to reach 1,271,746 units (Saidur et al. ,2007), an increase of 68% compared to 1999 level. Further, in a recent study conduct by the others of this paper during MAPEX 2011 in Kuala Lumpur to determine the percentage of air condoning usage among Malaysian households. 500 questioners have been distributed to home buyers and 208 participants have responded. The preliminary analysis of study suggests that 75.5% of Malaysians households are using air conditioning, while about 24.5 % are depending on natural ventilation or fans.

Conclusions

The thermal performance of a building is affected by the solar absorptance of roof. During a clear sky conditions up to about 1kW/m^2 of radiation can be incidental on a roof surface and between 20% and 90% of this radiation is typically absorbed. Results of observation survey on roof colors suggest that 90% of roof tiles in low rise Malaysian residential buildings are red followed by 10% black color tiles. In addition 32% of home buyers in Malaysia prefer blue color roof tiles, 20% brown color followed by 29% red, 15% green, 7% yellow and 5% for grey and white. The preference of dark color roof tiles by home buyers is mainly due to lack of information as well as the absence of systematic researches which address the benefits of light colors roofing materials in Malaysia. The maintenance difficulties associated with white color roofing system could also be another reason. Therefore, in order to make a total shift from dark color roof tiles to light color roofing system in Malaysia, private initiatives from researchers together with governmental support to conduct research on Solar Reflectance Index (SRI) of roof tiles and developing stainless light color roof tiles will be essential to make possible a sustainable development future.

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