# UPM Cool Roof Reduces Thermal Discomfort in a Terrace House by 82%

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*Key words:* Ventilation, Cool Houses, Temperature, Heat-Stress.

## Introduction

Our basic research at Universiti Putra Malaysia (UPM) over the last decade has discovered how houses heat up and cool down in the Malaysian humid tropics. Using a climatic approach and our novel temperature data-logging technique we have established that some 10 million Malaysians would suffer 2 to 3 times less thermal discomfort if they abandoned their urban concrete houses and lived under trees. This overheating is caused not so much by the climate itself but by the defective design of urban houses. Indeed, on a typical Malaysian day the outdoor shade environment is thermally uncomfortable for only 10 daylight hours. The outdoor environment is perfectly comfortable from around 6pm to 9am being within the 24$^0$C to 28$^0$C thermal comfort zone for 14 hours per day. In marked contrast the indoor environment of concrete houses is above the upper thermal comfort level for 19 to 24 hours per day. The outdoor air temperature in Malaysia never exceeds 36$^0$C. The excessive heat gain by concrete houses comes not from the air but from solar radiation heating up the concrete tiles, which can reach 50$^0$C on hot days. The heat is transferred to the air in the roof space and then transmitted via the ceiling to the living areas below. The heat is stored in the concrete walls and floor and is retained for much of the night. We term this the oven effect. Blocking the solar heat gain with a correctly designed roof to block solar heat gain using radiation foil and adequate insulation is the main subject of this report.

## Materials and Methods

*Temperature datalogging:* Hobo temperature sensors, purchased from NY Agency Kuala Lumpur, were programmed to record temperature, time and date every 24 minutes for 30 days and hung inside houses to record air temperature at mid roof space height and at 1.5m from the floor of bedrooms and living room. Twenty sensors, previously checked for accuracy according to manufacturer's instructions, were typically used per house. Sensors were downloaded into a computer and the data processed by Hobo Boxcar software and further in Excel spreadsheets. Mean hourly temperatures were obtained from sensors in the same room or attic.

*Thermal Discomfort Units.* One unit was defined as the discomfort caused to a resting person wearing light tropical clothing in a space where the average temperate in one hour was 1$^0$C above the upper thermal comfort temperature (taken as 28$^0$C or 30$^0$C under a ceiling fan). Thermal discomfort units were accumulated over 24 hours. The ideal design aim of a house is to reduce the thermal discomfort units suffered by its inhabitants to zero units per 24 hours on the hottest day of the Malaysian year.

*Cool Roof* The concrete tiles of a double storey terrace house were removed and replaced with a white metal roof (BHP Steel Lysaght Asia, Mewah® tile Clean Colorbond®) with double sided aluminum foil (Ann Bee Sdn. Bhd.) and Roxul rockwool insulation (Roxul Asia Sdn. Bhd.) in a design undergoing patent consideration.

## Results and Discussion

A side-by-side experiment was conducted in two 20 year old double storey terrace houses, next but one neighbours, in a row of ten houses in Subang Jaya. A temperature datalogging test was conducted for one month before the Cool Roof renovation and verified that test house and the control showed similar thermal performance. The same test was conducted during the May-June 2001 heat wave after the Cool Roof renovation of the test house. On a very hot day (June 1) where the outside temperature reached 35$^0$C the peak roof space (attic) air temperature of the Cool Roof house was also 35$^0$C compared to 48$^0$C in the original test house. Subsequent experiments over the following year established that the temperature in the attic space never exceeded the peak outdoor ambient temperature. Cool Roof therefore completely blocked solar heat gain in the attic.

The effect of Cool Roof as measured in thermal discomfort units per 24 hours in different rooms (with results from control house in brackets)

| | | |
|---|---|---|
| Bedroom 1 (facing SE), | 13 | units of thermal discomfort per 24 hours (1unit) |
| Bedroom 2 (middle room), | 13 | units of thermal discomfort per 24 hours (4 units) |
| Bedroom 3 (facing NE), | 23 | units of thermal discomfort per 24 hours (5units) |
| Living Room (downstairs), | 5 | units of thermal discomfort per 24 hours (0 units) |
| Kitchen, | 2 | units of thermal discomfort per 24 hours (0 units) |
| Average thermal discomfort | 11.2 | units of thermal discomfort per 24 hours (2.0 units) |

**Reduction in thermal discomfort in Cool Roof house 82%**

The thermal discomfort, an objective measure of heat stress, suffered by the occupants was reduced by 82%. The occupants, two scientists and their teenage daughter were asked to summarize their perceptions one month and again one year after their home was renovated with Cool Roof. Their considered comment "The temperature in our house is now tolerable at all times without air-conditioning" confirmed the objective measurements of reduced thermal discomfort.

## Discussion

Cool Roof does not cool down a house; it prevents it from heating up excessively. It is a highly effective way of passively blocking solar heat gain through the roof. Our computer simulation studies reported elsewhere show that to achieve the same reduction in thermal discomfort using whole house air-conditioning requires RM180 per month extra electricity. The other major source of heat gain in concrete houses is through the walls particularly those exposed to the afternoon sun. Our latest computer simulation studies, not reported here, show that shading the walls has a very beneficial effect on reducing still further the indoor thermal discomfort. Mechanical ventilation over night is very effective in reducing indoor temperature and actively cooling the thermal mass of the house as a buffer against the following hot day.

Consumers have a poor perception of metal roofs, considering them to be unacceptably noisy during heavy rain. However, a metal roof suitably insulated deadens the rain noise. In a separate experiment a single storey terrace house renovated with Cool Roof gave the same sound reading, 52decebels, in the living room during heavy rain compared to a neighbour's normal house a few doors away.

Random household surveys conducted by UPM final year project students consistently reveal that 50 to 75% of respondents regard their terrace houses to be too hot on around half the days of the year. On hot days inside terrace houses 62% report suffering from headaches and 37% get angry. These sociological studies confirm the objective thermal discomfort (heat stress) measurements reported here. Clearly, Malaysia's 2 million overheated concrete houses represent a serious though previously unrecognised community heath problem.

Mild but long term heat stress according to our informal questioning over many years causes sleep disorders. People find it difficult to get to sleep in hot bedrooms and wake up frequently. We hypothesise that heat stress caused by overheated houses, particularly during the regular March and may heat waves, turns humans into zombies, unable to think clearly and perform adequately.. This is dangerous and, we suggest, leads to higher accident rates at home, on the roads and at work and reduces national productivity since the population is too tired and confused to perform as normal humans.

## Conclusions

Long term basic research at Univerisi Putra Malaysia into how and why concrete houses heat up in the Malaysian humid tropics has led to the successful development of Cool Roof which completely blocks solar heat gain through the roof. Detailed temperature data-logging measurements in side by side experiments, using additional new methodology to estimate human thermal discomfort (heat stress), has clearly established that renovating a double storey terrace house with Cool Roof reduced the thermal discomfort by 82%. The invention can save terrace house owners the RM180 per month electricity otherwise necessary to achieve the same effect using whole house air-conditioning.

The main motivation of this work, however, has been our concern that Malaysia's hot houses are a serious community health problem, turning the urban population into zombies during heat waves.

## Benefits from the study

We have recommended renovating 2 million existing concrete houses with Cool Roof.. This national program would greatly benefit the urban population by relieving avoidable heat stress and lead to a much healthier and more productive life style. Unfortunately the Cool Roof renovation is not cheap, at an estimated commercial cost of RM10,000 for a terrace house. However, this is no more expensive that air-conditioning a terrace house with 4 air-conditioners and the 3 phase electricity cabling required by law. The electricity saving using Cool Roof if fitted to 2 million existing houses and 2 million new houses is estimated to be **RM260 billion** over a 30 year period. Cool Roof thus deserves a rightful place in Malaysia's energy policy.

## Patent(s), if applicable

We have been advised by relevant authorities that Cool Roof will be difficult to patent since it is comprised of existing commercially available products. We intend to incorporate Cool Roof along with other cool technology inventions into whole house designs which can be patented.

## Stage of Commercialization, if applicable

Our Thermal Comfort Houses are in the early stages of commercialization and prototypes are under construction at UPM.

## Project Publications in Refereed Journals

1. Nurizan Yahaya, Mohd Peter Davis and Loke Chaw Liang. 2000.Thermal comfort in medium and low cost double storey linked houses. *Malaysian Journalof Consumer and Family Economics 3:35-41*

2. Nurizan Yahaya, Chow Yee Lin and Mohd Peter Davis. 2002. *Malaysian Journalof Consumer and Family Economics 5:54-62*

## Project Publications in Non- Refereed Journals

1. Mohd Peter Davis and Nor Azian Nordin. 2002. UPM Cool Roof: A new invention for cool energy efficient tropical buildings. *Buletin Ingenieur 1:13-16.*

2. Mohd Peter Davis and Nor Azian Nordin. 2002. UPM Cool Roof: A National plan for renovating 2 million overheated houses. Building & Investment 3: 83-85.

## Project Publications in Conference Proceedings

Mohd Peter Davis and Nor Azian Nordin. 2002. UPM Cool Roof: Prospects for a new steel roofing system in a collapsing world economy. Malaysian Iron & Steel Industry Federation Seminar 27-28 September, Petaling Jaya.

**IRPA Project number:** 02-02-04-0012
**UPM Research Cluster: MEE**