NZS 4214:2006

New Zealand Standard

Methods of Determining the Total Thermal Resistance of Parts of Buildings

Superseding NZS 4214(Int):2002 and NZS 4214:1977

NZS 4214:2006

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COMMITTEE REPRESENTATION

This Standard was prepared under the supervision of the Thermal Resistance – Determination Methods Committee (P 4214) for the Standards Council established under the Standards Act 1988.

Committee P 4214 consisted of representatives of the following organisations:

Building Research Association of New Zealand (BRANZ)
Cement and Concrete Association of New Zealand (CCANZ)
Claddings Institute of New Zealand
Department of Building and Housing
Employers and Manufacturers (Northern) Inc. (EMA)
Energy Efficiency and Conservation Authority (EECA)
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New Zealand Standard

METHODS OF DETERMINING THE TOTAL THERMAL RESISTANCE OF PARTS OF BUILDINGS

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REFERENCED DOCUMENTS

Reference is made in this Standard to the following:

NEW ZEALAND STANDARDS

NZS 4218:2004	Energy efficiency – Small building envelope
NZS 4243:1996	Energy efficiency – Large buildings
NZS ISO/IEC 17025:1999	General requirements for the competence of testing and calibration laboratories

JOINT AUSTRALIAN/NEW ZEALAND STANDARD

AS/NZS 4859: - - - -	Materials for the thermal insulation of buildings
Part 1:2002	General criteria and technical provisions

INTERNATIONAL STANDARD

ISO 12576: - - - -	Thermal insulation – Insulating materials and products for buildings – Conformity control systems
Part 1:2001	Factory-made products

AMERICAN STANDARD

ASTM C1363:05	Standard test method for thermal performance of building materials and envelope assemblies by means of a hot box apparatus

AUSTRALIAN STANDARD

AS 1366: - - - -	Rigid cellular plastics sheets for thermal insulation
Part 3:1992	Rigid cellular polystyrene – Moulded (RC/PS – M)

OTHER PUBLICATIONS

ASHRAE Handbook, Fundamentals, American Society of Heating, Refrigerating and Air-conditioning Engineers Inc., 2001.

Building Industry Authority, The New Zealand Building Code Handbook and Approved Documents.

How to choose the most efficient windows for your home: Window Efficiency Rating Scheme (WERS)(published by WANZ).

Trethowen, H.A. and Delsante, A.E. A four-year site measurement of heat flow in slab-on-ground floors with wet soils, BRANZ Conference and Seminar Paper No. 76, 2000.

LATEST REVISIONS

The users of this Standard should ensure that their copies of the above-mentioned New Zealand Standards and referenced overseas Standards are the latest revisions. Amendments to referenced New Zealand and Joint Australian/New Zealand Standards can be found on www.standards.co.nz

FOREWORD

This Standard supersedes the Interim Standard, NZS 4214(Int):2002 *Methods of determining the total thermal resistance of parts of buildings*.

This Standard provides methods for determining the total thermal resistance of parts of buildings in steady-state environmental conditions and is intended to be used as a means of compliance with the relevant requirements of the New Zealand Building Code. Calculations have been updated to take account of the ventilated cavities now required.

REVIEW OF STANDARDS

Suggestions for improvement of this Standard will be welcomed. They should be sent to the Chief Executive, Standards New Zealand, Private Bag 2439, Wellington.

NEW ZEALAND STANDARD

METHODS OF DETERMINING THE TOTAL THERMAL RESISTANCE OF PARTS OF BUILDINGS

1 SCOPE

1.1 Thermal resistance

This Standard gives methods of determining the thermal resistance of building components and elements consisting of thermally homogeneous layers which may include air layers.

1.2 Elements and components

1.2.1

The methods may be applied to individual elements and components, or to complete assemblies such as walls, roofs and floors.

1.2.2

This Standard provides only limited methods for dealing with components, or elements containing reflective foil used as a radiant barrier, and the thermal performance of sub-floor spaces.

1.3 Inclusions

Three methods for the determination of thermal resistance are provided:

(a) Laboratory measurement;
(b) Site measurement; and
(c) Calculation.

1.4 Exclusions

(1) The methods are not intended to be applied to windows or glazing.

NOTE – Software packages such as THERM (http://windows.lbl.gov/software) and WINDOW (http://windows.lbl.gov/software) are available for calculation methods for glass.

(2) The methods for the calculation of the building envelope component *R*-values are not intended to be used in the calculation of *R*-values for use in computer thermal performance simulation programmes. The *R*-values in this Standard are intended to show compliance with the schedule and calculation methods in NZS 4218 and/or NZS 4243.

1.5 Interpretation

1.5.1

For the purposes of this Standard the word “shall” refers to practices that are mandatory for compliance with this Standard. The word “should” refers to practices which are advised or recommended.

1.5.2

The terms “Normative” and “Informative” are used in this Standard to define the application of the Appendix to which they apply. A “Normative” Appendix is an integral part of a Standard, whereas an “Informative” Appendix is only for information and guidance.

2 OBJECTIVE

The objective of this Standard is to provide building specifiers, designers, users, manufacturers, suppliers and installers with methods of calculation and measurement for determining the thermal resistance of building components and elements.

3 DEFINITIONS

For the purposes of this Standard the following definitions shall apply:

BUILDING ENVELOPE COMPONENT. An area of the building envelope, such as roof, wall, floor or glazing, of a given construction and to which a single thermal resistance value may be allocated.

EFFECTIVE EMITTANCE (E) of an air gap. An air gap with bounding surfaces with emittances e_1 and e_2 has an effective emittance of:

$$\frac{1}{E} = \frac{1}{e_1} + \frac{1}{e_2} - 1 \qquad \text{(Eq. 1)}$$

EMITTANCE (ε) of a surface. The ratio of the total heat radiation emitted by a unit area of the surface of a sample of material to the corresponding quantity emitted by a unit area of a full emitter (black body) at the same temperature.

MATERIAL THERMAL RESISTANCE (R_m). The thermal resistance between faces of a slab of given thickness of a uniform homogeneous material.

R-VALUE (TOTAL THERMAL RESISTANCE). The value of thermal resistance of a building element (e.g. wall, floor or roof) which is the sum of the surface resistances on each side of a building element and the thermal resistances of each component of the building element including any cavities in the element. It is determined by calculation or by measuring the temperature difference between the internal air on one side and the external air on the other side of a building component, when there is unit heat flow in unit time through unit area using internal and external conditions considered as typical for buildings (m^2 °C/W).

STANDARD TOTAL THERMAL RESISTANCE. For compliance purposes within New Zealand, the total thermal resistance when the outside surface thermal resistance is standardised at 0.03 m^2 °C/W and the inside surface thermal resistance is standardised at 0.09 m^2 °C/W.

SURFACE THERMAL RESISTANCE (R_s). The thermal resistance which arises between the external surface (R_{se}) or the internal surface (R_{si}) of a building component and the air adjacent to it.

SYSTEM THERMAL RESISTANCE (R_{sy}). The thermal resistance associated with a system or construction of materials where there may not be a single uniform homogeneous material between faces.

THERMAL BRIDGE RESISTANCE (R_b). The thermal resistance of the bridging portion of a building envelope component that is not continuous but is bridged by one or more sets of material passing through its thickness.

THERMAL CONDUCTIVITY (k). The heat flow (thermal transmission) in unit time through unit area of a slab of a uniform homogeneous material of unit thickness when unit difference of temperature is maintained between its two surfaces (W/mK)). It is related to material thermal resistance, for a material of thickness *l*, by the expression:

$$k = \frac{l}{R_m} \quad \text{(conversely,} \quad R_m = \frac{l}{k}) \qquad \text{(Eq. 2)}$$

THERMAL RESISTANCE (*R*). A measure of resistance to the flow of heat. It can be determined by measuring the temperature difference which is maintained between surfaces or planes when there is constant heat flow between them in unit time through unit area ($m^2\,^oC/W$).

TOTAL THERMAL RESISTANCE (R_T). The total thermal resistance, including surface thermal resistances, between the air on either side of a building element.

4 SYMBOLS AND UNITS

The following general symbols and units are used in this Standard together with others specific to certain applications.

Symbol	Quantity	Unit
A	area	m^2
l	thickness	m
k	thermal conductivity	W/mK
R_m	material thermal resistance	$m^2\,^oC/W$
R_{sy}	system thermal resistance	$m^2\,^oC/W$
R_b	thermal bridge resistance	$m^2\,^oC/W$
R_{se}	external surface resistance	$m^2\,^oC/W$
R_{si}	internal surface resistance	$m^2\,^oC/W$
R_T	total thermal resistance	$m^2\,^oC/W$

5 THERMAL RESISTANCE

5.1 Materials or assemblies of materials

5.1.1

The thermal conductivity of a material or thermal resistance of an assembly shall be determined by:

(a) Materials:

- (i) Laboratory measurement or calculation in accordance with AS/NZS 4859.1 (see also Appendices A to D)
- (ii) Field (*in situ*) measurements using conductivity probe (e.g. soils and rammed earth)
- (iii) Manufacturer's data in accordance with 5.1.1(a)(i) or 5.1.1(a)(ii)
- (iv) Tables E1(a) to E1(d), for materials other than insulation materials.

(b) Assemblies:

- (i) By calculation using 5.3 to 5.7, and/or the calculation procedure of 6.1 and 6.2
- (ii) Field (*in situ*) measurements using heat flux transducers
- (iii) Laboratory measurement using a hot box apparatus in accordance with ASTM C1363
- (iv) Manufacturers' data in accordance with 5.1.1(b)(ii) or 5.1.1(b)(iii) above
- (v) Computational methods, see ASTM/ISO/IEC Standards and Appendix D.

5.1.2 Laboratory measurements

Although AS/NZS 4859.1 lists suitable test methods and gives a minimum re-test frequency for the testing of insulation products, neither the test methods nor the Standard itself deal with all of the issues required under a product certification scheme, such as how to obtain and select the samples for test, and how to deal with results which fall below the declared value (including the use of statistics). A laboratory with accreditation (e.g. to NZS ISO/IEC 17025) or recognition for testing to the relevant Standards and procedures shall perform the measurements.

5.1.3 Field (*in situ*) measurements

5.1.3.1

Where a testing authority has an established capability of undertaking field measurements, and a published and recognised protocol for performing such measurements, total thermal resistance may be determined by methods such as the guarded hot-box or heat-flux meter (heat-flow meter) methods.

5.1.3.2

The thermal conductivity of materials such as soil may be determined by the heated needle-probe method.

5.1.4 Relevant conditions

All thermal resistance determinations shall apply for appropriate environmental and installation conditions. All factors which are known to affect installed thermal resistance of materials or assemblies shall be taken into account, including but not limited to:

(a) Relevant temperatures including the hot and cold surfaces of the insulation material and other relevant temperatures;

(b) Relevant air flows around the material which may cause external ventilation effects or convection within the material itself; and

(c) Radiant energy level, including effects due to adjacent hot or cold surfaces and radiation penetration through materials which have some transparency to infrared frequencies.

NOTE – Other factors such as material moisture content and workmanship may affect the actual value of the construction, but are beyond the scope of NZS 4214.

5.1.5 Mean temperatures

As required in AS/NZS 4859.1, thermal resistance may be determined at a standard mean temperature of either 23 ± 1 ^{o}C or 15 ± 1 ^{o}C. This value is assumed to apply over the whole operational temperature range, provided the thermal resistance of the material or assembly is sufficiently independent of temperature that it varies by less than 5 % from the value at the standard mean temperature over the extremes of the intended operating range. If this is not the case, then thermal resistance shall be determined at the appropriate mean temperature. Where testing laboratories are, for technical reasons, unable to measure at the appropriate mean temperature, thermal resistance may be determined by extrapolation of measurements performed at a minimum of two other mean temperatures.

5.1.6 Material uniformity

For it to be suitable for measurement in any test apparatus, the system thermal resistance of any material or assembly shall be uniform such that the metering area of the test apparatus is representative of the entire assembly or area of material.

5.1.7 Reflective materials

The thermal resistance of a reflective material or assembly shall be regarded as the combination of contributions by any bulk material which the material or assembly reflectively bounds, with consideration for the direction of heat flow. It shall be expressed as either System *R*-value (R_{sy}) or a Total *R*-value (R_T) (see section 3).

5.2 Surface thermal resistance

The thermal resistance offered by a surface is affected by the direction of heat flow, local air speed, the surface roughness, the surface wetness and the radiation conditions (e.g. the surface or other facing surface may be bright metallic). Where more detailed information is not available, Appendix E, table E3 shall be used. For compliance purposes within New Zealand, the following values shall be used:

R_{si} = 0.09 $m^2\,{}^{o}C/W$

R_{se} = 0.03 $m^2\,{}^{o}C/W$

5.3 Thermal resistance of air gaps

5.3.1 Enclosed air gaps

5.3.1.1

An enclosed air gap shall be an air gap between plane parallel surfaces of moderate smoothness and sealed against airflow on all boundaries.

5.3.1.2

The thermal resistance of enclosed air gaps for various directions of heat flow, temperature conditions and effective emittance (*E*) shall be taken from table E3 and used as in 5.3.1.4.

5.3.1.3

For suitable temperature differences, when using table E3, refer to AS/NZS 4859.1.

5.3.1.4

The thermal resistance values of enclosed air gaps given in table E3 represent ideal conditions which will not be encountered in practice. This is particularly the case with reflective air gaps which must be adjusted to obtain accurate estimates of practical *R*-values. See table E4 for details.

5.3.2 Ventilated air gaps

The thermal resistance of a ventilated air gap shall be taken as 0.45 times that of the corresponding enclosed air gap, and the thermal resistance of each layer between the ventilated air gap and outside air shall similarly be de-rated by a factor of 0.45 unless better information is available for a specific case (see an example case of this type in the following clause 5.4.1 and in Appendix F).

5.4 Sub-floor spaces

5.4.1 Floors suspended above the ground

5.4.1.1

Floors, typically timber suspended above a ventilated (to requirements in the New Zealand Building Code Handbook) but enclosed sub-floor space, have an overall thermal resistance from inside the building to the outside air which can be calculated taking into account a number of variables. The variables include:

(a) The resistance of the earth under the floor;
(b) The ventilation rate into the sub-floor;
(c) The thermal resistance of the sub-floor wall;
(d) The radiative and convective resistance under the floor.

5.4.1.2

Table E7 incorporates all four factors into one *R*-value for the sub-floor, which can then be added to the *R*-value for the floor section, and the interior and exterior surface resistances (R_{si} and R_{se}) to give the total *R*-value for the complete floor system from the interior to the exterior of the building.

5.5 Floors in continuous contact with the ground

5.5.1 Un-insulated slab-on-ground floors

For a floor in continuous contact with the ground, the resistance of the ground beneath the floor shall be estimated either from Equation 3 or from table E6. A situation where the ground water is less than 1 m below ground would require insulation to be under the whole floor for it to be thermally efficient – the calculation is not valid in these circumstances.

NOTE – The thickness of the external walls of the building have significant influence.

$$R = \frac{\pi \, . \, l \, . \, x}{2 \, . \, k \, . \, \ln\left[(1+x)\left(1+\frac{1}{x}\right)^{x}\right]} \quad \mathrm{m^2K/W} \qquad \text{(Eq. 3)}$$

where

$$x = \frac{2 \times L \times a}{l \times (L+a)} = \frac{2 \times A}{l \times P} \qquad \text{(Eq. 4)}$$

and

- *A* is the floor area in (m^2)
- *P* is the total floor perimeter (m)
- *a* is the half-width of floor (m)
- *L* is the half-length of floor (m)
- *l* is the external wall thickness (m)
- *k* is the soil conductivity (W/mK)
- *R* is the floor plus ground thermal resistance and does not include surface resistances or floor coverings ($m^2\,{}^oC/W$) (un-insulated)

where the half-width is half the shortest edge, and the half-length is half the longer edge of a rectangular floor slab.

NOTE – Refer to Trethowen and Delsante, Seminar Paper No. 76.

5.5.2 Insulated slab-on-ground floors

5.5.2.1
For whole-floor insulation, the thermal resistance of the (closed cell) insulation is added to the thermal resistance of the un-insulated floor.

5.5.2.2
For an edge-insulated floor, multiply the thermal resistance value from table E6 by the multiplier given in table E7.

5.6 Parts with embedded heating

The thermal resistance of components with embedded heating elements shall be taken as the total thermal resistance from the embedded heating element to the exterior air, including the thermal resistance of either the sub-floor space or the soil under a slab floor. The thermal resistance of the materials (such as topper pad or floor coverings) between the heating element and the interior air is ignored.

5.7 Thermal bridges

5.7.1

Thermal bridges shall be determined by the isothermal planes method as provided below:

(a) Select two planes parallel to the plane of the wall, which enclose the portion of structure within which thermal bridging occurs;

(b) Subdivide this portion into regions so that each has only one set of stacked "layers" within the region. Number these regions;

(c) Where metal framing is used, thermal bridging shall be of an "enclosing equivalent solid rectangle" (see Appendix F for worked examples);

(d) For each of these regions, calculate the area fraction (f_x) and the thermal resistance which would apply if that region existed alone;

(e) Calculate the thermal resistance of the selected portion, using Equations 5 and 6;

(f) Add the resistances of any layers outside the selected portion, to give the total thermal resistance.

$$\frac{1}{R_b} = \frac{f_1}{R_1} + \frac{f_2}{R_2} + \frac{f_3}{R_3} + \ldots \quad \text{(Eq. 5)}$$

and then:

$$R_b = \frac{1}{\left[\frac{1}{R_b}\right]} \quad \text{(Eq. 6)}$$

where

f_x is the fraction of the cross-section at right angles to the direction of heat flow occupied by each region, and where x = 1, 2, 3 etc.

R_x is the thermal resistance through the region corresponding to f_x

R_b is the thermal resistance through the bridged portion of the structure.

5.7.2

Equations 5 and 6 shall not be used where thermal bridges pass through a ventilated air gap (see 5.3). These cases need to be determined by appropriate test.

5.7.3

A metal frame, as shown in figure 1(a) and 1(b), can be replaced by a notional enclosing equivalent solid rectangle as shown in figure 1(c), which has a thermal conductivity which would give the same heat flow.

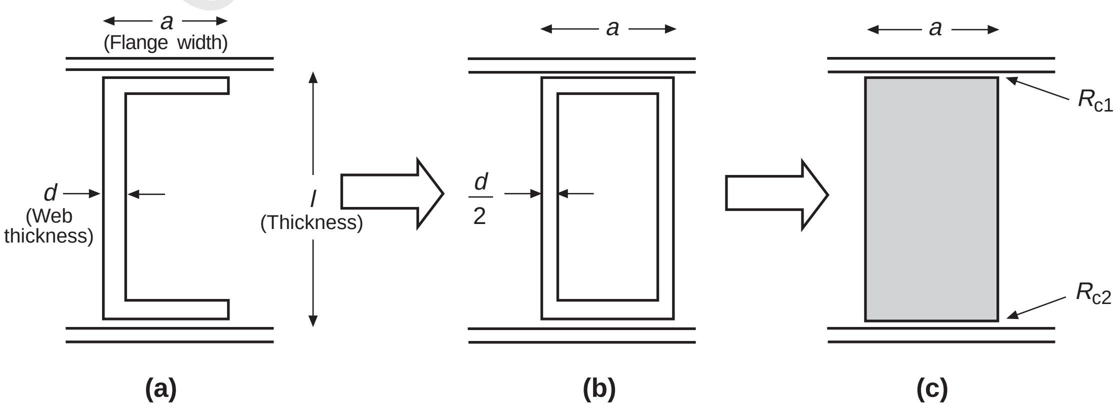

Figure 1 – Transformation method for metal frame sections

5.7.4
Since the heat transmitted through the metal web of metal framing of conductivity (k_m) represents most of the transmitted heat (because of its higher thermal conductivity), an "enclosing equivalent solid rectangle" would therefore transmit the same amount of heat if it had a thermal conductivity of:

$$k = \frac{d}{a} \times k_m \qquad \text{(Eq. 7)}$$

The thermal resistance of the equivalent rectangle is therefore:

$$R = \frac{l}{k} = \frac{a \times l}{d \times k_m} \qquad \text{(Eq. 8)}$$

The resistance of the whole metal frame is given in Equation 9.

$$R = \frac{l}{k} = \frac{a \times l}{d \times k_m} + R_{c1} + R_{c2} \qquad \text{(Eq. 9)}$$

where

R	is the resistance of the metal frame including contact resistances
R_{c1} and R_{c2}	are the contact resistances between metal frame and facing (usually less than 0.03 m^2 °C/W, which is equivalent to a gap of about 1 mm)
k_m	is the conductivity of the metal.

6 TOTAL THERMAL RESISTANCE

6.1 General
The total thermal resistance is the sum of all the homogenous layers, the surface layers, and any bridged layers.

6.2 Calculation procedure
The total thermal resistance of a plane building component consisting of layers perpendicular to the heat flow shall be calculated using the following expression:

$$R_T = R_{si} + R_1 + R_2 + \ldots\ldots + R_n + R_{se} \qquad \text{(Eq.10)}$$

where

R_T	is the total resistance
R_{si}	is the internal surface resistance
R_1, R_2, ...R_n	are the thermal resistances of each layer, including bridged layers
R_{se}	is the external surface resistance

Each air gap shall be considered as a layer (see 5.3).

6.3 Laboratory determination
The total thermal resistance of any wall, roof or floor assembly not including glazing shall be measured by the hot box method (refer to ASTM C1363).

6.4 Test considerations

All of the provisions of 5.1.2 to 5.1.7 that apply to materials or assemblies shall also apply to laboratory or field measurement of total thermal resistance.

APPENDIX A
VERIFICATION METHODS

(Informative)

A1 Approval rating of structural elements

A1.1

Site measurement is not suitable for establishing code compliance approvals, but may be applicable for confirming performance achievement after construction.

A1.2

If for any building system, laboratory measurement and calculation are found to not give consistently similar results (within approximately 10 %) when due cognisance is taken of the construction details and material condition, the measurement should take precedence.

A1.3

If laboratory and calculation methods do not consistently agree, steps should be taken to account for this before routinely accepting the construction.

A2 Approval rating of insulation materials and products

A2.1

The normal approval method for insulation materials is laboratory measurement. Steps should be taken to demonstrate a suitably high probability that a product tested for rating purposes will comply with the rating claimed over the declared life.

A2.2

For example, in the first year of testing, at least three separately obtained packs (or samples in the case of loose fill material) of the product (from different suppliers chosen independently of the manufacturer or distributor) are tested. This is repeated for a further two years (i.e. a test each four months and nine tests in total).

A2.3

The frequency of testing beyond the third year (or nine results) should then be based on a statistical analysis of the test results to date, correlation with information from the manufacturing quality control system, and the quantity of the particular product that is produced. (See ISO 12576-1.)

A2.4

Ratings may be established from generic information on the thermal properties of insulation materials after adjustment to appropriate bulk density, fibre or pore size, in-service moisture content, and *in situ* surface condition. This will only be possible when detailed information on the material is available, along with a suitable selection of test results for products composed of the same generic material.

APPENDIX B
GUIDELINES FOR TESTING LABORATORIES

(Informative)

B1 Testing laboratories

B1.1
Additional laboratory guidance on thermal resistance measurements is given in AS/NZS 4859.1.

B1.2
Test measurements required by this Standard should be made by a laboratory competent to perform the particular class of test.

B1.3
Test measurements should be reported by the test laboratory in a form that includes the following:
(a) Identity of the testing laboratory;
(b) Test report identity;
(c) Identity of the laboratory officer conducting the test;
(d) Date and place of test;
(e) Method of test;
(f) Statement of credentials of the laboratory in this type of work;
(g) Identification of method of sample procurement;
(h) A description of the material or assembly tested which is sufficiently detailed to enable an identical assembly to be constructed by an independent person;
(i) Conditions in which the test was conducted;
(j) Test results and measurement uncertainty; and
(k) Any other information necessary to the proper understanding and use of the test results.

B1.4
The test report should also contain any information required by the method of test, including any other information required by this Standard.

B2 Test reports

B2.1
Tests should include the following in the report:
(a) A method of test description of any modification to ASTM C1363 or of any alternative method used. Sufficient detail should be provided to enable an identical test to be conducted by an independent person, plus a statement that, in the opinion of the laboratory, the test specified by ASTM C1363 would yield the same test results;
(b) The measured thermal resistance including confidence limits of the test result;
(c) The standard total thermal resistance. It should include comment or adjustment for foreseeable service conditions.

B3 Field (*in situ*) tests

B3.1 *Method of test*
The method of test details should include:
(a) Dates, place and full details of test;
(b) The steps taken to ensure that the measured values properly correspond to the steady-state values.

B3.2 *Test conditions*

The conditions in which the test was conducted should include:

(a) Variations of inside air temperature and radiation conditions with time;

(b) Variations of inside air temperature with height above floor; and

(c) Variations of outside air temperature and radiation, wind and rain conditions with time.

APPENDIX C
THERMAL CONDUCTIVITY OF BULK INSULATION MATERIALS

(Informative)

C1

Bulk insulation materials generally range in thermal conductivity between 0.02 and 0.08 W/mK, with most fibrous materials in the range of 0.04 to 0.07 W/mK.

C2

If insulation products manufactured from these materials are compressed, the thermal resistance decreases such that a 2 % compression (decrease in thickness) results, approximately, in a 1 % lower thermal resistance.

C3

Materials such as rigid or semi-rigid foam plastics usually have thermal conductivities in the range of 0.02 to 0.04 W/mK.

C4

Loose-fill insulation products usually have a higher thermal conductivity than blanket type products manufactured from the same material at the same density. This is because the material is less homogeneous and often has large clumps of material with significant voids between the clumps, thus allowing for more air convection.

C5

Assuming the texture remains the same, adding an adhesive to loose-fill insulation to aid installation into walls will increase the total mass and therefore increase the density, but the thermal conductivity will remain the same (or possibly reduce).

C6

If a product has variations in density through its profile such as clumping in loose-fill installations, the thermal conductivity will be higher than a product at the same density but with a more uniform distribution of material.

C7

Thickness alone does not determine the likely thermal resistance of an insulation product, the density (or weight per unit area) is also required in order to estimate the thermal conductivity of the material. This assumes that the material is identifiable in terms of fibre diameter or cell size and the thermal conductivity versus density relationship is known for the particular material. Decreasing the fibre diameter or cell size will generally decrease the thermal conductivity for the same density of material.

C8

Reflective foil insulation functions in a different way to bulk insulation and the above generalisations do not apply. Some insulation products which make use of reflective foil have bulk insulation in the centre with foil on the surfaces. The bulk insulation component in such products will follow the generalisations listed above.

APPENDIX D
BIBLIOGRAPHY

(Informative)

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NZS 4243:1996	Energy efficiency – Large buildings

How to choose the most efficient windows for your home: Window Efficiency Rating Scheme (WERS), published by Window Association of New Zealand

APPENDIX E
TECHNICAL DATA

(Normative)

E1 Tables for calculating *R*-values

E1.1

Tables E1 to E7 provide generic technical data for the determination of total thermal values of building components. Many building publications contain tables listing the thermal conductivities and R-values of building materials. The generic data is not specific to particular products. Since the thermal resistance is dependent on so many factors, generic material data cannot be expected to give reliable enough information for accurate design purposes or determination of code compliance. Where the material is a main contributor to the insulation of the building component then the manufacturer's information must be sought, particularly for compliance purposes.

E1. 2

The *R*-value of a window or door has previously been known as the thermal resistance of the centre of the glass area (R_{cog}). This has ignored the effect of the framing, and the size of the glazing. When the WERS method is used to define glazing *R*-values, a "Standard Window" is used, of size 1800 mm wide x 1500 mm high with a central mullion and one opening light. The *R*-value (R_T) of the glass and frame is calculated, resulting in typical *R*-values for standard aluminium joinery of 0.26 and 0.15 m^2 $^oC/W$ instead of the traditional values of 0.33 and 0.18 m^2 ^oC /W. ➤

Table E1(a) – *R*-values of board and sheet material

Material		Density (kg/m³)	Conductivity (W/mK)	Thickness (mm)	Thermal resistance (m² ºC/W)
Gypsum plasterboard		800	0.22	7 9 12 15	0.03 0.04 0.05 0.07
Fibre-cement sheet		1470	0.25	4.5 6 7.5 9	0.02 0.03 0.03 0.04
Hardboard		1070 950	0.14 0.14	3 4.75 6	0.02 0.03 0.04
Particle board	– high density	700	0.14	3 5 6 8 12 15 19	0.02 0.03 0.04 0.05 0.08 0.10 0.13
	– medium density	600	0.11	9 12 15 18 25	0.08 0.11 0.14 0.16 0.23
	– low density	420	0.087	18 25 28 30 35 38	0.21 0.29 0.32 0.34 0.40 0.44
Plywood		550	0.13	3 6 9 12	0.02 0.05 0.07 0.09
Softboard		277	0.06	12 13 17 19	0.22 0.24 0.31 0.35
Cement-bonded woodwool		450 – 600	0.08	25 38 50 75	0.31 0.47 0.63 0.94

Table E1(b) – *R*-values of masonry materials

Material				Density (kg/m³)	Conductivity (W/mK)	Thickness (mm)	Thermal resistance (m² °C/W)
Bricks	Clay brick			1920	1.2		
	Fireclay	@	500 °C	620	0.2		
		@	500 °C	960	0.34		
		@	500 °C	1230	0.48		
		@	260 °C	1930	0.96		
		@	816 °C	1930	1.18		
	Silica	@	38 °C	2240	0.89		
		@	93 °C	2240	0.94		
		@	315 °C	2240	1.1		
		@	540 °C	2240	1.27		
		@	1370 °C	2240	1.9		
Concrete masonry units							
	Solid, normal density			2200	1.3	100	0.08
	Standard block (all cells filled)						
	100 mm	nil		2200	1.3	100	0.11
	150 mm	nil		2200		150	0.16
		1 in 5		2200		150	0.15
		1 in 3		2200		150	0.14
	200 mm	nil		2200		200	0.19
		1 in 5		2200		200	0.16
		1 in 3		2200		200	0.15
Renderings							
	Cement plaster			1860	0.8	10	0.01
	Gypsum plaster						
	– sand aggregate			1680	0.7	12	0.02
	– light aggregate			720	0.15	12	0.08
	Low density foamed			200 – 900	0.073 – 0.24		
Concrete							
	Structural concrete			2300	1.6	100	0.06
						150	0.09
						200	0.13

NOTE – Guide only as actual values are very dependent on density and moisture content, etc.

Table E1(c) – *R*-values of framing, floor and cladding materials

Material	Condition	Density (kg/m³)	Conductivity (W/mK)	Thickness (mm)	Thermal resistance (m² °C/W)
Timber	Softwoods (e.g. pine) @ 12 % moisture content (mc) @ 20 % mc	450 480	0.120 0.132	18 47 94 94	0.15 0.39 0.78 0.72
	Low density @ 12 % mc	300	0.086		
	Medium density	550	0.142		
	High density	800	0.196		
Weatherboards	Fibre-cement – without underlay – with underlay	1500	0.25	7.5	0.03 0.10
	Timber Bevelback – without underlay – with underlay Rusticated or shiplap	 550 550	 0.13 0.13		 0.14 0.28 0.16
Floor coverings	Carpet			10	0.17
	Rubber underlay			10	0.17
	Underfelt		0.065	12	0.19
	Cork	110	0.042	6	0.14
	Linoleum	1300	0.22	3	0.014
	Vinyl	2050	0.79	2	0.003
Roof cladding	Fibre-cement	1600	0.3	6.4	0.04
	Concrete tiles	2200	1.1	13	0.01
	Clay tiles	1900	0.85	13	0.01
	Bituminous felt	1600	0.43	4	0.01
	Metal (including metal tiles) (Metal roof cladding has no inherent insulation value, but may contribute by reflectivity)				
Asphalt	Bitumen	2250	1.22		
Bitumen	Pure	1060	0.16		
	Composition for floors	960 2400	0.16 0.99		
	Emulsion, cement, aggregate	1600 2000	0.46 0.61		
	Roofing membrane	1120	0.16	10	0.061

Table E1(d) – *R*-values of other common building materials

Material	Condition	Density (kg/m^3)	Conductivity (W/mK)	Thickness (mm)	Thermal resistance (m^2 °C/W)
Metals	Aluminium Steel Stainless Steel Copper Lead	2800 7800 7900 8900 11400	230 50 25 400 35		
Balsa wood			0.084		
Porcelain	Electrical	2400	1.44		
Rubber	Solid Butyl/EPDM Neoprene or nitrile Polyurethane	930	0.16 0.088 0.20 – 0.25 0.30		
Sand	Building, dry Wet	1500	0.30 1.7		
Soil (dependent on composition and moisture content)	Dry sandy Clay Rammed earth	 1500 1700 – 2200	0.26 1.0 – 1.5 0.46 – 0.81	 300	 0.37 – 0.65
Glass	Annealed or toughened float glass	2500	1.05	6	0.006
Air	Dry	1.2	0.025		
Water		1000	0.60	10	0.017
Ice	–46 °C –18 °C –1 °C	920	2.7 2.5 2.2		
Snow	Fresh, dry Packed		0.11 0.47		
Paints	Aluminium Anti-condensation Varnish Zinc-filled		0.46 0.16 0.32 2.2		
Paper	Building paper	1100	0.14 0.065	0.2 0.2	0.001 0.003
Plastics	PVC Epoxy resin Plastic laminate Polycarbonate PTFE Nylon Polyurethane or glassfibre resin Polyethylene or polyvinyl		0.17 0.20 0.21 0.23 0.24 0.25 0.30 0.40		

Table E2 – Surface resistance for air

Thermal resistance (m^2 °C/W)				
		Surface emittance (ε)		
Position of surface	**Direction of heat flow**	**Non-reflective** (ε = 0.90)	**Reflective** (ε = 0.20)	(ε = 0.05)
Still air				
Horizontal	Upward	0.11	0.19	0.23
45° slope	Upward 45°	0.11	0.20	0.24
Vertical	Horizontal	0.12	0.24	0.30
45° slope	Downward 45°	0.13	0.29	0.39
Horizontal	Downward	0.16	0.48	0.80

Moving air in any direction

Winter exterior condition (6.7 m/s) .... 0.03 (Non-reflective and reflective)

Summer exterior condition (3.4 m/s) .... 0.04 (Non-reflective and reflective)

NOTE –

(1) No surface has both an air space resistance value and a surface resistance value.

(2) Values are based on a surface-to-air temperature difference of 5.5 K and surface temperatures of 294 K.

(3) From ASHRAE Handbook, Fundamentals, American Society of Heating, Refrigerating and Air-conditioning Engineers Inc.

Table E3 – Thermal resistance for listed air space width and total emittance at a mean cavity temperature of 18 °C

Orientation and heat flow direction	Temp diff. (K)	Thermal resistance (m^2K/W)															
		13 mm air space								20 mm air space							
		Effective emittance (*E*)								Effective emittance (*E*)							
		0.03	**0.05**	**0.08**	**0.12**	**0.20**	**0.35**	**0.50**	**0.82**	**0.03**	**0.05**	**0.08**	**0.12**	**0.20**	**0.35**	**0.50**	**0.82**
Horizontal upwards	**6**	0.38	0.36	0.34	0.32	0.28	0.22	0.19	0.14	0.40	0.38	0.36	0.33	0.29	0.23	0.19	0.14
	12	0.31	0.30	0.28	0.27	0.24	0.20	0.17	0.13	0.33	0.32	0.30	0.28	0.25	0.21	0.18	0.13
	18	0.28	0.27	0.26	0.25	0.22	0.19	0.16	0.13	0.30	0.29	0.27	0.26	0.23	0.19	0.17	0.13
45° upwards	**6**	0.45	0.43	0.40	0.37	0.32	0.25	0.21	0.15	0.49	0.47	0.43	0.39	0.34	0.26	0.21	0.15
	12	0.40	0.38	0.36	0.33	0.29	0.23	0.19	0.14	0.40	0.38	0.36	0.33	0.29	0.23	0.20	0.14
	18	0.35	0.34	0.32	0.30	0.26	0.22	0.18	0.14	0.35	0.34	0.32	0.30	0.26	0.22	0.18	0.14
Vertical horizontal	**6**	0.47	0.44	0.41	0.38	0.32	0.25	0.21	0.15	0.64	0.60	0.55	0.49	0.40	0.30	0.24	0.17
	12	0.47	0.44	0.41	0.38	0.32	0.25	0.21	0.15	0.56	0.53	0.48	0.44	0.36	0.28	0.23	0.16
	18	0.45	0.43	0.40	0.37	0.31	0.25	0.21	0.15	0.49	0.47	0.43	0.39	0.33	0.26	0.21	0.15
45° downwards	**6**	0.46	0.44	0.41	0.38	0.32	0.25	0.21	0.15	0.68	0.63	0.57	0.51	0.41	0.31	0.24	0.17
	12	0.47	0.44	0.41	0.38	0.32	0.25	0.21	0.15	0.63	0.59	0.54	0.48	0.40	0.30	0.24	0.17
	18	0.46	0.44	0.41	0.38	0.32	0.25	0.21	0.15	0.60	0.57	0.52	0.46	0.38	0.29	0.23	0.16
Horizontal downwards	**6**	0.47	0.44	0.41	0.38	0.32	0.25	0.21	0.15	0.68	0.63	0.57	0.51	0.41	0.31	0.24	0.17
	12	0.46	0.44	0.41	0.38	0.32	0.25	0.21	0.15	0.68	0.63	0.57	0.50	0.41	0.31	0.24	0.17
	18	0.46	0.44	0.41	0.38	0.32	0.25	0.21	0.15	0.67	0.62	0.56	0.50	0.41	0.30	0.24	0.17

Table E3 – Thermal resistance for listed air space width and total emittance at a mean cavity temperature of 18 °C (continued)

Orientation and heat flow direction	Temp diff. (K)	Thermal resistance (m^2K/W)															
		40 mm air space								90 mm air space							
		Effective emittance (*E*)								Effective emittance (*E*)							
		0.03	**0.05**	**0.08**	**0.12**	**0.20**	**0.35**	**0.50**	**0.82**	**0.03**	**0.05**	**0.08**	**0.12**	**0.20**	**0.35**	**0.50**	**0.82**
Horizontal upwards	**6**	0.44	0.42	0.39	0.36	0.31	0.25	0.20	0.15	0.50	0.47	0.44	0.40	0.34	0.26	0.22	0.16
	12	0.37	0.35	0.33	0.31	0.27	0.22	0.19	0.14	0.42	0.40	0.37	0.34	0.30	0.24	0.20	0.15
	18	0.33	0.32	0.30	0.28	0.25	0.21	0.18	0.13	0.37	0.36	0.34	0.31	0.28	0.22	0.19	0.14
45° upwards	**6**	0.50	0.47	0.44	0.40	0.34	0.26	0.22	0.16	0.55	0.52	0.48	0.43	0.36	0.28	0.22	0.16
	12	0.41	0.40	0.37	0.34	0.30	0.24	0.20	0.15	0.45	0.43	0.40	0.37	0.32	0.25	0.21	0.15
	18	0.37	0.36	0.34	0.31	0.27	0.22	0.19	0.14	0.40	0.39	0.36	0.33	0.29	0.23	0.20	0.14
Vertical horizontal	**6**	0.66	0.61	0.56	0.49	0.40	0.30	0.24	0.17	0.64	0.60	0.54	0.48	0.40	0.30	0.24	0.17
	12	0.51	0.49	0.45	0.41	0.34	0.27	0.22	0.16	0.53	0.50	0.46	0.42	0.35	0.27	0.22	0.16
	18	0.45	0.43	0.40	0.37	0.31	0.25	0.21	0.15	0.47	0.45	0.42	0.38	0.33	0.26	0.21	0.15
45° downwards	**6**	0.87	0.80	0.70	0.61	0.48	0.34	0.26	0.18	0.83	0.76	0.67	0.59	0.46	0.33	0.26	0.18
	12	0.72	0.66	0.60	0.53	0.43	0.31	0.25	0.17	0.69	0.64	0.58	0.51	0.41	0.31	0.24	0.17
	18	0.63	0.59	0.53	0.48	0.39	0.29	0.24	0.17	0.62	0.58	0.53	0.47	0.39	0.29	0.23	0.17
Horizontal downwards	**6**	1.17	1.04	0.88	0.74	0.55	0.38	0.29	0.19	1.87	1.54	1.22	0.96	0.67	0.43	0.31	0.20
	12	1.14	1.01	0.86	0.72	0.54	0.37	0.28	0.19	1.74	1.46	1.17	0.93	0.65	0.42	0.31	0.20
	18	1.11	0.99	0.85	0.71	0.54	0.37	0.28	0.19	1.66	1.40	1.13	0.90	0.64	0.42	0.31	0.20

NOTE –

(1) Values apply for ideal conditions, i.e. air spaces of uniform thickness bounded by plane, smooth, parallel surfaces with no air leakage to or from the space. When accurate values are required, use overall *R*-values determined through guarded hot box testing. Thermal resistance values for multiple air spaces must be based on careful estimates of mean temperature differences for each air space. A single resistance value cannot account for multiple air spaces; each air space requires a separate resistance calculation that applies only for the established boundary conditions. Resistances of horizontal spaces with heat flow downwards are substantially independent of temperature difference.

(2) From ASHRAE Handbook, Fundamentals, American Society of Heating, Refrigerating and Air-conditioning Engineers Inc.

(3) Temperature difference (Temp. diff. – K) is the expected temperature change from one side of the air gap to the other.

Table E4 – Emittance values of various surfaces and effective emittance of air spaces

Surface		Effective emittance of air space	
	Emittance (ε)	**One surface emittance** (ε), **other 0.9**	**Both surfaces emittance** (ε)
Aluminium foil, bright	0.05	0.05	0.03
Aluminium foil with condensate just visible (> 0.5 g/m²)	0.30	0.29	—
Aluminium foil with condensate clearly visible (> 2.0 g/m²)	0.70	0.65	—
Aluminium sheet	0.12	0.12	0.06
Aluminium coated paper, polished	0.20	0.20	0.11
Steel, galvanised, bright	0.25	0.24	0.15
Aluminium paint	0.50	0.47	0.35
Building materials	0.90	0.82	0.82
Ordinary or float glass	0.84	0.82	0.82

NOTE – From ASHRAE Handbook, Fundamentals, American Society of Heating, Refrigerating and Air-conditioning Engineers Inc.

Table E5 – Thermal resistance of the ground and sub-floor space under a suspended floor

Floor area / Perimeter length	Thermal resistance (m² °C/W)		
	Exposed floor (pole house)	**Continuous perimeter wall, exposed to wind** (garage or foundation wall)	**Continuous perimeter wall, sheltered from wind** (garage or foundation wall)
1.0	0.00	0.06	0.10
1.5	0.00	0.09	0.15
2.0	0.01	0.11	0.20
2.5	0.01	0.14	0.25
3.0	0.01	0.17	0.30
3.5	0.01	0.20	0.35
4.0	0.01	0.23	0.40
4.5	0.01	0.26	0.45
5.0	0.01	0.29	0.50
5.5	0.02	0.31	0.55
6.0	0.02	0.34	0.60
6.5	0.02	0.37	0.65
7.0	0.02	0.40	0.70

Table E6 – Thermal resistance of the un-insulated ground under a slab floor

Floor area / Perimeter length	**Thermal resistance** (m^2 °C/W) For soil thermal conductivity *k* = 1.2 W/mK					
	Wall thickness (mm)					
	50	**100**	**150**	**200**	**300**	**500**
1.0	0.56	0.65	0.72	0.78	0.88	1.05
1.5	0.77	0.89	0.98	1.05	1.17	1.37
2.0	0.97	1.11	1.22	1.30	1.44	1.67
2.5	1.17	1.33	1.45	1.54	1.70	1.95
3.0	1.36	1.54	1.67	1.78	1.95	2.23
3.5	1.54	1.74	1.89	2.01	2.20	2.49
4.0	1.72	1.94	2.10	2.23	2.43	2.75
4.5	1.90	2.14	2.31	2.45	2.67	3.01
5.0	2.08	2.33	2.51	2.66	2.90	3.26
5.5	2.25	2.52	2.72	2.87	3.12	3.50
6.0	2.42	2.71	2.92	3.08	3.34	3.74
6.5	2.59	2.90	3.11	3.28	3.56	3.98
7.0	2.76	3.08	3.31	3.49	3.78	4.21

Table E7 – Multiplier factor for edge insulated slab-on-ground floors

Depth of edge insulation / Half the width of the floor	Multiplier (dimensionless) – Insulation thickness (mm)			
	25	**50**	**75**	**100**
0.030	1.02	1.03	1.04	1.04
0.035	1.02	1.04	1.05	1.05
0.040	1.03	1.05	1.05	1.06
0.045	1.03	1.05	1.06	1.06
0.050	1.04	1.06	1.07	1.07
0.055	1.04	1.06	1.07	1.08
0.060	1.04	1.07	1.08	1.08
0.065	1.05	1.07	1.08	1.09
0.070	1.05	1.08	1.09	1.10
0.075	1.05	1.08	1.10	1.11
0.080	1.06	1.09	1.10	1.11
0.085	1.06	1.10	1.11	1.12
0.090	1.06	1.10	1.12	1.13
0.095	1.07	1.11	1.12	1.13
0.100	1.07	1.11	1.13	1.14

APPENDIX F
WORKED EXAMPLES

(Informative)

Figures F1 to F3 provide information on the method of calculation when taking account of a thermal bridge. The examples have the layers numbered from the exterior to the interior.

F1 Example of timber framed wall

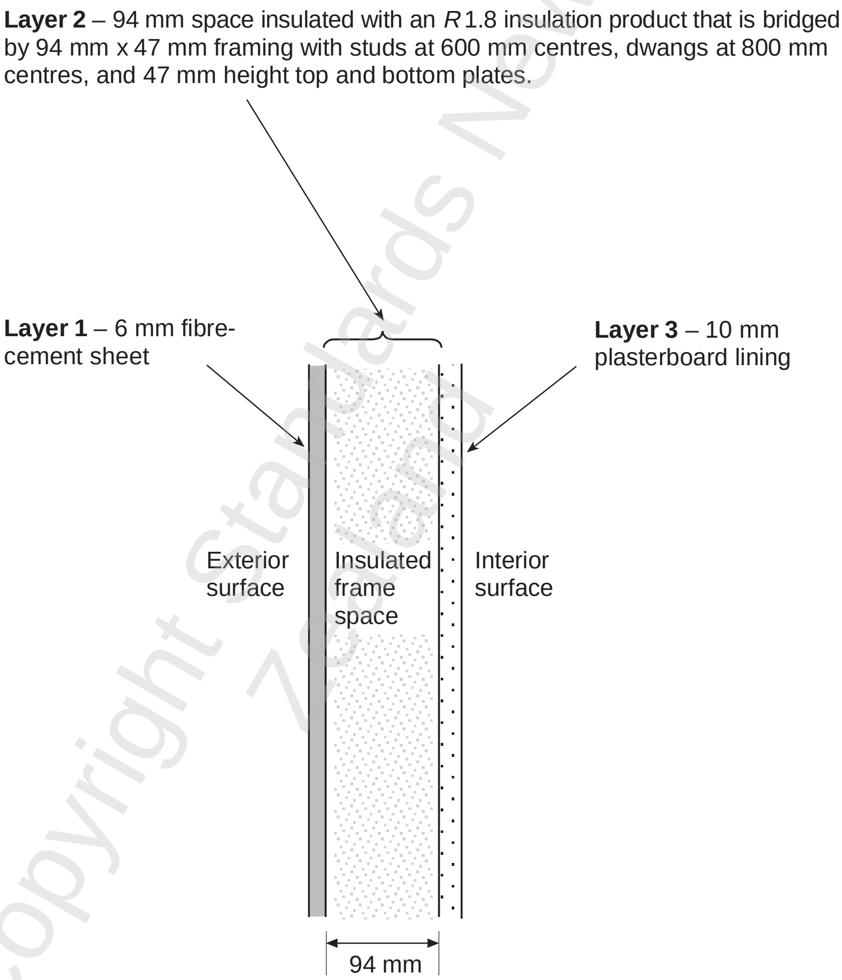

Figure F1 – Timber frame

	R ($m^2\,{}^oC/W$)
Exterior surface resistance, R_{se} (see 5.2)	0.03
Layer 1 – 6 mm fibre-cement	0.03

Layer 2 – (see 5.7)

R_1 (94 mm thick R 1.8 insulation product) = 1.80

R_2 (94 mm deep timber framing, $k = 0.12$ W/mK) $= \dfrac{l}{k} = \dfrac{0.094}{0.12} = 0.78$

Assuming that the wall is 2.4 m high:

$$f_1 = \frac{(600 - 47) \times (2400 - 4 \times 47)}{600 \times 2400} = 0.849, \qquad f_2 = 1 - 0.849 = 0.151$$

Using Equations 5 and 6:

$$\frac{1}{R_b} = \frac{f_1}{R_1} + \frac{f_2}{R_2} = \frac{0.151}{0.78} + \frac{0.849}{1.8} = 0.665$$

$\therefore R_b = \dfrac{1}{0.665} =$ 1.50

Layer 3 – 10 mm plasterboard	0.04
Interior surface resistance, R_{si} (see 5.2)	0.09
Total thermal resistance, R_T	**1.69** $m^2\,{}^oC/W$

The wall underlay has not been shown. Such material may be ignored in a similar example but may be important in cavity construction when considering whether an air space is ventilated or non-ventilated, and if the surface facing an air space is reflective or non-reflective.

F2 Example of brick veneer wall

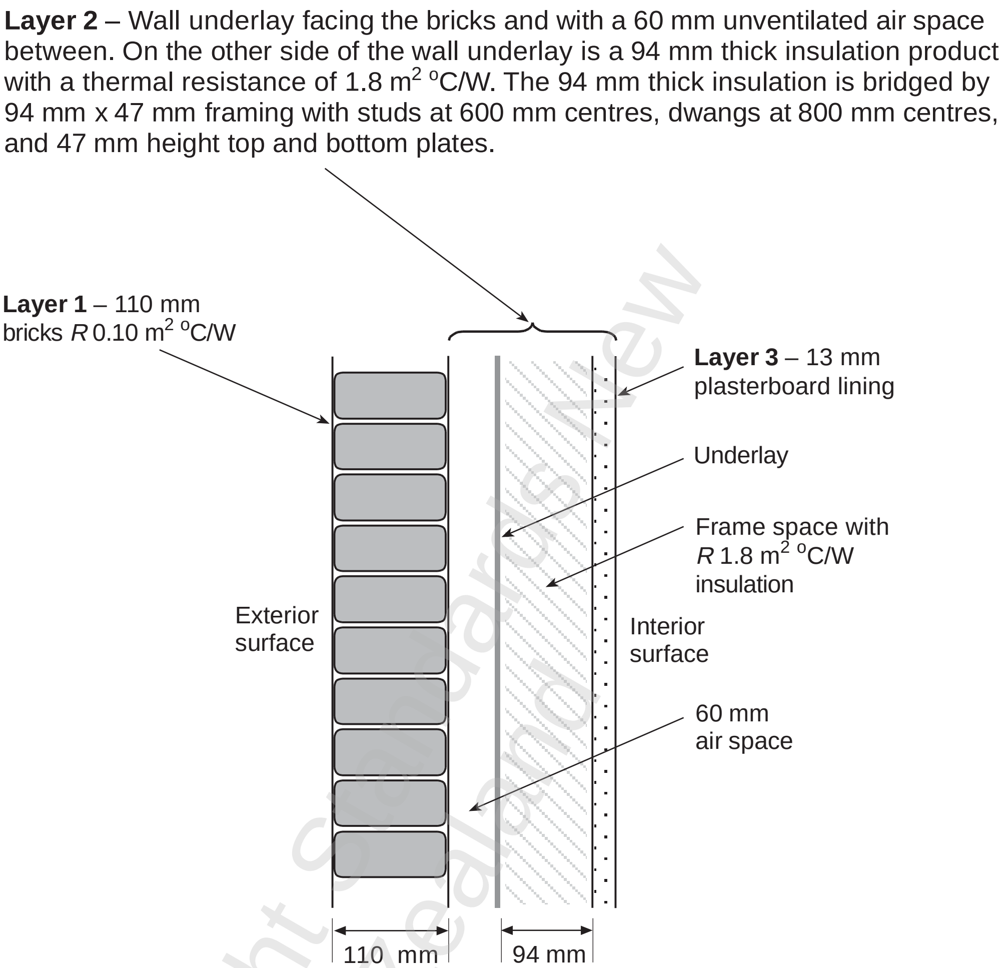

Figure F2 – Brick veneer and timber frame

Based on a thermal conductivity for pine framing timber of 0.12 m² ºC/W, the thermal resistance of the thermal bridge is $= \frac{0.094}{0.12} = 0.78$ m² ºC/W.

The thermal resistance of the bricks (and mortar) is available from either generic data tables or from the manufacturer's data sheets.

Layer 2 extends from the inward facing surface of the bricks to the exterior facing surface of the interior lining because the frame space is non-homogeneous, and a bridged layer is never bounded by an air space.

The thermal resistances of the 60 mm air space is determined using table E3. For this example it is assumed that there is a 6 K temperature difference across the air space. Since this example represents a wall, the air space orientation is vertical and the heat flow direction is horizontal. The *R*-value of the 60 mm air space is therefore 0.17 m² ºC/W.

For Layer 2 assuming the same frame area ratio as in example F1:

	Area ratios	Thermal resistances
For the frame area	$f_1 = 0.151$	$R_1 = 0.17 + 0.78 = 0.95$ m^2 °C/W
Area excluding frame	$f_2 = 0.849$	$R_2 = 0.17 + 1.80 = 1.97$ m^2 °C/W

The combined resistance of Layer 2 is:

$$R_b = \frac{1}{\left(\frac{f_1}{R_1} + \frac{f_2}{R_2}\right)} = \frac{1}{\left(\frac{0.151}{0.95} + \frac{0.849}{1.97}\right)} = \frac{1}{(0.159 + 0.431)} = 1.70 \text{ m}^2\,^{\circ}\text{C/W}$$

Adding up the thermal resistance of all three layers and the surfaces:

R_{se} (exterior surface) 0.03

Layer 1 (cladding) 0.10

Layer 2, R_b (air space and insulated frame space) 1.70

Layer 3 (lining) 0.05

R_{si} (interior surface) 0.09

Total Thermal Resistance, R_T .... **1.97** m^2 °C/W

Because the air space is vertical, its *R*-value does not depend on the direction of heat flow (either inward or outward).

For ceilings and floors, there is likely to be a difference in total *R*-value between winter and summer conditions because the thermal resistance of horizontal air spaces depends on the direction of heat flow. If there is air exchange into and out of the air spaces then the calculation may need to include a de-rating factor in winter and a pro-rating factor in summer. Other de-rating effects are contamination or damage to the foil surface, and condensation.

In practice, the air space behind the bricks should not be treated as an unventilated air space since there will be drainage holes along the bottom of the wall (see example F4).

F3 Example of steel framed wall

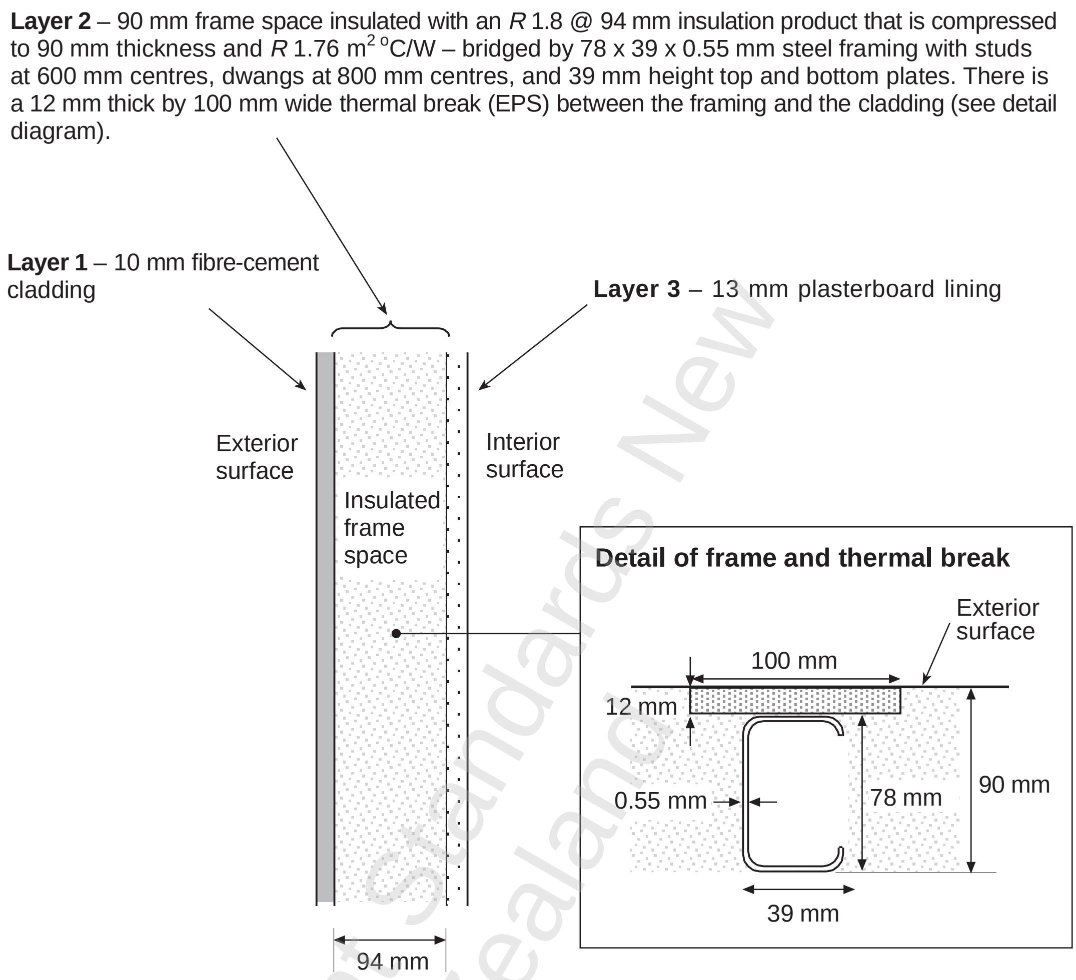

Figure F3 – Steel frame

The steel frame has a much higher thermal conductivity than the insulation and therefore acts as a thermal bridge between the interior lining and exterior cladding. The 12 mm expanded polystyrene (EPS) strip acts as a thermal break between the exterior cladding and the steel frame, reducing the thermal bridging effect from the steel frame. There is likely to be no significant contact resistance between the EPS and the exterior cladding because the EPS is compressible and its thermal conductivity is not orders-of-magnitude different from that of the cladding, but there is still expected to be a contact resistance between the frame and the EPS, along with the contact resistance between the frame and the interior lining.

Layer 2 extends all the way between the interior surfaces of the lining and cladding because they are homogenous layers that bound non-homogenous layers between them.

The *R*-value of the insulation is estimated as 1.76 m^2 °C/W, or 2 % less than the nominal *R* 1.8 m^2 °C/W (at 94 mm) of the insulation product because it is compressed 4 % (0.5 x 4 % = 2 %) (see C2). ➤

The thermal resistance of the thermal break is $= \dfrac{0.012}{0.041} = 0.29$ m² °C/W

where the thickness of the EPS is 0.012 m and the thermal conductivity is 0.041 m² °C/W.

Transforming the stud into an equivalent rectangular shape, and using Equation 9, the thermal resistance of the steel stud R_s is:

$$R_s = \frac{39}{0.55} \times \frac{0.078}{50} + 0.29 + 0.03 + 0.03 = 0.46 \text{ m}^2\,{}^{o}\text{C/W}$$

This includes the thermal break and two contact resistances of 0.03 m² °C/W.

For Layer 2 and a wall height of 2.4 m:

	Area ratios	Thermal resistances
For the frame area	$f_s = 1 - \dfrac{(600-39) \times (2400 - 4 \times 39)}{600 \times 2400} = 0.126$	$R_s = 0.46$ m² °C/W
Insulation area excl. EPS area	$f_{ins} = \dfrac{(600-100) \times (2400 - 4 \times 100)}{600 \times 2400} = 0.694$	$R_{ins} = 1.76$ m² °C/W
EPS area excluding frame area	$f_{EPS} = 1 - 0.126 - 0.694 = 0.180$	$R_{EPS} = 1.76 + 0.29 = 2.05$ m² °C/W

(R_{EPS} ignores the extra compression of the insulation from 90 mm to 78 mm)

The combined resistance of Layer 2 is:

$$R = \frac{1}{\left(\dfrac{f_s}{R_s} + \dfrac{f_{ins}}{R_{ins}} + \dfrac{f_{EPS}}{R_{EPS}}\right)} = \frac{1}{\left(\dfrac{0.126}{0.46} + \dfrac{0.694}{1.76} + \dfrac{0.180}{2.05}\right)} = \frac{1}{(0.27 + 0.39 + 0.09)} = 1.32 \text{ m}^2\,{}^{o}\text{C/W}$$

Adding up the thermal resistance of all three layers and the surfaces:

Exterior surface resistance, R_{se} (see 5.2) 0.03

Layer 1 (cladding) 0.04
Layer 2 (insulation & frame + thermal break) 1.32
Layer 3 (lining) 0.05

R_{si} (interior surface) 0.09

Total Thermal Resistance, R_T .... **1.53** m² °C/W

The wall underlay has not been shown. Such material may be ignored in a similar example but may be important in cavity construction when considering whether an air space is ventilated or non-ventilated, and if the surface facing an air space is reflective or non-reflective.

F4 Example of ventilated wall cavity

Re-calculating example F2 with the 60 mm air space treated as being ventilated:

In practice, the air space in the brick veneer wall in example F2 should be treated as a ventilated air space because of the drainage openings along the bottom of the wall.

De-rating of the thermal performance applies only to materials on the exterior of the ventilated air space.

Adding up the thermal resistances of the layers from the interior to the bricks:

R_{si} (interior surface) 0.09

Layer 3 (lining) 0.05

Layer 2, R_b (air space and insulated frame space) 1.70

R_T 1.84

Layer external to ventilated air space for which de-rating applies:

Layer 1 (bricks) 0.10

De-rating of Layer 1 by 45 % 0.06

R_{se} (exterior surface) 0.03

Total Thermal Resistance, R_T .... **1.93** $m^2\ {}^oC/W$

NOTES

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