Attention: The Secretary
Senate Inquiry: Energy Efficient Homes Package (Home Insulation Program)

SUPPLEMENTARY SUBMISSION
Connection between R-values in Home Insulation Program & Building Code of Australia

I am the Managing Director of Wren Industries, manufacturer of CONCERTINA FOIL BATTS insulations.
I have provided written and oral testimonies to the Senate Inquiry - Energy Efficient Homes Package (also known as HIP - Home Insulation Program) on 17 Feb: refer Submission 15 and Questions On Notice 12.
http://www.aph.gov.au/Senate/committee/eca_ctte/eehp/submissions.htm

The following reference documents are provided to the Senate Inquiry as additional, important and very much in the national and consumer interest for best practice in Building Energy Efficiency for the reduction of Australia's Green House Gas Emissions. The comments below make frequent mention of the Building Code of Australia (BCA). The BCA and HIP have close linkage and a case exists to challenge - in both BCA and HIP - the regulatory levels of thermal insulation, direction of heat flow, and failings in the Australian-NZ Insulation Standard AS/NZS-4859.1.

CSIRO – Division of Building Research – Highett (Melbourne) VIC *3 documents

CSIRO-NSB 163(Notes on the Science of Buildings) "Thermal Insulation – Installation & Materials" (1991)
Pg 2 "AMOUNT OF INSULATION" Sections 7.01, 7.02, 7.03
Quote: "For Australia's temperate coastal regions, insulation (for ceilings) with a thermal resistance of **R values of 1.5 to R2.0** would be generally adequate"

CSIRO Sheet 10-20 "Insulating Your Ceiling"(1981)
Refer: "HOW MUCH SHOULD I USE?"
Quote: "For batts and loose fill (insulation) this Division suggests using an amount that will provide a thermal resistance of **R2.0.** This recommendation can be justified on economic grounds after consideration of several factors such as future fuel costs, interest rates and marketing factors".

CSIRO – Rebuild (June 1981)
Page 4 * this is part of an unsighted CSIRO periodical – one page only revealed.
Quote: "Insulation rated R2 will reduce the heating load by about 30%. **Increasing this to R4 will only reduce the heating load by a further 2%** (ie 32%)".

LAW OF DIMINISHING RETURNS
All three CSIRO files tell the same story, which directly impacts onto the levels of Total R-values (for new house construction) specified in the BCA - Building Code of Australia 2010(6 Star house energy efficiency) version and earlier BCA versions. According to the *Law of Diminishing Returns* (ie increasing insulation beyond a certain point does not give any substantial additional thermal or economic benefit) **BCA roof-ceiling Total R-values cannot be and have not been unquestionably justified.**

Additional Supportive Reports
James Fricker is the engineer in Australia who co-ordinates the majority of Total R-value assessments of insulation materials, both bulk and reflective foil. His reports, herein referenced, reinforce the above CSIRO advice. See http://fricker.net.au/ - go to Law of Diminishing Returns.
Mr.Fricker's report was originally commissioned for ACIMA – the cellulose association.
See ACIMA website: http://www.acima.asn.au/ - go to MORE INFO.

OVERVIEW
The HIP program R-values for ceilings ranged from R3.0 – R4.0 depending on Climate Zone assignment.

If R2.0 in ceilings was adequate insulation for CSIRO in 1981 and 1991, then why are R-values under HIP and under the BCA 2010 (R4.1 – R5.1 explained below) now being accepted? One reason could be because of the power of the vested commercial interest in the manufacture of fibreglass batts.

High R-values in Australia are often justified by reference to high R-values for building energy efficiency in the USA. This is a pointless connection because vested interests in USA do the same thing as in Australia. Fibreglass batt manufacturers vigorously push high R-value bulk insulations everywhere across the world in defiance of the Law of Diminishing Returns, as well as not subjecting their fibre batt insulations against realistic high temperature effects (refer Wren original Senate testimony).

Another reason for higher R-values today might be that historic R-value advice in Australia was focused on energy savings for winter, rather than summer, and with the ever increasing demand for airconditioning some might say that there is a need to have more insulation. If that is so, then R-values also need to be assessed for realistic summer roof space conditions as what occur across Australia, rather than anchoring the Australian-NZ Insulation Standard (AS/NZS-4859.1) on a USA laboratory test method which is based on very cold dominant winter climates of USA and Europe. Australia is the direct reverse - much milder winters and longer hotter summers. The current laboratory test method is inadequate and misleading – it measures thermal resistance of bulk insulations at a maximum 33degC, which is not representative of more typical Australian roof spaces temperatures of 50-70degC.

Cellulose (loose fill insulation) and polyester insulation industries concur with the "Law of Diminishing Returns", because it is based on known science and truth, and have serious difficulties with installing their own products with increasing thicker bulk insulation depths. The fibreglass insulation industry exploit this and keep marketing a never ending upward spiral of high 'material R-values' (resistance of the batt itself) to satisfy the 'Total R-values'(resistance of the entire ceiling-roof system) according to the BCA. The driver of all this is the never ending increase of House Energy Star Ratings as set by the BCA, recently adopted in 2010 at 6 Star for national roll out. The validity of Star ratings versus building energy efficiency has been challenged by many experts for years, but governments continuously ignore this. Are commercial vested interests driving upward star ratings?

The BCA will contend that their determination of Total R-values for ceilings (walls and floors as well) is totally justified. I contend that it is not, because the BCA bases its R-value decisions on technical modeling reports which are neither supported by peer review nor published for consumer comment. Again, these decisions are critical to the consumer's ability to achieve Sustainable Building Energy Efficiency and contribute to the reduction of national greenhouse gas emissions.

The overarching issue is that the historic CSIRO information here in this Submission has been in the public domain for decades, but ignored by regulators and building specifiers for far too long. Why? A pretty good reason would be the decades of fibreglass batt marketing. We all know the famous marketing slogan "fatter is better" – it is legendary, it is false and should be challenged under the ACCC and Trade Practices. Consumers get bombarded with endless streams of repetitious information, so effectively they believe it and so do governments.

Now let's extend this to Home Insulation Program. Of course the Federal Government privately consulted the fibreglass insulation industry ahead of any other bodies, two companies control about 70% of all sales of bulk and foil insulations. The government embarked on the HIP believing whatever the fibreglass industry told them, and look where we are today – just read the news. A "total train wreck" for all sectors of the industry. This is why the rectification process of HIP must continuously consult **the entire and all sectors of the insulation industry** and be alert to challenge whatever the fibreglass industry says in future.
And now 16 June, CSR Bradford Insulation have been appointed to clean up HIP:
http://www.bpn.com.au/Article/Bradford-cleans-up-governments-insulation-mess/518873.aspx
And increasing fires due to bulk insulations: http://www.abc.net.au/news/stories/2010/06/16/2927894.htm

In order to publicize the historic CSIRO information and with the increasing power of the internet, some years ago I decided to create an array of FACT sheets for the Wren website - http://concertinafoilbatts.com/foilfacts.htm in order to educate the public as well as the Building Code of Australia regulators. In particular refer: FACTS-8 "Law of Diminishing Returns".

In concluding this "Overview", I bring to the Public and National Consumers' attention that the above information leads on now to another discussion of a decision by the ABCB (Australian Building Codes Board) that should be put on the table.

INACCURATE DESIGNATION OF HEAT FLOW DIRECTION IN BCA CLIMATE ZONES & ABUSE OF REGULATORY PROCESSES IN FORMULATION OF BUILDING ENERGY EFFICIENCY REGULATIONS IN 2003

In 2003 the ABCB set its BCA National Climate Zone Heat Flow Directions where it assigned Perth, WA as a "***Winter Heat Flow (Heat Flow Out) Climate Zone***". This decision was based on consultations with West Australian Gallop Labor Government of the day who it said in a letter to AFIA it had consulted with FARIMA (Fibreglass & Rockwool Insulation Manufacturers Association), now ICANZ, in the face of overwhelming evidence and objection presented by AFIA (Aluminium Foil Insulation Association) who presented a technical report which included data and graphs from Western Power showing there was a higher consumption of cooling energy used during the summer months as opposed to a lower consumption of energy being used during the winter months for Perth. These files still exist today and are held by the AFIA.

In the public and national interest these mistakes cannot be allowed to be continued or repeated, and in fact ought to be corrected.

CONDENSATION

Reports on condensation are also included in this Supplementary Submission to assist the Senate Inquiry. The subject of condensation is complicated and cannot be concisely summarized although the following quotations are provided.

AS1562.1(1992) "Design and Installation of sheet roof and wall cladding" - Appendix A
"Bulk insulation keeps ceilings warmer and roofing cooler than if no insulation is installed in the cavity and, being porous, allows water vapour to reach the cold roof surface where it condenses. In addition to the physical dangers to the structure and finishes, **the increase in moisture content can reduce the effectiveness of the bulk insulation by up to 30%.** Consequently, a vapour barrier should always be installed on the warm side of any bulk insulation."

Prof R.Aynsley – "National Guidelines needed To Avoid Condensation Damage" - 14 June 2010
"Conclusions: Serious damage to buildings from condensation is increasing in Australia as building envelopes are tightened and thermal insulation is increased to increase energy efficiency. There is an urgent need for Australian Codes and standards to be updated to provide detailed guidance to building designers for condensation control across all of Australia's climatic conditions".
Refer also Aynsley Senate testimony (17 and oral).

In light of the above warnings however, under HIP and the BCA, bulk insulations are able to be used in roof-ceilings in any location of Australia. With increasing litigation cases regarding condensation and building damage, the usage of bulk insulations needs to be re-examined.

INSULATION IN WARM CLIMATES

Refer attachment *Aynsley- Insulation in Roof Spaces.* This report underpins the Senate Inquiry testimony of Prof Richard Aynsley and runs parallel to the AHRC 1981 QLD Report - Renouf testimony: "Answers to Questions on Notice" – 12. The Aynsley report here presents a supporting case to challenge high BCA ceiling R-values.
Aynsley report's conclusions
For naturally ventilated houses in regions of Australia, with little or no winter heating requirement, a single layer of aluminium foil insulation in ceilings is preferable to bulk insulation. Reflective foil limits the daytime surface temperatures of the ceiling…and prevents infrared radiant heat gains to occupants, and provides low thermal resistance to upward heat flow which promotes rapid cooling of the house after sundown.

This unique feature of aluminium foil insulations used in ceilings has profound implications for reducing energy demand for cooling of buildings, both naturally ventilated as well as refrigeratively cooled.

GROSS OVERSTATEMENT OF TOTAL R-VALUE OF FIBREGLASS INSULATION UNDER WINTER CONDITIONS

Senate Inquiry: Submission 23 Attachment 5 - Brian Tikey: Aluminium Foil Insulation Association.
http://www.aph.gov.au/Senate/committee/eca_ctte/eehp/submissions.htm

WINTER Research testing project examining the thermal performance of fiberglass batts in ceilings (Univ SA).
Summary
This report revealed substantial divergence between 'Material R-value' and 'Total R-value'. This research paper was published in 2009 and presented to the ABCB at the Australian Building Codes Board International Conference: "**Building Australia's Future**", Gold Coast, Australia, 20-23 September, 2009. The ABCB have since appeared to be sitting on the report instead of acting on it in consultation with its authors (**M. Belusko, F. Bruno, W. Saman**) and Institute for Sustainable Systems and Technologies, University of South Australia.

NB: the BCA "Building Energy Efficiency Provisions" are founded on specified minimum Total R-values for differing climates in Australia.
Refer http://www.abcb.gov.au/index.cfm?objectid=7384D713-28B9-11DE-835E001B2FB900AA

Univ SA is also quoted in the Senate ORAL testimony by Tim Renouf
http://www.aph.gov.au/hansard/senate/commttee/S12816.pdf see page 81.
Univ SA is capable of undertaking an equivalent testing program for SUMMER to gauge the Total R-value effect in-situ (real, not laboratory) from intense downward high temperature radiation upon fibreglass batts. The federal government needs to fund such testing because the fibreglass industry never will because they fear the results.

CONCLUSION

It would appear that only the Senate Inquiry can make something happen. The claimed thermal benefits of ever increasing R-value in buildings is total nonsense, because it is in defiance of the Law of Diminishing Returns and the BCA has no such proof. BCA 2010 Total R-values are listed here to better illustrate my point. And where are the economic and thermal comfort justifications for making houses 6 Star?

For the Senate Inquiry's interest, the **BCA May 2009** states R-value for ceilings in Climate Zones 1 & 2 (dominant hot climates - northern Australia & coastal QLD) = **Total R2.7**. It was decided in June 2009 by COAG to raise ceiling Total R-values to **R5.3** uniformly across BCA Climate Zones 1-7. For Zones 1 & 2, this was a 100% increase – an astonishing increase that nobody could believe at the time.

BCA 2010 R-values have been amended to **R4.1 - 5.1**(depending on roof colour) – a range of **52% to 89%** increases in Total R-values from BCA 2009. This is still a set of unjustified R-values. A widely held belief was that the fibreglass industry were behind the original R5.3 so that they could market and sell R5.0 batts, plain and simple, and knowing that loose fill cellulose and polyester batt products could not. Then a deluge of criticisms hit the ABCB (responsible for the BCA) and seem to have relented somewhat in modifying the range of specified Total R-values.

I believe this Senate Inquiry needs to direct a secondary investigation into:

i) all claimed thermal R-values of all insulation materials, in particular bulk insulations which must be subjected to high inward radiation loads, for reasons explained in the Renouf/Aynsley testimonies, and including AHRC QLD (1981) insulation testing report http://www.aph.gov.au/Senate/committee/eca_ctte/eehp/submissions.htm "Answers to Questions On Notice" – 12.

ii) limitations of insulation R-value benefits according to the Law of Diminishing Returns

iii) condensation and effects on insulation materials

iv) impacts of the above on the BCA and need for overhaul of the BCA Building Energy Efficiency Provisions. The ABCB Regulatory Impact Statement for the BCA 2010 can be challenged if this Senate Inquiry will question it. As stated in the RENOUF oral testimony, the outcomes of this Senate Inquiry have the power to immediately question the validity of the national roll out of the BCA 2010 6 Star R-values, state by state.

v) comparative thermal testing between foil and bulk insulations in hot climates – it has never been done in Australia and is absolutely necessary to end the 50 year arguments between bulk versus foil.

vi) BCA climate Zone heat flow direction for Perth, Western Australia.

The Senate needs to be mindful that northern hemisphere high R-values are all driven by winter heating energy efficiency regulations (ie heat flow out), because that is the clearly dominant direction of energy flow for the majority of the North America and Europe. Australia has much milder winters and longer hotter climates.

It is the contention of the of all the Wren Inds/Renouf Senate Inquiry testimonies that bulk insulations are the wrong insulation materials for climates in Australia experiencing dominant warm to hot climates and low or zero winter heating requirements. Reflective foil insulations are superior. Australia needs its own local insulation products better suited for our climates, rather than products suited for the northern hemisphere.

Thank you for this opportunity to provide further information to the Senate Inquiry.

Regards,

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NOTES ON THE SCIENCE OF BUILDING

Division of Building, Construction and Engineering

CSIRO
AUSTRALIA

NSB 163

Revised
August 1991

Thermal Insulation — Installation and Materials

INTRODUCTION

Thermal insulation reduces the amount of heat flowing through the envelope of a building. It makes a building easier to cool in summer and easier to heat in winter.

The main reasons for using insulation in buildings are:

a) to reduce the cost of heating and cooling a building while maintaining comfortable conditions and
b) to improve the comfort of occupants of buildings which are not fitted with heating or cooling systems.

This Note discusses factors to be taken into account when installing thermal insulation and will help in selecting the most suitable materials.

HOW THERMAL INSULATION WORKS

1.01 Thermal insulation is the property of a material that enables it to slow down the flow of heat. All building materials have some insulation property but many common ones do not give sufficient insulation against winter cold or summer heat.

1.02 Thermal insulation materials can be broadly grouped as either bulk insulation or reflective insulation. Bulk insulation works by means of small air pockets or trapped bubbles of air, or other gas, which retard the flow of heat inside the material. Perfectly still air is a good insulator. Reflective foil laminate reduces the flow of heat by reflecting radiation away on the warm side and giving out only a little on the cool side.

1.03 Consideration should be made of the interaction between climate and the occupancy patterns of the building. A building in the tropics that is occupied only at night can be of lightweight, well ventilated and uninsulated construction. It will cool at night and thus provide comfortable conditions during the hours it is occupied. On the other hand, a building in a cold region that is to be heated throughout the day should be insulated to make it easier and cheaper to heat.

1.04 Insulation may make a house warmer on summer evenings as it prevents heat loss. This effect normally occurs with buildings that have heavyweight construction, ie. cavity brick walls and concrete slab floors. If insulated, these constructions should be provided with good night ventilation to help dissipate the heat that has been stored in the structure.

1.05 Insulation may also make a house cooler in winter due to the exclusion of heat gains that would otherwise be conducted through the structure. This is most significant where rooms have little solar heat gain through the windows.

WHERE TO USE INSULATION

ROOFS

2.01 A large proportion of the heat inside a building is lost through roofs and ceilings on winter nights. Insulating with either bulk or reflective foil laminate, or both, will reduce the loss and will also help to keep the inside cooler in summer.

2.02 Insulation is easy to fix in a pitched roof because the bulk material can be laid on top of the ceiling. The manhole cover should be insulated but insulation must not be put hard up against chimneys and flues or over recessed lighting fixtures, it creates too great a risk of overheating and thus of fire. In colder climates, cold water storage tanks in the roof space should be insulated. The space between the tank and the ceiling should not be insulated to allow some heat to flow to the tank and prevent the water from freezing.

2.03 In cathedral-style roofs it is possible to insulate only at rafter level. If the insulation is not itself also a vapour retarder then a vapour retarder should be installed on the warm side of the insulation. This helps prevent condensation at the colder surfaces of the roof structure beyond the insulation.

WALLS

3.01 The commonest type of wall insulation is placed in the cavities of the external walls during construction. The purpose of the cavity is to keep the inner surface of the wall dry, and hence any added insulation must not let water across. Porous insulation should be so placed that it does not conduct water across the gap. Impervious insulation should be used where contact with both outer and inner leaves is unavoidable. Thermal insulation is rarely necessary in internal walls.

FLOORS

4.01 A carpet with thick underlay is a good insulator. Timber floors will be warmer if the underside is protected from the wind by some form of enclosure of the sub-floor space. In colder climates concrete slab-on-ground construction generally gives a better thermal performance than uninsulated timber flooring. In very cold climates perimeter insulation is useful for slab-on-ground while bulk or reflective foil laminate can be used under timber flooring.

WINDOWS

5.01 Windows are very poor insulators. A lot of heat flows out through the glass on winter nights and in through the glass during summer days. Close fitting curtains that fall to the floor or to the window sill, with a pelmet at the top, will slow the passage of heat. Well designed and correctly installed window shades will help to keep out solar heat during summer. Reflective glass or a reflective film on the outside of the glass will help too.

5.02 In the more extreme climates of Australia double glazing can be considered. Generally it will reduce the flow of heat by conduction by about 50%. Double glazing should be used only in a well insulated building after careful consideration of costs and benefits.

THERMAL MASS

6.01 Bricks, concrete and stone are heavyweight materials with high heat storage capacity. They take time to heat up and time to cool down. It should be noted however that they are not good insulators and need to be used in conjunction with insulation to achieve optimum building thermal performance.

6.02 The thermal mass can be used to advantage in climates with hot days and cool nights. Heat gains during the day can be stored and prevented from leaving by insulation and can then be released during night hours to the interior space.

6.03 Combinations of heavy and light construction can be adopted in tropical climates. The daytime living areas should be of a heavier construction than the sleeping areas. This permits the thermal mass in the daytime areas to reduce the peak temperature while the night-time areas are able to cool quickly to facilitate night comfort.

6.04 See NSB No. 21 – House design for temperate climates[5], NSB No. 32 – House design for Australian cold-winter climates[6] and NSB No. 63 – House design for hot climates[7].

AMOUNT OF INSULATION

7.01 The amount of insulation that is economically justifiable depends on the type of construction and local climatic conditions. Money saved by thermal insulation will vary not only with building design and layout but also with the lifestyles of the occupants and the pattern of their use of energy. Some people consider that feeling comfortable is more important than saving energy.

7.02 The initial insulation added to a surface makes the most significant effect. As extra insulation is added an increasing proportion of the total heat transfer occurs through paths that have not been insulated; doors, windows etc. It is better to consider all of the heat paths in a particular building rather than to insulate one of them heavily.

7.03 Benefits are not directly proportional to the R value (see 12.01) of the insulation because the surfaces being insulated have an initial thermal resistance. For Australia's temperate coastal regions, insulation with a thermal resistance of 1.5 to 2.0 m^2K/W (or R values of 1.5 to 2) would be generally adequate for ceilings. For roof/ceilings in buildings that need significant winter heating, AS 2627–1983[8] gives recommended levels for various locations.

CONDENSATION AND VAPOUR RETARDERS

8.01 Vapour generated within a building, by respiration, cooking, washing etc, passes through normal porous wall materials to the outside. The inside surface of an insulated wall normally keeps warm and hence dry. Even so, condensation may occur out of sight within the wall where the vapour on its passage through is cooled to a low enough temperature. This may occur at the inner surface of the outer leaf or even in the outer layers of insulation. This condensation may be sufficiently serious to cause damage to the wall.

8.02 Condensation damage can be avoided by putting a vapour retarder on the warm side of the insulation. This slows the passage of vapour into the wall and thus helps prevent condensation. Condensation in buildings is discussed in greater detail in NSB No. 61[2].

8.03 In regions prone to frosts it is good practice to install in walls a vapour retarder on the indoor side of thermal insulation. This helps prevent vapour being frozen into ice within the material of the outer walls which can cause them to fracture.

8.04 Some thermal insulating materials have a vapour retarder attached, usually a reflective aluminium foil. These foils will not only form a vapour retarder but will increase the insulating effect if an airspace can be created adjacent to them. For example, by laying the foil over the ceiling joists beneath the insulation. This generates enclosed airspaces between the reflective foil laminate and the ceiling.

INSULATION AND VENTILATION CONTROL

9.01 The flow of heat in and out of a building is strongly influenced by deliberate ventilation or random air leakage. The better the building is insulated, the more significant the effect. Air leakage around door and windows (and even through the gaps in construction) negates the effect of the insulation. Doors and windows should be weather-stripped and gaps and cracks should be looked for and sealed.

9.02 Sufficient ventilation is required for control of condensation, odours and for normal respiration.

EFFECT OF COLOUR ON TEMPERATURE

10.01 Solar radiation on a surface will heat it to a temperature much higher than the air temperature. The increase depends on a number of factors including the angle of inclination of the surface to the sun and the colour of the surface. Dark surfaces get appreciably hotter than light surfaces. Highly reflective surfaces, such as polished aluminium, are the coolest of all.

INSULATION AND TEMPERATURE PATTERN

11.01 The combined effects of air temperatures, sun and wind create a time/temperature pattern inside a building – the thermal response to the climate. Insulation reduces the extent of the ups and downs in this pattern but cannot by itself make a building warm or cool. If hot days are followed by hot nights the inside must be cooled and insulation will keep the cost of cooling down. If it is cold day and night, the inside has to be heated and insulation will reduce the heating costs. With warm days and cool nights insulation as part of an energy conscious overall design will reduce (and maybe obviate) the need for artificial heating and cooling.

11.02 If possible the construction should be designed so the sun shines through windows when the weather is cool and should be screened by overhangs, blinds and obstructions when the weather is hot.

11.03 Thermal insulation will not maintain any particular difference in degrees Celsius between internal and external air temperatures. The temperature difference will be determined by factors such as the weather, the ventilation rates, the areas of glass and their orientation, and heat releases from occupants and appliances inside the building.

MATERIALS

12.01 Thermal insulation materials have been grouped according to their physical qualities and other factors. General information on the principles of thermal insulation and its installation in buildings is given.

PERFORMANCE AND R VALUE

13.01 The usefulness of different insulation materials can be evaluated if their thermal resistances (R values) are known. The R value is the measure of resistance that a particular thickness of a material presents to the flow of heat. Generally, this resistance is proportional to the thickness although this doesn't apply to some low-density materials. Typical thermal resistance values for a range of frequently used insulation materials are given in Table 1. For comparison purposes, an ordinary pitched, tiled roof with a plasterboard ceiling without sarking has a thermal resistance to the upward flow of heat of about 0.3 m^2K/W (an R value of 0.3).

13.02 There is a wide choice of thermal insulation materials. In deciding which type will work best in a given situation, the following factors should be considered

- unit cost,
- ease of installation,
- thermal resistance of the product,
- thermal resistance of the installed system,
- thickness and durability,
- reaction to fire,
- possible health hazard,
- resistance to vermin,
- acoustic benefit (if any) and
- absorption of water and water vapour

TABLE 1. Typical values of thermal resistance.
The actual value for a particular material will depend on the density of material, its moisture content and the mean temperature at which thermal resistance depends on the actual emissivity of the surfaces, the size of the airspace adjacent to the reflective surface and the direction of heat flow.

Material	Thickness mm	Thermal resistance for listed thickness (m^2K/W) (R Values)
Glass fibre batts	100	2.0
Rockwool	75	2.0 – 2.3
Cellulose fibre (fire retarded)	100	2.6
Expanded polystyrene	50	1.3
Rigid polyurethane (aged)	100	3.7 – 4.0
Flexible/polyurethane	100	2.6
Poly-isocyanurate	100	3.7
Urea-formaldehyde foam	50	1.4
Vermiculite (exfoliated)	100	1.5
Vermiculite concrete 1:3	100	0.23
Expanded perlite	100	2.2
Sea grass	100	2.2 – 2.7
Carpet	6	0.09 – 0.12
Carpet underlay	15	0.24 – 0.40
Caneite board	12	0.23
Double-sided reflective foil		
(a) in a wall cavity with airspace on both sides		1.00
(b) in a pitched roof as sarking with top surface covered with dust and		
(i) heat flow up (winter)		.4
(ii) heat flow down (summer)		1.0

FIRE RESISTANCE

14.01 It is important to ensure that thermal insulation does not add any further fire hazard to that which might already exist in a structure. Building regulations in most Australian States control two aspects of the fire hazard that might be presented by insulation materials; how readily they will spread fire (the spread-of-flame index) and how much smoke they produce when they burn (the smoke-developed index.) Measurement of these is made at the CSIRO Division of Building, Construction and Engineering in accordance with AS 1530 Part 3-1982[1].

INSULATING MATERIALS

15.01 **Glass fibre.** Glass fibre insulation is made with glass fibres bound together with a binder. It is light weight and of low density and is available in batt and blanket form. Batts will fit tightly between ceiling joists while blankets are longer and are useful for insulating large spaces such as under metal deck roofs. Batts don't need fastening between ceiling joists but under timber floors or in cavity walls they can be fastened with chicken wire or other means. Both are made in a variety of thicknesses to suit a range of building and industrial applications.

15.02 Glass fibre itself will not burn, spread fire or generate smoke. When made into batts, the binder material is generally combustible and so it is then important to consider the fire rating of the total batt.

15.03 Glass fibre has no food value to attract vermin but it is permeable to water vapour. If water condenses in it, the insulation value is reduced but a vapour retarder correctly installed will reduce or prevent condensation. The use of vapour retarders is discussed later and in NSB No. 61[2]. Glass fibre also has good sound-absorption qualities and if installed in a cavity wall, will help reduce the transmission of noise.

15.04 **Rockwool.** Rockwool is made by melting volcanic rock and spinning it into fibres which are bound together with a binder. Rockwool is rather denser than glass fibre and its R value per unit thickness is higher, making it useful when space is limited. Rockwool is made into batts in a number of thicknesses and is available also in granulated form to be poured or blown into wall and ceiling spaces. Rockwool has similar fire properties to glass fibre and has good sound absorption qualities.

15.05 **Cellulose fibre.** Cellulose fibre insulation is a loosefill greyish material produced from waste paper to which fire-resistant chemicals have been added. Many chemicals are available for this but their possible corrosiveness and susceptibility to fungal growth should be considered.

15.06 Loosefill materials like cellulose fibre tend to settle and this reduces the R value to some extent. Settlement depends on the product density and the environmental conditions. AS 2462-1981[3] stipulates that cellulose fibre should have a density in the range 30-50 kg/m^3.

15.07 Care must be taken to see that the material fills all of the space to be insulated and that strong air currents, particularly in a roof, do not redistribute the loose material in such a manner as to reduce the overall insulation quality.

15.08 **Rigid Cellular Polystyrene.** Commonly available in extruded or moulded forms, polystyrene is a polymer of styrene, a derivative of benzene and ethylene. Cellular polystyrene is manufactured for thermal insulation as batts or boards and in the form of beads for loose filling of cavities.

15.09 Cellular polystyrene will begin to soften at surface temperatures above 80°C and will also soften after exposure to many common organic solvents. Its water permeability is low but a vapour retarder might still be necessary where condensation is likely.

15.10 Cellular polystyrene is combustible but for building applications, flame-retardant chemicals are added. Polystyrene should not be exposed to flame or other ignition sources and should be protected by a skin of fire-resistant construction material.

15.11 Extruded cellular polystyrene boards can be used to insulate flat roof structures of the IRMA type (Insulated Roof Membrane Assembly) and for perimeter insulation of concrete floors.

15.12 It is important to use extruded rather than moulded polystyrene for these applications because the extruded variant has a closed cellular structure that does not absorb moisture.

15.13 Both extruded and moulded cellular polystyrene boards can be used to insulate cavity walls. They are installed during construction and care must be taken to make sure that the boards are held against the inner leaf to avoid bridging the cavity. Cellular polystyrene is a poor sound absorber.

15.14 **Polyurethane and poly-isocyanurate foams.** These cellular plastics are available as either rigid materials or they can be foamed on the job.

15.15 Rigid polyurethane foam has one of the highest R values for unit thickness and is useful where space is limited. Ageing of the material can lead, however, to some insulation loss by outward diffusion of the trapped cellular gases. Polyurethane insulation has been sprayed underneath corrugated iron roofs to shelter livestock in cold climates and in the manufacture of sandwich panels by placing it between two sheets of protective material. This sandwich material is light, insulates well and has a high strength-to-weight ratio.

15.16 Polyurethane is combustible and even though flame-retardant grades are available, it should be covered with fire-resistant construction for most building uses in accordance with building regulations. It should not be used where temperatures exceed 100°C.

15.17 Poly-isocyanurate foams are similar to polyurethane but have a somewhat better fire performance; they spread fire less readily and produce less smoke.

15.18 **Urea-formaldehyde foam.** Urea-formaldehyde foam is generally made by mixing an aqueous solution of formaldehyde-based resin, a liquid foaming agent containing a surfactant, an acid catalyst and compressed air. Additives such as fillers can reduce shrinkage and improve stability and the foam can be injected via holes into the wall cavities of existing structures. Some formaldehyde gas is released during curing and ideally, this should cease when the process is complete.

15.19 In some cases it has been found that formaldehyde gas continues to be released for very long periods. It depends on the specific formulation of the foam and the temperature and humidity encountered. There are potential health hazards associated with the presence of formaldehyde gas in quantities above the limits set by health authorities and the use of urea-formaldehyde foam as insulation material should be approached with caution until questions about health and durability are resolved.

15.20 **Vermiculite and Perlite.** Vermiculite consists of silicates of aluminium-iron-magnesium. In structure it is like mica but it expands considerably when heated. This 'exfoliation' gives it its insulating properties. Vermiculite is sometimes used as a plaster aggregate or mixed with portland cement to form vermiculite concrete. It is non-combustible and non-corrosive but has high water permeability unless treated with a repellent.

15.21 Perlite is a naturally occurring material consisting mainly of aluminium silicate. Like vermiculite, it can be expanded, is non-combustible and has high water vapour permeability. It is mainly used as an insulation board or as lightweight insulating concrete after mixing with portland cement.

15.22 **Sea grass.** Sea grass (Hetrozostera tasmanica) is also known as eel grass, muelleri or zostera marina. It comes from a grass-like plant and after drying forms a twined mass of hollow fibres which are easy to install. The prospective user should check that the sea grass offered is suitably fire resistant. The fire resistant properties are considered satisfactory if, when tested in accordance with AS 1530 Part 3[1], the spread-of-flame index is 0 and the smoke-developed index no greater than 4.

15.23 **Reflective Insulation.** Where heat transfer by radiation is a significant component of heat flow, a reflective surface can be used as a barrier. Reflective aluminium foil laminate is the favoured product because it has a highly reflective surface, is durable and is cheap to purchase. To act as an efficient radiation barrier, aluminium foil must have an air space of at least 25 mm adjacent to it.

15.24 Reflective aluminium foil is available as a laminate in roll form consisting of a core of kraft or bituminous, fibre-reinforced paper faced with aluminium foil on one or both sides. Foil laminates are graded into classes A and B depending on their fire properties and in accordance with AS 1903-1976[4]. A product with a flammability index of 5 or less is deemed to be class A; all other laminates are class B. When insulating around a hot metal flue, the foil should be cut back to leave no less than 50 mm of clear space. Two or more layers of reflective foil each separated by an air space are better than one.

15.25 Aluminium foil-backed plasterboard is useful as an insulation material. As the inner lining of a stud wall construction it eliminates the need for a separate vapour retarder. Glass fibre batts backed with aluminium foil are also good. In a conventional pitched roof they should be placed on top of the ceiling joists rather than between them if benefit from the high reflectivity and low radiation is to be gained. Correct vapour retarder location is most important.

15.26 The use of vapour retarders to minimise the risk of condensation in buildings is discussed in detail in NSB No. 61[2].

15.27 When installing reflective insulation under timber flooring it must be remembered that wood must be kept dry; perforated foil can be used wherever trapped water vapour might cause damage. For installation under floors over crawl spaces the foil laminate should be secured over the floor joists and have a sag of 25 to 65 mm.

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INSULATING YOUR CEILING

WHAT TYPES OF THERMAL INSULATION ARE THERE?

There are two types of insulation used in roofs – bulk and reflective. Bulk insulation uses the low thermal conductivity of still air for its insulating effect. Reflective insulation relies on the properties of a highly polished metallic surface to reflect large amounts of heat whilst only absorbing and emitting small amounts.

BULK INSULATION			REFLECTIVE INSULATION
Batts	**Loose fill**	**Other**	
Expanded polystyrene Fibre glass Rock wool	Cellulose fibre Eel grass Expanded polystyrene Rock wool	Urea formaldehyde foam	Aluminium foil Aluminium foil batts Composite aluminium foil/foam batts

WHAT ARE THEY MADE FROM?

Cellulose fibre is usually made from newspapers which are pulverized to give a fine fluff. Since paper is flammable, a fire retardant such as a mixture of borax and boric acid is added by the manufacturer.

Eel grass is a seaweed collected from locations such as Western Port Bay, Victoria. It is dried in the sun and no further treatment is necessary.

As their names imply, glass fibre and rock wool are made of glass and rock respectively. The base materials are melted at high temperatures and then formed into a mat of fine fibres.

Urea formaldehyde foam is made from a mixture of a resin and a hardener, each dispersed in water. Small proportions of other materials may also be included. It is available as a foamed *in situ* material (not recommended for roof spaces) or as a batt foamed between layers of aluminium foil.

Expanded polystyrene is a plastics material commonly used as a packing around fragile goods and in the construction of portable ice boxes.

Reflective insulation is available in rolls as a laminate of aluminium foil on each side of a base material, usually paper. Extra strength is obtained by reinforcing with filaments of glass fibre. It also is available with foil on only one side of the paper, but this is not recommended for building applications.

Aluminium foil is also available in the form of batts, about 25mm thick, consisting of two layers of reflective insulation separated by ribs. The batts are placed on top of the ceiling joists, and give good insulation against summer heat. When they are installed so as to give a sealed airspace below them, they also provide acceptable winter insulation. These should only be used in a horizontal position and even then their fire performance is questionable.

HOW ARE THEY INSTALLED?

Loose fills such as cellulose fibre, glass fibre and rock wool can be placed by hand or blown in by compressed air. The use of a blower sometimes enables inaccessible ceiling areas to be covered. Eel grass is a fibrous loose fill material which is placed by hand and cannot be blown. Glass fibre and rockwool batts are placed by hand.

Reflective insulation may be installed on the top of ceiling joists or under roof sheathing. For low slope metal deck applications it is often combined with a layer of glass fibre in the form of a composite blanket.

WHAT IS REQUIRED FOR GOOD PERFORMANCE?

The first essential for good performance of ceiling insulation is that the insulation be applied without gaps, otherwise the thermal insulating effect can be considerably reduced. When using reflective insulation, the sheets should be overlapped 150 mm and batts must be butted firmly against each other to prevent air movement through the gaps.

Loose-fill materials should be prevented from falling through ceiling ventilators and any other openings in the ceilings. This can be done by placing batts around the opening or by installing a surround of another material such as timber or metal.

For reflective insulation to work, it is essential that the foil faces an air-space at least 25 mm deep. Upward facing foil will soon be covered with dust which nullifies the effect of the reflective surface. When you are quoted an insulating value for reflective insulation always enquire if dust has been allowed for on the upward facing surfaces.

ARE THERE ANY FIRE HAZARDS?

Cellulose fibre, eel grass, expanded polystyrene, reflective insulation and urea formaldehyde should be kept at least 90 mm clear of any hot flues. As a precaution against overheating of recessed electric light fittings, bulk insulation should not cover them.

Electrical wiring in roof spaces should be in good order and not overloaded. The increase in wire temperature bought about by such overloading will be greater if the wires are covered with insulation. This could easily constitute a fire risk.

Cellulose fibre could be a hazard if it is not treated with sufficient fire retardant by the manufacturer. It is difficult for the homeowner to check this properly, but some indication can be obtained by warming the material and applying a flame. Flame spread indicates inadequate retardant but minimal flame spread is still no guarantee of adequate treatment. Reflective insulation with a fire retardant incorporated is available for situations where regulations require non-combustible materials. Expanded polystyrene is only acceptable if enclosed between non-combustible materials (e.g.placed on a plaster ceiling and covered with fire retarded reflective insulation). The other insulating materials are accepted as not constituting a fire risk and although eel grass will flame if a match is held to it, the flames die as soon as the match is removed.

ARE THERE ANY HEALTH RISKS?

There have been many suggestions that glass-fibre home insulation may cause cancer but extensive and continuing investigations overseas have so far failed to show any connection between glass fibre and cancer. The handling of rock wool and glass fibre causes temporary skin irritation to most people and it is therefore wise to keep skin covered and to wear a face mask when installing these materials, although the irritation usually disappears after washing with soap and warm water. There should be no further problems after installation is complete.

Ureaformaldehyde foam is currently under investigation by health authorities with regard to the possibility of formaldehyde gas being carcinogenic.

The other insulating materials listed have not been associated by health authorities with any health risks.

HOW MUCH SHOULD I USE?

For batts and loose fill this Division suggests using an amount that will provide a thermal resistance expressed as 'R2' (that is, 2 units of resistance in the SI system of units). For loose-fill materials, that is about 100 mm or the depth of ceiling joists, whichever is the lesser. This should provide a thermal resistance in excess of 'R2' unless unusually small ceiling joists are used.

This recommendation can be justified on economic grounds after consideration of several factors such as future fuel costs, interest rates, and marketing factors.

WHICH ONE IS THE BEST?

All the materials listed will provide satisfactory insulation and therefore the choice is dependent on personal preferences and price. To assist in this choice, the method outlined below gives one method of determining 'value for money'.

Obtain prices for the various types of insulation under consideration. Ask each salesman the installed thermal resistance that his material will provide, (called the 'R value') and the total cost. Divide the cost by the 'R value'.

Example

	Insulation A	Insulation B
Total cost	$260.00	$300.00
Installed 'R value'	1.5	2.0
$\frac{\text{Total cost}}{\text{Installed 'R value'}}$	173	150

Insulation B has the higher 'R value' and will provide better thermal comfort in summer, greater fuel savings in winter and is cheaper per unit 'R value'. In general, where summer conditions predominate, the use of reflective insulation is probably adequate if an air conditioning unit is not installed.

WHAT ELSE?

- The Division is unaware of cases where loose fill materials have blown around in a roof space.
- Vermin in materials is rarely a problem and none of the materials discussed are particularly attractive to vermin.
- If loose fill materials are properly placed above a ceiling, settlement will be small enough to be neglected.

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Builders and Insulation

In the past, few home owners have thought about insulating their new home before they have taken up occupancy. In this respect, the builder has not needed to concern himself with the technicalities of insulation. He has more likely viewed the use of aluminium foil in the walls for instance as a means by which he can close up the house against weather rather than as a means for the home owner to save energy.

However today's energy conscious world is changing all this. The client should now insist that the walls, and the ceilings following the roof slope, be insulated by the builder because of the difficulties of fitting insulation later. Reduction of capital cost at the time of building is of paramount importance to many, and if any insulation is to be omitted, it should be where its future installation is relatively simple, i.e. above the ceiling in pitched roofs. In some cases the builder will be expected to not only install the insulation, but recommend the materials and quantities to be used. This trend is likely to increase in the future. Builders should, therefore, have a general knowledge in respect to the application and economics of the insulation materials available.

Using reflective foil laminate means that care is required with electrical wiring unlike the above example.

Insulation provides a thermal resistance to reduce the rate at which heat escapes from the home. The reduced heat leakage means that less fuel is burned and therefore money is saved. This saving soon pays off the original cost of the insulation. In general, the higher the thermal resistance of the insulation (expressed commercially as an 'R' value) the lower the heat leakage will be, but there is an economic optimum. For Australian homes, we recommend the maximum amount of batt or loose-fill insulation for ceilings as that which corresponds to an 'R' value of 2. For walls, the suggested insulation is aluminium foil, or the currently available R1.5 batts.

Insulation rated R2 in the ceiling will reduce the heating load by about 30%. Increasing this to R4 will only reduce the heating load by a further 2 per cent (i.e. to 32%).

Further information on insulating materials and our recommendations for ceilings are covered in a recently revised issue of our Information Sheet 10–20. Copies are available from the Division's Publication Officer at Highett.

With brick veneer walls, reflective foil insulations are the most commonly used materials.

These materials are available in rolls as a laminate of aluminium foil on each side of a base material, usually paper. Extra strength is obtained by reinforcing with filaments of glass fibre. They are also available with foil on only one side of the paper, but this type is not recommended for building applications.

For reflective foils to work, they need to face an air space of at least 25 mm. Their effectiveness may be reduced by many factors. The Division has been carrying out research in this area and this is referred to in another article in this issue.

Australian Standard AS 1562.1 – 1992

Design and installation of sheet roof and wall cladding
Part 1: Metal

APPENDIX A

ROOF VENTILATION, WATER VAPOUR AND CONDENSATION

(Informative)

Condensation is one of the biggest single items contributing to the deterioration of buildings. It can occur in all types of buildings, largely due to poor design or inappropriate use of materials and, once present, it is difficult to eliminate. The moisture is deposited within the structure, usually in inaccessible places and any damage caused is expensive to rectify. The problems which can be encountered can include rotting of timber or corrosion of structural steel, reduction in the efficiency or bulk insulation, physical deterioration of ceilings made from absorbent materials and staining of walls and ceilings. Clearly, prevention is simpler and less expensive than cure.

Water vapour occurs naturally in the air and substantial quantities are added by such day to day activities as cooking, washing dishes and clothes, drying clothes indoors, combustion heating, showering and bathing, perspiration and the breathing of occupants and plants. The amount of vapour that can be supported by the air varies with temperature and pressure – as air warms it is able to support more water vapour. Conversely, as air cools relative humidity rises until it becomes saturated (the dew point). Cooling below dew point causes the vapour to condense as droplets of water.

All roofing absorbs radiation and becomes warmer. In turn this heat is radiated at the rate dependant upon the emittance of the roofing. The emittance of radiant heat can continue after the source of the heat is no longer present and the roof temperature can drop below that of the surrounding air. On cold clear nights, metal roofing temperatures of around five degrees (C) below the outside ambient temperature are quite common. When a build-up of water vapour occurs under these conditions, the water vapour will condense on the underside of the low temperature roof sheet. The condensation occurs as dew and excess quantities fall from the roof as droplets. With very low pitch roofs, there is very little natural ventilation. Warm air naturally rises but has little tendency to move laterally, except when a strong wind blows into roof vents or causes substantial differences in air pressure on opposite side of the building. Consequently, ventilation of the roof space will not prevent condensation on the underside of the cold roofing.

A vapour barrier, generally metallic foil or plastic film, will inhibit the passage of water vapour. Correctly placed, it will prevent water vapour from reaching the cold surface. It should always be placed on the warm side of the structure, generally on the lower side of the roof where it is kept above dew point during cold weather. Where a ceiling is involved, the vapour barrier is usually, for aesthetic reasons, placed immediately above the ceiling lining. In air-conditioned buildings in hot, humid climates, the reverse applies – the vapour barrier is placed on the outside of the structure. In temperate climates, the foil sheet can also provide thermal insulation and support for bulk insulation in contact with the roof sheeting. In cold climates, or where greater insulation is desired, an additional vapour barrier or insulation sheet should be installed just above the ceiling.

Bulk insulation keeps ceilings warmer and roofing cooler than if no insulation is installed in the cavity and, being porous, allows water vapour to reach the cold roof surface where it condenses. In addition to the physical dangers to the structure and finishes, the increase in moisture content can reduce the effectiveness of the bulk insulation by up to 30%. Consequently, a vapour barrier should always be installed on the warm side of any bulk insulation.

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NATIONAL GUIDELINES NEEDED TO AVOID CONDENSATION DAMAGE

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Introduction

We have all seen condensation form on the bathroom mirror after a shower during cooler months of the year. This is H_20 going through condensation phase change from a gas as water vapour to a liquid water (CSIRO, 1995).

When H_20 is in its gas phase as water vapour it obeys the *Gas Laws*. The water vapour responsible for condensation in buildings is only one of the gases that make up air in earth's atmosphere but each gas in air acts independently according to the Gas Laws. At a given atmospheric pressure, the temperature at which water vapour in the air condenses is called the dew point temperature. The science of psychrometry provides various equations that allow characteristics of water vapour in air to be calculated (Gatley, 2005). Graphically dew point temperatures can be read off a psychrometric chart for standard atmospheric pressure along the saturation line for any combination of humidity and air temperature. Computer software is also available to perform the relevant calculations to determine dew point temperatures.

Surface condensation occurs when the temperature of a surface is at or below dew point temperature of water vapour in the air adjacent to the surface. Condensation can also occur within porous building materials where the temperature of the material is at or below the dew point temperature of water vapour present. This is referred to as *interstitial* condensation.

In the past simplistic straight-line graphs of steady-state temperature and vapour pressure profiles through construction were used to estimate location where condensation may occur. Sophisticated computer software is currently being developed to dynamically model temperatures and vapour pressure and dew point temperature throughout a construction as they vary with time.

Sources of water vapour

There are two sources of water vapour to be considered with regard to potential condensation. The most obvious source is from the atmosphere as rain or just high humidity. The other source is from activities within the building such as the water vapour we exhale as well as washing and cooking with hot water.

Condensation control

Traditionally condensation in buildings is controlled by ventilation and providing drainage planes (Lstiburek, 2006). For example the inside face of the external brickwork in a cavity-brick wall is a drainage plane. Any moisture seeping through the external brickwork drains down the wall to flashings that directed it out through weep-holes near the base of the wall. The cavity was open at the top of the wall and ventilating air flow passed into the cavity through the weep-holes at the bottom of the wall up through and out the top of the cavity. Water vapour is transported through building construction by air movement and differences in water vapour pressure. Where cavities are ventilated air transports more water vapour than differences in vapour pressure (Lstiburek, 2002 & 2007).

Most tall commercial buildings have thin curtain walls to maximize internal rentable area. Some of these curtain walls have drainage systems others attempt to provide an impervious barrier (Lstiburek & Carmody, 1994). Thin sheet materials on exterior surfaces change temperature much more quickly than heavy concrete or masonry materials and pose greater risks of condensation if seals leak. Where materials such as fibrous insulation or gypsum wallboards in walls need to be protected from condensation by water, vapour barriers are installed during the construction process otherwise serious mould contamination can occur (LBL, 2009), Figure 1. The LBL newsletter (LBL, 2009) suggest that 21% of current asthma cases in the USA are attributable to mould and dampness related conditions in homes with a national annual cost of $3.5 billion. Evidence also suggests that exposure to mould and dampness in offices and schools result in similar health impacts.

Figure 1. Mould on a ceiling due to moisture from above

Inadequate insulation of air conditioning ducts located in non-conditioned spaces or air conditioning plenums are also potential causes for condensation in buildings (Lstiburek, 2007).

It is important to ensure that the vapor barrier is installed in a position on the warm side of where the dew point temperature is expected to occur. That may sound like a simple procedure but the dew point temperature location within the construction moves over time and seasons. The warm side of a construction can also reverse within 24 hours in arid desert climates and with seasons in more temperate climates. Contemporary design of water vapour control are complex, based on dynamic computer analysis, they utilise vapour barriers often of different vapour permeability or smart vapour barriers that can change their permeability.

An example of the application of air film disturbance to control condensation is on the underside of a large un-insulated metal roofed over plant rooms in the humid tropical city of Townsville, in Queensland. Each night radiation to the night sky resulted in the temperature of the roofing iron falling to around 5°C below the ambient outdoor air temperature, and below the dew point temperature of the very humid air. It literally rained inside the roof space. The large roof space was fitted with ceiling fans blowing upwards. These ceiling fans disturbed the air film on the underside of the metal roofing and continuously circulated warmer air in the roof space effectively raising the temperature of air moving adjacent to the underside of the roof. Condensation was controlled. This type of condensation is evident in the morning on the underside of metal verandah roofs as in Figure 4.

Figure 4. Condensation on the underside of a metal verandah roof

If bulk insulation such as fiberglass, polyester, rockwool or cellulose is on a ceiling below such a metal roof then it will be made damp by falling condensation. This will severely reduce the R-value of the insulation and if moisture accumulated at the bottom of the insulation damp ceilings can lead to mold, corrosion, and wood rot.

The condensation under the roof would not have arisen if sarking or anti-con insulation had been installed underneath the metal roofing (AS 1562.1, 1992). However the cost of retrofitting sarking or anti-con insulation after the roof had been installed is usually prohibitive.

Consequences of increasing building energy efficiency

Recent attempts to increase the energy efficiency of Australian buildings have resulted in tighter sealing and greater thermal insulation of external building envelopes.

In the past, unintentional leakage allowed air flow to remove excess water vapour from buildings. Now that buildings are more tightly sealed unwanted water vapour inside buildings has les opportunity to escape to the outdoors. This can lead to condensation and associated dampness, mould (Brennan & Burge, 2005), health issues, corrosion, decay and in extreme cases structural collapse. Where there is significant mould contamination the consequence is usually demolition.

Limitations of the Australia Building Code and Australian Standards

Recent changes to the Building Code of Australia call for increased R-values of thermal insulation to increase the energy efficiency of buildings. When the R-value of thermal insulation located near the warmer inner surface of the building envelope, in a cold climate is increased, the temperatures are decreased in cavities near the cold outer surface of the building envelope. This increases the probability of condensation occurring in such outer cavities.

Australian building codes and standards lack detailed guidance on control of condensation over the wide range of climatic conditions across the country. British Standards (BS, 2002), European Standards (ISO, 2002) and American standards (ASTM, 2009) on the other hand have recently been updated to help stem the increasing frequency of substantial damage to buildings due to condensation. British and European building standards use SI units but relate to a relatively narrow range of climatic conditions. Condensation control standards from the USA are likely to be more relevant to Australia as US climates encompass alpine, temperate, hot arid and warm humid tropical climates. Standards from the USA would need to be converted from imperial units to SI units.

There is serious lack of authoritative advice on designing buildings to avoid damage from condensation. For example, explanatory information provided for clause 3.12 of Volume 2 of the Building Code of Australia (2010) on thermal insulation provides a caution regarding significant damage that arises when condensation occurs. There is no detailed guidance on how to determine when, where, and how often it is likely to occur.

Another example is provided in Appendix A of the Australian Standard AS 1562.1 (1992) on design and installation of sheet roof and wall cladding. While the information in Appendix A on roof ventilation, water vapour and condensation is well intended, it is in an *informative* section of the standard. When a building specification states that all relevant work on a project must be done in accordance with a particular Australian standard this has been interpreted by judges in NSW to mean that *informative* sections do not need to be followed. This has effectively limited the liability of building contractors but doe not identify where liability for condensation damage rests.

Conclusions

Serious damage to buildings from condensation is increasing in Australia as building envelopes are tightened and thermal insulation is increased to increase energy efficiency. There is an urgent need for Australia Codes and standards to be updated to provide detailed guidance to building designers for condensation control across all of Australia's climatic conditions.

End Note

Dr Richard Aynsley joined the Big Ass Fan Company full time in Lexington, Kentucky in 2003. Prior to that, he was a building science consultant to the company on the design and performance of large industrial ceiling fans while serving as Dean of Engineering, Technology and Management at Southern Polytechnic State University in Marietta, GA, USA. He holds a bachelors degree with first class honors in Architecture as well as a Ph.D. in building aerodynamics from the University of New South Wales. His MS(ArchEng) was gained from Pennsylvania State University at State College, PA. While working as Director, Research & Development at Big Ass Fans he secured 3 US patents for Big Ass Fan designs of airfoil fan blades and winglets. He is currently a director of Big Ass Fans Australia Pty Ltd at Loganholme, Queensland.

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INSULATION OF ROOFS IN WARM CLIMATES

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ABSTRACT

There is currently no guideline for builders or home owners to indicate what would be appropriate thermal insulation in roofs to control summer heat gain through roofs in naturally ventilated houses in regions with little or no winter heating requirement. Australian Standard AS 2627.1-1993 indicates recommended values of thermal insulation for roofs and walls at numerous locations around Australia. These recommended values are based on an economic analysis balancing the lifetime cost of installing the insulation during construction against the heating and cooling energy cost over that lifetime. These levels of thermal insulation assume that the house has a closed envelope and is heated or cooled to maintain indoor thermal comfort. In warm, humid climatic regions, houses are often designed with open envelopes to benefit from natural ventilation. Two objectives are proposed for thermal insulation in roofs of houses with efficient cross-ventilation in regions with little or no winter heating requirement. The first is to limit the daytime surface temperatures of the ceiling to prevent infrared radiant heat gains to occupants. The second objective is to design roof insulation that promotes rapid cooling of the house after sundown. A field study to investigate the thermal conditions in houses in a warm humid climate region, and the resulting indoor thermal conditions, was based on a survey of 92 houses in Townsville, Queensland, Australia. A procedure for evaluating roof insulation alternatives is provided.

Keywords: energy efficient, houses, warm climates, natural ventilation, roof insulation.

INTRODUCTION

There is currently no guideline for builders or home owners to indicate what would be appropriate thermal insulation in roofs to control summer heat gain through roofs in naturally ventilated houses in regions with little or no winter heating requirement. Australian Standard AS 2627.1-1993 indicates recommended values of thermal insulation for roofs and walls at numerous locations around Australia. These recommended values are based on an economic analysis balancing the lifetime cost of installing the insulation during construction against the heating and cooling energy cost over that lifetime. These levels of thermal insulation assume that the house has a closed envelope and is heated or cooled to maintain indoor thermal comfort. In warm climates, with little or no winter heating requirement, houses are often designed with open envelopes to benefit from natural ventilation. From field, computational fluid dynamics and boundary layer wind tunnel studies, it has been shown that air change rates in well designed, cross-ventilated

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houses are extremely high, often hundreds of air changes per hour. Computer modelling has shown that when the air change rate exceeds 30 air changes per hour, indoor air temperature can be assumed to be the same as outdoor shade air temperature (Willrath, 1998).

A RATIONALE

Two objectives are proposed for thermal insulation in roofs of houses with efficient cross-ventilation in regions with little or no winter heating requirement. The first is to limit the daytime surface temperatures of the ceiling to prevent infrared radiant heat gains to occupants. The second objective is to design roof insulation that promotes rapid cooling of metal roofs of house after sundown by radiation to the night sky.

A FIELD STUDY

During February and March of 1996, a field study of ceiling temperatures in 92 non-air conditioned houses was conducted by graduate research students and faculty from the Australian Institute of Tropical Architecture, James Cook University, in Townsville, Australia. Of the 92 houses, data from 21 buildings were rejected for comparative purposes due to building type. Some were schools, some data records were incomplete, or data had been incorrectly entered in the survey forms. Data included; outdoor air temperature, indoor air temperature, ceiling temperature, indoor globe temperature, indoor WBGT index, roof colour, roof material, ceiling insulation, eaves overhang, wall construction, and time of observations. All data was collected between 11:00 AM and 1:00 PM while walls were shaded and the sun was overhead. Detailed analysis of the data from the survey can be found in Sariman (1998). The main purpose of the study was to determine the degree to which infrared radiation from hot ceilings was a significant influence on indoor thermal comfort in houses. This study extended work in Africa by Koenigberger and Lynn (1965). This publication suggests that surface temperatures of ceilings should not exceed ambient indoor dry bulb air temperature by more the 4K.

Based on the adaptive indoor thermal comfort zone established by Auliciems and Szokolay (1997) and adopted by ASHRAE for naturally conditioned buildings, 79% of the houses surveyed had indoor dry bulb air temperatures exceeding 24°C to 29°C, the comfort zone to satisfy 90% of occupants for the three hottest months. Thermal neutrality dry bulb air temperature for this comfort zone was 26.1°C. Poor thermal design of the roof contributed to about 50% of the houses.

Of the houses surveyed, 49% of the roofs were unpainted metal. Ten percent of the houses surveyed had metal roofing with a coloured paint finish. A further 10% of the houses surveyed had white or off-white painted metal roofing. The colour of the remaining 41% of the houses surveyed ranged from beige, green, dark green, yellow, and brown. In summary, 90% of the houses surveyed had roof colours that were not white or off-white colour.

As the Townsville region is, on occasions, subjected to tropical cyclone winds it was not surprising to observe that 86% of the roofs on the houses surveyed had ribbed metal roofing. Field measurements have shown these roofs reach temperatures of up to 8K below ambient air temperature by radiating to the night sky (use 5K for design purposes) (Dan and Aynsley, 1998). The remainder of the houses had tile roofs, except for one with corrugated asbestos cement roofing.

Of the 71 houses surveyed, 56% had no insulation under the roof or above the ceiling. The remainder of the houses had varied types of insulation. In two of the houses, ceiling insulation was provided over ceilings in only some rooms. Four of the houses had cellulose fibre above the ceilings. Four houses had reflective foil insulation. Three houses had fiberglass or rockwool insulation. One house had expanded polystyrene insulation, and one house owner could not remember the type of insulation installed.

In the 71 houses used from the survey, 38% had bedrooms with ceiling temperatures more than 4K above indoor air temperature. In 39% of living rooms, ceiling temperatures were more than 4K above indoor air temperature. In 44% of kitchens, ceiling temperatures were more than 4K above indoor air temperature.

ADAPTIVE THERMAL COMFORT

In ventilated buildings without air conditioning using the new adaptive comfort criteria in ANSI/ASHRAE Standard 55-2004, thermal neutrality for *operative comfort*, t_{oc}, based on mean monthly outdoor air temperature, t_{out}, can be calculated using the following equation (ASHRAE, 2001).

$t_{oc} = 18.9 + 0.255\ t_{out}$ °C Equation 1

With a mean daily air temperature of $(31.3 + 23.8)/2 = 27.6$°C in Townsville, QLD during January, $t_{oc} = 18.9 + 0.255(27.6) = 25.9$°C

There is significant individual variation in human thermal response. This variation in thermal response can be accommodated by defining a *thermal comfort zone*, CZ. CZ_{80} satisfies 80%, or CZ_{90}, 90% of a population (Auliciems and Szokolay, 1997).

$CZ_{80} = 18.9 + 0.255\ t_{out}$ +/- 3.5 °C Equation 2
$CZ_{90} = 18.9 + 0.255\ t_{out}$ +/- 2.5 °C Equation 3

ANSI/ASHRAE Standard 55-2004 suggests the 80% satisfaction level for normal design. For example the 80% thermal comfort zone for January (t_{oc} =25.9°C for July) in Townsville, based on the adaptive thermal comfort model, is 25.9 +/- 3.5 = 22.4°C to 29.4°C.

AIR FLOW FOR SUMMER COMFORT

Air movement is highly effective in creating a cooling sensation on exposed skin, This moderates hot summer conditions. Air movement does not cool the air. This is why air movement is so energy-efficient in restoring indoor thermal comfort. This cooling sensation is effective in warm climates where the air temperature is less than 96°F (35.6°C), about 2°F below core body temperature. An equation for estimating the cooling sensation of airflow over exposed skin was suggested by Szokolay (1998).

$$CS = 6(V-0.25) - (V-0.25)^2 \quad °C \quad \text{Equation 4}$$

where V is the mean air speed in meters per second (Figure 1). Note 1 m/s is equivalent to 196.9 feet/minute or 2.2 miles per hour.

The 0.25 m/s value in Equation 4, represents minimum perceptible airflow in early versions of ANSI/ASHRAE Standard 55. The current ANSI/ASHRAE Standard 55-2004 indicate the minimum perceptible airflow as 0.2 m/s or 40 fpm. For this reason the writer suggests revising Equation 4 to reflect this lower value. Equation 5, has a peak cooling sensation of 8.99°C at 3.3 m/s.

$$CS = 6(V-0.2) - (V-0.2)^2 \quad °C \quad \text{Equation 5}$$

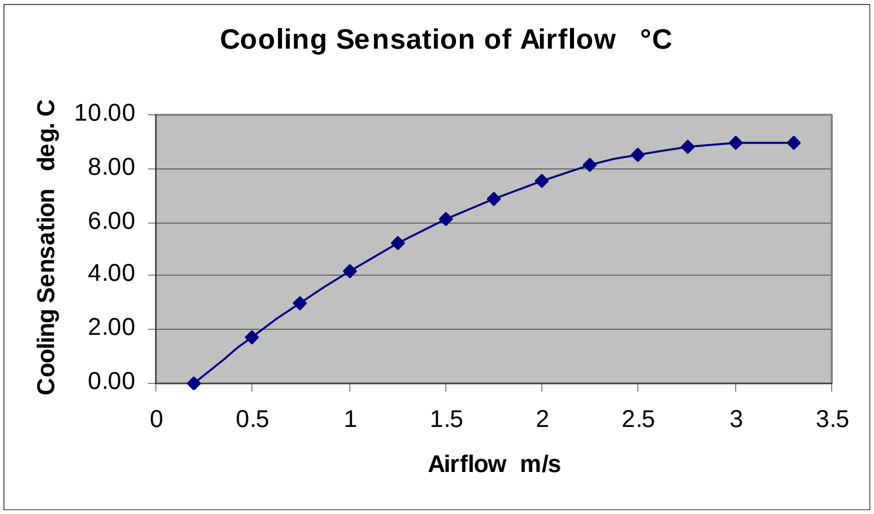

Figure 1. Plot of Cooling Sensation of Air Flow Using Equation 5.

If the outdoor air temperature in Townsville, Australia on a January day reaches 34°C, what airflow is needed to restore thermal comfort to the t_{oc} for January? 34°C – 25.9°C = 8.1°C. It would require airflow of 2.25 m/s (or 443 fpm or 5.0 mph or 4.4 knots) to give a cooling sensation of 8.1°C. The typical sea breeze in Townsville at 3 pm in January exceeds 7.7 m/s. (Aynsley, 1996). Indoor air velocities near wall openings of cross-ventilated houses in Townsville exposed to the sea breeze is typically around 0.25 of the external wind speed at a height of 10m in airport terrain roughness (Aynsley and Su, 2003).

ROOF INSULATION

Alternative techniques of thermal control include use of bulk insulation and reflective air spaces. Use of bulk insulation in the form of various fibre materials, such as fiberglass, mineral wool, cellulose, or expanded polystyrene, have the same thermal insulation value regardless of the direction of heat flow up or down. In contrast, the thermal insulation value of reflective air spaces provided in HVAC industry handbooks is up to 3 times greater when heat flow is downward than when heat flow is upward (AIRAH Handbook, 2000). This means that bulk insulation will slow the dissipation at night of heat which accumulates inside a building during the day more than reflective air spaces in roofs.

Another consideration is the adverse effect of moisture on fibrous insulation. This results in reduced insulation value due to dampness, and damage to building fabric from damp insulation. The moisture involved typically comes from condensation on the underside of metal roofs or by air conditioned cooling of building surfaces as a result of temperatures below ambient dew-point. Temperatures of metal roofs can fall by up to 8K below ambient air temperature due to radiant cooling to the night sky. This cooling often brings metal roofing temperatures below the dew-point of ambient air (Dan and Aynsley, 1998). To avoid condensation on the underside of metal roofs in warm humid climates, fibrous insulation is placed as a blanket hard against the underside of the metal roofing using the roofing metal as a vapour barrier with another vapour barrier on the underside of the insulation. Edges of such blanket insulation should be tape sealed to prevent moisture entry.

Condensation can occur on reflective foil surfaces during nocturnal cooling. This has the advantage of increasing the emissivity of the surface which in turn increases nocturnal heat loss through roofs. With the solar heating of the roof after sunrise, the moisture on the reflective foil evaporates generally without damage to the surface of the reflective foil. A study in Florida (Beal and Chandra, 1995) noted very little corrosion on the surface of reflective foil. It was limited to a narrow strip along the eaves line in a saltwater, waterfront location.

How Much Insulation?

Australian Standard AS 2627.1-1993 indicates recommended values of thermal insulation for roofs an walls at numerous locations around Australia. Values recommended for Townsville are R3.5 (3.5 $W/m^2.K$) in the roof/ceiling. These recommended values are based on an economic analysis balancing the lifetime cost of installing the insulation during construction against the heating and cooling energy costs over that lifetime assuming common indoor thermal comfort criteria. These levels of thermal insulation are appropriate in fully air conditioned buildings. In warm humid climate regions, where buildings are often designed with open envelopes to benefit from cooling airflow, the role of thermal insulation is to limit the surface temperatures of indoor surfaces to prevent heat gains to building occupants from infrared radiation on occupants. Typically the day-time air change rate, through well designed naturally ventilated houses, is from 100 to 600 air changes per hour. At these rates the air passes through the building in a few seconds and its temperature and humidity remain the same as ambient outdoor air. During evenings when breezes die away, ceiling fans are typically used to provide indoor air movement.

Sol-air Temperature Control

Sol-air temperature T_e is that outdoor air temperature that would cause the same amount of heat entry into a surface as the combined effects of air temperature and solar radiation exchanges. ASHRAE (1997) gives the following equation for estimating sol-air temperature.

$$T_e = T_o + \alpha I_t / h_o - \varepsilon \Delta R / h_o \qquad °\mathrm{C}$$

where: T_o = outdoor dry bulb air temperature °C; α = absorptance of surface solar radiation; I_t = total solar radiation incident on surface W/m^2 ; h_o = coefficient of heat transfer by long-wave radiation and convection at outer surface W/m^2.K; ε = hemispherical emittance of surface; ΔR = difference between long-wave radiation incident on surface from sky and surroundings and radiation emitted by blackbody at outdoor air temperature W/m^2

For example, what would the sol-air temperature of zinc/aluminium coated corrugated steel roofing with a slope of 20° at noon in Townsville under a partly cloudy sky with a good breeze 7 m/s in January when the outdoor air temperature is 32°C ?

Table 1. Surface Conductances & Solar & Infrared Radiation Exchange Properties

Surface Conductance h_o W/m^2.K				Radiation Properties			
Surface	Air Flow Exposure	Low ε	Normal ε	Material	Solar α and ε	Solar Reflect-ance	Infrared ε (50°C)
Roofs	sheltered	11.1	14.3	red tiles	0.65	0.35	0.85
	normal	20.0	25.0	white tiles	0.40	0.60	0.50
	exposed	50.0	50.0	metal	0.4	0.60	0.40
Walls	sheltered	12.5	9.1	brick light	0.40	0.60	0.90
	normal	14.3	16.7	brick dark	0.80	0.20	0.90
	exposed	33.3	33.3	paint (white)	0.30	0.70	0.95
				paint (black)	0.96	0.04	0.96

Absorptance of surface solar radiation by weathered zinc/aluminium is approximately 0.60. Total solar radiation incident on a horizontal roof surface on a sunny day in Townsville during January is typically 1,400W/m^2. With a slope of 20° this radiation intensity is reduced according to the cosine rule to COS 20° x 1400 = 1316 W/m^2 and ΔR is approximately 105 W/m^2 for clear skies, 59 W/m^2 for partly cloudy skies, and 24 W/m^2 for overcast skies. The ε for weathered zinc/aluminium is approximately 0.4. The coefficient of heat transfer h_o for a low ε surface with a breeze of less than 4 m/s (sheltered) is 11.1 W/m^2.K from the Table 1.For design purposes use sheltered exposure and partly cloudy sky. For a dark green painted metal roof under a partly cloudy sky in sheltered exposure, the sol-air temperature would be:

$$T_e = T_o + \alpha I_t / h_o - \varepsilon \Delta R / h_o \qquad °C$$
$$= 32 +(0.8 \times 1316 / 11.1) - (0.95 \times 59 / 11.1) = 97.7\ °C$$

This temperature is similar to field measurements of temperatures of metal roofing with dark coloured paint finishes in Townsville.

Roof Insulation Required to Limit Ceiling Temperature to 38°C

When roofs consist of lightweight materials such as metal cladding, the temperature differences across each element in multi-layer construction is proportional to the thermal resistance of each element. When the sol-air temperature on the upper surface T_e is high, the total thermal resistance R_t of the roof construction to limit the ceiling temperature to 4K above indoor air temperature can be written in terms of the thermal resistance of the indoor air film at the ceiling R_{iaf} :

$$R_t = R_{iaf}\,(T_e - T_o)/4 \qquad \mathrm{m^2.K/W}$$

For example consider a timber framed roof with a plasterboard ceiling roofed with zinc/aluminium surface steel roofing in sheltered conditions 3 m/s breeze under a partly cloudy sky which, from the calculation above, has a sol-air temperature of 101°C. Based on the proportionality between thermal resistance and temperature difference across the resistive element in a construction, the total thermal resistance of the roof required to limit the temperature across the indoor air film under the ceiling to 4K is:

$$R_t = R_{iaf}\,(T_e - T_o)/\,4 \qquad \mathrm{m^2.K/W}$$
$$= 0.16\,(101 - 32)\,/\,4 = 2.76\ \mathrm{m^2.K/W}$$

Thermal resistance of the roof without added insulation is:

Outdoor air film	0.04
Metal roofing	0.00
Roof space	0.46 (high ϵ surfaces, ventilated, heat flow down)
Plasterboard 13mm	0.08
Indoor air film	<u>0.16</u>
Total	0.74 m^2.K/W (< 2.76 unsatisfactory)

The increase in thermal resistance to reach 2.76 m^2.K/W is 2.76 – 0.74 = 2.02 m^2.K/W.

Material	**Thermal Resistance**	**Temperature Drop**	**Temperature Profile**
	m^2.K/W	K	101°C (Sol-air T)
Outdoor air film	0.04	69 x 0.04/2.76=1.00K	100.0°C
Metal roofing	0.00	69 x 0.0/2.76=0.00K	100.0°C
Added R	2.02	69 x 2.02/2.76=50.5K	49.50°C
Roof space	0.46	69 x 0.46/2.76=11.5K	38.00°C
Plasterboard 13mm	0.08	69 x 0.08/2.76=2.00K	**36.00°C**
Indoor air film	<u>0.16</u>	69 x 0.16/2.76=4.00K	32,00°C
Total	2.76 m^2.K/W		

Also note that that the surface temperature on the underside of the ceiling of 36°C is 4K more than 32°C the indoor air temperature. Comparison will now be made of bulk and reflective insulation solutions to the added thermal resistance using data from the AIRAH Handbook (2000).

163mm of fiberglass (density 6.25kg/m^3) has a thermal resistance of 2.84 m^2K/W. For mid-day heat flow down, the resistance to heat gain is:

Material	**Thermal Resistance**	**Temperature Drop**	**Temperature Profile**
	m^2.K/W	K	101°C (Sol-air T)
Outdoor air film	0.04	69 x .04/3.58 =0.77K	100.23°C
Metal roofing	0.00	69 x 0.0/3.58 =0.00K	100.23°C
Roof space	0.46	69 x 0.46/3.58=8.87K	91.36°C
163mm fiberglass	2.84	69 x 2.84/3.58=54.74K	36.62°C
Plasterboard 13mm	0.08	69 x 0.08/3.58=1.54K	**35.08°C**
Indoor air film	0.16	69 x 0.16/3.58=3.08K	32.00°C
Total	3.58 m^2.K/W (similar to the AS2627.1-1993 standard value of 3.5)		

For heat flow up assuming an indoor air temperature of 34°C due to increased occupancy and lower ventilation, and temperature of metal roofing is outdoor air -5K due to radiant nocturnal cooling through the roof to the night sky (Dan and Aynsley, 1998), the resistance to heat flow up is:

Material	**Thermal Resistance**	**Temperature Drop**	**Temperature Profile**
	m^2.K/W	K	
Metal roofing	0.00	7 x 0.00/3.03=0.00K	26.89°C
Roof space vented	0.00	7 x 0.00/3.03=0.00K	26.89°C
163mm fibreglass	2.84 (6.25kg/m^3)	7 x 2.84/3.03=6.56K	33.45°C
Plasterboard 13mm	0.08	7 x 0.08/3.03=0.18K	**33.63°C**
Indoor air film	0.11	7 x 0.16/3.03=0.37K	34.00°C
Total	3.03 m^2.K/W		

Note small rounding errors tend to occur in temperature profile calculations such as the 26.89°C versus the actual value of 27°C.

Single sided reflective sarking with the reflective surface facing down, fixed under roofing battens, creates a 30mm air space with a thermal resistance for downward heat flow of 0.15 m^2.K/W and a reflective ventilated roof space with a resistance to heat flow down of 1.36 m^2.K/W. Reflective foil fixed 100mm over the bottom chord of roof trusses above the ceiling provides a single sided reflective air space with a resistance to heat flow down of 1.42 m^2.K/W.

Material	**Thermal Resistance**	**Temperature Drop**	**Temperature Profile**
	m^2.K/W	K	100.99°C (Sol-air T)
Outdoor air film	0.04	69 x 0.04/3.21=0.86K	100.13°C
Metal roofing	0.00	69 x 0.00/3.21=0.00K	100.13°C
30mm air space	0.15	69 x 0.15/3.21=3.22K	96.91°C
Roof space vented	1.36 (reflective)	69 x 1.36/3.21=29.23K	67.68°C
100 mm air space	1.42 (1 side refl.)	69 x 1.42/3.21=30.52K	37.16°C
Plasterboard 13mm	0.08	69 x 0.08/3.21=1.72K	**35.44°C**
Indoor air film	0.16	69 x 0.16/3.21=3.44K	32.00°C
Total	3.21 m^2.K/W		

For heat flow up (nocturnal radiant cooling) increased indoor load and less ventilation is:

Material	**Thermal Resistance** m^2.K/W	**Temperature Drop** K	**Temperature Profile**
Metal roofing	0.00	7 x 0.00/0.67=0.00K	26.48°C
30 mm air space	0.00 (vented)	7 x 0.00/0.67=0.00K	26.48°C
Roof space	0.00 (vented)	7 x 0.00/0.67=0.00K	26.48°C
100 mm air space	0.48 (1 side refl.)	7 x 0.48/0.67=5.01K	31.49°C
Plasterboard 13mm	0.08	7 x 0.08/0.67=0.84K	**32.33°C**
Indoor air film	0.11	7 x 0.16/0.67=1.67K	34.00°C
Total	0.67 m^2.K/W		

CONCLUSIONS

Evening hours are the most critical for indoor thermal comfort in naturally conditioned houses in Townsville as the occupancy tends to increase and the sea breezes tend to die away by 9:00PM when many people are trying to go to sleep. Ceiling fans can provide useful air flow during this critical period.

Two objectives have been proposed for thermal insulation in roofs of houses with efficient cross-ventilation in regions with little or no winter heating requirement. The first is to limit the daytime surface temperatures of the ceiling to less than 4K above indoor air temperature to prevent infrared radiant heat gains to occupants. The second objective is to design reflective roof insulation with a low thermal resistance to upward heat flow to promote rapid cooling of the house after sundown.

It can be seen from the above calculations that the reflective foil insulation works like a one way thermal valve. Thermal resistance to downward daytime heat flow to limit ceiling temperature is 3.21 m^2.K/W. The same reflective insulation has a much reduced thermal resistance of 0.67 m^2.K/W to upward heat flow due to radiant cooling to the night sky. In comparison, bulk insulation such as fiberglass that has a thermal resistance to downward daytime heat flow of 3.58 m^2.K/W, has a thermal resistance to upward heat flow due to radiant cooling to the night sky of 3.03 m^2.K/W.

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Condensation in Houses

Condensation on walls of kitchens, bathrooms, and laundries that are in use during cold weather is a familiar occurrence, and there is a general awareness that wall surfaces and their decorative finishes should be selected for durability. However, condensation of a more sustained and damaging nature can occur in concealed spaces, as is indicated in NSB No. 32. The most serious form of condensation damage is rot hazard to structural timbers of timber-frame construction, but other damage can be caused to ceilings, wall linings, and paintwork.

The purpose of the present Note is to consider in detail the formation of condensation in concealed positions, which is a problem that is often wrongly regarded as unusual in Australia. Paradoxically, this problem is accentuated where certain improved practices in building are adopted without due regard to the new circumstances created.

SOME BASIC FACTS

1.01. Although the technical considerations that cause condensation are elementary, the growth of the problem suggests that many people fail to visualise clearly the circumstances that lead to condensation. For this reason, the subject is examined here right from its basic principles.

1.02. **Water vapour.** Because water vapour is a component of air, it is always present in the air within a house, in quantities that vary on a seasonal basis and with the domestic habits of the occupants. The quantity of water vapour that can be held in the air within a space increases with the temperature of the air. At any particular temperature, air that contains the maximum amount of water vapour it can hold is saturated and has a relative humidity of 100 per cent. Though the relative humidity of air in rooms is generally less than 100 per cent, warm air commonly encountered in winter in well heated rooms of homes does not need to be cooled a great deal before it becomes saturated. Still further cooling of the air leads to the deposition of free moisture as condensation. The temperature at which condensation first occurs is the dewpoint temperature of the air at that time; its numerical value increases with the amount of water vapour that is contained in the air.

1.03. Water vapour, being in the gaseous state, exerts a pressure that is greater when more of it is present in the air. In cold weather, pressure is greater indoors than outdoors, particularly in heated rooms of a house into which much water vapour is liberated without restriction, by cooking, ablution, and laundry processes, or by the combustion of liquid fuels or town gas in unvented appliances. Vapour will then be under pressure to escape outdoors through the bounding construction where it can cause condensation problems as described in subsequent paragraphs. In principle, such rooms should be vented directly to the atmosphere, preferably with the aid of an exhaust fan in the case of kitchens and in spaces where laundry is dried indoors or where wash boilers are used.

1.04. **Vapour barriers.** Most common building materials permit the passage of water vapour through them at rates that warrant their being classified here as permeable. Exceptions include metallic foils and bituminous membranes which are often reinforced with paper, felt, and plastic film and which have such low permeability that they can be regarded as vapour barriers. Rather less effective vapour barriers are provided by coatings of certain types of paint that have low permeability; these include paints with bitumen and epoxy-resin bases, and some latex-based paints.

1.05. **Temperature gradient.** A temperature difference commonly exists between the air against the indoor surface of an external wall of a house and that against the outdoor surface. This difference is accentuated in the case of heated rooms. It is possible to calculate the approximate temperatures within a wall, by the application of principles given in literature for heat transmission under stable conditions. Broadly, the temperature of an element within a wall is assessed from the temperature difference existing across the wall, the overall thermal resistance of the wall, and that proportion of the overall thermal resistance that exists between the element and one side of the construction.

1.06. However, it is not instructive to compute temperature gradients through construction in order to assess the possible occurrence of condensation within it, unless the temperature is maintained essentially constant while consistently low outdoor temperatures occur – circumstances that are uncommon in Australia.

1.07. **Variability of dewpoint temperature.** Another factor that precludes precise analysis of the domestic condensation problem is the wide variability in the humidity of indoor air, and hence in the value of the dewpoint temperature. Not only does the dewpoint temperature vary from room to room in a house, and from time to time, according to the domestic activity, but it can also be variable from house to house, because of differing domestic habits in the use of lids on cooking pots, the period of bathroom showers, the degree of ventilation, and so on.

A source of vapour

CRITICAL CLIMATIC CONDITIONS

2.01. Because condensation can occur under a wide range of conditions – even those of a relatively mild winter – a practical basis must be established for examining the problem. It is suggested somewhat arbitrarily (though not necessarily conservatively) that the occurrence of condensation within the external walls of a house is likely to be acute at times in areas where the mean minimum winter temperature is 4°C or lower, or where provision is made for continuous high-efficiency heating because of the coldness of the winter season. The following list gives some areas that experience a mean minimum winter temperature of 4°C or lower.

Armidale, N.S.W.
Ballarat, Vic.
Bathurst, N.S.W.
Benalla, Vic.
Bendigo, Vic.
Bridgetown, W.A.
Bushy Park, Tas.
Canberra, A.C.T.
Condobolin, N.S.W.
Cooma, N.S.W.
Dubbo, N.S.W.
Griffith, N.S.W.
Hamilton, Vic.
Katoomba, N.S.W.
Lameroo, S.A.
Launceston, Tas.
Oatlands, Tas.
Omeo, Vic.
Sale, Vic.
Scone, N.S.W.
Stanthorpe, Qld.
Tamworth, N.S.W.
Wagga, N.S.W.
Zeehan, Tas.

Other relevant data are published by the Bureau of Meteorology.

CONDENSATION DAMAGE

3.01. **To timber.** The damage to structural timbers in dwellings by sustained wetting resulting from condensation can occur in timber-frame walling, flooring systems, and roof framing, under conditions discussed in subsequent paragraphs. In all such circumstances, the condensation problem can be reduced by the appropriate use of a vapour barrier.

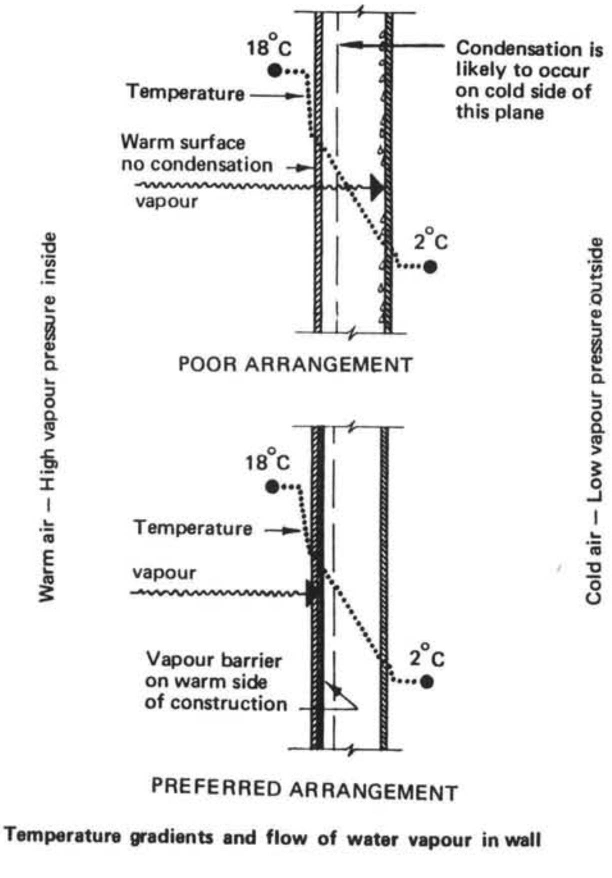
3.02. **To surfaces and ceilings.** Condensation damage to wall linings, paintwork and ceilings is also discussed in later paragraphs.

CONDENSATION IN WALLING

4.01. **Cavity walls.** Condensation in brick cavity walls of houses is not a major problem under Australian climatic conditions. It is a practical problem only where brickwork or applied render, affected by condensation, is decorated with a paint susceptible to damage when on a wet base, or where the disruptive action of frost must be expected.

4.02. **Sarking.** The practice of sarking weatherboard cladding applied to timber framing is to be commended, as is the selection of a sarking material judged to have a long life. Unfortunately, the sarking materials that are likely to have the longest service life are frequently vapour barriers also. Thus a vapour barrier often is unwittingly fixed immediately behind the external cladding where, in a cold-winter region, it can accelerate the deposition of moisture on studs, plates, and noggings, and can retard the subsequent drying.

4.03. Where the critical temperature conditions already noted are likely to be encountered, it is good



Temperature gradients and flow of water vapour in wall

practice to provide a vapour barrier at the wall lining, over the insides of the studs. Joints between successive strips of vapour-barrier materials should be lapped and folded, and securely fixed against a solid backing. Under no conditions of fixing should there be reason to believe that the inner vapour barrier might be more permeable than the sarking. Where similar materials are used for both purposes, it is desirable that joints in the material at the sarking position be merely lapped to ensure weathertightness. Alternatively, nominal ventilation to the outside can be provided for the spaces between adjacent studs, though this provision will reduce the thermal resistance of the wall, and will introduce the problem of ensuring weathertightness of the construction.

4.04. **Wall surfaces.** Although this Note is concerned primarily with condensation in concealed spaces, reference is made to two less familiar aspects of condensation on wall surfaces.

4.05. One of these is the likely occurrence in winter of condensation on the indoor surface of external walling of heavyweight single-thickness construction. The frequent lack of inherent thermal resistance in this type of construction tends to reduce the temperature of internal surfaces of the wall construction below the dewpoint temperature of the indoor air.

4.06. The second matter has a paradoxical component, in that the incorporation of thermal insulation in timber-frame external walling can, at times, induce condensation on (or in) external cladding – to the detriment of applied finishes – in climatic circumstances where condensation would not form in corresponding uninsulated construction. The explanation is that thermal insulation can so impede the outward flow of heat from a house that the external cladding becomes colder than otherwise would be the case. Clearly, the foregoing represents a borderline condition, but it does accentuate the need to assess carefully the possible implications of varying the thermal characteristics of traditional construction.

CONDENSATION IN ROOFS

5.01. **Metal roofs.** The dripping of condensation from the underside of roof sheeting, with consequent damage to ceilings, is a matter of common experience. Proprietary absorbent paints and other applied finishes are available commercially, but their use in existing construction can prove difficult in practice. Where the winter climate is essentially sunny, it is feasible to intercept this 'frost drip' by laying over ceiling joists a metal-foil, plastic, or other impervious membrane, to serve as a drip tray, pending the evaporation of the water intercepted.

5.02. Increased ventilation in a roof space cannot be relied upon to alleviate frost drip; it can even aggravate the problem. This is because metal roof sheeting, in particular, when exposed to a clear night sky, can become colder than the outdoor air and can thereby condense additional moisture from the increased quantity of air passing through the roof space. This problem is examined more fully in NSB No. 78, paragraphs 4.05 to 4.07.

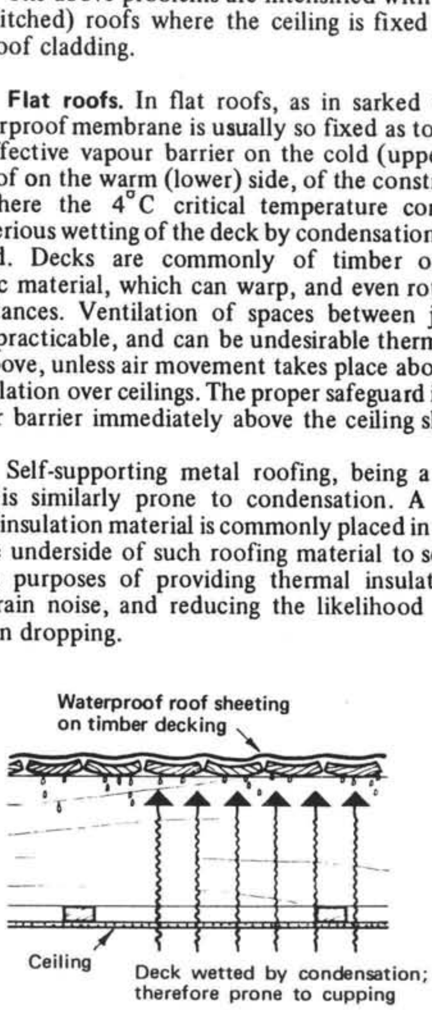
5.03. **Vented ceilings.** The frost-drip problem will be accentuated if rooms or appliances that liberate water vapour, are vented directly into the spaces beneath metal roofs. It is even desirable that light fittings recessed into ceilings should be sealed to the ceiling sheeting to avoid gaps through which water vapour could pass freely into the roof space. Likewise, the tops of wall cavities that communicate with sub-floor spaces should be covered.

5.04. **Tiled roofs.** The venting of humid spaces into a roof space is conducive to the formation of condensation on sarking under tiled roofs also. The problem is intensified where the sarking behaves as an effective vapour barrier because of the presence of, say, a metal-foil or plastic film beneath the roof. In this case, ventilation of the roof space is helpful. Effective natural ventilation is, however, often difficult to ensure in a hipped roof, and it is a thermal disability in cold weather, and possibly a bushfire hazard in summer.

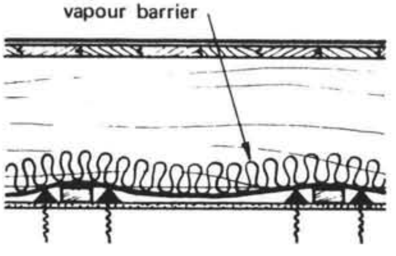
5.05. The above problems are intensified with skillion (single-pitched) roofs where the ceiling is fixed parallel to the roof cladding.

5.06. **Flat roofs.** In flat roofs, as in sarked walling, the waterproof membrane is usually so fixed as to behave as an effective vapour barrier on the cold (upper) side, instead of on the warm (lower) side, of the construction. Thus where the 4°C critical temperature conditions occur, serious wetting of the deck by condensation is to be expected. Decks are commonly of timber or other cellulosic material, which can warp, and even rot, in the circumstances. Ventilation of spaces between joists is seldom practicable, and can be undesirable thermally, as noted above, unless air movement takes place above thermal insulation over ceilings. The proper safeguard is to put a vapour barrier immediately above the ceiling sheeting.

5.07. Self-supporting metal roofing, being a vapour barrier, is similarly prone to condensation. A fibrous thermal-insulation material is commonly placed in contact with the underside of such roofing material to serve the multiple purposes of providing thermal insulation, reducing rain noise, and reducing the likelihood of condensation dropping.



POOR ARRANGEMENT



PREFERRED ARRANGEMENT

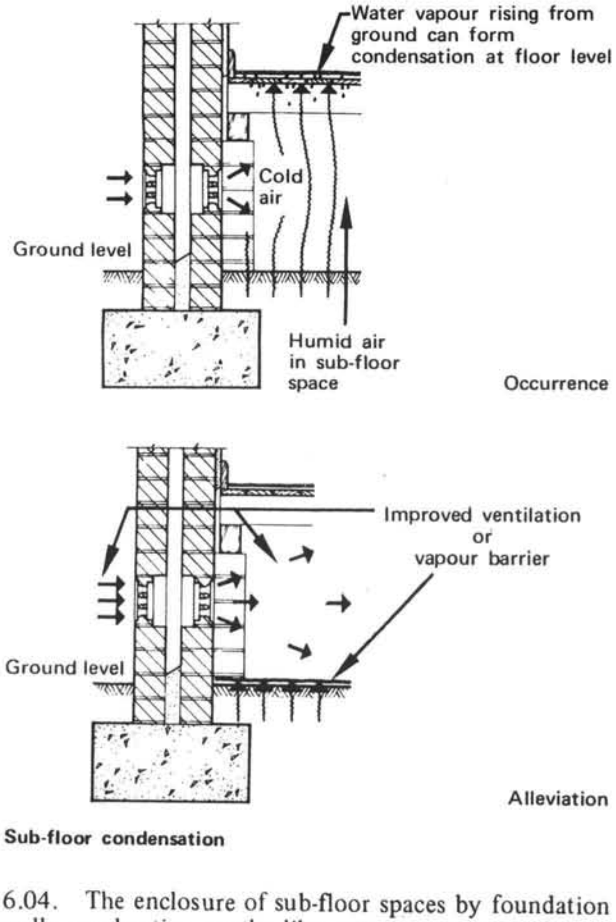
Temperature gradients and flow of water vapour in flat roof

CONDENSATION UNDER FLOORS

6.01. **Ventilation.** Although building regulations require the provision of permanent ventilation openings to enclosed underfloor spaces, and do so reasonably, this provision is quite nominal, and is often ineffectual for various reasons. However, vent openings required by regulation are usually adequate to safeguard against excessive humidity where the site is reasonably dry. Even so, account should be taken of the effect upon sub-floor conditions where sustained watering of gardens or lawns is practised close to a house.

6.02. Where soil beneath a house retains the form of a ball once having been squeezed in the hand, that soil is unduly damp in the present context, and is likely to induce rotting of the floor construction. Improved sub-floor ventilation will improve matters, except that in winter it can lead to the formation of condensation on the floor construction adjacent to points of entry of cold outdoor air.

6.03. **Vapour barriers.** Here again, the use of a vapour barrier is the preferred treatment and, in this case, the barrier is laid over the damp ground. Usually it is sufficient merely to lap adjacent strips of the vapour barrier, and to weight the lapped edges with earth, or brickbats commonly to be found beneath a house. Where such treatment is undertaken, it should cover all ground within perimeter walls. Some water vapour will still rise from the ground, but the reduced quantity can be satisfactorily diluted by normal sub-floor ventilation, thus inhibiting the formation of condensation.



Sub-floor condensation

6.04. The enclosure of sub-floor spaces by foundation walls, or sheeting, or the like, serves to maintain higher air temperatures within the space in winter. The tendency for water vapour from the space above to condense under flooring is thereby reduced.

6.05. Condensation under floors is a more difficult problem in snow country. The precautionary treatment is to prevent water vapour from passing downwards into the floor. However, practical considerations require that the vapour barrier be placed under the floor boards, with consequent loss of thermal insulation between the warm indoor space and the vapour barrier. This factor, together with those of severity of the winter climate, and of constructional details, often makes it necessary to provide thermal insulation under the vapour barrier, so that the temperature of the vapour barrier will remain above dewpoint temperatures. If this condition is not achieved, condensation can occur in the floor-boards or at their underside. One approach to the problem is to provide a double-boarded floor, with the vapour barrier between the two thicknesses of boarding; another approach, applicable to carpeted floors, is to lay the vapour barrier over the customary single-boarded floor, prior to laying the carpet.

6.06. It is to be noted that enclosure of sub-floor spaces will aggravate the condensation problem associated with damp ground, and render it more imperative to cover the ground, as discussed in paragraph 6.03.

SUMMARY

7.01. The preceding discussion can be highlighted as follows:

- Condensation on the internal surfaces of walls of kitchens, bathrooms, and laundries is largely inevitable when those rooms are in service during cold weather.
- Likewise, frost drip from metal roofs is to be expected where cold conditions occur.
- Conditions conducive to rot in timber are likely within enclosed sub-floor spaces over damp ground.
- Condensation within external walling, and in floor and flat-roof construction, should be viewed as a hazard where the mean minimum winter temperature is around 4°C or lower.
- Where climatic conditions as in the item above occur, the use of vapour barriers, in accordance with the preceding discussion, should be regarded as normal good practice.

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2. KEOUGH, J.J. 'Selected Australian Climatic Data'. *Technical Study* No. 36. Commonwealth Experimental Building Station, Sydney, 1951.
3. *Climatic Averages Australia.* Bureau of Meteorology, Melbourne, 1956.

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NOTES ON THE SCIENCE OF BUILDING

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BUILDING TECHNOLOGY *file*

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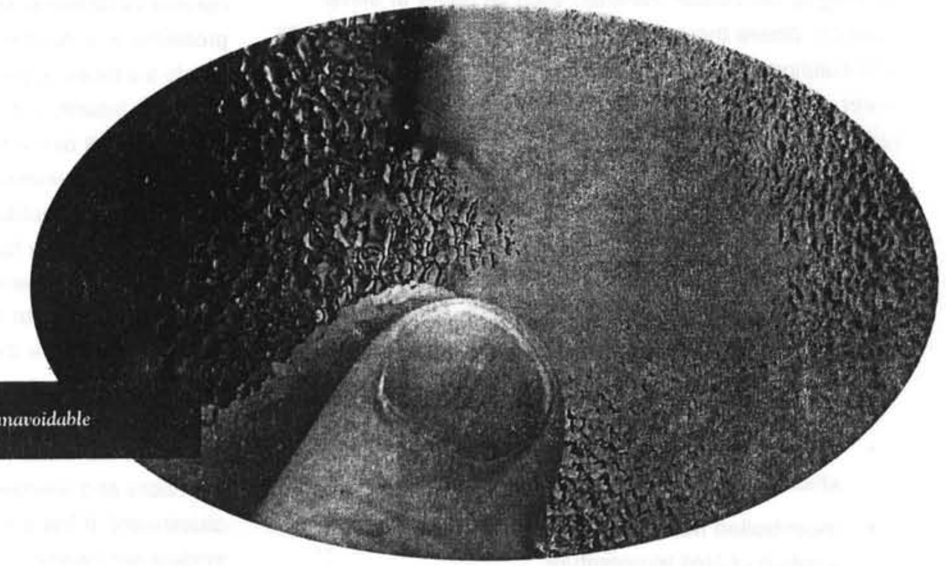
Condensation on internal surfaces is the cause of unsightly mould growth in houses and of water collecting under and dripping from factory roofs. However it often occurs within the building fabric where it may not be so obvious. This may be of greater consequence, leading to decay of timber and otherwise threatening the structural integrity of the building. Ironically, this interstitial condensation can be the result of incorrect use of thermal insulation intended to stop surface condensation.

Condensation



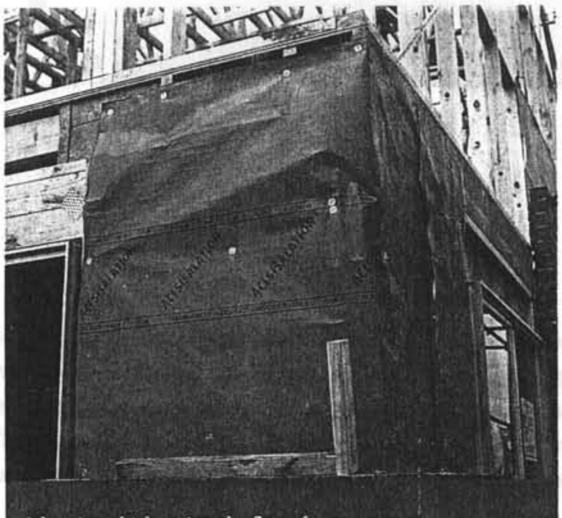
Condensation is sometimes unavoidable

What is Condensation

Condensation arises because warm air can hold more moisture than cold air. For example, air at 25°C can hold about 20 grams of water per kilogram of air. This is its maximum water content so it corresponds to 100% humidity. If air in this state is cooled to 15°C then its maximum water content falls to about half this value and about 10 grams of water must condense out of each kilogram of air. This will occur as a fog of liquid droplets if the air is cooled as a mass, or as condensation on a surface if that surface provides local cooling of the air around it.

The air around us is generally not saturated although it may be warm enough to store a considerable amount of moisture. In this state its relative humidity is less than 100%. However, if this air is cooled below its dewpoint (i.e. cooled to a temperature where its relative humidity would exceed 100% so that it cannot contain all of the water originally present) then a fog or condensation will occur. If the air is relatively moist then the dewpoint temperature will be not far below the actual air temperature so condensation occurs readily. Drier air will have a dewpoint which is proportionately low, so that condensation will only occur if it comes into contact with surfaces which are much colder.

The movement of moisture may be controlled in buildings by selectively incorporating elements which inhibit or allow the passage of water vapour as required. A vapour barrier is a material, typically reflective aluminium foil or polyethylene sheet, which has a high resistance to the flow of water vapour. Where membranes are incorporated in buildings (for other reasons) and high vapour permeance is required, such membranes may be perforated with small holes or be made of a highly permeable material, such as paper or some plastics. Where there is free exchange of air between parts of a building then it is not possible to restrict the flow of water vapour, and moisture generated in one place will rapidly spread to others. It is therefore possible to have condensation in a cold part of a building caused by water vapour which is sourced some distance away.



A barrier which resists the flow of water vapour

Condensation in Buildings

The ingredients for condensation are essentially one or more of the following:

- the presence of moisture levels which are too high
- the presence of temperatures in the building fabric which are too low
- uncontrolled flow of water vapour from a source to a region of cold temperature.

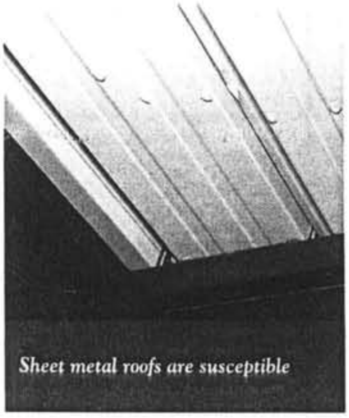
Moisture levels within buildings are often higher than outdoors. There are numerous reasons for this. One source of moisture is the ground. Moisture levels in the ground depend upon the local microclimate and on soil characteristics as well as on the local release of water by activities such as watering. Concrete slabs generally provide a waterproof barrier to ground moisture but buildings with suspended timber floors (typical of many houses) are quite susceptible to high indoor humidity arising from moist subfloor spaces. In older buildings with inadequate (or failed) damp courses in masonry walls, moisture may be wicked into the building through the masonry. In this case there is likely to be local damage due to the rising damp but in addition there is a ready source of indoor moisture which may condense elsewhere in the building.

Indoor air can become moist because the occupants and some domestic appliances produce water vapour. Typical quantities of water vapour produced in the home are (in litres per hour):

• Adult (breathing)	0.1
• Hot bath	1.5
• Washing machine	3.0
• Clothes drier	5.0
• Hot shower	10.0

Many domestic and industrial appliances such as gas-, oil- and kerosene-fired stoves, burners and heaters produce large quantities of water as a product of combustion. This problem does not arise with flued appliances, where the products of combustion are removed to outdoors.

Low temperatures within a building also arise from a number of different sources and contribute to condensation problems in a number of different ways. Condensation on inside surfaces is generally a winter (or heating season) problem. Insufficiently insulated surfaces become cold enough to fall below the dewpoint of indoor air and condensation necessarily occurs. Sheet metal roofs are particularly susceptible because they 'look up' at a cold night sky. They can fall to a temperature which is actually below the outdoor ambient by a phenomenon known as 'radiation cooling' to the cold sky. In an otherwise well-insulated structure there may be heat bridges which allow surfaces which are cooled by close contact with outdoors or the ground to exist within the warmer interior space. Typical examples are water pipes, structural steel or aluminium members and window panes and their frames (especially if aluminium). If the interior surfaces of the building have inadequate vapour resistance, condensation may occur within wall, roof or floor structures where the building fabric is colder and may approach outdoor temperature.



Sheet metal roofs are susceptible

In climates where summer humidity is high, condensation can be a summer problem, particularly if mechanical cooling is in use. Water vapour may condense on the outside of the building if it is inadequately insulated or contains heat bridges and is cooled from inside. As in the winter case, water vapour may penetrate the building fabric, this time from the outside and condense on cold interstitial surfaces. The cold parts of air-conditioning equipment (such as evaporator lines) are subject to condensation if inadequately lagged and it is possible for walls adjacent to indoor evaporator units, or in the cold airstream from them, to be subject to condensation.

Preventing Condensation

Climate

Because climate (particularly temperature and humidity) is a central factor in the risk of condensation, it is not possible to set guidelines which are universally appropriate. In general, areas with higher humidity are more likely to experience problems. In addition, regions with cold, wet winter climates are likely to have problems during the heating season and regions with hot, humid summer climates are likely to experience problems in their cooling season.

New constructions

Severe condensation problems often occur in new buildings, as construction moisture stored in the structure adds to the moisture generated by the occupants and their activities. It takes up to 12 months for new masonry walls, concrete floors and timber framing to dry out. Some drying is to outdoors but much of the moisture is released to the inside or interstitially where it may be the major cause of a temporary condensation problem.

Good design

Many condensation problems will not arise if the correct steps are taken in the design and construction of the building. Vapour barriers may be crucial and will be specified by the designer if there is a particular risk to some part of the building fabric. They are only effective if installed to an adequately high standard without penetrations or gaps. Vapour barriers are most frequently specified under concrete slabs and under sheet metal roofs, in the latter case often in conjunction with blanket insulation. Often membranes such as reflective foil are specified in buildings for other purposes such as insulation or sarking. When used incorrectly they may contribute to a condensation problem by preventing the escape of water vapour from areas where relative humidity levels may become excessive. In general, vapour retarders should be placed on the warm side of building elements within which there is the potential for condensation and membranes which breathe should be placed on the cold side.

Use exhaust fans in bathrooms

Good design includes providing adequate levels of thermal insulation so that surface temperatures remain high enough to prevent condensation. This may require that particular attention be paid to potential problems with heat bridges in the construction. Higher levels of insulation may introduce unforeseen problems where they are incorporated into construction styles which have previously been relatively immune to condensation. This is because insulation, whilst it keeps some surfaces warm, also keeps other surfaces cold. A simple example is domestic roof spaces. High levels of ceiling insulation mean that roof spaces are colder as they are not heated to the same extent from below. Tiled roofs are relatively immune from condensation as they are well ventilated to outdoors but incidences of condensation within pitched roof spaces with sheet metal roofs are increasing in line with the trend to higher levels of ceiling insulation.

Condensation on window glass is generally prevented by the use of double glazing. This is expensive but its use is spreading in both domestic and commercial construction. Where climate and building moisture generation dictate, condensation on single-glazed window panes is unavoidable. Poorly designed aluminium frames may similarly be guaranteed to have a condensation problem. Increasing attention is being paid to frame designs which incorporate thermal barriers between indoor and outdoor aluminium sections.

Unflued gas, oil or kerosene heating should be avoided in buildings where condensation problems may be anticipated.

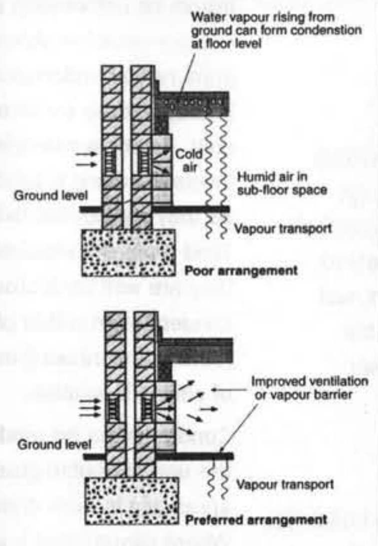
Ground moisture

Excessive watering of lawns and garden beds close to buildings is a potential cause of indoor condensation problems. Buildings sited in areas which are inherently very wet are also likely to experience problems. This may include buildings built into the sides of hills where the water table may be very close to ground level. Leaky roof gutters and leaking water pipes are other obvious sources of excess ground moisture.

Ventilation

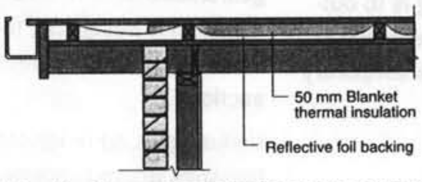
Ventilation is an effective way of removing moisture generated within a building and keeping the relative humidity low. Exhaust fans should be used in bathrooms and laundries at any time when moisture is being produced. Electric clothes driers should be vented to outdoors. With some models, permanent vents to outdoors can be fitted. With units which vent only through the front door, the laundry window should be opened and the connecting door to the rest of the building should be closed whilst the drier is in operation. Range hoods should be used in kitchens as moisture is generated not just as part of cooking but also as a combustion product from the gas burners in cooktops and ovens.

Condensation can occur in subfloor spaces where there is inadequate ventilation. This may lead to decay of timber framing and flooring. Subfloor spaces should be adequately ventilated. Where serious problems occur a vapour barrier at ground level may also be required.

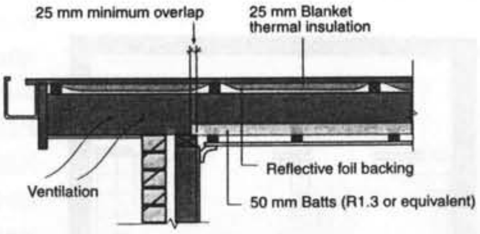


Sub-floor condensation

Condensation under metal deck roofs which are not insulated from the space below (which may be a roof space) is a common problem. In commercial and industrial buildings where significant amounts of water vapour are generated by work activities, increased ventilation to outdoors is likely to be of assistance. It is a common practice in domestic and commercial construction to ventilate bathroom, laundry and kitchen areas into the roof space from where it is assumed the moisture will dissipate. However, where there is an uninsulated sheet metal roof, condensation on its underside is a likely occurrence. It is desirable to have fixed ventilation at eaves or gable ends for such roofs and to ensure that exhausts into the roof space area are ducted direct to outdoors.



Flat metal roof, exposed beams (applies also to cathedral roofs)

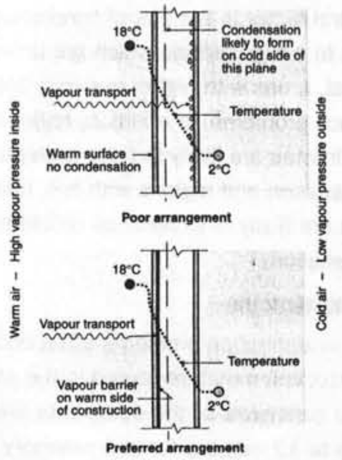


Flat metal roof, concealed beams

Rooms such as bedrooms which experience condensation problems in winter generally benefit from small continuous amounts of ventilation through partially opened windows. Ventilation in this way is at some energy cost as the building will either be colder or more expensive to heat.

Heating

Condensation on internal walls and ceilings in winter may be greatly reduced by keeping internal temperatures higher by additional heating. As with ventilation, this is generally more beneficial if it is continuous and will necessarily entail higher heating costs.



Condensation control relies on good design detail

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