A COLLABORATIVE FIELD AND LABORATORY STUDY OF SUMMER THERMAL CONDITIONS IN ROOFS **12 Jan 2000**

Introduction

Australia has less severe winters and longer summer conditions than North America and Europe, the source of most thermal modelling for buildings.

There have been significant advances in field measurement technology in Australia since the development of the NatHERS software. The most significant developments have been in measurement of ventilating air changes using tracer gas (Chan, 1999); measurement of low velocity air flow near surfaces and in confined spaces (Parker et al, 1991). Heat transfer in roof spaces under extreme conditions by convection and infrared radiation within fibrous insulation and multiple cell reflective cavities is not adequately accounted for by current design practices. It has been demonstrated (Langlais et al, 1990) (Parker et al, 1991) that heat transfer through insulation is not proportional to temperature difference across the insulation in roof spaces at high temperatures >40°C (air temperatures >40°C occur regularly under metal roofs during summer in Australian houses).

With house energy rating referenced to NatHERS becoming widespread across Australia it is important that the ratings produced using NatHERS are soundly based and follow world's best practice.

Some conditions in roof spaces, on which little field data is available such as roof space surface conductances, have the potential to strongly influence heat transfer through a roof space. Of particular interest are:

- Air speed on the underside of roofing and sarking which has a major influence of surface heat conductance values.
- Air speed adjacent to the upper surface of the ceiling or bulk insulation on top of the ceiling which has a major influence on surface heat conductance values.
- Temperatures at the upper surface of the ceiling, which indicate the combined effects of roof space air temperatures and radiant heat transfer through the roof space.
- Temperatures on the underside of sarking in a roof space which indicate the contribution to heat transfer upward through a roof space by conduction and convection.

Modelling of summer heat transfer through roof spaces in NatHERS can be significantly affected by roof space air change rates. Almost nothing is known regarding the range of these air change rates in Australian houses because of past difficulties in measurement. While some data are available from other countries, air change rates are likely to be strongly influenced by local wind conditions and Australian construction practices which differ from construction practices elsewhere. Where air change rates in roof spaces are low, significant vertical thermal stratification is likely to occur within the roof space for which there is no data. Such stratification would cause significant spatial differences between roof space air temperatures and sol-air temperatures on the exterior of the roof. These differences would cause large spatial variations in heat entry into the roof space currently not accounted for in NatHERS.

Collaborative Study
It is proposed that a collaborative study be undertaken by Dr Angelo Delsante and Robin Clarke of the CSIRO Division of Building Construction and Engineering together with related field studies by Professor Richard Aynsley at James Cook University in Townsville.

Laboratory Study
Recent development of very low density fibre insulation batts has created concern regarding the possibility of significant heat transfer by infrared radiation penetration and convection. While these effects are well known to exist in theory no physical data confirming the theory exist. Current heat transfer testing procedures for insulation batts focuses on heat transfer due to differences in air temperature across test specimens. Using current thermal performance data for such products in NatHERS could lead to significant errors in heating and cooling loads. Robin Clarke from CSIRO at Highett has a one metre square heat flow meter apparatus which could be used to measure the data needed. Further information on this component of the collaborative study is attached (Appendix A).

Computer Modelling
House energy rating software such as NatHERS and BERS by necessity make certain assumptions regarding heat transfer. One such assumption in the CHENATH engine of these programs is that averaging the thermal resistance to heat flow up and heat flow down in reflective roof spaces will not result in appreciable error in total energy rating when integrated over a full year.

This assumption may be reasonable in temperate climates where heating and cooling energy for a typical house are fairly evenly balanced. This assumption is probably less than reasonable for houses in warmer climates winterless which have dominant cooling requirements. In tropical coastal regions of Australia where there is virtually no heating requirement the assumption is likely to lead to significant errors. Angelo Delsante will use data collected in field studies and laboratory tests to validate current computer modelling in the NatHERS software. Further information on this component of the collaborative study is attached (Appendix B).

Field Studies
The longer duration of warm to hot weather and reliable onshore breezes in Townsville make it an ideal location for such a study of field data on thermal conditions in roof spaces of Australian houses during summer. Defence Housing Authority has agreed to provide access to 30 of the houses for such a study. Collection of primary data, at hourly or shorter intervals, in each house would continue for at least one week and up to two weeks if the weather is variable. Some secondary data would be collected at less frequent intervals.

Researchers under the direction of Professor Richard Aynsley at the Australian Institute of Tropical Architecture (AITA) have had considerable experience in field studies of thermal conditions in buildings for State Government agencies and corporate clients. An example was the community project measuring summer ceiling temperatures in approximately 100 houses was conducted by the AITA at James Cook University in 1996. The proposed field studies would include placement and retrieval of CSIRO passive tracer gas sources and samplers for analysis of air changes in roof spaces by Colin Chan at the CSIRO Division of Building Construction and Engineering, Highett. Further information on this field study component is attached (Appendix C).

Timing

It is proposed that the study would commence early in 2000 and continue for 12 months so as to include two periods of the hottest weather in Townsville. The first 6 one week runs would act a pilot run for later data collection. With this arrangement, analysis of data collected in the early part of the year can inform collection of data throughout the rest of the year.

COST SUMMARY

CSIRO Components:	
Analysis of data and improvements to thermal modelling in NatHERS software by Angelo Delsante	$20,000
Laboratory study of heat transfer through low density bulk insulation	$55,000
Travel: One trip to Townsville from Melbourne early in study by Angelo Delsante and Robin Clarke	$3,000
Provision of passive tracer gas sources and samplers and analysis of data for air change measurements in roof spaces of four houses including the cost of 1 visit to Townsville by Dr Colin Chan to inspect placement of sources and samplers.	$15,000
Sub Total	$93,000
AITA Components:	
Postgraduate researchers for 12 months installing data collecting equipment and archiving electronic data records and graphing results.	$70,000
Supervision time by Professor Richard Aynsley over 12 months @ 10%	$11,335
Local travel to building sites around Townsville for installation of equipment and data retrieval - 60 x 14 km trips	$450
Consumables - Thermocouple wire, heat flux sensors, data storage media etc.	$4000
Sub Total	$85,785
Grand Total	**$178,785**

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APPENDIX A

THE PERFORMANCE OF CEILING INSULATIONS IN ROOF SPACE ENVIRONMENTS

Robin Clarke
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November 1999

Introduction

This proposed work aims to clarify current understanding of the real in-situ performance of a variety of ceiling insulations. There is considerable uncertainty and debate about the numerous factors which may cause actual thermal resistances to differ from "standard values" derived from laboratory "hot plate" measurements. These factors have not been studied for Australian conditions. Hot plate measurements isolate the measurement sample between two temperature-controlled plates. This is a precisely defined but artificial environment. There is no heat exchange by convection between the insulation and its surroundings. The radiation field around the sample is stable and uniform, defined simply by the temperatures of the opposing plates. In this situation, it is possible to make precise measurements which accurately demonstrate the effects of small changes to density, thickness and other factors which influence performance. However this environment may not be a realistic representation of an actual roof space, where temperature, radiation and convection effects may be quite different, and may lead to different heat flows through the insulation than would be predicted by relying simply on the "rated" thermal resistance of the insulation.

It is proposed to study the key factors which may affect the in-situ thermal resistance of thermal insulation materials by using an extended version of the one-meter-square heat flow meter apparatus operated by CSIRO at Highett. These factors arise simultaneously in a ventilated roof space when the top surface of a batt or other insulation at ceiling level is cooled convectively by air movement and at the same time receives a high radiation load from a hot tiled or sheet-metal roof above. For fibrous batts of sufficiently high density, there is negligible air movement through the fibres (because they are of sufficiently low permeability) and there is negligible penetration of radiation (because it is highly absorbed by the fibres). In such a case, heat flow through the batt correlates closely with the temperature difference across it and the effective thermal resistance is not expected to differ from the rated value which would be derived from measurement in a hot plate apparatus. However, for batts of very low density, convection and radiation may both be able to penetrate. Radiation penetration would almost always contribute to a higher heat flow for the same top surface temperature than would be the case during thermal measurement, effectively producing a lower thermal resistance in-situ than the rated value of the batt. On the other hand, convection can have two alternate effects. In general, convecting air which is cooler than the insulation it passes through will have the effect of reducing heat flow and improving the effective thermal resistance in summer. Conversely, ventilation by cooler air in winter represents a short circuit which will have a negative impact on performance and effective thermal resistance. For this reason it is critical to understand ventilation patterns in roofspaces so that experimental conditions are appropriate. Other parts of this proposal address this question.

It is therefore proposed to measure a range of ceiling insulations with the top surface of the insulation open to the space above it, rather than in contact with an isothermal plate. The test facility will duplicate the summer case with high levels of radiation from a hot surface impinging on the insulation at the same time as there is cooler air ventilating across the top of the insulation.

Proposed Measurements

It is proposed to construct an expanded version of the current CSIRO heat flow meter apparatus at Highett which is in regular use for measuring the thermal properties of materials according to the American (USA) standard ASTM C 518, the general heat flow meter standard. The current CSIRO apparatus operates in the classic arrangement, locating the test sample between two one-metre-square aluminium plates which are held at different temperatures within the range 10 °C to 60 °C. The plate assembly has adjustable spacing of up to 220 mm between the plates, whilst the whole plate assembly may be rotated to alter sample orientation and heat flow direction. Thermal properties are derived from measured heat flow through the 460 mm square metering area in the centre of one of the plates.

Although the heat flow meter apparatus is relatively large for a facility of this type, it is nevertheless too small for the proposed experimental program where roof space conditions are to be duplicated, especially in relation to height, where the space between ceiling insulation and a hot roof may be up to several metres. An expanded version of the apparatus will be constructed incorporating its proven features (hardware and software) but operating on a larger scale. Plate area will be increased to 1.8 m square and the spacing between plates will be increased to 1.0 m or greater. The apparatus will operate only in the horizontal mode and will incorporate a closed loop ventilation system so that the space above the batt may be ventilated with cooled or warmed air at constant temperature. The surfaces of the space above the insulation, comprising the top plate and its skirts, will in general be controlled to a temperature higher than the ventilating air. Temperature conditions will be in accordance with those measured in the field in concurrent studies. The upper plate will have the capability of operating at up to 80°C.

The apparatus will be capable of determining the effective thermal resistance of most types of ceiling insulations, including reflective materials or materials which combine bulk and reflective components. It will be particularly useful for low density bulk materials, where it will identify the effect of possible convection and radiation transmission through the insulation. In general, this may be simply achieved by performing a pair of measurements, with and without a thin sheet of opaque material (such as paper) on top of the insulation to prevent radiation and convection from occurring. The thermal resistance of a thin opaque material would be very close to zero so that there would be a negligible effect on conduction heat flow due to its presence. If there is greater heat flow through the insulation into the bottom plate when the sheet is absent, the existence of additional heat flow mechanisms, such as convection and radiation, is indicated. The apparatus will be capable of measurement to a resolution and repeatability of considerably better than 1 %, so that even a small effect will be clearly resolved. Since thermal resistance values may be simply derived from these heat flows, results would be directly calculable as a reduced thermal resistance due to the convective and radiative effects.

Construction of the New Facility

Construction of the new larger plate assembly will be simplified by the horizontal-only geometry and the use of heat flow meter techniques which are well established and have been used successfully by CSIRO for many years. Existing software will adapt to the new facility with minimal modification, providing direct logging of thermal resistance as well as the collection of detailed statistical data. Data logging equipment identical to that used for the existing apparatus is available for use in the new facility.

The existing heat flow meter apparatus has no facility for ventilating across the top of a sample. In order to achieve this, a precision recirculating cool air system must be constructed. Heat flow meters do not function well where there are fluctuations in heat flow, tending to produce large spurious signals which may mask the underlying steady state effects of interest. Therefore, an ultra-high stability control of temperature and flow rate is required for the recirculating air so that true steady-state conditions and stable heat flow meter response can be generated. A long term temperature stability of 0.1 °C and a short term stability of 0.02 °C would be design targets for this facility. High-stability chillers are available and this level of performance is achievable but construction to a high standard would be essential. Similarly, careful duct design would be required to establish constant even airflow across a sample at a controlled range of flow rates.

Timing

Approx. 4 - 6 months to construct and commission facility and perform measurements

Cost

$55,000, including measurement of 10 insulation configurations

APPENDIX B

FIELD STUDY OF SUMMER THERMAL CONDITIONS IN ROOFS

Angelo Delsante
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November 1999

The proposed measurements cover the information needed to improve computer simulation of roofspaces.

The proposal covers 30 houses in Townsville sufficient to cover a representative range.
Parameters of particular interest for modelling purposes are:

- Air speed at the underside of the roof (for roofs without sarking) or the underside of the sarking (for roofs with sarking)
- Air speed at the top of the ceiling surface, between the joists or between the battens if the ceiling is battened out from the trusses (for ceilings without bulk insulation), or at the top surface of the bulk insulation
- Temperature at the top of the ceiling surface, between the joists or between the battens (for ceilings without bulk insulation), or at the top surface of the bulk insulation
- Temperature of the underside of the sarking if present

Parameters such as temperatures, air speeds, and solar radiation, will be logged continuously at a maximum of 1-hour intervals.

We recommend that the project proposal include a laboratory study of radiant heat transfer through low-density bulk insulation. A revised proposal by Robin Clarke is attached (Appendix A).

Air change rates in the roofspaces are of considerable interest. Continuous monitoring would be ideal but may be technically or financially out of the question. However, it would still be useful to measure average air change rates over short periods using passive tracer gas techniques, and correlate them with local mean wind speed over the same period. This involves installing several tracer gas sources in the roof space and installing and removing samplers at the beginning an end of each measurement period (say a week). The tracer gases are harmless to humans. Such a study has already been done in four houses in Melbourne. Because the houses are occupied, a potential problem is to convince the householders that the tracer gases are harmless, and it may be necessary indemnify JCU and CSIRO from any possible legal action.

CSIRO has been developing its own passive tracer gas technique, but it is not yet ready for field use. Thus we would need to use a Swedish company, PentIAQ, as we did for the Melbourne houses. They can mail the sources and samplers and analyse the returned samplers. We could look at measuring three or four houses:

- Tiled roof, no sarking
- Tiled roof with sarking
- Steel roof (with and without sarking?)

We would need to do about 6 one-week runs for each house. The exercise is straightforward but needs very careful management, in particular the handling of sources and samplers to ensure that the sources are not contaminated before being installed in the roof space. We will need to consider how this series of measurements fits in with the other measurements.

Additional estimated costs

- Analyse data, improve model in NatHERS software: $20,000 (Angelo Delsante)

- One trip to Townsville for two people early on in project: $3,000 (Angelo Delsante, Robin Clarke)

- Laboratory study of radiant heat transfer through low-density bulk insulation (see attached proposal): $55,000 (Robin Clarke)

- Passive tracer gas measurements in three or four houses: $15,000 (includes cost of sources and samplers, 1 trip to Townsville for Colin Chan, who supervised the Melbourne measurements if air change rates, and a few days of our time. Does **not** include JCU staff time required to install and remove sources and samplers, and generally manage the measurements).

Total additional costs: $93,000

APPENDIX C

A FIELD STUDY OF SUMMER THERMAL CONDITIONS IN ROOFS

by

Professor Richard Aynsley, James Cook University, Townsville

Aim:

To conduct a summer field study of thermal conditions in roofs to inform assumptions made in thermal computer modelling of houses for energy rating purposes.

Summer thermal issues in roofs on which there is little field data are:

- Air changes in ventilated roof spaces
- Thermal stratification in ventilated and non-ventilated roof spaces
- Airflow rates between tiles and sarking
- Roof space temperatures with various insulation over ceilings
- Indoor surface temperatures of ceilings with various roof insulation
- Radiant heat fluxes from roofing into roof spaces
- Relative heat transfer through ceilings between centre of the roof and its perimeter

Basic House Roof Types to be Studied

Hipped roof - ridge line North/South, ventilated and unventilated
metal - with and without reflective foil under battens
tile - sarked & unsarked

Hipped roof - ridge line East/South, ventilated and unventilated
metal - with and without reflective foil under battens
tile - sarked & unsarked

Gabled roof - ridge line North/South, ventilated and unventilated
metal - with and without reflective foil under battens
tile - sarked & unsarked

Gabled roof - ridge line East/South, ventilated and unventilated
metal - with and without reflective foil under battens
tile - sarked & unsarked

Roof Structure:

Traditional rafter/purlin framed
(high impedance to air movement across top of ceiling)

Contemporary roof truss with battened ceiling
(less impedance to air movement across top of ceiling)

Insulation Materials

A wide variety of thermal insulation materials, provided and installed by suppliers, will be monitored including bulk, batts and reflective foils with air spaces alone and in combination with bulk insulation or batts.

Strategy:

- Measurements over a period of a week to indicate influence of day-to-day fluctuations and provide for a sufficient range of outdoor conditions to allow comparison between houses.
- In some cases indoor conditions will be monitored in a house before and after the installation of various types of roof insulation.
- Some stand alone monitoring devices will be used to minimise the need for wiring back to central dataloggers.
- Reference outdoor conditions to be monitored include ambient outdoor shade dry bulb and wet bulb air temperatures, unobstructed eaves height wind speed and direction, and incident solar radiation, and sky (cloud) conditions.

Innovative Technologies to be Used:

- Thermal imaging will be used to provide visual displays of the variation in surface temperature across roofing and ceiling materials.
- State-of-the-art passive tracer gas technology will be utilised to measure air change rates in roof spaces under the supervision of Colin Chan from CSIRO Division of Building, Construction and Engineering.
- Infrared heat flux measurement will provide direct data on infrared heat flow in roof spaces.
- Spot surface temperature measurements with thermocouples will provide numerical data to interpret thermal imaging.
- Indoor heat stress would be monitored using WBGT Area monitor with datalogging capability.

Other instrumentation:

- Precision airflow measurements will be made with Dantech and Visicalc thermal anemometers with calibration traceable to NIST.
- Heat flux sensors will be embedded in gypsum ceiling board (manhole covers) to quantify heat flux over time which can be related back to temperature differences across components to validate thermal resistances.
- General surface and roof space air temperatures will be monitored using thermocouples through a multiplexer and datalogger.

Expected Outcomes

- Field data from this project will indicate the thermal behaviour of roof insulation materials alone and in combination under humid summer conditions which dominate the summer climate along East coast regions of Australia.

- This field study will indicate effective means for controlling summer heat gain through roofs in air conditioned and naturally ventilated houses along the East coast of Australia.

- Field data from this project will indicate how well the algorithms used in current house energy rating software model the thermal performance of various arrangements of bulk and reflective thermal insulation materials.

- Field data from this project will indicate the reliability of existing house energy rating software models of summer heat gains through roofs. This will ensure that the estimations of summer contribution of heat gain through roofs to a NatHERS house energy rating is realistic. Reliable estimates of potential summer cooling energy savings will provide confidence in estimates of reductions in associated greenhouse gas emissions.