Extract taken from:

TECHNICAL HANDBOOK

4th Edition

achieving
recognition

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Heat transfer, thermal resistance and reflective insulation

Terminology:

RESISTANCE, symbol R, units $m^2 \cdot K/W$, is the measure for the thickness.

RESISTIVITY is the resistance per thickness, units $m \cdot K/W$. Resistivity=1/k.

CONDUCTANCE, symbol U, units $W/(m^2 \cdot K)$, is the measure for the thickness. $U = 1/R$.

CONDUCTIVITY, symbol k, units $W/(m \cdot K)$. $k = 1/\text{Resistivity}$.

(The difference between Celsius temperatures has the unit "K", Kelvin.)

All heat transfer comprises the sum of :

CONDUCTION (molecular vibration - solid, liquid & gas),

CONVECTION (movement, i.e. fluid only), and

RADIATION (only applies to gas).

Thus $U = U_{conduction} + U_{convection} + U_{radiation}$ and the combination thermal resistance is calculated by $R=1/U$.

Dense solids have packed molecules, so thermal conduction is higher than through contained gases. Dense solids have much lower thermal resistance than an equal air space. Still air is thus classified as a thermal insulator.

But when the air is turbulent, there is very significant heat transfer (e.g. wind chill in an antarctic blizzard). The air must be still to be a good insulator.

When there are buoyancy effects or forces moving fluid particles, there may be significant heat transfer by convection, (e.g. attic air warmed through an uninsulated ceiling may buoyantly rise and be lost into the winter night, adding to heating bills).

For a sealed roof attic, conduction and convection may be low, so radiative heat transfer may dominate. In such cases, the addition of a Reflective Foil Laminate (RFL) will almost eliminate the radiative heat transfer, so the AIR-GAP becomes a REFLECTIVE INSULATING AIR SPACE.

In walls too, without a suitable air gap, the reflective surface provides no insulation value.

E.g. 5mm of air conduction (excluding convection and radiative heat transfer) has R0.19. Include the radiation component, and thermal resistance is about R0.17 (reflective), or R0.10 (non-reflective).

The in-service R of reflective insulation depends on the cavity air temperature, the air gap, the orientation, and the infrared emittance (which is affected by dust).

Dust on reflective foil surfaces increases its infrared emittance (reduces its reflectance). Independent research supports use of the following resulting emittances from the dusting of upward facing bright foils. (Downward facing foils do not accumulate dust):

0.02	Best possible, no dust (new bright foil)
0.03	No dust (after 5 years)
0.1	Slight dust cover (after 5 years)
0.4	Moderate dust cover, in dusty environment (after 5 years)
0.7 to 0.8	The worst possible result, not justified in the field, but achieved from laboratory tests, where foil is coated with a thick layer of dust, and is the emittance of the dust itself.

Reference: Cook, J C, Yarbrough, D W and Wilkes, K E (1989) *Contamination of Reflective Foils in Horizontal Applications and the Effect on Thermal Performance.* ASHRAE Trans., vol.95, part 2, 677-681. (Results of tests on reflective foil surfaces with coatings of applied dust, and others collected from the field in Chicago).

Heat transmission through building structures

$Q = U \cdot A \cdot K$

where:

Q = Heat transmission (W)

U = Coefficient of heat transfer (conductance) ($W/m^2 \cdot K$)

A = Area of surface (m^2)

K = Temperature difference across the building element (Kelvin)

The following information is concerned with the calculation of U for various building elements.

Overall Heat Transfer Coefficient (U)

The overall heat transfer coefficient, U is the rate of heat transfer through unit area of a building element when there is unit difference between the ambient air temperatures on either side of the element. It is calculated as the reciprocal of the sum of the resistances of the individual components of the elements.

Example: For a cavity wall section with total resistance $R_T = R_{SI} + R_1 + R_A + R_2 + R_{SO}$,

$$\text{where: } U = \frac{1}{R_{SI} + R_1 + R_A + R_2 + R_{SO}}$$

R_{SI} = $1/f_{SI}$ = inside surface air film resistance

R_{SO} = $1/f_{SO}$ = outside surface air film resistance

R_A = air space resistance

R_1 = x_1/k_1 = inner wall resistance

R_2 = x_2/k_2 = outer wall resistance

f_{SI} = inside wall surface film coefficient (W/m^2 K)

f_{SO} = outside wall surface film coefficient (W/m^2 K)

x_1, x_2 = thickness of materials (metre)

k_1, k_2 = thermal conductivity of materials (W/m^2 K)

In the following pages, Overall Heat Transfer Coefficients (U) have been calculated for a number of constructions commonly encountered in Australia.

The values of resistance used in the calculations have been chosen after due consideration of the accuracy of available data.

Thermal bridging

With softwood framed walls, the effect on U values is small enough to be ignored. With highly-insulated walls having hardwood or metal frames, the effect may be significant. (Refer ISO 10211.1, NZS 4214, and *A Manual for Calculating R-values Using the Isothermal Planes Method*, H.A. Trethowan NRANZ 1997.)

In cold climates, high rates of heat transfer through thermal bridges may produce local cold spots, which in some situations may cause condensation on the indoor surface.

Heat transmission through building structures (cont)

Air film resistances (R_{SI}, R_{SO})

The resistance values of surface air films decrease with increasing surface roughness, increasing air movement over the surface, and increasing surface emittance (decreasing reflectance).

Standard values of outside air movement of 6.0 and 3.0 m/s have been used for winter and summer building calculations respectively. (At these air velocities, surface emittance is not relevant).

For still air, air film resistance depends on surface infrared emittance and its orientation.

The table "Thermal Resistance of Air Films" summarises appropriate values for buildings.

For air conditioned buildings, indoor air movement may be such that the still air resistance does not apply indoors.

For single-glazed windows, the resistance to heat flow is predominantly only the surface resistances.

Air space resistance (R_A)

Still air is an insulator and the addition of a reflective surface provides cost-effective further insulation by reducing radiant heat transfer. This applies for both summer and winter applications as the physics of winter radiant heat loss are similar to summer radiant heat gain. The insulation rating cannot be easily calculated except for parallel-faced still air cavities, and this value depends on mean air space temperature, infrared emittance, and surface temperatures. Historical values (as listed) are often used for calculations, but research is needed to update these values for modern construction.

Reflective foil laminates can provide high additional R to cavities, however sun reflectance can be dangerous to installers on a sunny day.

So-called "anti-glare" foils (properly called "semi-reflective foils") are reflective foil laminates with a thin layer of dye (typically pale blue or green) resulting in infrared emittance of 0.1 to 0.2. When sunlit, they are less blinding to installers, but the foil treatment reduces thermal resistance of the adjacent air space, but not the larger reduction due to other surface coatings.

References

Tye, R P (1985), *Upgrading thermal insulation performance of industrial processes*, Chemical Engineering Progress (Feb) 30-34.

Tye, R P (1986), *Effects of product variability on thermal performance of thermal insulation*, Proc. 1st Asian Thermal Properties Conference, Beijing, China.

Tye, R P and Desjarlais, A O (1983), *Factors influencing the thermal performance of thermal insulations for industrial application*," in Thermal Insulation Materials and Systems for Conservation in the 80s, F A Govan, D M et al, eds. ASTM STP 789:733-748.ASHRAE (2005).

ASHRAE *Fundamentals* 2005, Ch.25 *Thermal and Water Vapor Transmission Data*. Table 1.

Thermal resistance of air films

Wind speed (m/s)	Surface position	Directon of heat flow	Resistance (m^2 · K/W)	
			High emittance surface	Low emittance surface
Still air	Horizontal	Up	0.11	0.23
		Down	0.16	0.80
	45° slope	Up	0.11	0.24
		Down	0.13	0.39
	22.5° slope	Up	0.11	0.24
		Down	0.15	0.60
	Vertical	Horizontal	0.12	0.30
6.00 m /s (winter)	Any position	Any direction	0.03	
3.00 m/s (summer)	Any position	Any direction	0.04	
0.50 m/s (internal air movement)	Any position	Any direction	0.08	

Thermal resistance of pitched roof spaces

Roof Space type	Directon of heat flow	Resistance (m^2 · K/W)	
		High emittance surface	Low emittance surface
Ventilated	Up (winter)	nil	0.34
	Down (summer)	0.46	1.36
Non-ventilated	Up (winter)	0.18	0.56
	Down (summer)	0.28	1.09

Note: 'Low emittance' refers to Reflective Foil Laminates (RFL) with emittance of 0.05 or less.

Heat transmission through building structures (cont)

Thermal resistance of airspaces

Nature of parallel facing surfaces enclosing cavity	Position of airspace	Directon of heat flow	Resistance (m² · K/W)	
			20mm width	100mm width
High emittance surfaces	Horizontal	Up	0.15	0.17
		Down	0.15	0.17
	45° slope	Up	0.15	0.16
		Down	0.17	0.17
	Vertical	Horizontal	0.15*	0.16
One surface of low emittance	Horizontal	Up	0.39	0.48
		Down	0.57	1.42
	45° slope	Up	0.49	0.53
		Down	0.57	0.77
	Vertical	Horizontal	0.58*	0.61
Two surfaces of low emittance	Horizontal	Up	0.41	0.51
		Down	0.63	0.75
	45° slope	Up	0.52	0.56
		Down	0.62	0.85
	Vertical	Horizontal	0.62*	0.66

NOTE:

*For vertical airspaces greater than 20 mm with horizontal heat flow, the value of resistance for 100 mm should be used.

Calculation of U values for roof-ceiling combinations requires knowledge of the resistance of the airspace between the ceiling and the roofing material. Resistance values are given in the preceding table "Thermal resistance of pitched roof spaces".

"Low emittance" refers to the air space being bound by a reflective foil surface with emittance of 0.05 or less. This excludes foils with anti-glare treatment.

Where RFLs are used, the foil itself has almost zero thermal resistance, however the low emittance of the reflective side of the foil may substantially improve the thermal resistance of the adjacent air space by reducing radiant heat transfer.

RFLs facing upward into ventilated cavities are assumed to become ineffective due to dust deposition over the life of the building, but vertical and downward facing foils are assumed to remain dust-free, reflective and beneficial.

(For further details refer AIRAH Journal, October 1997 *"Computational Analysis of Reflective Air Spaces"*).

Ventilation of building envelope

When building codes permit, conditioned building envelopes should not be vented to the outside. Ventilation in heated and/or cooled buildings reduces energy efficiency. It also increases the potential for moisture either through wind driven rain or through introduction of humid ambient air. Moisture in bulk insulation reduces its insulation rating and should be avoided. Ventilation increases the risk of wind damage to the building through increased lifting forces; it increases fire damage through easier spread of fire; it increases corrosion of metal framing and fixtures due to access of salt and pollution in the air.

Radiant barriers should be included whenever radiation is a problem. This applies to the whole of Australia. The reflective side must be used in conjunction with an adjacent air space (or two adjacent air spaces if double sided). Often one side is semi-reflective ("anti-glare") with a reduced emittance
of around 0.2.

Reflective foil insulation typically tests at 0.03 emittance in Australia. Low emittance insulation is taken to range from 0.03 to 0.05.

When timber construction components in building cavities, such as walls or under floors, are exposed to the outside air through vents, there should be adequate ventilation openings in these vents to prevent build up of moisture in these cavities. There should not be any connection from these cavities to the inside of the building, nor to the roof spaces from these areas.

Infrared emittance values of selected materials

Material	Temperature (°C)	Emittance @8-14µm (average measurements)
Aluminium foil (bright)	25	0.02
Aluminium foil (bright)	100	0.03
Aluminium foil (oxidised)	93	0.09
Aluminium foil (anti-glare)**	38	0.10-0.25
Aluminium foil (slight dust)**	38	0.05
Aluminium foil (mod. dust)*	38	0.25
Aluminium paint (26%)	38	0.30
Brick (red, rough)	21	0.93
Clay tiles (fired)	70	0.91
Concrete (rough)	38+	0.94
Copper (polished)	38	0.03
Galvanising (bright)	38	0.23
Galvanising	38	0.28
Ice (smooth)	0	0.97
Paint (any colour)	93	0.90-0.96
Paper	38+	0.93
Sand	20	0.76
Shale	20	0.69
Soil	38	0.38
Soil (black loam)	20	0.66
Water	38	0.67
Wood	low	0.80-0.90
Wood- beech (planed)	70	0.94
Wood – oak (planed)	70	0.91

Source for most items (with permission) Newport Electronics:
http://www.newportus.com/Products/Techncal/MetlEmty.htm

* Based on average measurements

** based on several studies, in particular Cook et al (1989) *"Contamination of Reflective Foils in Horizontal Applications and the Effect of Thermal Performance".* ASHRAE Trans. 95, 2, 677-681.