Test Houses for Roof Thermal Performance Testing

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ABSTRACT

Two test houses were built at a location within UiTM Pahang, Jengka campus. The houses were made of plywood with cement bases and 5° single pitch metal deck roofs. The houses, H1 and H2, were built in an open area and at a distance to each other; and in the East- West direction to minimize wind and shading effect. Temperature sensors were attached to the top surface of the roofs; and also on the inside surface of the radiant barrier for both houses to monitor their temperature profiles. Data was collected for a period of time using a computer placed in one of the houses. From the data, it was found that both houses showed similar temperature profiles except that the house, H2, containing the computer, is consistently hotter on average by 0.62°C on the inside and by 0.32°C on the outside. A correction to the H2 temperature is made by subtracting the respective average temperature difference values. The corrected temperatures of H2 were then compared to the temperatures of H1 and their differences were found to be statistically insignificant. This result proved that both houses were thermally the same within the limits of uncertainties. Consequently, the test houses could be used for further roof testing purposes with one of the houses to serve as control.

Keyword: *Roof systems, roof thermal performance, roof temperature*

Introduction

In order to facilitate local research in roof insulation material properties, two test houses, H1 and H2, were built within the campus area of UiTM Pahang, Jengka, located at 3°45'N and 102°34'E. The area chosen as the site of the test houses is an open area far from any existing building to minimise shading and wind obstruction. The houses were built using the same materials and of the same dimension.

Temperature data from both roofs was collected from 29th February to 6th March 2008. The data was then analysed as an indicator of the thermal properties of roofs. From the data, it Could be determine if the two houses are thermally identical, and as a consequent, if the houses could be used for roof and insulation material testing purposes.

Literature Review

In their studies on the climate of the Klang valley, Zain-Ahmed, Sayigh, Surendran, and Othman (1998) found that the mean temperature of the hottest month is 27.8°C and that of the coolest month is 25.9°C. Wind speeds are predominantly low with a mean value of 1.2 m/s. Sunshine hours are between 4.7 to 7.2 hours a day with an annual mean of 6.2 hours. Daily solar irradiation ranges from 13.8 MJ/m^2 to 19.3 MJ/m^2. This shows that the building envelope in the region may get very high solar gains during the day, especially the roofs, which are the structure most exposed to the sun. Consequently, the reduction in heat gains through roofs would contribute in reducing the energy need of buildings in tropical climates.

The simplest and most established method for reducing the transfer of thermal energy due to solar gain through roofs is by the use of thermal insulation materials and radiant barriers. Many researches have been carried out to investigate heat transfer through roofs, some by means of simulations as done by Al-Sanea (2002). Other studies done by Florides, Tassou, Kalogirou and

Wrobel (2002), Parker, Barkaszi, Chandra, and Beal [2004], Mohd Noor, Abdul Rahman, Zain-Ahmed, and Sulaiman (2005), and Harimi, D., Harimi,M., Kurian, Bolong, Zakaria and Gungat (2005), carried out in-situ temperature measurements to test the thermal performance of different roofs.

In field studies, especially in the tropics, many challenges has to be faced. External and sometimes uncontrollable factors such as climatic conditions, surrounding vegetations, and presence of critters, have to be taken into account, as opposed to controlled laboratory environments.

Houses Site, Dimensions and Material

The test houses were built such that H2 is exactly to the north of H1. The houses have a dimension of 3.05 m by 3.05 m. Their roofs have 91.4 cm of overhang at all sides. The roofs are of 5° single pitch facing the east. The East-facing roof is to get the high solar gain in the morning since in the tropical region it is frequently heavy clouds or rain in the afternoon. The two houses were separated 4.88 m from each other, measured from roof tip to roof tip.

The roofing material is of metal deck of off-white colour manufactured by Bluescope Steel (M) Sdn. Bhd. Immediately under the roof is a radiant barrier in the form of double sided Bison-foil aluminium foil supplied by Morken (M) Sdn. Bhd.. The walls are constructed of 12-mm-waterproof–plywood. Each house has a door and two windows which remain closed throughout the monitoring period. Both houses were deliberately constructed with numerous air gaps to simulate the general state of under-roof-space in buildings in the region.

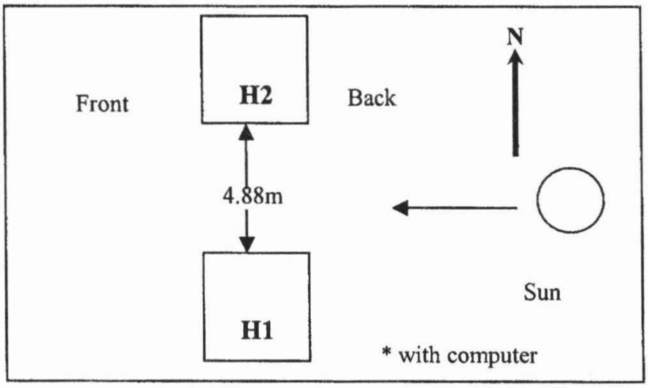

Figure 2: Dimension of the Test House.

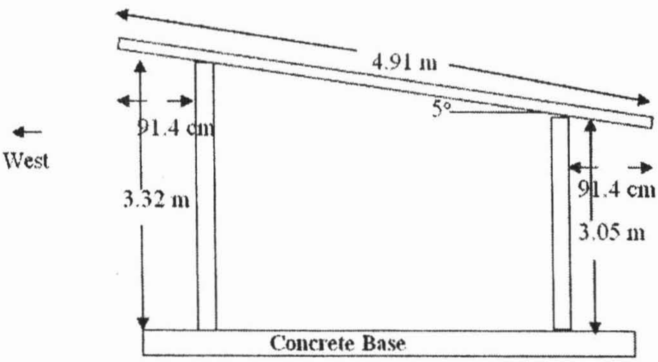

Figure 1: Layout Plan of the Test Houses

Sun Orientation

The houses were built 4.88 m away from one another to avoid shading between them. As shown in figure 2, the houses were built facing the west with the 5° single-pitched roof facing the rising sun.

The possibility of shading was estimated by calculating the solar declination angle δ and solar zenith angle θ_z ,at noon.

Using the equation presented by Spencer (as cited in Iqbal,1983, p.7) the declination angle, δ, is calculated using Equation 1 below:

$$\delta = \begin{pmatrix} 0.006918 - 0.399912\cos\Gamma + 0.070257\sin\Gamma - 0.0067580\cos 2\Gamma \\ + 0.000907\sin 2\Gamma - 0.002697\cos 3\Gamma + 0.00148\sin 3\Gamma \end{pmatrix}(180/\pi) \text{ degrees,} \quad (1)$$

where Γ is the day angle calculated from:

$$\Gamma = 2\pi(d_n - 1)/365 \quad (2)$$

where d_n is the day number.

Taking the 3rd of March as a reference, the day number is 62 (assuming February to always have 28 days), δ is calculated to be -7.02°.

The solar zenith angle is calculated from Equation 3 (Iqbal,1983):

$$\cos\theta_z = \sin\delta\sin\phi + \cos\delta\cos\phi\cos\omega \quad (3)$$

where ϕ is the latitude (North positive), and ω is the hour angle.

For Jengka, the latitude ϕ is 3.75° N, and ω, the hour angle is 0 at noon. Using these values, the solar zenith angle θ_z was found to be 10.77° at noon 3rd March 2008.

The maximum value of δ for the location is during summer (21/22 June) and winter solstice (21/22 December). At this two times, the declination is approximately +23.5° and -23.5° respectively. The value of θ_z at these two times at solar noon is 19.75° and -27.25° respectively.

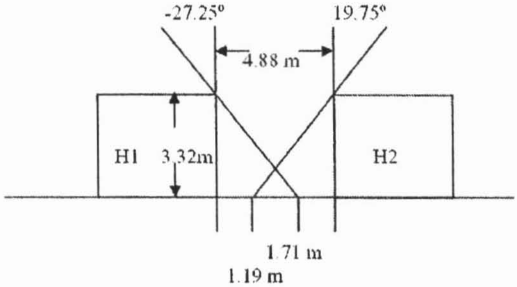

Figure 3: Maximum Shading at Summer and Winter Solstice

Figure 3 above, shows that at winter solstice, at noon, the maximum shadow length between the houses is 1.71 m; and at summer solstice, at noon, the maximum shadow length is 1.19 m. The calculations showed that the distance between the two houses, 4.88 m, is sufficient to ensure that at all times there will be no shadowing of either house due to each other

Roof Temperature Monitoring

The temperature of the roofs was monitored by installing K-type thermocouples at four points on each surface. The cold junction compensation setting of each module are calibrated and their readings are found to be within +/- 0.14 °C. The readings are then logged every minute using ADAM-4018 modules interfaced to a desk top computer. The temperature readings are then saved and analysed using Microsoft Excel and SPSS software.

Results and Discussions

The average value of the temperature data for each surface was calculated and plotted as shown by Figure 4, below:

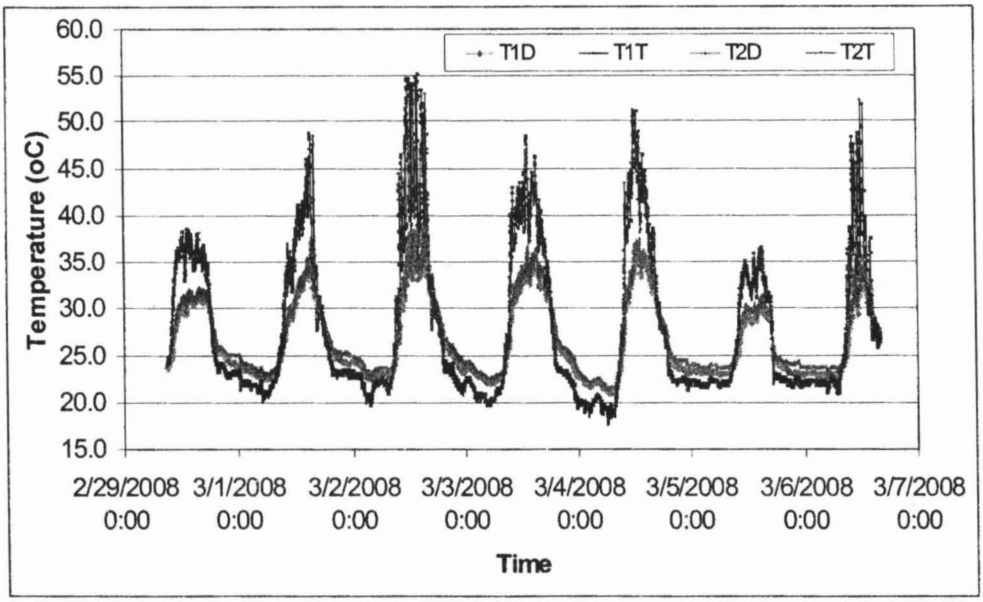

Figure 4: Roof-Surface Temperature Values: T1D (Inside of House 1), T2D (Inside of House 2), T1T (Outside of House 1), and T2T (Outside of House 2)

The observed temperature variation is consistent with observation made by Mohd Noor et al [2005] for metal deck roofs and also by Harimi et al in their study on concrete tile roofs. The outer temperature recorded is much higher during the day, but during the night, the outer roof surface became cooler than the inside surface temperature. During the daylight hours, the external temperature rises higher than the air temperature due to the solar gains. However, during the night, the external temperature is cooler due to long wave radiation and condensation. On the other hand, the inside temperature has a smaller magnitude of variation. During the day, it recorded relatively lower themperatures due to some resistance of the building materials to heat transfer. During the night the thermal resistance works in the opposite direction. Coupled with the heat capacity of the building materials, they slow down the cooling of the building during the night.

As mentioned, external and sometimes uncontrollable factors such as climatic conditions, surrounding vegetations, and presence of critters, may effect the temperature profile. The graph shows very erratic temperature changes, most pronounced during noon. This effect is due to climatic conditions such as changes in cloud coverage, wind and rain. To smoothen the profile, the temperatures are converted to average value for the observed period, in this case, 7-day-averaged value.

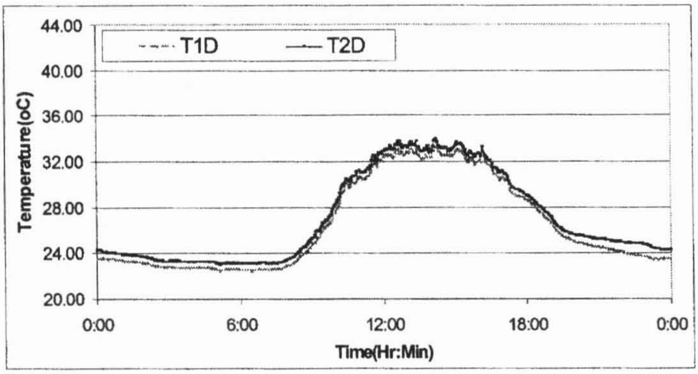

Figure 5: 7-day-averaged Roof-surface Temperature Values:
T1D (Inside of House 1), T2D (Inside of House 2).

Figure 5 above compares the 7-day-averaged inside surface temperature of H1 (T1D) and H2 (T2D). As expected, both houses have generally similar temperature profiles. However T2D is consistently higher than T1D. The average difference between both temperatures was found to be 0.52°C.

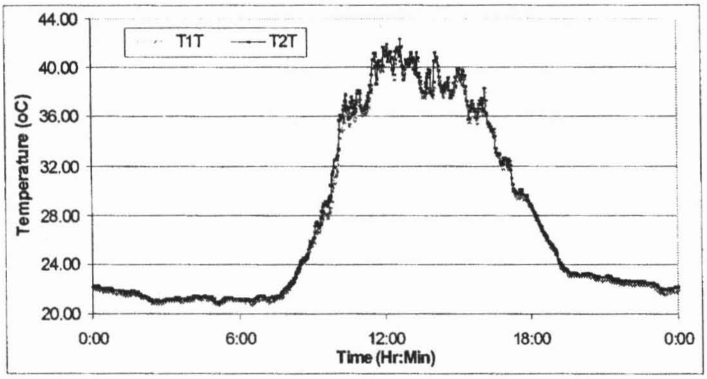

Figure 6: 7-day-averaged Roof-surface Temperature Values:
T1T (Outside of House 1), and T2T (Outside of House 2).

Figure 6 above compares the 7-day-averaged inside surface temperature of H1 (T1T) and H2 (T2T). As in figure 5, both houses also have generally similar outside temperature profiles. Similarly, it was found that T2T is consistently higher than T1T. In this case, the average difference between both temperatures was found to be 0.32°C.

From these results, in could be concluded that H2 is consistently slightly warmer than H1. Considering that both houses were identical in dimension and material, it could be concluded that the cause of the difference is the running of the desk top computer in H2.

In order to proof that the temperature differences are consistent throughout the observation period, the temperatures of H2, i.e. T2D and T2T were corrected using the calculated average temperature difference values. Table 1 below summarise the descriptive statistical values of the temperatures.

Table 1: Descriptive Statistical Values of 7-day-averaged Values of T1D (Inside of House 1), T2D (Inside of House 2), T1T (Outside of House 1), T2T (Outside of House 2), T2D' (Corrected), and T2T' (Corrected).

Variable	N	Min	Max	Mean	SD
T1T	1440	20.67	41.73	27.24	7.16
T1D	1440	22.42	33.26	26.38	3.86
T2T	1440	20.81	42.38	27.56	7.22
T2D	1440	23.01	33.93	27.00	3.83
T2T'	1440	20.49	42.06	27.24	7.22
T2D'	1440	22.39	33.31	26.38	3.83

The corrected temperatures T2D' and T2T' were then tested statistically with temperatures of H1 as independent samples using Non-parametric tests based on the Mann-Whitney test. The result is summarised in table 2 below.

Table 2: Non-parametric Statistical Test (Mann-Whitney Test) of Inside Temperature, TD, and Outside Temperature, TT, for both Houses.

	TT	TD
Mann-Whitney U	1009639	1025987
Z	-1.217	-0.485
Assymp. Sig(2-tailed)	0.223	0.628

The result shows that after correction, the temperatures for both houses are not significantly different. As such, it could be concluded that both houses thermally the same within the limits of uncertainties. To further improve the reliability of the measurements, the period of observation may be prolonged. The growth of surrounding vegetations should also be controlled as also critters such as rats, squirels and bees.

Conclusion

From the data, it was found that both houses showed similar temperature profiles except that the house, H2, is consistently hotter due to the presence of a desk top computer. After making a correction to the H2 temperatures, the difference in temperatures of the two houses were found to be statistically insignificant. As such, it can be concluded that the houses are thermally identical and could be used for further roof testing purposes with one of the houses to serve as control.

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