SOLAR ABSORPTANCE AND UNINSULATED HOUSES IN THE HUMID TROPICS

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ABSTRACT A study by the Australian Institute of Tropical Architecture was undertaken using the energy rating software BERS to determine the influence of using low absorptance paint on the thermal performance of uninsulated houses in the warm humid tropics of Australia. It was found that using such paints reduced the cooling energy load in air-conditioned houses and the number of degree hours naturally ventilated houses were outside a preset comfort zone.

1 Introduction

The residential sector in Australia uses around 24% of total primary energy consumption (Hyde 1996). Of this, heating and air conditioning energy use is 35% for Australia and 15% for Queensland (NEAC 1981). It is these two areas however, where it is hoped that energy savings can be made. Pressure to conserve energy has resulted in a renewed importance being given to the aim of providing thermal comfort in the home without undue wasting of energy (Goudie 1993; Lim & Rao 1984). This paper reports on a study at the Australian Institute of Tropical Architecture using the energy rating software BERS to examine the influence of low absorptance paint on energy savings in air conditioned houses and thermal comfort in naturally ventilated houses in Townsville, North Queensland. Comparisons are made on the houses with and without low absorptance roof paint.

1.1 Heat gain and thermal comfort

In order to achieve an acceptable level of thermal comfort householders resort to either mechanical (air conditioning) or non-mechanical (passive) means. Air conditioning can be expensive both in the initial outlay cost and in the amount of energy that is subsequently used. This is especially the case in warm humid climates. Passive alternatives to air conditioning can be used to achieve an acceptable level of thermal comfort. One of the most effective of these is the use of light coloured, highly reflective paint on the exterior of the house.

A dark coloured surface will absorb more solar radiation than a light coloured surface. As a building's energy balance is dependent upon the net solar radiation present at its external surfaces, (Akbari *et al*, 1990) the exterior colour of the building is important in determining the effect solar absorptance will have on thermal performance. This issue has been of interest for a number of years especially when considering the influence of colour on lightweight, non-insulated building. The use of light colours on the exterior of such buildings is an effective way of decreasing the cooling energy load (Taha *et al*, 1988).

1.2 Sol-air temperature

Heat gain in houses is influenced by number of factors including heat sources such as stoves, people, lighting, hot water heaters, cooking equipment etc. Other principal sources are also solar radiation and outdoor air temperature. When these latter two factors are combined this value is known as sol-air temperature and is calculated using the following equation:

$$T_e = T_o + (\alpha G / h_o) - (\in \delta R / h_o)$$

where : T_o = the outdoor dry bulb temperature ^{0}C
α = solar radiation absorptance;
G =global solar irradiance , W/m^2;
h_0 =surface heat transfer coefficient for radiation and convection;
δR =net longwave radiation W/m^2
$\in$ =hemispherical emittance of surface (0.9 for paint).

1.3 Building practices in Australian tropical regions

In the humid tropical regions of Australia such as Townsville it has been common practice for houses to be built with uninsulated metal roofs thus reducing initial building cost. In terms of thermal performance in the humid tropics the roof is the most important part of a building as it receives the most exposure to solar radiation. Painting the roof with a light coloured, highly reflective paint seeks to minimise the solar heat gain through the roof while maintaining the ability of the house to lose heat quickly after sunset. The aim is to improve indoor summer thermal comfort in naturally ventilated houses and/or reducing the cost of operating cost in air-conditioned houses.

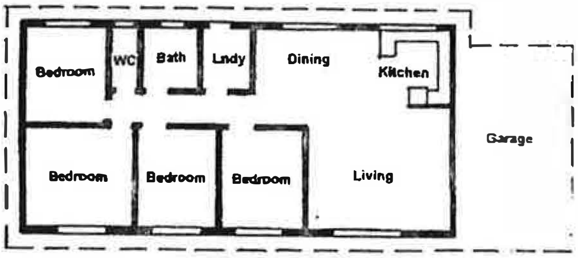
Studies have been undertaken previously to determine the effect of exterior colour on the thermal performance of a building. Ballinger (1996) used the Nationwide House Energy Rating Scheme (NatHERS) as a simulation tool in determining the influence of colour on a building's thermal performance in Alice Springs, while Taha *et al*, (1988) used a DOE-2.1C, a building energy analysis program to simulate the direct effects of colour on the cooling energy required by a lightweight construction house in Sacramento, California. These studies have not focussed specifically on humid tropical climates however, nor have they differentiated between air conditioned and naturally ventilated dwellings.

2 Methodology

2.1 The houses

Two different model houses were used in the study. House 1 is based on a rectangular, four bedroom house with a large, open living area (Fig.1A). The long walls are on a North-South axis and the shorter East and West facing walls have no windows. The floors are carpeted in the living area, bedrooms and hallway while the bathroom and laundry have ceramic tiles. The total floor area for huse 1 is 78m^2.

House 2 is based on an irregular shaped, three bedroom design (Fig.1B). Unlike the first house this design is carpeted in the bedroom zone only and also features windows on every orientation. The latter means that exposure to the western sun would contribute significantly to heat gain with this design. The total floor area for house 2 is 130.3m^2.



2.2 Location and climate

The model houses have been given addresses in Townsville, North Queensland (19.3° S, 146.8'E). The summer diurnal temperature range is 6.7K and the climate is warm humid tropical with an annual solar radiation average of 19904kJ/m^2.

2.3 The program

Simulations were run for the study using the Building Energy Rating Scheme (BERS). BERS uses the energy rating software CHENATH, produced by the CSIRO, and has a graphical interface, which allows input of floor plans. The software has limitations in that it includes preset solar energy absorptances of light (25%), medium (50%) and dark (80%). The low absorptance roof paint used in the study has an absorptance of 11%, less than half that of the lowest absorptance available in the program. As a result the thermal simulation underestimate the benefit of using lower absorptance paint.

Simulations:
Two series of simulations were run for each of the houses, (one series for Air-conditioned premises and one for naturally ventilated), with each series containing three sets of simulations. The same dimensions and colour combinations were used in each set however the construction of the exterior wall differed for each set (Figs.3-6). The house was divided into three zones, living zone and bedroom zone, (inclusive of the hallway, toilet and bathroom) are air-conditioned and the laundry (and garage for House 2) form the unconditioned zone. These zones were the basis for running simulations.

2.4 Estimating the Influence of 11% solar absorptance on thermal performance

The influence of changes in the solar absorptance of external surfaces on cooling loads was established by multiple BERS runs, in which the external solar absorptance was changed. As the solar energy absorbed is directly proportional to the external solar absorptance, the change in cooling load for a particular change in solar absorptance can be used to predict, by proportion, the change in cooling loads for further degrees of change in solar absorptance. This technique was used to quantify the cooling load reduction when external solar absorptance is decreased to 11%.

3 Results

3.1 BERS simulations

The results for the air-conditioned houses are stated in MJ/m^2 per annum. For the naturally ventilated houses the results are provided in degree hours, a measure of indoor overheating being the product of the extent that dry bulb air temperature exceeds the comfort zone and the duration in hours (Aynsley, 1998). Figures quoted here are for concrete block construction with a metal deck roof.

House 1: Rectangular 4 bedroom. The best performances overall were gained using the colour combinations with the light roof. Wall colour had very little effect on the result. Cooling energy load increased with each successive roof/wall colour combination with a significant increase from light roof to medium roof and again from medium roof to dark roof. (Fig.2) The percentage reduction gained by using lightest paint as opposed to the darkest paint was 54%. The graphs for the naturally ventilated house also indicate roof colour as the more significant factor in determining how many degree hours the house is outside the comfort range set by the program (Fig.3). The percentage reduction in degree hours of overheating gained using lighter paint was 74%.

House 2: Irregular shaped 3 bedroom. BERS indicates that roof colour is the more significant factor in determining cooling energy load used by this housing design (Fig.2). The percentage reduction of cooling load achieved by using the lightest paint was 44%. For the naturally ventilated house the percentage reduction of degree hours of overheating was 75%, with roof colour again being the more influential factor in thermal performance (Fig.3).

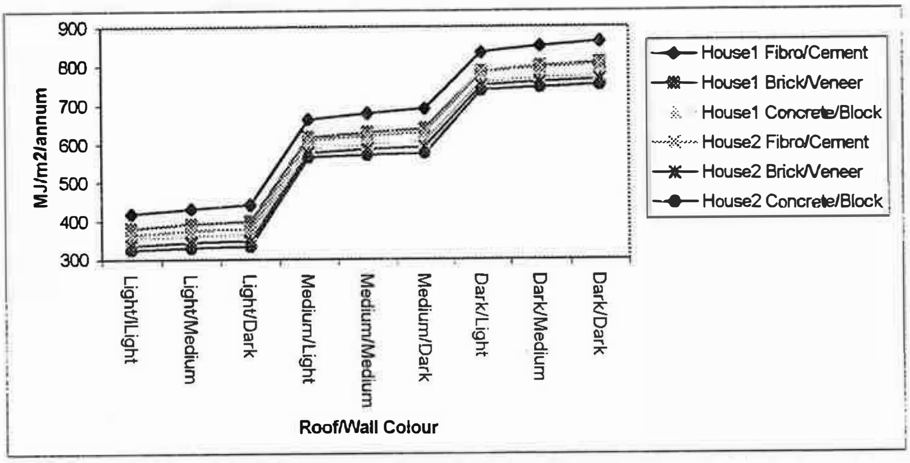


Fig.2 Energy load vs exterior colour: house 1 & 2 (air conditioned)

3.2 Cooling energy calculation and BERS

The values for the sol-air calculations are set in BERS using climatic data file, building orientation, solar geometry and surface conductance. The only part of the calculation that the user can alter is solar absorptance (α). The user chooses an α value by selecting from dark (80%), medium (50%), or light (25%) exterior colour. Simulations were run on BERS for each of the available α values (80%, 50% & 25%). The preset levels of absorptance used by the BERS program leads to a problem in extreme climates such as summer in the humid tropics. The highly reflective roof paints available today have absorptance levels as low as 11%. By restricting the choice of absorptance levels to those mentioned above thermal simulations done by the BERS program underestimate the benefits of using such paints. This is demonstrated in Table 1.

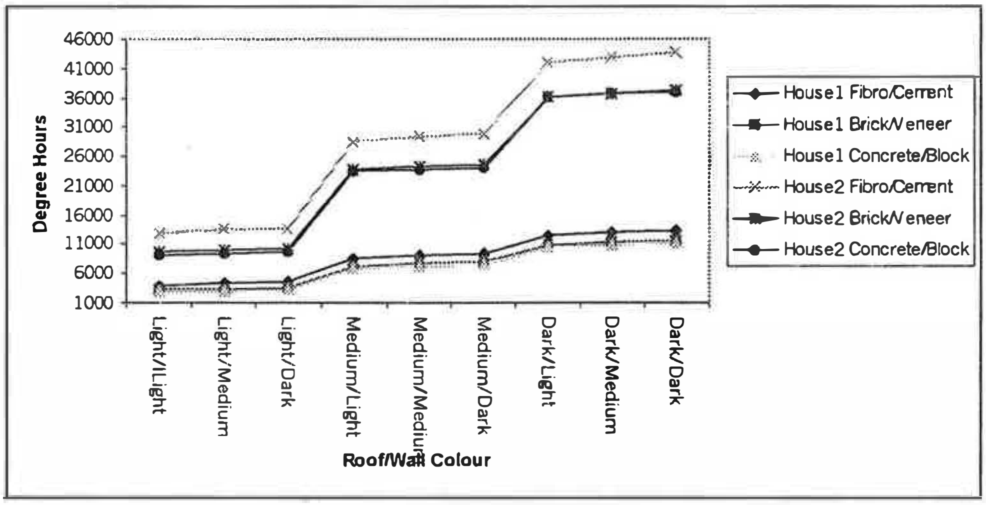


Figure 3: Degree-hours of overheating vs exterior colour: houses 1 & 2 (naturally ventilated)

Using the preset values in BERS a reduction of solar absorptance yields from dark to light would be 55% (80-25=55). If the level of high reflectance paints (11%) could be used then the reduction of solar absorptance could be increased to 69% (80-11=69). If a 55% reduction in solar absorptance yields a 54% reduction in cooling load for House 1 then a 69% reduction in solar absorptance would give 54/55x69=67.7%. This means that BERS fails to account for a further reduction of cooling load by 13.7% achieved by the use of a lower solar absorptance (11%) finish.

These findings are relevant to both houses and for both air-conditioned and naturally ventilated conditions. House 2 shows a further 11.2% cooling load reduction when solar absorptance is reduced to 11% (44/55x69=55.2). The naturally ventilated versions of House 1 and House 2 show a further reduction of degree hours of discomfort of 18.8% (74/55x69=92.8), and 19.1% respectively (75/55x69=94.1) using the low solar absorptance finish (11%). This reduction is also unaccounted for by BERS.

Type	AC Dark MJ/m2/a @80%	ACLight MJ/m2/a @25%	Cooling Difference (%)	Cooling Difference @11%	NVDark DegHrs @80%	NV Light DegHrs @25%	Reduction Deghrs (%)	Reduction Deghrs @11%
House 1	773.3	353.4	54	67.7	44412	11594	74	92.8
House 2	749	325	44	55.2	36924	9256	77	94.1

Table1 Thermal evaluations of house1 and house2 with external roof and wall absorptances of light (25%) and dark (80%) for air conditioned (AC) and naturally ventilated (NV) premises.

3.3 Sol-air temperature and light coloured paints:

Manual calculations show that the use of highly reflective light coloured paint significantly reduced the calculated Sol-Air Temperature at the external surfaces of the houses. Percentage reduction in temperature ranged from 31%, (51.7°C/dark exterior to 32.6°C/light exterior), for an open exposure under a clear sky to 63%, (98.6°c/dark exterior to 36.2°C/ light exterior), for a sheltered exposure under a clear sky.

4 Conclusion

The effect of exterior paint colour on the amount of cooling energy used by two typical, uninsulated house designs found in the humid tropics of Australia has been examined in this paper. Ballinger found in his 1991 study that the influence of insulation eventually cancelled out the benefits of using highly reflective exterior colour. This study concentrates on uninsulated houses. For air-conditioned houses the amount of energy used in sensible cooling was used as an indicator of thermal performance, while for naturally ventilated houses the number of degree hours the house is above the comfort band and therefore, overheated was used. It was found that using light coloured highly reflective paints provides benefits in energy savings for air-conditioned houses and in more hours of thermal comfort for naturally ventilated premises. The use of light coloured, highly reflective paint was found to be a significant factor in reducing the sol-air temperature of the exterior of the houses. As a reduction in sol-air temperature leads to reduction in cooling loads and overheating the significance of colour in reducing these factors is re-enforced by these findings.

There is no direct output from BERS to determine the contribution from low solar absorptance finishes to energy efficiency. However multiple runs of the BERS program for two particular houses using the specified input values of Dark (80%) and Light (25%) indicate an improvement in cooling loads and degree hours of discomfort for the 55% reduction in absorbed solar energy. As the relationship between absorbed solar energy and surface absorptance is linear one can extrapolate, using linear interpolation, the effect surfaces with lower absorptance will have on cooling loads and degree hours discomfort.

In conclusion it is generally acknowledged that in lower latitudes the roof is exposed to solar radiation for much longer and loses heat to the night sky more effectively than the external walls of a building. Therefore it would be expected that roof colour would have a significant influence in reducing cooling load for air-conditioned houses, and the number of degree hours naturally ventilated houses are outside a set comfort zone. This was found to be the case with the results obtained from BERS.

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