HUYS ADVIES

TABLES FOR THERMAL INSULATION IN HIGH ALTITUDE AREAS OF THE HIMALAYAS

Technical Working Paper ~ Number 3 with Adjusted Values for Reflective Foils

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February 2012 (adjusted)

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Photo on Cover Page

Contractor in Tajikistan lifting a piece of EPS low-density insulation from a prefabricated wall panel. The material is often used for building instant houses.

The low weight and high insulation value of the low density EPS, combined with very little absorbing of moisture, makes it a durable insulation material, highly suitable for earthquake zones.

A one meter thickness has an insulation value of $R_C = 25.0\ m^2.K/W$.
Each 4 cm (1.5 inch) thickness has an insulation value of $R_C = 1.0\ m^2.K/W$.

Because the EPS is damp proof, rooms sealed with this material need to be constantly ventilated with fresh air when occupied. If a heating stove is placed in the room, air with oxygen is required for the burning process, as well as a chimney to remove the flue gas. Use of gas or kerosene heaters in rooms requires good ventilation to get rid of the smoke gasses and humidity.
Increasing the thickness of the material also increases the thermal insulation value in a linear way, but it does not always reduce the energy requirements with the same percentage because other physic aspects become more important.

Changes from Former Edition

The main changes in this February 2012 edition are a further precision of the insulation values of the reflective foils and the required larger air spaces between them. A separate graph is provided to indicate the insulation values of different cavities in combination with the reflective foils.

The main finding was that some factories producing these multi-layer reflective foils supplied very high insulation values, which did not correspond with reality. In some cases, factories gave insulation values for foils including the insulation value of the adjoining air spaces. The applicable values for these reflective foils depend on the direction of the heat flow and opposite materials used in the same cavity. Different foils give different emissivity (ε) and reflection (r) properties. The new chart gives the insulation value per heat flow direction, type of material and air distance. The graph shows that for some positions, the reflective foils are more effective with increased space.

1. INTRODUCTION

The Technical Working Papers incorporate knowledge gained from more than 30 years experience in project development and implementation in several development countries. Much time has been dedicated to providing practical information on how to realise beneficial, low-cost solutions for the inhabitants of the mountain regions of the Himalayas.

Introducing technologies without adapting these to local circumstances in not always possible because of socio-economic circumstances. Existing, proven technical solutions have been modified taking into consideration local customs, skills and building materials; ease of transport; availability of materials in the local markets of the mountain regions and possibility of introducing new items; and the affordability by the village people.

Making the buildings more comfortable and reducing Internal Air Pollution (IAP) in traditional and new high altitude buildings are important aspects linked to thermal insulation. The document incorporates the best experiences in house improvements to improve the life of other people living in similar and often remote mountain regions.

> For low-income people, it is important to find appropriate solutions taking into consideration the local economy of the people and local entrepreneurs, as well as the available skills, tools, materials and other resources, to create affordable products for an improved living conditions and livelihood.

Technical Working Paper #3 (linked to TWPapers #1 and #2) provides an overview of the most common thermal insulation values of building materials. Similar to the other two papers, this paper will regularly be updated when new figures are found. This paper can be used as part of curriculum development and vocational training.

Additional technical working papers will cover the various types of thermal insulation and technical details of roof, wall and floor constructions, windows, doors, etc. of the most efficient types of construction, taking into consideration cost, available local materials and level of skills.

This paper covers the general values of building materials and includes the following themes:

- Various names of the products with their specific weight.
- Different mass weights of these products and their common humidity values.
- The λ value of the material in W/m.K (metric system).
- The R value of the material or the $R_{Construction}$ value in $R_C = m^2.K/W$.
- The thermal insulation values of air cavities between building materials and between reflective foils, horizontal and vertical.
- Air to material (inside) and material to air (outside) transmission coefficients.
- Heat storage capacity of the materials.

The data has been collected from European databases, but comparing new materials should be related to the same type of material as mentioned in these databases. In many cases, the material specifications may vary a little, but the overall and comparative calculations of constructions will give a good indication of the total insulation value of a building.

The same calculation methods can be used for the application of thermal insulation to reduce the (electricity) costs of air conditioning of buildings and improving the internal climate.

2. HUMIDITY INTERPRETATION

Winter air is not only cold, but also dry. When this air is substantially heated when it enters the house, it becomes very dry. The inside wall constructions therefore will also be dry, unless condensation occurs of breathing air, kitchen humidity or gas and kerosene heaters.

Occupants living and cooking in a house produce vapour. This vapour will raise the inside air humidity level and be absorbed by the walls. All outside shell structures of the building will be subject to humidity transfer from the humid inside to the dry outside and will receive inside condensation when the outside temperature gets low enough. This is a natural process, in which the humidity pressure in the air tends to equalize between inside and outside. When the vapour cools down, it will condensate. In very cold regions, vapour barriers on the warm side of the construction will reduce condensation inside the construction, if fully sealed with tape over all joints.

Dry Values
In high altitudes and especially during frost, the air humidity outside is generally low to very low. The insulation values for such climate zones are for totally dry outside shell constructions.

(Mountain Climates)
Mountain regions are dryer than temperate or humid climates, but still have some air humidity. The estimated values for outside constructions exposed to the climate conditions are indicated in brackets (value). These values assume that a little humidity exists in the structural elements from the inside out (from warm to cold), but not large condensation.

{Temperate Climates}
In temperate or sea climates with medium to high air humidity and regularly rain, the outside building shell is nearly always humid. The standard dry value of λ or the R_m values should not be used for the outside shells of the building, even if these are under full roof coverage.
For most building materials used in outside constructions, the dry λ value needs to be increased by 25%; for more porous materials, the value needs to be increased by 30%; and for very porous construction materials increased by 35%.
These values are indicated in Accolades {value}. These values are based on standards used in Europe and on a yearly average, having occasional rain on a weekly basis.

[Humid Climates or Wet]
The table gives no values for very humid climates. In very humid climates, the air humidity is constantly high and ample ventilation of the buildings is necessary. In these cases, the insulation value of the building is not very relevant unless air conditioners are used.

Air Conditioners
In hot, warm or humid climates where the inside of the building is permanently cooled with electric air conditioners (A/C), substantial condensation will occur:

- Inside the outside shield of the construction when the insulation value of the wall is little.
- Inside the inside shield of the wall when the humidity level inside substantially increases.

Increasing the inside wall thermal insulation and placing vapour barriers on the outside faces of the building will prevent this.
Air conditioners and room fans will move the cooled air around the room, limiting condensation forming on the surface of the wall finishing. Condensation will easily evaporate from the outside shell with solar heating. Full vapour proofing is usually only the case with the roofing.

2.1 ***Moisture Absorption***

Each material has its own characteristics in relation to moisture absorption. Porous materials can absorb more than dense materials. The colours in the list indicate the possibility of moisture absorption of the material as percentage of their own mass. The added moisture will negatively affect the thermal insulation value of the material. The figures give the vapour diffusion resistant factor μ.

Very low moisture absorption	Low moisture absorption	Little moisture absorption	Much moisture absorption	High moisture absorption	Very High moisture absorption
μ = > 100	**μ = 50 - 100**	**μ = 25 - 50**	**μ = 10 - 15**	**μ = 5 - 10**	**μ = 1 - 5**

In the table of material characteristics, these colour indications are given for only a few building materials. Other building materials having the same structure will most likely have similar characteristics. A high moisture absorption characteristic (low μ) means that these materials need to remain dry when used for thermal insulation. Two materials need a closer look:

(a) Glass Wool

Glass wool is finely spun glass, making an airy blanket which has considerable air incorporated and therefore is highly insulating.[1] Compressing this material will increase the density and reduce the air inside, thereby sharply reducing its insulation value. Quality control on the manufacturing of glass wool assures that it automatically expands when no pressure is applied. Non-quality-controlled glass wool (non-expansive) may therefore be subject to high moisture absorption.

The moisture absorption of lightweight thermal insulation materials is by weight percentage.
Glass wool, airy, good quality and non-compacted has an insulation value of: $R_m = 25\ m^2.K/W$
Glass wool with 10% by weight of moisture has an insulation value of: $R_m = 20\ m^2.K/W$
Glass wool with 50% by weight of moisture has an insulation value of: $R_m = 15\ m^2.K/W$
Glass wool with 100% by weight of moisture has an insulation value of: $R_m = 10\ m^2.K/W$

Glass wool having a higher volume weight when bought than the 150 kg/m^3 as indicated in the table will have a lower insulation value to start with.

Similar values apply to Rockwool or mineral wool. Rockwool is easy to work with and does not require protective clothing.

Advantages of glass wool are: (1) mice cannot live inside glass wool insulation because of the fine glass fibres, and (2) it is non-flammable.
Disadvantages of glass wool: (1) it releases fine glass splinters into the air and skin, and (2) gloves and breathing masks should be worn when working with this material.

Glass wool rolls having an unclear origin can be found in the markets. When unrolled for applying the glass wool thermal insulation, it does not expand sufficiently. When the material is purchased in open markets, the humidity content may be elevated, reducing the suggested insulation value.

[1] When the material is too finely spun, it loses its elasticity and gets easily pressed together; thus losing insulation value. Fibreglass is the USA name for glass wool. Fibreglass (UK term) is web-like and used for reinforcing polyester composites.

(b) <u>Sheep and Yak Wool</u>

Sheep and yak wool are natural materials and have other characteristics. They are being increasingly used as thermal insulation materials, especially in ecologically sustainable buildings.[2]



The thickness of sheep wool blankets can vary from a thin 5 cm to 20 cm thickness. Wool is a nice material to work with. The batts (sheets) are held together with 12% polyester.

Some <u>advantages</u> of sheep wool are:

- √ **Manages Moisture** – Natural wool fibres can absorb and release 30% of their weight in moisture.
- √ **Moisture Absorption** of natural wool hardly reduces its thermal insulation value.
- √ **Non-Flammable** – Wool naturally extinguishes flames and does not support combustion (4% borax).
- √ **Acoustic Insulation** of wool is very good (50dB for 10 cm).
- √ **Air Quality** – It does not give off formaldehyde (wood insulation products), nitrogen dioxide and sulphur dioxide; sheep's wool absorbs and breaks them down.
- √ **Stays Where You Put It** – Wool insulation doesn't settle downwards over the years.
- √ **Rapid Environmental Payback** – Wool requires 85% less energy to manufacture than traditional glass wool. This is partly due to the shorter time it takes for processing real wool.

The <u>disadvantages:</u>

- ☒ It is not commonly available and expensive when it is available.
- ☒ The thermal insulation value is about 10-15% lower than high quality glass wool.

Felt is commonly used as floor insulation sheets or blankets. Felted sheep and yak wool is thoroughly compacted to make it firm to walk on. The insulation value per weight of the material will substantially increase when it is kept fluffy and is not felted.

Local industries can develop the production of thin, fluffy wool insulation materials attached to highly reflective foils for wall and ceiling insulation. This will create employment and reducing CO_2 emissions at the same time.

[2] Photos: Doscha© sheep wool insulation.

The picture on the right shows a thermal insulation material commercially available in Europe. The 5 mm layers of fluffy sheep wool are alternated with a 0.1 mm thick polyester film with a metalized reflective coating on two sides. However, more than three reflective foils is not useful.

The thermal insulation value of this type of multi-layer insulation is high due to the layers of reflective foil, added with some insulation value of the wool. The wool is resilient and keeps a narrow spacing between the foils in tact, which is necessary to let them reflect the infrared radiation.

Using locally available reflective foil with PE backing, thermal insulation blankets can be made with sheep wool, such as shown in the photo on the right (photo: MSDSP, Khorog, Tajikistan).

The insulation value of each design can be calculated to determine the most cost-efficient blanket. The cost efficiency is the relation between the production cost and the insulation value.

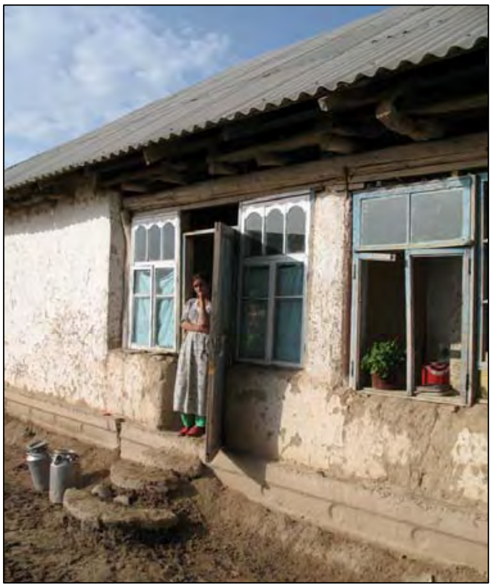
Installation Cost
The cost efficiency of an insulation product however, does not depend only on the net material cost, but on the total cost after the installation is completed in a construction. Transport, ease of application, the insulation materials themselves and the finishing materials are all part of the installation cost.

The most cost-efficient solution can only be determined by comparing the overall installation cost with the insulation value. The higher insulation value will cause greater savings in energy consumption for all the years thereafter. It has a cumulative saving effect.

The construction in the above picture is made from the thick sheep wool backed with reflective foil, a space, common plastic foil (0.1 or 0.2 mm recycled), fine wire-mesh and plastered with cement plaster. The picture is made after the first cement plaster coat. A second cement plaster and lime coat will provide a smooth and durable finish. A plinth, white washing or wallpaper will finish the job, according to the liking of the house owner.

2.2 Hygroscopic Materials

Some materials are hygroscopic or capillary, meaning they can suck up water from below, against the force of gravity. This is the case with porous masonry, cement mortar joints, adobe blocks and rammed clay-soil constructions. Sealing these materials above the foundation with a waterproofing course will avoid humidity from rising into the construction.



Thick plastic foils, Ruberoid®[3], butyl rubber, EPDM[4] and asphalt paper[5] are waterproof materials that provide good solutions for a damp proof course. In the photo (right), the house owner used high-density reinforced concrete poles to stop the capillary flow of water from the foundation upwards.

Rising moisture from the soil and then evaporation in dry weather may cause crystallization of the mineral and salts in the water, which will cause damage to the surface of the wall and result in erosion of the wall construction as can be seen in the left picture.

Both adobe blocks and rammed earth walls are hygroscopic materials and have high moisture absorption characteristics. A benefit is that the hygroscopic characteristic of adobe and clay-soil construction materials helps to stabilize the possible air humidity fluctuations inside the house, improving inside climate.

These soil-based materials also have a fairly high mass and heat storage capacity. For changing the moisture from the wall into vapour and releasing the vapour into the air, considerable energy is required. This energy to evaporate moisture is drawn from the wall structure, causing it to cool down.

During the night, when the air temperature drops and the relative humidity of the air increases, this humidity will be absorbed again by the adobe walls. Since the walls have been warmed up during the day, they will release some of the warmth back into the room at night, thus regulating both the air humidity and the room temperature. This is an important reason why houses with adobe wall constructions are comfortable in warm climates. The opposite is the case with cement buildings.

Because sheep and yak wool can absorb and release humidity, they also help to stabilize the internal humidity level in the house.

[3] Brand name of good quality waterproof (roofing) foil for building construction.
[4] Synthetic rubber of Ethylene, Propylene and Di Monomer with added black soot and sulfur.
[5] Asphalt paper is glued together by heating. When used outside on the roof or exposed to the sun, it needs to be protected from UV solar radiation (white gravel or grit).

3. TABLE – MATERIALS

The following long table of material characteristics needs to be read with caution where the humidity of the construction materials is concerned. The humidity levels depend on climate conditions, amount of vapour produced inside the building and the possible condensation by cold weather outside, or air conditioners inside with hot weather.

The density column gives in some cases a range for similar materials. As the mass and density of a material gets higher, the conductivity value λ will also increase and the R_M value will reduce. With an increased mass of the material, the heat storage capacity will also increase, but different materials have different heat storage (and release) characteristics.

W = Watt   m = meter   K = Kelvin $R_M = 1/\lambda$
Calculation of $R_C = R_M$ x thickness in m, value in m^2.K/W

Bold are tested figures or standards for the environmental temperature range between minus 20°C and 100°C. The values change with higher temperatures. *Cursive are estimated values.*

#	Density kg/m^3	Material Description	Conductivity λ=W/m.K	Resistance R_m=m.K/W	Specific Heat Cap. W/kg.K
1	**0.05**	**Vacuum 95%**	**0.001**	**1000**	
2	0.8	Krypton gas (insulation gas in double glass windows, high cost)	0.009	110	
3	0.9	Argon gas (insulation gas between double glass windows, medium cost)	0.017	59	**0.089**
4	**1**	**Dry air at sea level**	**0.023**	**43**	**0.197**
5	**1**	**Air, low humidity** (water vapour = 1.4 kJ/kg.K)	**0.025**	**40**	*0.208*
6		**SEALANTS, SOFT PLASTIC**			0.389
	1200	**Silicon mastic, pure**	**0.35**	**2.85**	
	1450	**Silicon mastic with fillers**	**0.50**	**2.0**	
	750	**Silicon foam**	**0.12**	**8.33**	
	20	**Poly-Isocyanurate plastic foam (PIR), two-component material**	**0.03**	**33**	
	10	**Polyethylene foam, Polyurethaan foam (PU-PUR)**	**0.03**	**33**	**0.333**
	10	**Polyurethane board**	**0.04**	**25**	**0.389**
	20 **35** **40**	**Polyisocyanuraat foam (PIR) from Recticel** **Other types PIR** **Other types PIR**	**0.02** **0.026** **0.035**	**50** **38.5** **28.6**	
	30	**Resol foam, Fenol formaldehyde foam (PF)** **Urea formaldehyde foam, Phenol foam**	**0.025**	**40**	**0.389**
	10	Resol foam, gas filled spray can	0.02	50	
	25	**Gas-filled expanded Polyurethane**	**0.02**	**50**	
	30	Fibre glass fibres spray-blown with adhesive	0.02	50	
	25	Low Density Polyethylene foam underlay (PE), grey	0.045	22	
	35	**Extruded Polystyrene foam (XPS),**	**0.027**	**37**	**0.417**
	20	**Expanded Polypropylene (EPP)**	**0.034**	**30**	**0.389**
	20 **30** **40**	**Expanded Polystyrene foam (EPS), low density** **medium density:** Thermopor, Tempex, Perlite **high density:** "puni foam" (local name)	**0.035** **0.04** **0.045**	**28.6** **25** **22**	**0.403**
	25 **50**	**Polyvinylchloride foam**	**0.027** **0.035**	**37** **28.6**	
7		**PLASTICS, HARD**			0.278
	1180	**Polymethylmeth acryl (PMMA) Plexiglas**	**0.18**	**5.55**	
	1050	**Acrylic plastic, transparent, Plexiglas**	**0.20**	**5**	
	900	**Polyproeen**	**0.20**	**5**	
	1200	**Polycarbonate (PC, Lexan)**	**0.20**	**5**	
	1100	**ABS polymer**	**0.20**	**5**	
	1390	**Polyvinylchloride PVC hard plastic (pipes)**	**0.17**	**5.9**	
	1400	**Polyethylene terephthalate (PET)**	**0.15-0.24**		
	980	**High Density Polyethylene (HDPE)**	**0.50**	**2**	

#	Density kg/m^3	Material Description	Conductivity λ=W/m.K	Resistance R_m=m.K/W	Specific Heat Cap. W/kg.K
	920	**Low Density Polyethylene (LDPE)**	**0.33**	**3**	
	1300	**Polyester panels glass fibre reinforced**	**0.20**	**5.0**	
	930	**Polyetheen**	**0.20**	**5.0**	
	1000	Hard artificial composite materials	2.0	0.5	
	300	*Plastic waste, PP, PET, HDPE, foil crumpled, collected in PP woven agricultural bags*	*0.10*	*10*	
	200	*Empty PET + HDPE bottles in PVC plastic bags*	*0.07*	*15*	
8		WOOL STRUCTURE			0.417
	15	**Sheep wool expanded blanket 90%, borax 10% (factory)**	**0.039**	**25**	
	15	WoolBloc™ or Latitude® natural wool	0.035	28	
	200	Sheep wool, loosely thread spun (Doscha™)	0.06	20	**0.472**
	220	Felt from yak wool	0.07	14.3	
	240	*Yak wool, fluffed, non-spun*	*0.08*	*12.5*	**0.472**
	300	*Wool carpet, densely spun sheep wool, synthetic wool carpet*	*0.10*	*10*	
	125	**Glass wool Ecotherm™ or Knauff™, joints sealed**	**0.03**	**33.3**	**0.222**
	150 **200**	**Glass wool, loose, expanded (6 to 12 cm blankets)** **Glass wool, loose and 50% moist**	**0.04** **(0.06)**	**25** **(16.6)**	**0.222**
	300 **450**	**Glass wool, pressed together by weight** **Glass wool, pressed together and 50% moist**	**0.08** **(0.12)**	**12.5** **(8.3)**	**0.250** **0.278**
	160 **200**	**Rock wool, loose, expanded (6 to 12 cm blankets)** **Rock wool, loose, 50% moist**	**0.045** **(0.06)**	**22** **(16.6)**	**0.222** **0.250**
	150 *200*	*Finely fluffed-up yak wool + anti-insect herbs* *Finely fluffed wool with 25% moisture by weight*	*0.06* *(0.07)*	*16.7* *(14.3)*	**0.472**
	25	**Silicate foam pellets**	**0.04**	**25**	**0.222**
	110	**Cellular foam glass, closed cell structure**	**0.045**	**22**	**0.233**
9		PAPER, CORK			0.555
	160	Paper pulp, shredded paper, plain	0.05	25	**0.555**
	200	*Non-compacted corrugated cardboard from boxes*	*0.07*	*15*	
	200	**Fine shredded cellulose + borax salt**	**0.025**	**40**	**0.555**
	180	**Cork, natural bark from tree**	**0.042**	**23.8**	**0.464**
10		STRAW, HEMP			0.555
	240	Loosely stacked straw or thatch, dry	0.08	12.5	
	300 350 400	Straw, lightly compacted (human weight)	0.10 *(0.2)* *{0.4}*	10 *(5)* *{2.5}*	**0.583**
	350 **400** **450**	**Straw or thatch for outside roofing, 40-50 cm thick**	**0.16** **(0.22)** **{0.44}**	**8** **(4.54)** **{2.27}**	
	100	**Straw (wheat) baling package in length of reeds** **Straw (wheat) baling package perpendicular**	**0.08** **0.05**	**12.5** **20**	**0.583**
	300 *350*	*Branches, fine, packed, lightly compressed, with air* *Humid in non-waterproof roof constructions*	*0.10* *(0.12)* *{0.13}*	*10* *(8.3)* *{6.7}*	
	500 *600*	*Branches, fine, packed, compressed with clay soil* *Humid in non-waterproof roof constructions*	*0.20* *(0.25)* *{0.3}*	*5.0* *(4.0)* *{3.33}*	
	35	**Hemp fibre**	**0.045**	**22.2**	**0.694**
	30	**Flax**	**0.04**	**25**	**0.431**
11		GYPSUM			0.222
	600	**Gypsum panels, thermal insulation plaster**	**0.16**	**5.9**	
	800	**Gypsum blocks**	**0.18**	**5.6**	
	850- **900**	**Gypsum panels, fire retardant, waterproof, impact resistant. Gypsum panels**	**0.25** **0.30**	**4.0** **3.3**	
	1200	**Gypsum**	**0.43**	**2.3**	
	1500	**Gypsum**	**0.56**	**1.8**	
	800	**Gypsum board (carton board on two sides), "dry wall" panels**	**0.60**	**1.66**	**0.233**
	1600	**Gypsum-sand / lime-sand plaster on wall**	**0.80**	**1.25**	
	1200	**Gypsum plaster**	**0.40**	**2.5**	
	1300	**Gypsum plaster**	**0.57**	**1.75**	

#	Density kg/m³	Material Description	Conductivity λ=W/m.K	Resistance R_m=m.K/W	Specific Heat Cap. W/kg.K
12		**PLYWOOD, MDF**	**Outside +20%**		**0.278**
	250	**Fibre board extra light, soft board, pin board**	**0.07**	**14.3**	
	300	**Plywood, low density**	**0.09**	**11.1**	
	530	**Plywood, tri-ply and multiplex, low density**	**0.13**	**7.8**	
	700	**Plywood, tri-ply and multiplex medium density**	**0.17**	**5.9**	
	1000	**Plywood, high density, waterproof**	**0.24**	**4.2**	
	250	**Fibre board and lightweight, light LDF**	**0.07**	**14.3**	
	400	**Fibre board and light LMDF**	**0.1**	**10**	
	600	**Fibre board medium density (MDF)**	**0.14**	**7.1**	
	800	**Fibre board high density (HDF)**	**0.18**	**5.6**	
	800	**Hard board, medium density**	**0.20**	**5**	
	850	**Cement-bonded wood fibre sheets**	**0.23**	**4.3**	
	1000	**Hard board, high density (Masonite™)**	**0.35**	**2.8**	
13		**TIMBER**	**Outside +20%**		**0.278**
	500	**Timber low density pine wood**	**0.13**	**7.7**	
	700	**Timber, medium density pine wood**	**0.18**	**5.6**	
	820	**Timber, high density pine wood, sawn air dry**	**0.20**	**5**	
	750	**Timber, Poplar, sawn, air dry**	**0.18**	**5.6**	
14		**WOOD PRODUCTS**			**0.278**
	300	**Chip wood panel**	**0.10**	**10**	**0.278**
	450	**Chip wood panel, low density**	**0.12**	**4**	**0.278**
	600	**Chip wood panel medium density**	**0.14**	**7.14**	**0.278**
	900	**Chip wood panel high density**	**0.18**	**5.56**	**0.278**
	500	*Straw, wood shavings, compressed under load, dry*	*0.20*	*5*	*0.417*
	800	**Fibre cement panels, lightweight**	**0.3**	**3.3**	
	1000	**Wood fibre cement chipboard, average**	**0.23**	**4.35**	**0.278**
	1500	**Fibre cement high density roofing sheets**	**1.0**	**1**	**0.292**
	250	Loose wood fibre and shavings, curls, dry	0.085	12	*0.417*
	250	*Loosely compressed fine dry branches (heather), not soil filled*	*0.10*	*10*	
	280	*Loose sawdust from sawmill, dry*	*0.09*	*11*	
	290	*Loose wood shavings from plane machine, dry*	*0.10*	*10*	
	280	**Loose wood fibre fine**			**0.555**
	300	**Soft board, low density**	**0.10**	**10**	
15		**ADOBE CLAY-SOIL, STRAW**			**0.222**
	1000 1100 1200	Clay soil straw mixture (volumes 1:1), lime bonded	0.35 *(0.50)* *{0.7}*	2.9 *(2.0)* *{1.43}*	
	1300 **1350** *1400*	**Clay-soil straw mixture (volumes 2:1)**	**0.60** *(0.9)* *{1.2}*	**1.67** *(1.1)* **{**0.83*}*	
	1300 1400 1500	Soil, not compacted, low clay/humus content	0.71 *(0.8)* *{0.9}*	1.4 *(1.25)* *{1.1}*	
	1500 *1600* *1700*	*Clay soil, slightly compacted*	*1.10* *(1.2)* *{1.3}*	*0.9* *(0.83)* *{0.77}*	
	1500 *1600* *1700*	*Soil compacted*	*1.0* *(1.1)* *{1.2}*	*1.0* *(0.91)* *{0.85}*	
16		**WATER**			
	1000	**Water, cold**	**0.58**	**1.72**	**1.164**
	950	**Ice** (with specific melting heat of 335 kJ/kg)	**2.21**	**0.45**	**0.617**
17		**RUBBER**			
	910	**Natural rubber**	**0.13**	**7.7**	
	1200	**Ethylene propylene dieen monomer (EPDM), massif hard rubber (car tyres), ebonite**	**0.17**	**5.9**	
	1240	**Neoprene solid**	**0.23**	**4.35**	
	1200	**Butyl (isobutene)**	**0.24**	**4.17**	
	500	**Roofing material, Ruberroid™, asphalt paper**	**0.12**	**8.3**	**0.278**

#	Density kg/m³	Material Description	Conductivity λ=W/m.K	Resistance R_m=m.K/W	Specific Heat Cap. W/kg.K
18		**ADOBE AND CLAY SOILS**			**0.222**
	1000	*Adobe two-block masonry with half filled joints (50 cm thick walls)*	*0.45 (0.52) {0.6}*	*2.22 (1.92) {1.67}*	
	1100	**Adobe blocks (dried clay-soil)**	**0.48** (0.54) *{0.6}*	**2.08** (1.85) *{1.67}*	
	1400	**Sand-soil cement mixture (volumes 10:1)**	**0.60** (0.75) *{0.9}*	**1.67** (1.33) *{1.11}*	
	2000	**Sand-cement block solid, low quality**	**0.65** (0.8) *{0.95}*	**1.54** (1.25) *{1.05}*	
	1500	**Lime brick interior masonry in cement joints**	**0.70**	**1.43**	
	2000	**Compressed loam bricks (pressure 5 Mpa) Average 3% to 4% moisture absorption Maximum 7% moisture absorption**	**1.13 (1.16) {1.2}**	**0.88 (0.86) {0.83}**	**0.278**
19		**TILES**			**0.222**
	2300	**Ceramic and porcelain**	**1.30**	**0.78**	**0.222**
	2000	**Ceramic tile flooring/walls on cement mortar**	**1.50**	**0.67**	**0.222**
	2100	**Double baked hard flooring tiles**	**1.50**	**0.67**	**0.222**
	1000	**Synthetic marble (kitchen tops)**	**0.20**	**5.0**	
	1500	**Terrazzo flooring, broken marble in lime-cement mortar**	**0.41**	**2.44**	**0.222**
20		**BRICKS, MASONRY with joints**			**0.228**
	1800 2000	**Lime sand brick (inside walls) masonry**	**1.20 (1.35) {1.5}**	**0.83 (0.74) {0.67}**	
	600 700	**Baked brick masonry, soft quality, in low quality lime-cement mortar joints**	**0.20 (0.25) {0.30}**	**5.0 (4.0) {3.33}**	**0.222**
	800 900	**Baked brick masonry, low quality, in low quality lime-cement mortar joints**	**0.30 (0.37) {0.45}**	**3.33 (2.70) {2.22}**	**0.225**
	1000 1100	**Baked brick masonry, basic quality, in normal cement mortar joints**	**0.50 (0.57) {0.65}**	**2.0 (1.75) {1.54}**	**0.228**
	1200 1400	**Baked brick masonry medium soft density in medium cement mortar joints**	**0.60 (0.78) {1.16}**	**1.67 (1.28) {0.86}**	**0.231**
	1500 1600	**Baked brick masonry, medium hard density, in strong cement mortar joints**	**0.70 (0.79) {0.87}**	**1.43 (1.63) {1.15}**	**0.233**
	1700 1800	**Baked brick masonry, hard density, in strong cement mortar joints**	**0.85 (0.95) {1.06}**	**1.17 (1.05) {0.94}**	**0.235**
	1900 2000	**Baked brick masonry, high density, non-porous, waterproof very strong cement mortar joints**	**0.9 (1.07) {1.25}**	**1.1 (0.93) {0.8}**	**0.236**
	2100 2200	**Clinker brick water proof masonry**	**1.10 (1.25) {1.4}**	**0.9 (0.8) {0.71}**	**0236**
	1350	**Porous aerated baked bricks, Poriso™ stone**	**0.35 (0.40) {0.45}**	**2.85 (2.50) {2.2}**	
	1000	**Lightweight insulation bricks**	**0.30 (0.35) {0.40}**	**3.33 (2.85) {2.5}**	
	2000	**Concrete brick for masonry, dense quality**	**1.60 (1.8) {2.0}**	**0.62 (0.55) {0.5}**	

#	Density kg/m^3	Material Description	Conductivity λ=W/m.K	Resistance R_m=m.K/W	Specific Heat Cap. W/kg.K
21		**PLASTER TYPES**			**0.278**
	1100	Light clay-soil lime plaster on wall	0.80 (0.92) {1.08}	1.25 (1.1) {0.92}	**0.278**
	1400	**Lightweight lime-sand plaster on wall**	**0.90 (1.04) {1.17}**	**1.1 (0.96) {0.85}**	**0.278**
	1800	**Sand-cement plaster on wall (volume 10:1)**	**1.15 (1.32) {1.49}**	**0.87 (0.76) {0.67}**	**0.278**
	1900	**Sand-cement plaster on walls (volumes 8:1)**	**1.30 (1.49) {1.69}**	**0.77 (0.67) {0.59}**	**0.278**
	1900	**Cement mortar for joints**	**0.93 (1.04) {1.16}**	**1.07 (0.96) {0.86}**	
	1600	**Lime mortar for joints**	**0.70 (0.80) {0.91}**	**1.43 (1.25) {1.1}**	
	1100	**Gypsum mortar for joints**	**0.37 (0.42) {0.48}**	**2.7 (2.38) {2.08}**	
	1300	**Gypsum mortar for joints**	**0.52 (0.49) {0.46}**	**1.92 (2.04) {2.17}**	
	1100 1500	**Dispersion mixed mortar**	**0.70 (0.8) {0.91}**	**1.43 (1.25) {1.1}**	
	200	**Insulating mortar**	**0.10 (0.112) {0.125}**	**1.0 (0.89) {0.8}**	
22		**STONE MASONRY. Depending on rock type. Light porous lava rock gives better insulation.**			**0.222**
	1500	*Loose two-stone/rubble masonry (70-80 cm) with little clay*	*1.20 (1.38) {1.56}*	*0.83 (0.72) {0.64}*	
	1600	*Loose two-stone masonry (40-50 cm) in full clay soil-adobe*	*1.40 (1.61) {1.82}*	*0.72 (0.62) {0.54}*	
	1800	*Non-dressed stone masonry, 10% cement mortar (8:1) gaps*	*1.50 (1.68) {1.87}*	*0.66 (0.59) {0.53}*	
	1900	*Dressed 2-stone masonry, 10% cement mortar (8:1) and gaps*	*1.60 (1.8) {2.0}*	*0.62 (0.55) {0.5}*	
	2000	Dressed 2-stone masonry, 30% light cement mortar (10:1)	1.70 *(1.91) {2.12}*	0.6 *(0.52) {0.89}*	
	2200	Two-stone masonry in 30% strong mortar (6:1)	2.0 *(2.25) {2.5}*	0.5 *(0.44) {0.4}*	
23		**GAS CONCRETE**			
	500	**Gas concrete masonry blocks, dry**	**0.15**	**6.7**	
	700	**Gas concrete masonry blocks, dry**	**0.20**	**5**	
	1000	**Gas concrete, dry**	**0.47**	**2.13**	
	1350	**Poriso stone (Porotherm®, factory made ceramic bricks)**	**0.38**	**2.63**	
24		**CONCRETE**			**0.278**
	2000	**Reinforced concrete, low quality, not vibrated**	**1.35**	**0.74**	**0.278**
	2200	**Reinforced concrete, medium quality, 1% steel**	**1.70**	**0.59**	**0.278**
	2300	**Reinforced concrete, good quality, 1% steel**	**2.30**	**0.43**	**0.278**
	2400	**Reinforced concrete, good quality, 2% steel**	**2.40**	**0.42**	**0.278**

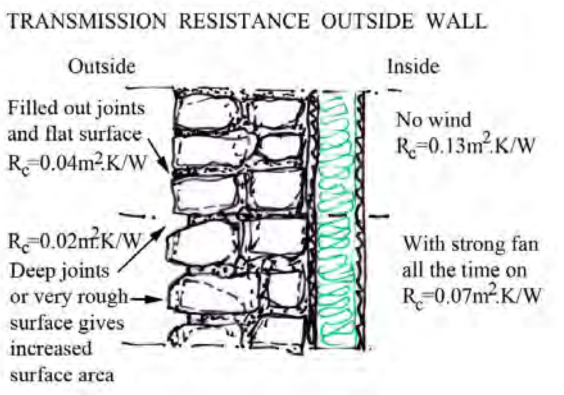
#	Density kg/m³	Material Description	Conductivity λ=W/m.K	Resistance R_m=m.K/W	Specific Heat Cap. W/kg.K
	200	**Aired lightweight cell concrete (expanded gas bubble concrete) – For moist outside add 40%**	**0.08**	**12.5**	**0.222**
	300 400	**Aired lightweight cell concrete (expanded gas bubble concrete) – For moist outside add 40%**	**0.12**	**8.3**	0.222
	400 500	**Aired lightweight cell concrete, (expanded gas bubble concrete) – For moist outside add 40%**	**0.14**	**7.1**	0.222
	500 600	**Aired lightweight cell concrete, (expanded gas bubble concrete) – For moist outside add 40%**	**0.16**	**6.25**	0.222
	600 700	**Aired lightweight cell concrete, (expanded gas bubble concrete) – For moist outside add 40%**	**0.18**	**5.5**	0.222
	700 800	**Aired lightweight cell concrete, (expanded gas bubble concrete) – For moist outside add 40%**	**0.22**	**4.5**	0.222
	1000 1200	**Fast building cement block, hollow 10-11.5 cm**	**0.45**	**2.22**	
	1000	**High-furnace sinter-based concrete**	**0.23 (0.27) {0.31}**	**4.35 (3.7) {3.2}**	
	1300	**High-furnace sinter-based concrete**	**0.30 (0.34) {0.39}**	**3.3 (2.94) {2.56}**	
	1600	**High-furnace sinter-based concrete**	**0.45 (0.52) {0.59}**	**2.22 (1.92) {1.69}**	
	1900	**High-furnace sinter-based concrete**	**0.70 (0.79) {0.88}**	**1.43 (1.26) {1.14}**	
	2000	Prefab reinforced concrete floor elements with long internal tube-shaped hollow spaces.	1.16	0.86	
25		**STONE, MINERALS**			**0.25**
	100	**Vermiculite, volcanic mineral**	**0.053**	**18.8**	**0.25**
	30	Expanded vermiculite (made impermeable)	0.017	59	
	150	**Perliet, volcanic mineral**	**0.05**	**20**	**0.25**
	1750 1800	**Lime-sand stone, natural and artificial**	**1.50 {0.81}**	**0.66 {1.23}**	**0.222**
	1750	**Artificial stone**	**1.3**		**0.278**
	2000	**Sandstone light, soft**	**2.0 {2.5}**	**0.5 {0.4}**	
	2600	**Sandstone, dense, hard**	**4.00 {5.0}**	**0.25 {0.2}**	
	2200	**Quarts**	**1.40**	**0.71**	
	2200 2800	**Slate stone**	**2.20 {2.75}**	**0.45 {0.36}**	
	2500 2700	**Granite**	**2.80 {3.5}**	**0.36 {0.28}**	
	2550	**Marble light, soft**	**2.20 {2.75}**	**0.45 {0.36}**	
	2800	**Marble dense, hard**	**2.90 {3.5}**	**0.34 {0.28}**	
	2500	**Glass window, float glass, Natron calcium**	**0.90**	**1.1**	
	2700 3000	**Basalt**	**3.5 {4.34}**	**0.28 {0.23}**	
26		**METALS**			
	7800	**Metal sheet, roofing sheet, siding, corrugated iron**	**50**	**0.02**	**0.133**
	2800	**Aluminium and aluminium mixtures, including aluminium window frames**	**160**	**0.006**	**0.244**
	8900	**Copper and copper pipes**	**380**	**0.0026**	**0.106**
	7500	**Cast iron**	**50**	**0.02**	
	11300	**Lead**	**35**	**0.0285**	
	7900	**Stainless steel**	**17**	**0.059**	
	7200	**Zinc**	**170**	**0.0059**	

Conversion factor: 3.6 kJ/kg.K = W/kg.K

4. TRANSMISSION RESISTANCE

The above figures may vary slightly depending on the actual product. The specific weight gives an indication for the actual thermal insulation value. Increasing the weight per m^3 (density) will generally lower the insulation value. The possible level of humidity needs to be estimated and depends on the local climatic and in-house circumstances.

After calculating the different layers of the construction, the air cavities and the internal and external transmission coefficients need to be added to obtain the overall thermal resistance of the construction.



These transmission coefficients will vary according to the circumstances. Radiation and convection both play a role in determining the transmission value.

When the outside wall of the building is very rough with deep joints or protruding stones, the radiation surface is larger as well as the cooling by the wind.

In areas with permanent strong wind, the transmission factor can again be lowered with R_C=0.01m^2.K/W.

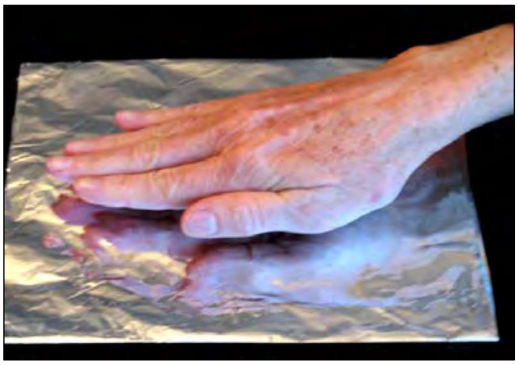
When the outside wall or ceiling is not exposed to the outside climate, but ample ventilation does exist because the roof is not totally sealed, the outside transmission value can be increased to R_C= 0.8m^2.K/W.

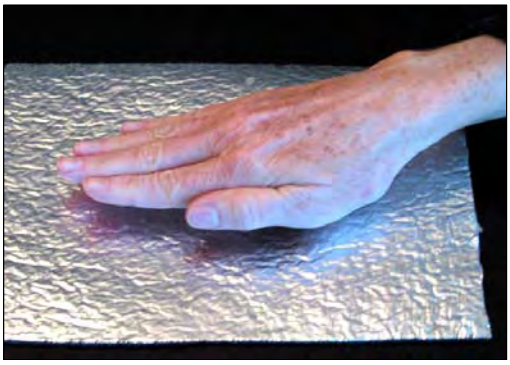
Type of Roof	**ROOF PLANTATIONS – Type of Vegetation**	**Thickness**	**R_c=m^2.K/W**	
Light vegetation	**Moss with sedum, sedum with herbs, decorative grass with herbs**	**0.05 m = 0.10 m = 0.15 m =**	**0.06 total 0.15 total 0.25 total**	
Heavy vegetation	**Low plantations fully covering soil, grass fields, low shrubs, high shrubs and small trees**	**0.10 m = 0.30 m = 0.50 m = 1.00 m =**	**0.10 total 0.20 total 0.30 total 0.50 total**	
Direction	**TRANSMISSION VALUES**		**R_c=m^2.K/W**	**With light Fan**
Smooth ← → Surface	**Horizontal from room air to wall or window**	**inclusive**	**0.13**	**0.10**
↓↓↓↓	**Downwards from room air to floor**	**inclusive**	**0.17**	**0.11**
↑↑↑↑	**Upwards from room air to ceiling or roof**	**inclusive**	**0.10**	**0.8**
Smooth ← → Surface	**Outside transmission resistance to wall, normal climate conditions without strong winter winds**	**inclusive**	**0.04**	
Rough ← → Surface	Outside transmission resistance to wall, very windy situation – very exposed building	inclusive	0.02	
Under Shelter ↓ ↑	Outside transmission resistance to the flat roof, under full roof cover roof cover (slight ventilation)	inclusive	0.08	

5. CAVITIES

5.1 Reflective Plastic Foils and Cavities

Reflective foils are produced by condensing aluminium metal vapour onto a plastic foil. The effect is that the openings between the large plastic molecules are closed and the foil becomes more gas tight. This will reduce the transmission of oxygen and moisture through the plastic. Food products will therefore be better preserved.



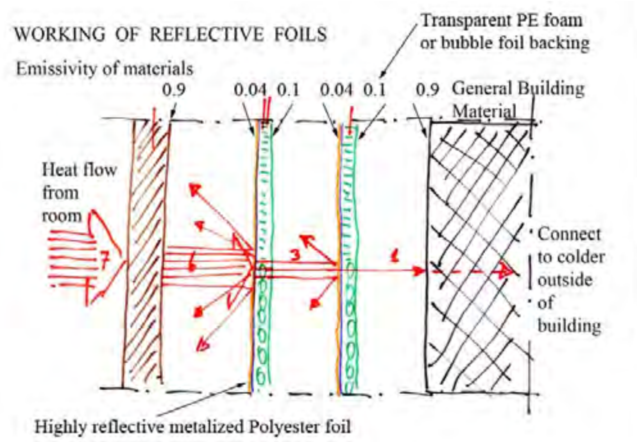


The metallization with aluminium produces a shiny effect and reflects heat radiation (same as infrared radiation). This can be tested by holding your hand low over a reflective foil. The better the heat reflection of the foil, the faster you feel the radiated warmth from your hand bouncing back to you.

In physical science, high reflection goes together with a low emission coefficient.[6]
In researching the differences between foils, it is easier to test the emissivity than the reflection.
The sketch shows the effect of reflective foils on the heat flow.

The most effective foils for thermal insulation are those being highly reflective on both sides. However, the cost of installation of reflective foils with a thin PE layer on one side may be less because they are easier to work with or the foil may be cheaper.

For comparing different types of insulation constructions, the entire insulation value of the construction needs to be compared with all the construction costs to determine the best cost efficiency.



The following conditions apply:

- These foils should not be in full contact with the building materials, otherwise the heat transfer will go through the foil. A minimum distance of 1 cm is recommended. The graph on page 16 shows increased insulation value with further increased distance.
- The effect of blocking the heat flow also depends on the type of materials on each side of the cavity; reflective foil, PE foam or bubble foil, and general building materials (timber, cement).
- The insulating effect of the metalized foils also depends on the main direction of the heat flow. For this reason, three graphs are supplied, each for one heat flow direction.

[6] For more information on the subject, see the following websites: http://en.wikipedia.org/wiki/Emissivity
http://www.optotherm.com/emiss-physics.htm ; http://en.wikipedia.org/wiki/Radiant_barrier
http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/absrad.html#c1

These three positions are as follows:

- 🡡 Vertical heat flow from below upwards; this occurs with ceilings of warm rooms.
- 🡠 or 🡢 Horizontal heat flow, such as in vertical cavity walls. In these cavity walls, it is important that the vertical convection of the air be reduced by horizontal interruptions.
- 🡣 Downward heat flow; inside and under the floor of a warm room or under a hot roof.

The quality of the reflective foil has also influence on its reflective value. The best foils are aluminium foil (Alum) and double-sided metalized polyester (HRF2). The metalized foils are commonly used in the food packing industry. When a thin PE backing or plastic film is applied over the reflective side, the reflective property will be slightly less (RFPE).

When pure aluminium foil is applied in cavities that can have a moisture environment, they will corrode and this corrosion lowers their reflective value. In this respect, the plasticized reflective foils have an advantage. The plastic coating may never be exposed to the sunlight (UV radiation).

The graphs on the next page include the insulation values for air cavities between General Building Materials (GBM) and foils. These cavities are not ventilated. In the graphs (black line) and the table below, the cavities between GBM and GBM are indicated.

TABLE OF RELEVANT RESISTANCE FIGURES OF ENCLOSED AIR CAVITIES
TOTALS FOR VERTICAL AND HORIZONTAL CAVITIES: R_C=m^2.K/W

Thickness of Air Layer in cm	Thickness of Air Layer in Inches Approximate	Horizontal Cavity with Warm Side Below (ceilings) Upward resistance 🡡	Vertical Cavity Transfer Resistance Horizontal Measure 🡠 & 🡢	Horizontal Cavity with Warm Side Above (hot roofs, floors) Downward Resistance🡣
0.5	¼”	0.11	0.11	0.11
0.7	1/3”	0.13	0.13	0.13
1.0	½”	0.15	0.15	0.15
1.5	5/8”	0.16	0.17	0.17
2.0	¾”	0.16	0.175	0.18
2.5	1”	0.16	0.18	0.19
> 5.0	2”	0.16	0.18	0.21

The above values are based on a combination of radiation that crosses the air layer and the insulating value of the air itself. These two opposite factors work at the same time (parallel).

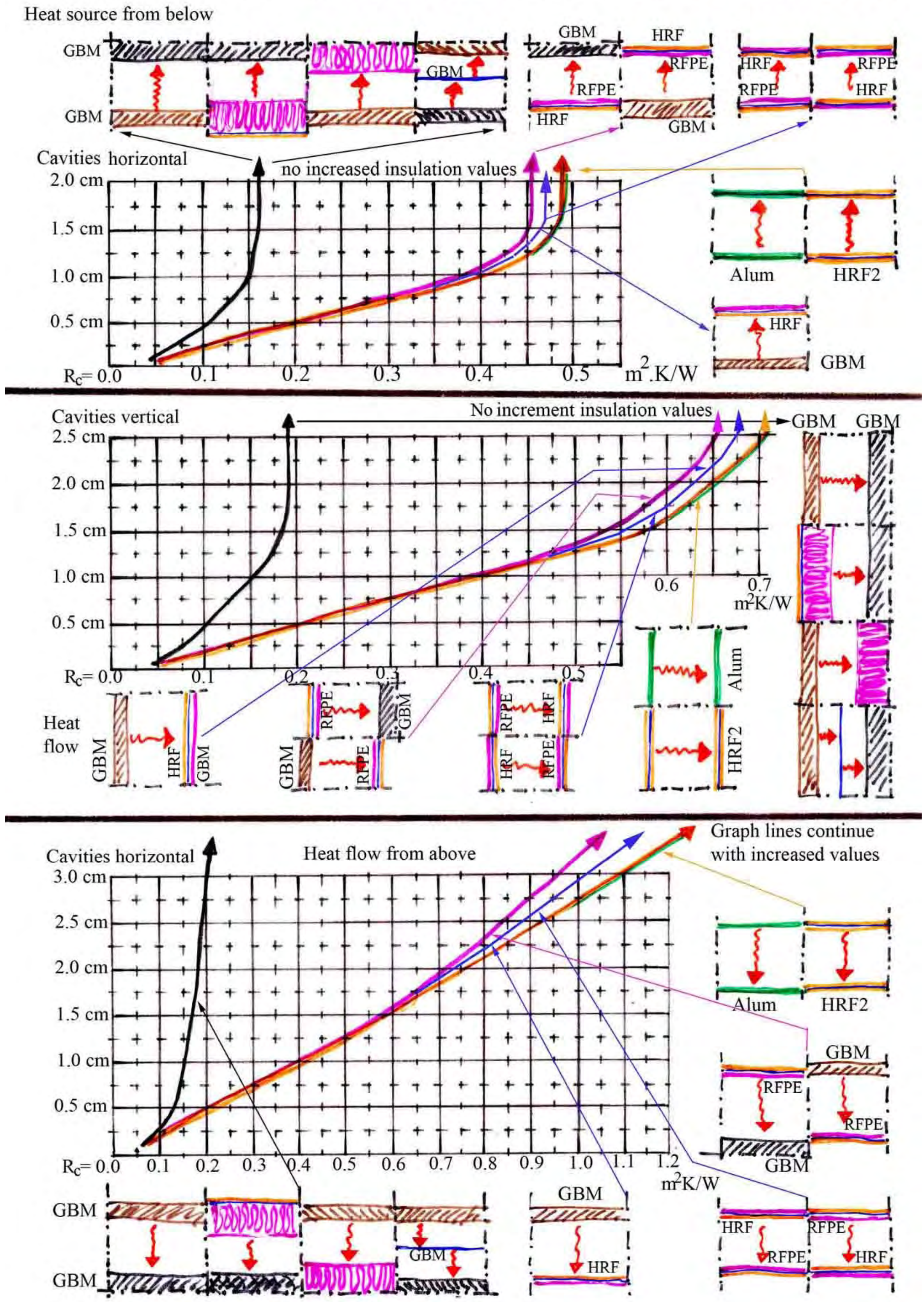
The above table shows that a vertical air cavity wider than 2 cm (¾”) will be less effective than when the same space is filled with 2 cm wood shavings (R_C = 0.02 x 12 = 0.24 m^2.K/W) or 2 cm straw (R_C = 0.02 x 15 = 0.3 m^2.K/W); this is due to the increased air circulation for wider spaces. Air cavities wider than 2 cm (¾”) therefore need to be filled with air-storing materials. The graph below also shows that increasing the air cavities more than 1.5 cm does not increase the insulation value for vertical and horizontal heat flows, and only a little bit for downward heat flow.

GBM = General Building Materials (stone, straw, glass wool, timber, cement plaster, etc.)
HRF = Highly Reflective Foil (such as metalized polyester)
HRF2 = Highly Reflective Foil with two sides metalized
RFPE = Reflective Foil with Polyethylene foam, or plasticized reflective foil.
Alum = Aluminium (the difference between shiny side and non-shiny side is not very important.)

To determine the total insulation of a construction, all cavities before and after the foil need to be added up together with the GBM insulation, and outside wall transmission coefficients.

The document HA Technical Working Paper #2 provides some examples (version February 2012).

INSULATION VALUES FOR CAVITIES AND REFLECTIVE FOILS



Print this page in colour for easy reference.

Currently, the most easily available (low cost) reflective foils are the so called “under-carpet” foils with a combination of metalized polyester foil and thin (3 mm) Polyethylene Foam (in the chart RFPE). Other foils exist having metalized polyester foil backed with transparent bubble foil. Both these foils (RFPE) have a slightly lesser emission value than metalized foils with reflective surfaces on both sides (HRF2).

For calculating the insulation value of these cavities, the insulation value of the foil material itself is not included as this is only a very small amount. The insulation value of the PE foam or the bubble foil should be added to the insulation value of the cavity (small amount).

5.2 <u>Commercial Products</u>

Below are some thermal insulation values of commercial products. These values are not provided by the factories, but are a combination of calculations or certification by standard institutes.

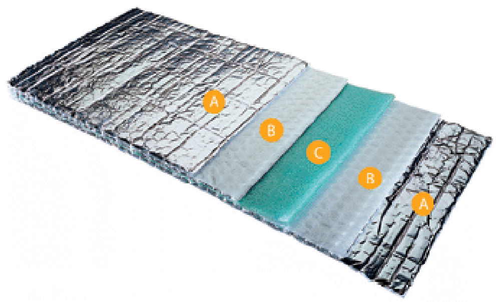
VERTICAL	**Reflective Side towards Heat Source** Minimum **25 mm** airspace on reflective side Insulation value of more air space needs to be added	**λ=W/m.K**	**R_c=m^2.K/W**	**25 mm air included**
ALUthermo® Quattro – 7 layer prefabricated with 4 aluminium foils of 30 micron thick, 1 x 3 mm fire-resistant PE foam and 2 bubble foils (air bubbles 4 mm) – Total 14 mm thick		Inclusive air layers	1.1 + 0.65 1.1 = 1.30	1 x 25 mm air 2 sides
Airflex® – 5 layer prefabricated with 2 aluminium foils of 30 micron thick, 1 x 3 mm fire-resistant PE foam and 2 bubble foils (air bubbles 4 mm) – Total 12 mm thick.		Inclusive air layers	1.0 + 0.65 1.0 + 1.30	1 x 25 mm air 2sides
Airtec® – 3 layer prefabricated with 2 aluminium foils of 30 micron thick, 2 bubble foils (air bubbles 4 mm) – Total 5 mm thick Value single use and when used double as per drawing below		Inclusive air layers	1.0 + 0.65 1.0 + 1.30	1 x 25 mm air 2 sides
SuperQuilt® – 19 layer prefabricated with fibre-reinforced metalized foils (2x), metalized foils (7x), polyfill blankets (5x) and thin PE foam foils (6x) – Total thickness 4 cm		Exclusive air layers both sides	2.5	
Isobooster® – prefabricated multi layer, including two metalized polyethylene foils and six highly transparent polyethylene bubble foils – Thickness 2.4 cm (T1)		Inclusive air layers	2.4 + 0.65 2.4 + 1.30	1 x 25 mm air 2 sides
Isobooster® – prefabricated multi layer, including four metalized polyethylene foils and eight highly transparent polyethylene bubble foils – Thickness 4.0 cm (T2)		Inclusive air layers	3.4 + 0.65 3.4 + 1.30	1 x 25 mm air 2 sides
Tonzon® - Thermo sheets for in the wall or roof construction. The reflective foils need a minimum space of 2.5 cm in between them and in between the outside cavity with the general building material.		Inclusive outside air layers	0.7 + 1.30	2 foils
Horizontal under the floor				
Tonzon® - Thermo pillows for under the floor. Double sided metalized film on polyester. See picture. Exists in two foil and three foil design, the total height of the bags is about 15 cm		Exclusive outside air layers	2.7 3.7	2 foils 3 foils

Note: Aluminium (coated) foils need to be applied in **fully dry areas.** Humidity will cause slight surface corrosion on the shiny aluminium surface and **permanently and substantially degrade** the reflective value and thereby the thermal insulation value.

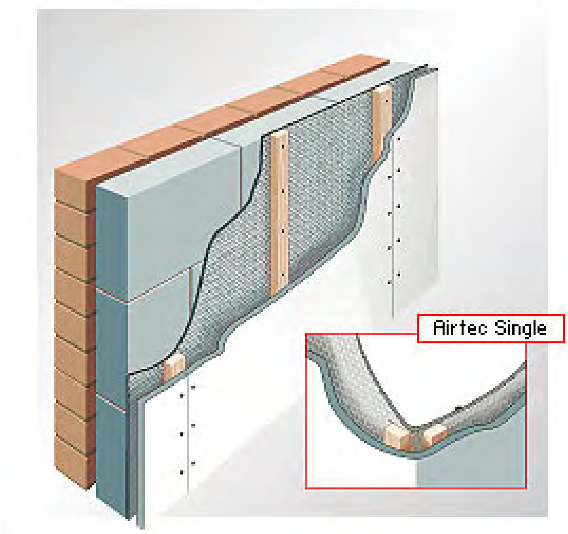
🡐 Isobooster

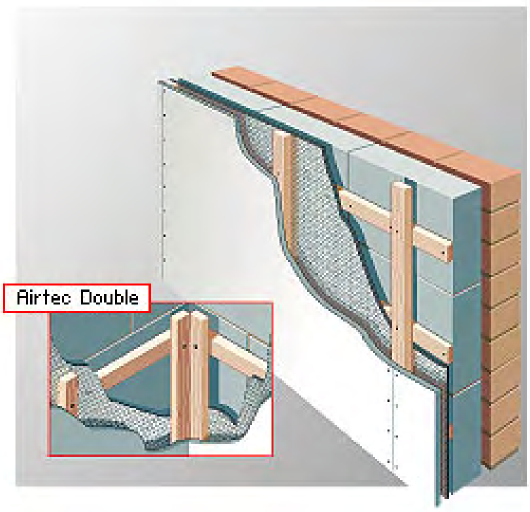
The black colour is the reflective foil. The Polyester bubble foil can be replaced with fluffy wool or airy cotton wool. The total insulation value will slightly reduce when the intermediate layers are less transparent for infrared radiation (such as fluffy wool or cotton).

← ALUthermo Quattro ↓Airflex



Samples of pre-manufactured thermal insulation products available in the market. Other manufactures reproduce similar products. The 99% pure aluminium reflective foils are more durable and more fire-resistant than the metalized polyester plastic foils. The internal aluminium foils, according to some calculations, do not provide much reflective power or insulation value; but they do substantially increase the cost of the foils.



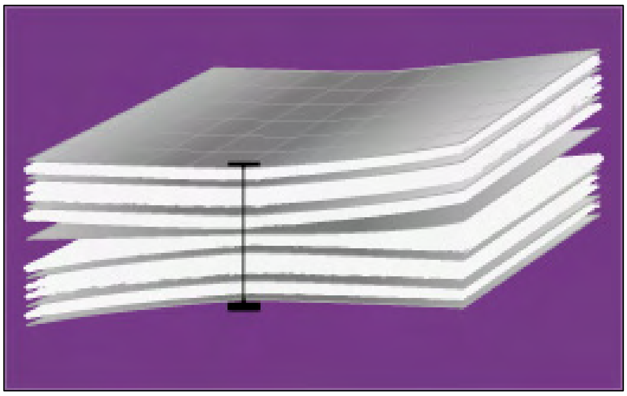


← Airtec

Drawing of the application of Airtec with single (less effective with R_C= 1.0 + 0.65) and a double airspace (25 mm each: R_C= 1.0 + 1.30) in front of the reflective foil.

The double application requires additional support timber, which will increase the construction cost, but will substantially increase the insulation value.

↓ Super Quilt



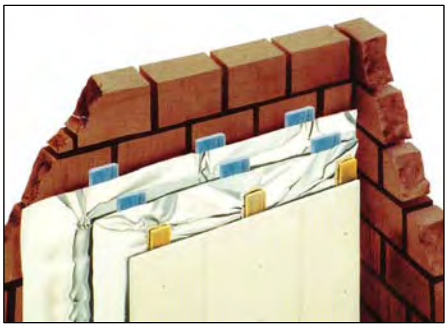
Super Quilt is a combination of reflective foils and wool. Other similar designs are coming in the European market. Insulation values of these multi-layer products are not easily certified.

The above descriptions are not an advertisement or promotion, but are provided to assist in explaining the differences between the various products and their application. The thermal insulation values depend largely on the method of application and the precise observation of the air spaces between materials.

The application of double-sided reflective foils (polyester) is realized by TONZON® as per pictures below (pictures from TONZON advertisements).

Two reflective foils on 2.5 cm thick (timber) strips against inside of outside wall and covered with board.

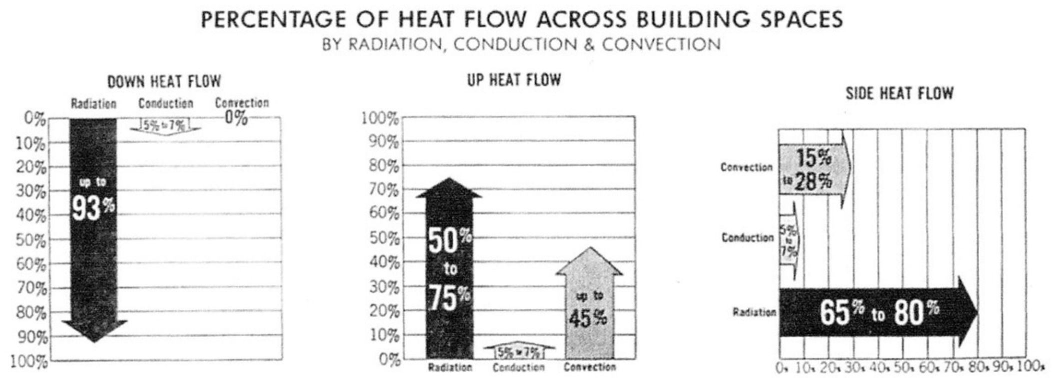
Far Right: 2 reflective foils on 2.5 cm strips against an inclined construction such as a roof; not yet covered.



Under floor or roof insulation of free hanging three reflective foils of TONZON®. Because of the air pillows being created (thermo-pillows), this solution has an additional thermal insulation value. The two-foil design (right side in picture) has a $R_C = <2.7m^2.K/W$ and the three-foil design (left side in picture) $R_C = <3.8m^2.K/W$. In these cases, the additional thickness of the air layers counts.

5.3 ***Calculation of Thermal Insulation Values***

The main finding was that some factories supplied very high insulation values, which did not apply in reality. The applicable insulation values for house insulation depend also on the width of the cavities.



Source: "Air Spaces Bounded by Bright Metallic Surfaces" from ASHREA, American Society of Heating and Airconditioning Engineers

The above chart gives a general impression of the great importance of reflective surfaces in thermal insulation. While traditional insulation materials work on the reduction of conduction, the metalized foils work as reflective surfaces (one or more layers) and therefore have more insulation effect.

The total R_C value (total thermal resistance of the different layers in a wall, ceiling or floor) is calculated by adding the various thermal resistance values of each layer or cavity together, plus inside and outside wall insulation values. In addition, the inside and outside transfer resistance must be added **between the outside air and the wall** ($R_{S\text{-}out}$ = variable depending on the roughness of the wall and wind speed) and the transfer resistance **between the inside air and the wall** (fixed $R_{S\text{-}in} = 0.13$ $m^2.K/W$ for horizontal transmission).

If the heat from outside (sun radiation on roof) needs to be stopped, metalized reflective foils or the aluminium foils need to be facing the heat source. In slightly ventilated horizontal cavity spaces under the floor or roof, dust will settle on the metalized or aluminium foils and strongly reduce the effectiveness of the foil over time to about half its value in the table.

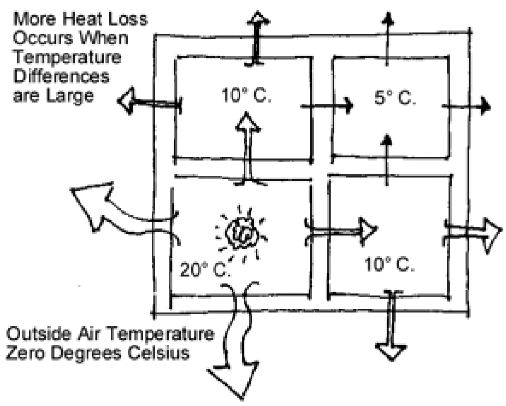
The placing of a simple plastic foil or other non-PE backed foil above the reflective foil will avoid dust settling on the lower reflective foil.

If humid air from inside the house condenses inside the wall or roof construction, that humidity needs to be evacuated to avoid fungus (summer period) or freezing (winter period). If not done, both situations may damage the construction. **The vapour or moisture blockage needs to be on the warm, humid side of the construction.** Any moisture inside a construction will lower the thermal insulation value and cause additional condensation. This occurs often in the winter.

5.4 Additional Spaces

When air cavities become very wide (such as deep built-in cabinets, wardrobes, small rooms, corridors and storage rooms), the inside wall transmission values can be added to the insulation value of the cavity.

The precise calculation of the insulation value of these additional rooms is complicated as the side walls, as well as the heat storage capacity of the enclosed air, need to be taken into consideration. However, adding these two transmission values gives a close approximation. In addition, the insulation values of the separating walls need to be added.



Adjoining rooms and closed unheated roof areas (attic) act as a temperature buffer. The table gives the combined values for the two wall-to-air transfer resistances together. The inside and the outside wall or roof insulation value needs to be added to this value.

Thickness of Air Layer in cm	Thickness of Air Layer in Inches Approximate	Horizontal Cavity with Warm Side Below (ceilings) Upward resistance ↑	Vertical Cavity Transfer Resistance Horizontal Measure ← →	Horizontal Cavity with Warm Side Above (hot roofs, floors) Downward Resistance ↓
30 – 45	1 ft – 1.5 ft	0.14 + 0.16	0.12 + 0.18	0.14 + 0.23
45 – 90	1.5 ft – 3 ft	0.20 + 0.16	0.18 + 0.18	0.20 + 0.24
>90	> 3ft	0.27 + 0.16	0.26 + 0.18	0.27 + 0.25

In calculating the insulation value of a building, all insulation between the heated space and the outside can be added.

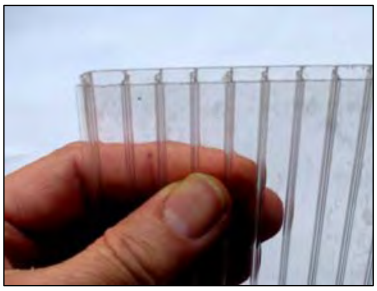
When planning for improving thermal insulation, the areas with the lowest insulation value between the heated room and the outside should be insulated first. In addition, the insulation values of the different constructions should be close to each other. When one area is poorly insulated, that area will be the largest heat leakage.

6. WINDOWS

Relevant Insulation Value or Thermal Resistance of Windows (Including Frame)

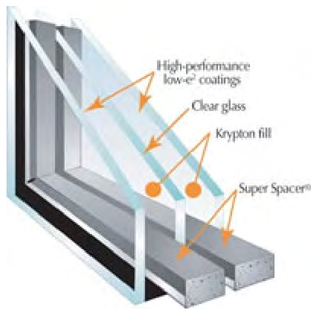
	Type of Window with Glass R value = 1/λ	1/U= R_g Glass: **R=m^2.K/W**	R_f Value Window Frame	R_w Value of Total Window
	Single Glass			R/m^2
1	Wooden window frame with whole glass sheets 3-4 mm thick. Glass window closes precisely in window frame with double (insulating) joint structure.	1/5.8 = 0.172	0.417	**0.19**
2	Wooden window frame with whole glass sheets 3-4 mm thick. Window closes precisely in frame with single joint structure.	1/5.8 = 0.172	0.312	**0.18**
3	Wooden window frame with whole glass sheets 4 mm thick. Glass window does not close precisely with single joint.	1/5.8 = 0.172	0.20	**0.17**
4	Wooden window frame with cracked glass sheets 3 mm thick. Glass window does not close precisely, small gaps single joint.	1/6.5 = 0.154	0.20	**0.15**
5	Wooden window frame with broken glass sheets 3 mm thick, 50% areas covered with plastic foil. Glass window does not close precisely in frame with small gaps in single joint.	1/8 = 0.125	0.20	**0.12**
	Double Glass	R_g Value Glass: **R=m.K/W**	R_f Value Window Frame	R_w Value of Total Window
6	Wooden window frame with double whole glass sheets 4 mm thick, space between glasses 2 cm. Window closes precisely in frame with double (insulating) joint structure.	1/2.8 = 0.357	0.417	**0.36**
7	Wooden window frame with double whole glass sheets 3-4 mm thick, space between glasses 2 cm. Window closes precisely in frame with single joint structure.	1/2.8 = 0.357	0.312	**0.32**
8	Wooden window frame with double whole glass sheets 3-4 mm thick, space between glasses 2-3 cm. Glass window does not close precisely in frame with small gaps in single joint.	1/2.8 = 0.357	0.2	**0.27**
9	Wooden window frame with double whole glass sheets 4-12-4 mm thick, space between glasses 12 mm. Glass window closes precisely in frame and has single joint.	1/3.0 = 0.33	0.2	**0.30**
10	Wooden window frame with laminated glass sheet 3-1-3 mm. Window closes precisely in frame without gaps, single joint.	1/3.7 = 0.270	0.312	**0.28**
11	Wooden window frame with laminated glass sheet 3-1-3 mm. Window does not close precisely in frame (some ventilation).	1/3.7 = 0.270	0.312	**0.15**
12	Wooden or PVC plastic (metal core) window frame with insulation glass 4-20-4 mm thick and dry air filling. Window closes precisely in frame with double joint structure.	1/2 = 0.50	0.50	**0.50**
13	Wooden or PVC plastic (metal core) window frame with insulation glass 4-20-4 mm thick and dry air filling. Window does not close precisely in frame with single joint structure.	1/2 = 0.50	0.40	**0.45**
14	Wooden or PVC plastic window frame with factory manufactured and sealed insulation glass 4-15-5 mm thick and dry air filling with thermal reflective inner coating. Window closes precisely in frame with double joint.	1/1.2 = 0.83	0.50	**0.75**
15	Wooden or PVC plastic window frame with factory manufactured and sealed insulation glass 4-15-5 mm thick and **Argon** gas filling with thermal reflective inner coating. Window closes precisely in frame with double joint.	1/1.0 = 1	0.50	**0.9**
16	Wooden or PVC plastic window frame with factory manufactured and sealed insulation glass 4-15-5 mm thick and **Krypton** gas filling with thermal reflective inner coating. Window closes precisely with double joint structure.	1/0.8 = 1.25	0.50	**1.2**
17	Add-on window 3 mm glass without reflective coating, 2 cm air cavity.			**0.2**

	Triple Glass Windows	R_g Value Glass: **R=m.K/W**	R_f Value Window Frame	R_w Value of total Window
18	Three ordinary glass windows in timber frames, well closing.			**0.45**
19	Triple glass window in wide single timber frame without heat reflective coating or gas filling 4-6-4-6-4 mm.	1/ 2.4 = 0.41	0.50	**0.44**
	Special Glass Windows			Glass only
20	High performance vacuum glass, 6.2 mm, IR coating			**0.72**
21	Ultra thin insulating glass, thick 5.8 mm, layered, IR coating			**0.28**
	Metal Window Frames	R_g Value Glass: **R=m.K/W**	R_f Value Window Frame	R_w Value of Total Window
22	Metal window frame profile with 4 mm glass, good closing	1/5.8 = 0.172	0.125	**0.143**
23	Aluminium window frame with 4 mm glass. Wide framing.	1/5.8 = 0.172	0.05	**0.10**
	Thick Plastic Foil (Table Cloth) Insulation Curtain			R_C Value
24	Single full transparent thick (0.13 mm) plastic foil screwed and sealed against the whole window frame. With timber strips. Air layer 2 cm.			0.1
25	Double full transparent thick (0.13 mm) plastic foil screwed and sealed against the whole window frame. Air layers 2 x 2 cm. Winter Insulation Insert (Wii) for RHW.			0.2
26	Single full transparent thick (0.13 mm) plastic foil screwed or fitted tight against only the glass frame. Airspace < 2 cm.			0.08
27	Single decorative or blinding roll curtain, closing PRECICELY against the window frame or wall. Air space to glass < 8 cm.			0.07
28	Single decorated or blinding roll curtain, closing less precise against all walls around the window. Air space to glass > 8 cm.			0.06
	Polycarbonate (Plastic) Hollow Honeycomb Sheet			
29	Clear, fully translucent, 6 mm thick, separators 10 mm, only.			0.13
30	6 mm Polycarbonate, 2 cm in front of an existing glass window and adequately air sealed around the sheet.			0.28
31	Clear, fully translucent, 10 mm thick, separators 10 mm only.			0.27
32	10 mm Polycarbonate, 2 cm in front of existing glass window and adequately air sealed around the sheet.			0.40



🡐 Polycarbonate fully transparent sheet 6 mm thick

Triple glass window➔



7. RECOMMENDED MINIMUM INSULATION

The Recommended Minimum Average R_C Value for buildings with about 5 son hours per day.

The Recommended Minimum <u>Average</u> R_c Value = $\left\{ 0.5 + \frac{\text{Altitude in m}}{1000 \text{ m}} \right\} m^2.K/W$

This value needs to be adjusted for the amount of solar heat intake.
The insulation value of the ground floor should be minimum <u>half of the above values</u>. This is because the △T between room air and ground temperature is about half of the △T between room air and the air outside the ceiling or wall.

The Recommended Minimum <u>Average</u> R_c Value Floor = $0.5 \times \left\{ 0.5 + \frac{\text{Altitude in m}}{1000 \text{ m}} \right\} m^2.K/W$

The value needs to be added with R_C 0.1 m^2.K/W for every sun hour less.
In a mountain environment such as the Himalayas, the shadow of the mountains can leave buildings in the shade for half a day or longer when the winter sun is low. For fully shadowed or overcast regions in the winter, it means adding R_C = 0.5 m^2.K/W.

Recommended Minimum Average R_c Value for Buildings with About 5 Sun Hours/Day

Minimum Winter Temperature Celsius	Approximate Altitude Above Sea Level	Minimum Insulation R_c in m^2.K/W	Recommended Minimum R_c in m^2.K/W 5 Sun Hours/Day	Recommended R_c in m^2.K/W Only 2.5 Sun Hours	Recommended R_c in m^2.K/W Without Sun Hours
0º C	1200 m (4000 ft)	R_c = 1.2	R_c = 1.7	R_c = 1.95	R_c = 2.2
-5º C	1500 m (5000 ft)	R_c = 1.5	R_c = 2.0	R_c = 2.25	R_c = 2.5
-10º C	1800 m (6000 ft)	R_c = 1.8	R_c = 2.3	R_c = 2.55	R_c = 2.8
-15º C	2200 m (7500 ft)	R_c = 2.2	R_c = 2.7	R_c = 3.95	R_c = 3.2
-20º C	2700 m (9000 ft)	R_c = 2.7	R_c = 3.2	R_c = 3.45	R_c = 3.7
< -30º C	3000 m (10,000 ft)	R_c = 3.0	R_c = 3.5	R_c = 3.75	R_c = 4.0

Ground floor thermal insulation values should be minimum <u>half</u> of the above values.
When sleeping on the floor, the insulation should be increased for improved comfort. Improving the insulation under the body will reduce loss of body heat through contact. Using beds, whereby the insulating mattress does not make contact with the floor, also reduces heat loss through contact.

<u>Warning</u>
With the application of impermeable plastic or metalized foils in the walls of a room, ventilation must be adequate to guarantee sufficient oxygen for the inhabitants. The metalized reflective foils avoid heat loss, but have the disadvantage that additional ventilation becomes more important because the natural ventilation that exists through traditional walls is blocked by the plastic.

Transportable kerosene or bottled gas heaters for space heating have three important disadvantages: (1) they rapidly burn op the oxygen in the room, much faster than ten people breathing; (2) they produce large amounts of humidity as part of the exhaust gasses; and (3) they produce CO_2 gasses as exhaust.

When the oxygen amount in the room becomes very low, the combustion will be incomplete and the exhaust gasses of the kerosene and gas burners will produce CO (Carbon Monoxide), an odourless poisonous gas causing people to lose concentration, become drowsy, get red faces, fall asleep and eventually die. The combination of well-sealed rooms and open kerosene/gas burners can therefore be **deadly without sufficient ventilation**, especially in bedrooms.

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