BlueScope | steel CONNECT

APPLICATIONS OF ROOF THERMAL INSULATION IN TROPICAL CLIMATE

Applications of Roof Thermal Insulation in Tropical Climate

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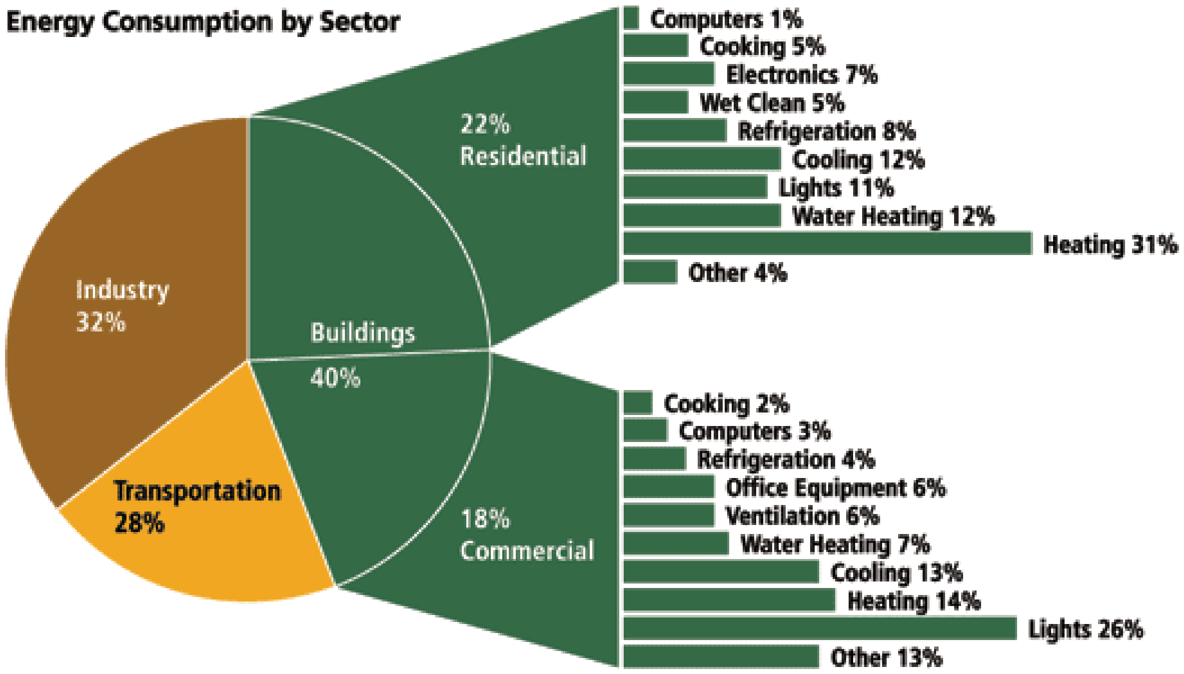
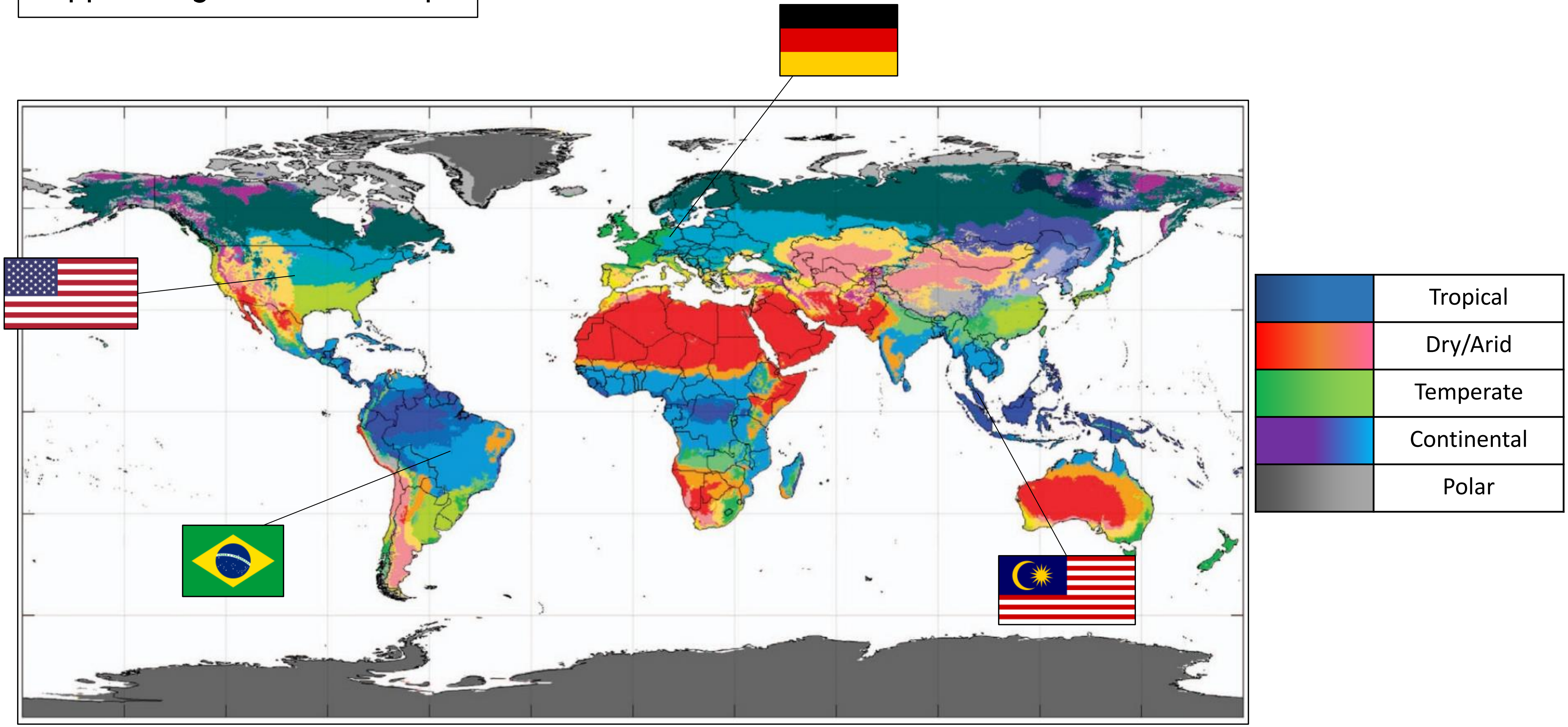
World energy consumption for buildings

Globally, **Buildings consume up to 40% of the total global energy**. By the year 2030, the consumption is expected to increase to 50%. In Malaysia, buildings consume a total of 48% of the electricity generated in the country.

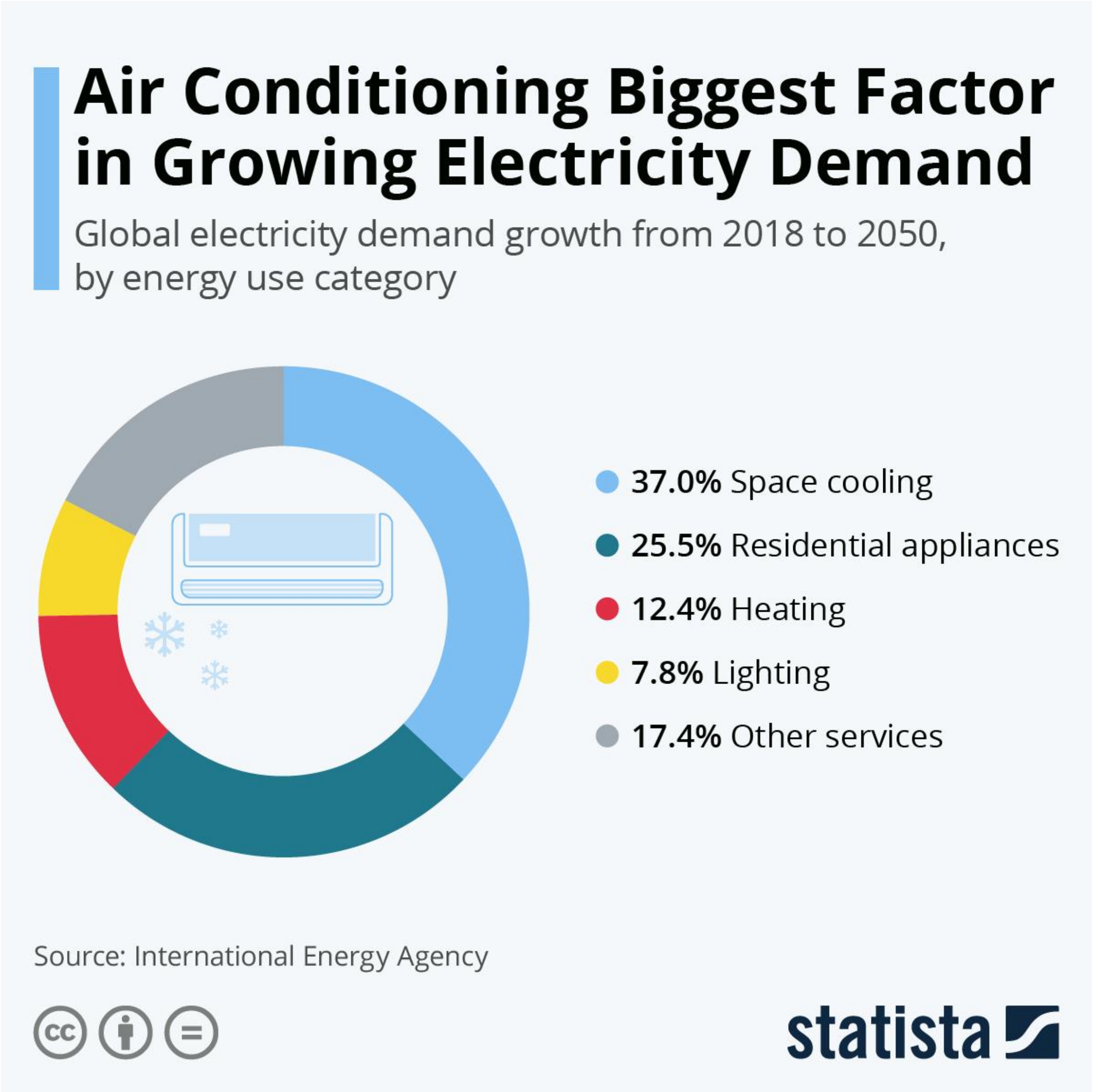


Source: J.S. Hassan, R.M. Zin, M.Z.A. Majid, S. Balubaid, M.R. Hainin, Building energy consumption in Malaysia: An overview, J. Teknol. 70 (2014) 33–38. doi:10.11113/jt.v70.3574.

Koppen-Geiger Climate Groups

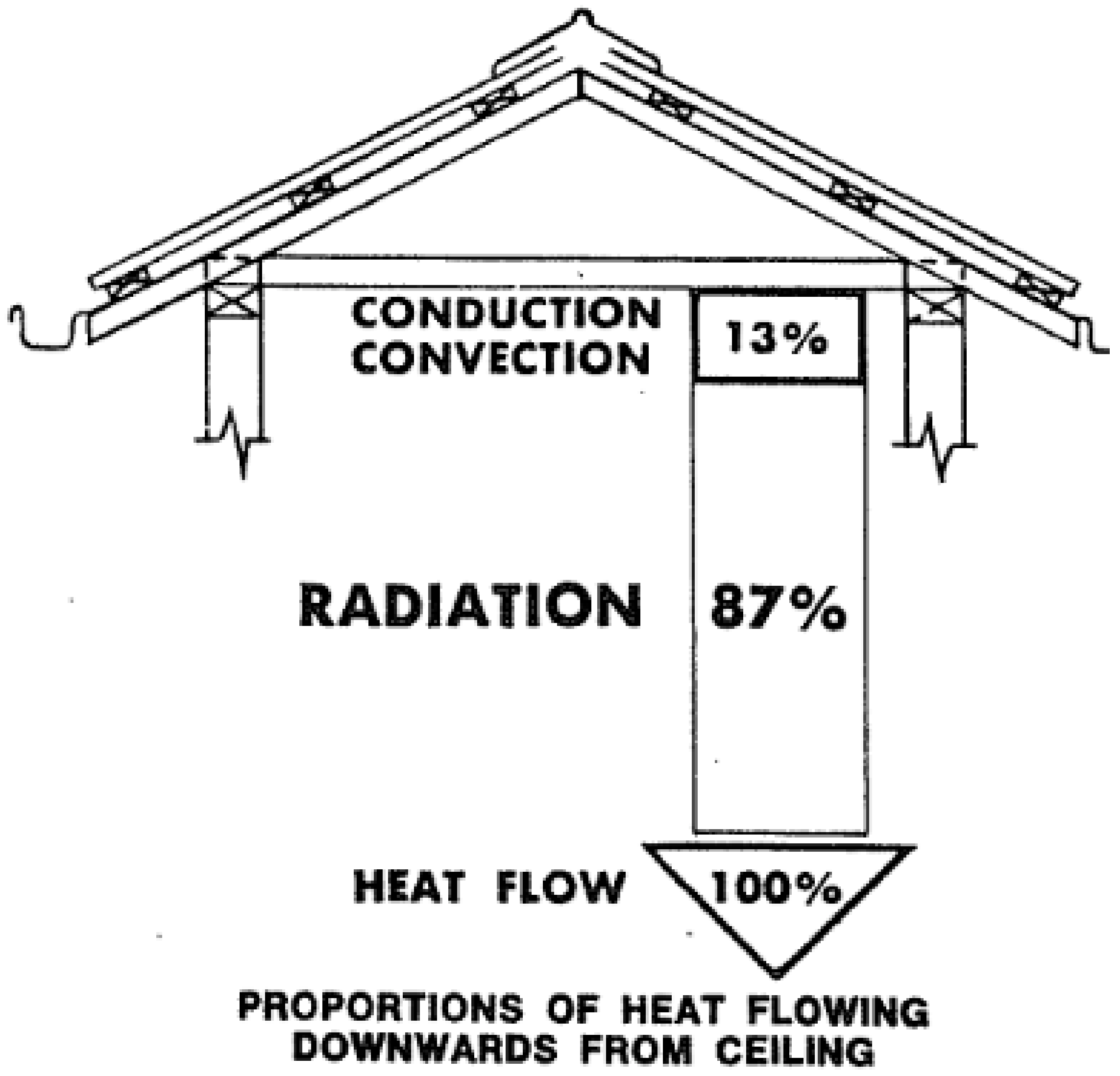


Increasing demand for AC System

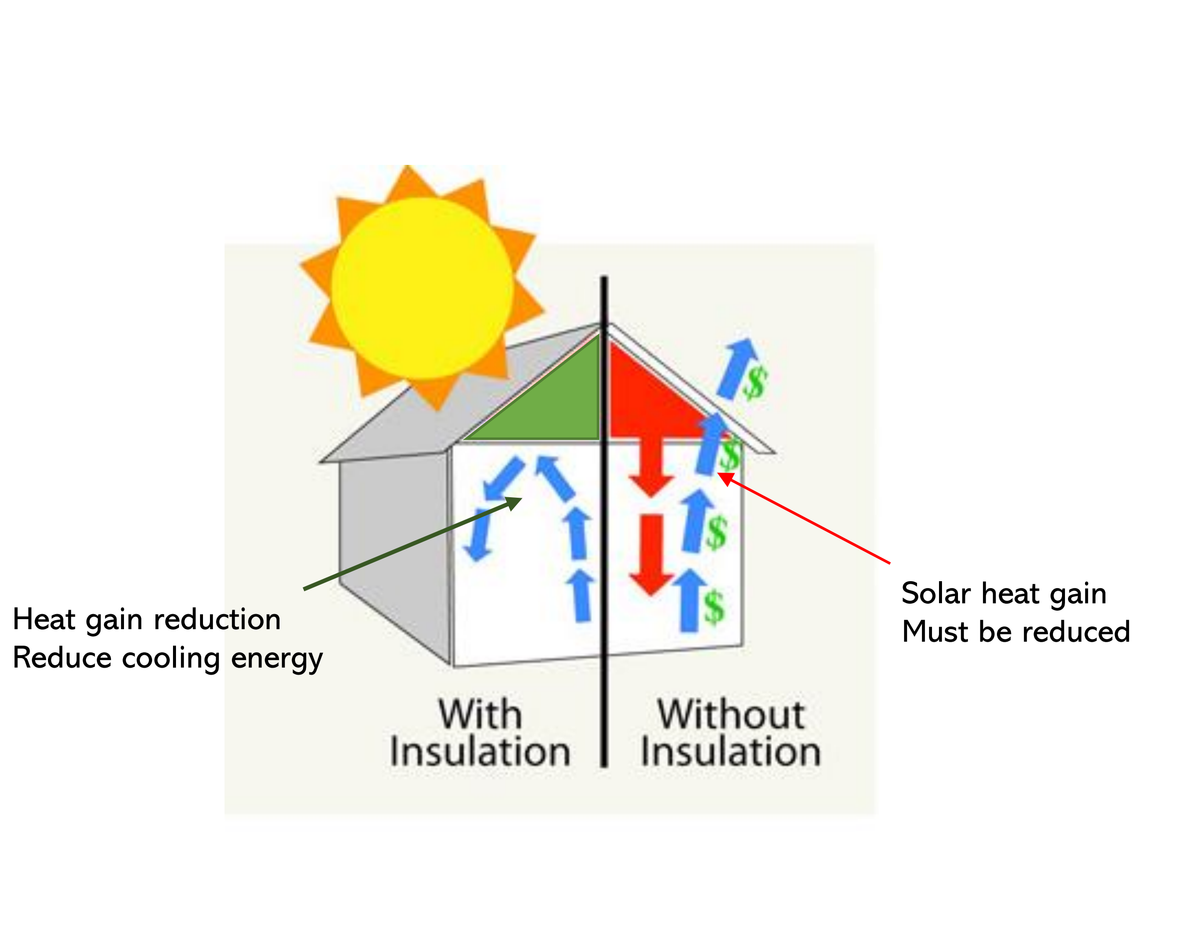


Heat transfer through the roof

- Roof component is responsible for the **highest building's solar heat gain.**
- Up to **87% of heat entering** an indoor space is by **radiative heat transfer**, followed by **conductive and convective heat transfer**.



Why is roof insulation important?



To save cooling energy, it is vital to reduce **solar heat gain** by using **insulation material**

Source: www.comstockairyuma.com

Commercially available roof thermal insulations

Reflective Foil

1. Radiant Barrier (RB)

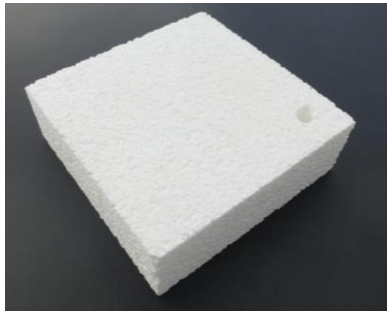
Example: Woven aluminum foil, paper aluminum foil

2. Reflective Insulation (RI)

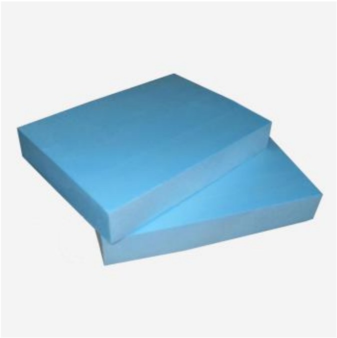
Example: Bubble aluminium foil, foam aluminium foil, bubble foam foil

Mass Insulation

1. Expanded Polystyrene (EPS)



2. Extruded Polystyrene (XPS)

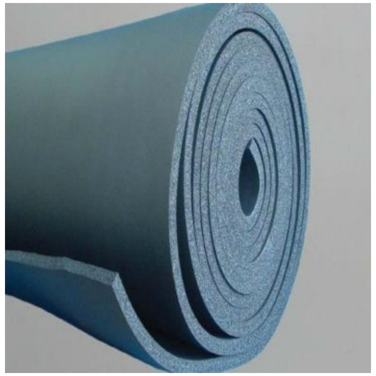


3. Rockwool

4. Mineral wool (MW)

5. Fibreglass

6. Polyethylene (PE)



7. Polyurethane (PU)

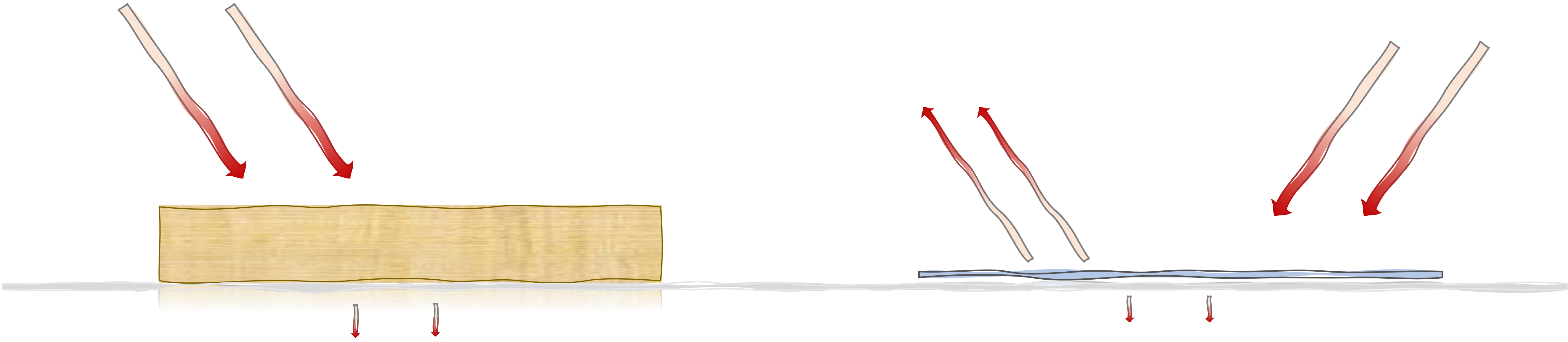
8. Siporex

How do these two types of insulations work?

Hot outdoor environment

Mass insulation

Reflective foil



Mass insulation

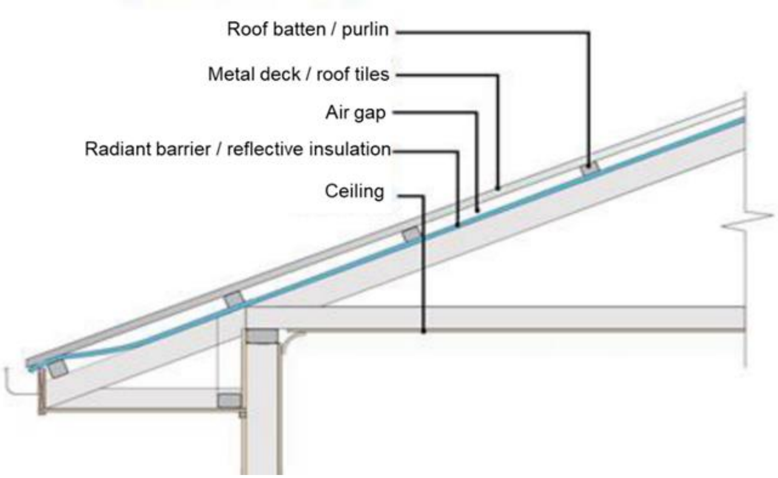
1. Low thermal conductivity and high thermal resistance (R-value)
2. Works to **trap and slow down** conductive heat gain or lost

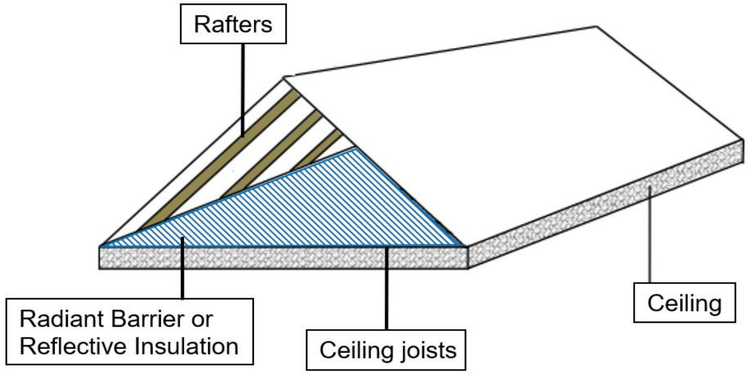
Cold indoor environment

Reflective foil

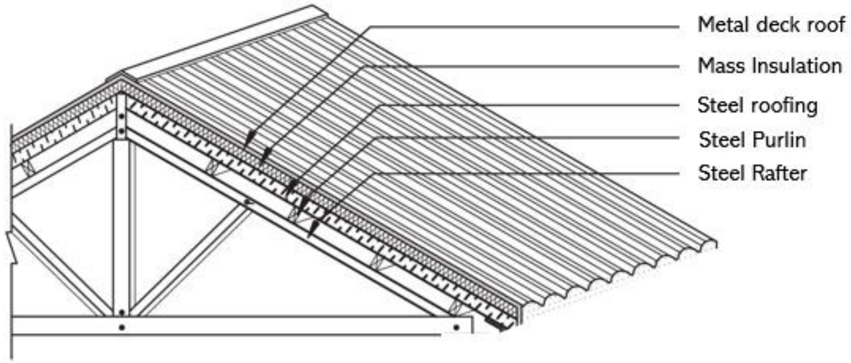
1. High reflectivity > 95% and low emittance, $\varepsilon < 0.05$
2. Works to **block and reflect radiant** heat back towards the source. The lower the emissivity value the better.

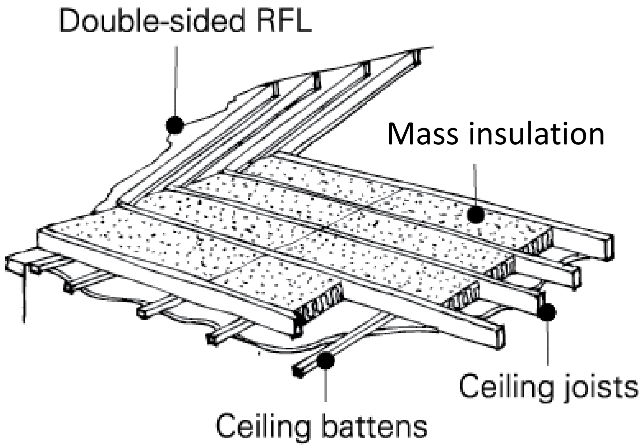
Reflective foil



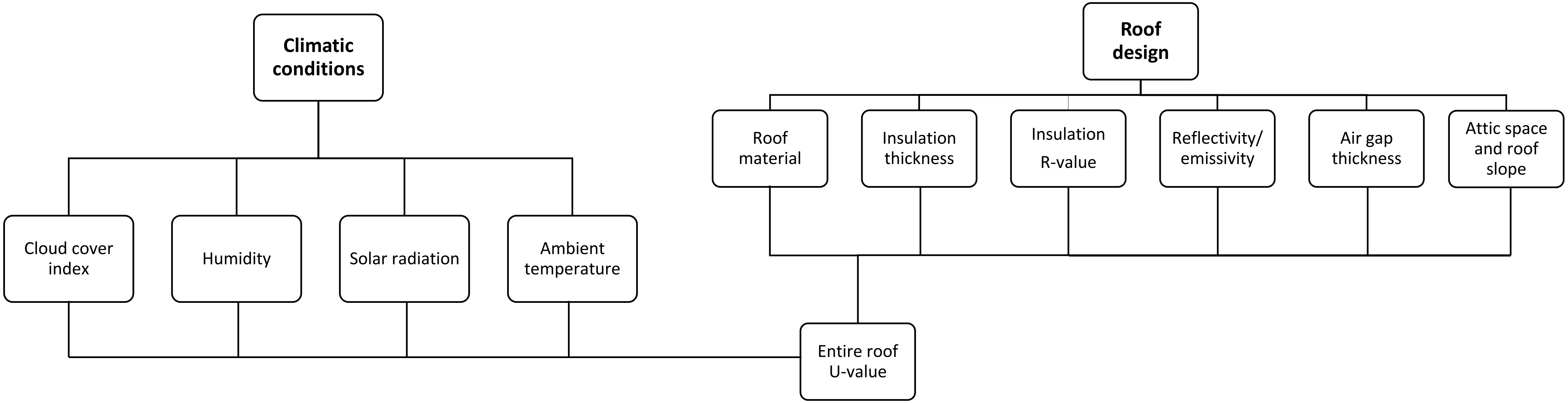


Mass insulation





Factors affecting the performance of a roof insulation subjected to transient environmental conditions



Source: Chitrarekha Kabre (2010), Medina et al (2006)

Definition of Emissivity

- **Emissivity (e)** is defined as:

"The ratio of the thermal radiation from unit area of a surface to the radiation from unit area of a full emitter (black body) at the same temperature".

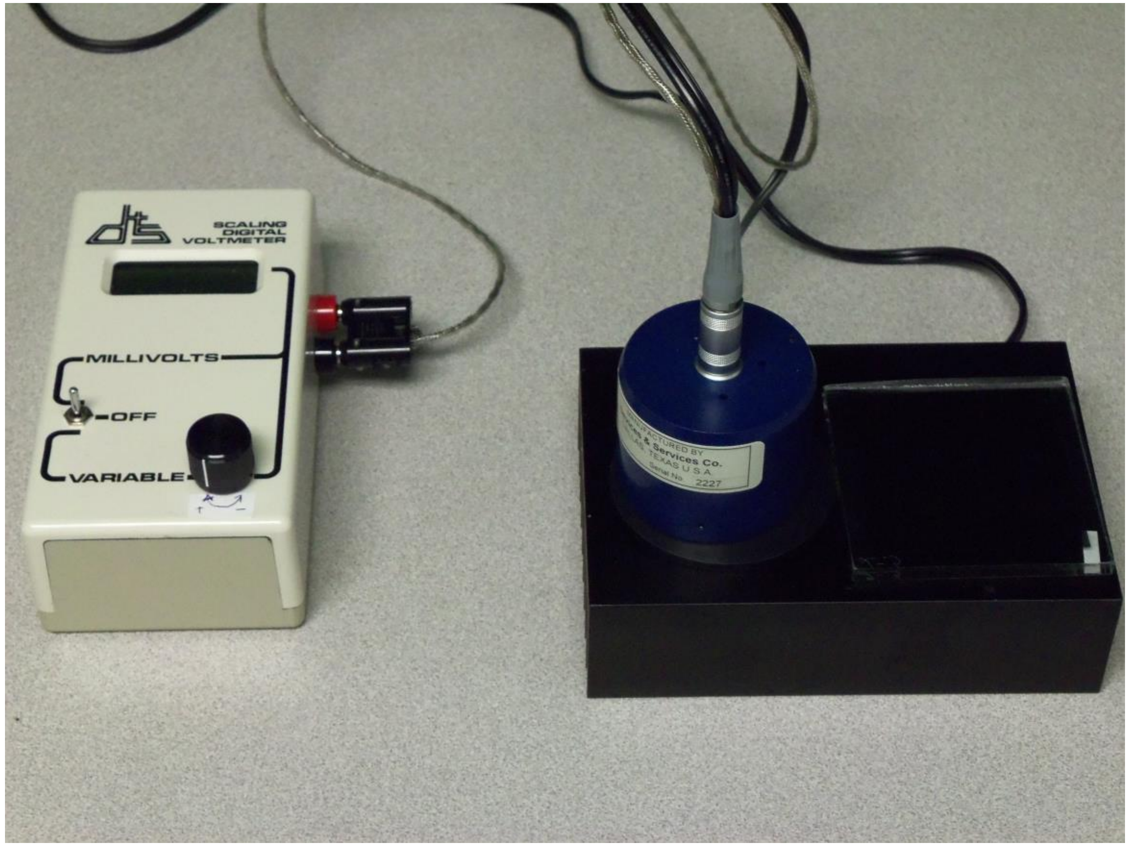
The emissivity of aluminium foil is 0.03 to 0.05 at temperature of surfaces in building spaces. E.g. attics, habitable rooms etc. This means that the material "emits" only 3 to 5% of the amount of heat that a black body would emit fi it were at the same temperature.

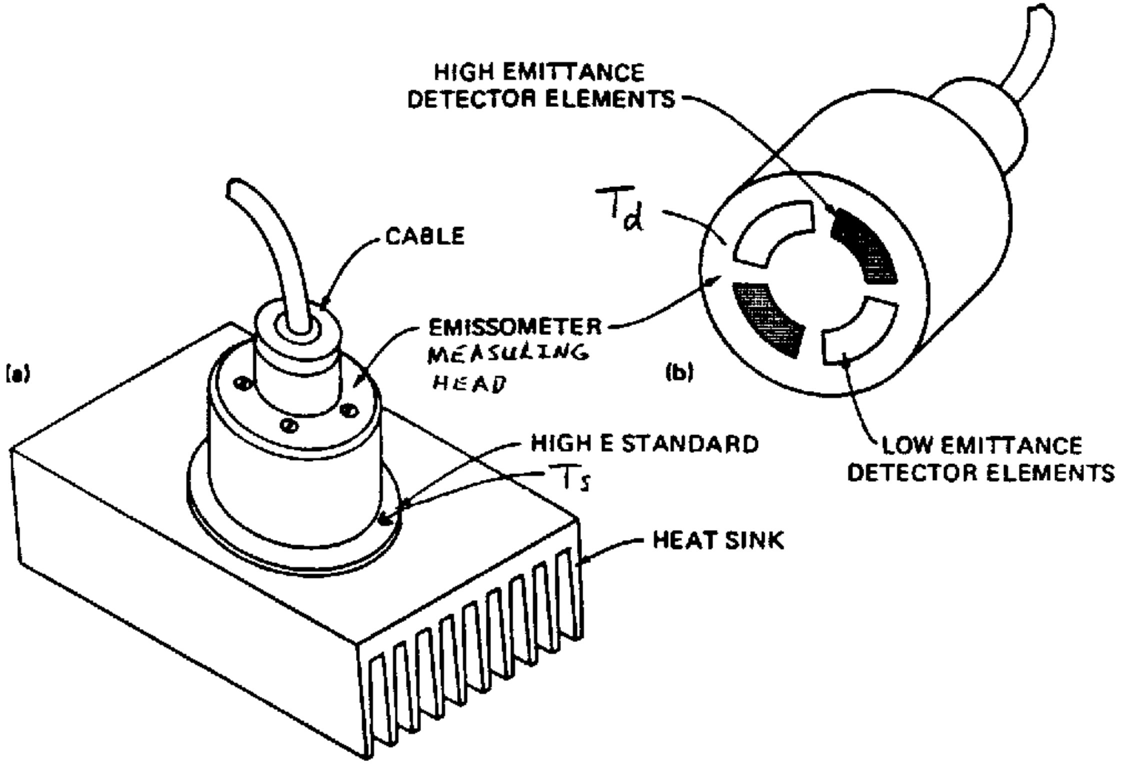
Most building materials such as wood and tiles have an emissivity of 0.8 to 0.9, i.e, their surface emits 80 to 90% of the amount of heat which would be emitted by a black body at the same temperature.

Material	ε
Aluminum foil	0.04
Asbestos board	0.96
Asbestos paper	0.93
Asphalt (paving)	0.97
Brass (hard rolled—polished with lines)	0.04
(somewhat attacked)	0.04
Brick (red—rough)	0.93
Brick (silica—unglazed rough)	0.80
Carbon (T—carbon 0.9% ash)	0.81
Concrete	0.94
Copper (plate heavily oxidized)	0.78
Frozen soil	0.93
Glass (smooth)	0.94
Gold (pure highly polished)	0.02
Granite (polished)	0.85
Ice	0.97
Marble (light gray polished)	0.93
Paper (black tar)	0.93
Paper (white)	0.95
Plaster (white)	0.91
Plywood	0.96
Tin (bright tinned iron sheet)	0.04
Water	0.95
Wood (freshly planned)	0.90

Source: HASSALL, D Reflective Insulation.pdf, (n.d.).

Emissometer – to measure emissivity (ASTM C-1371)



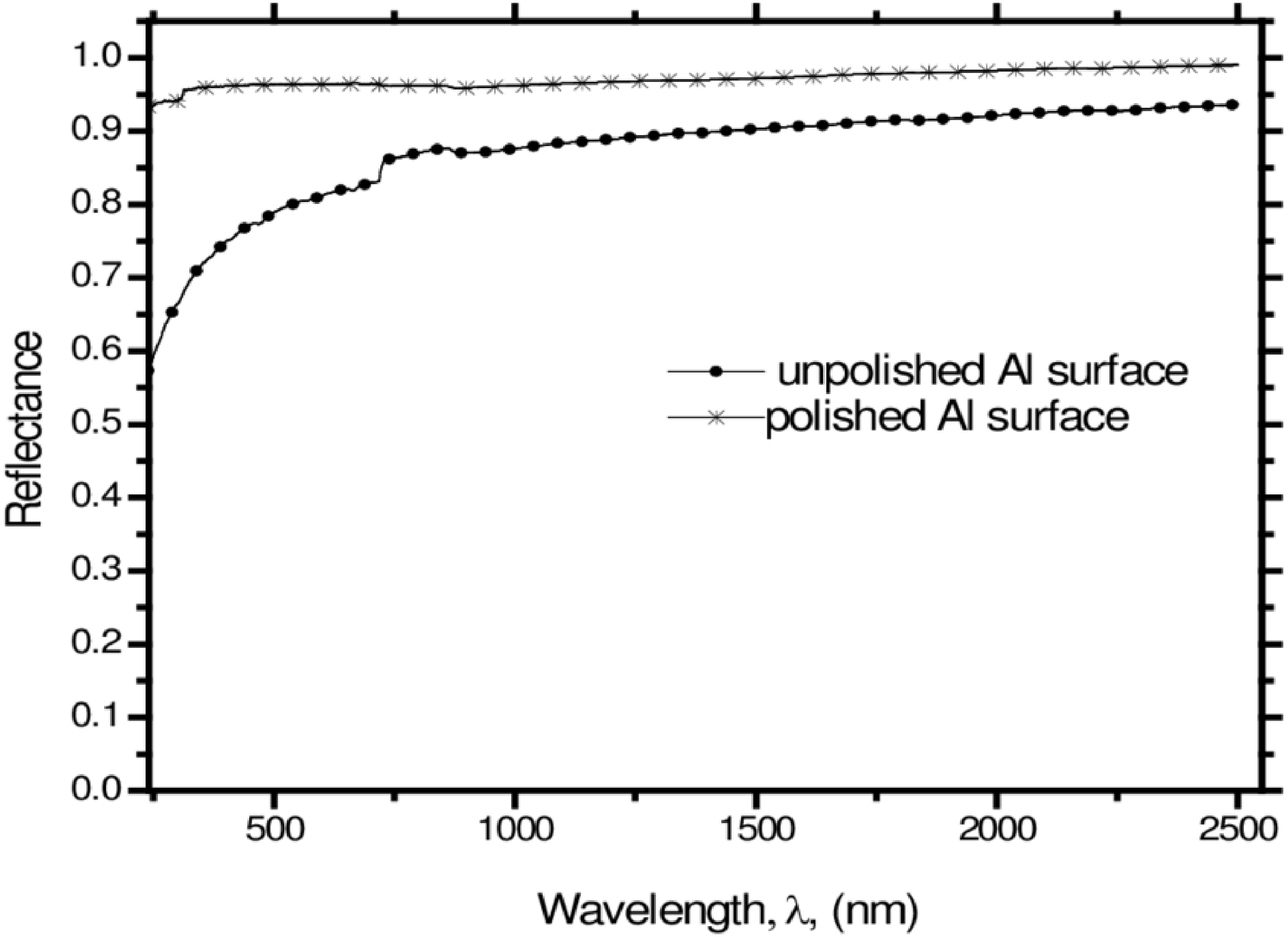


Definition of Reflectivity

- Reflectivity (r) is defined as:

"The ratio of the amount of thermal radiation reflected from a surface to that which falls on its surface."

Aluminium foil has the high reflectivity of 0.95, i.e. it reflects 95% of the incident thermal radiation, whereas the surface of most building materials and the surfaces of mass insulation have low thermal reflectivity – usually about 0.10.



Source: HASSALL, D Reflective Insulation.pdf, (n.d.).

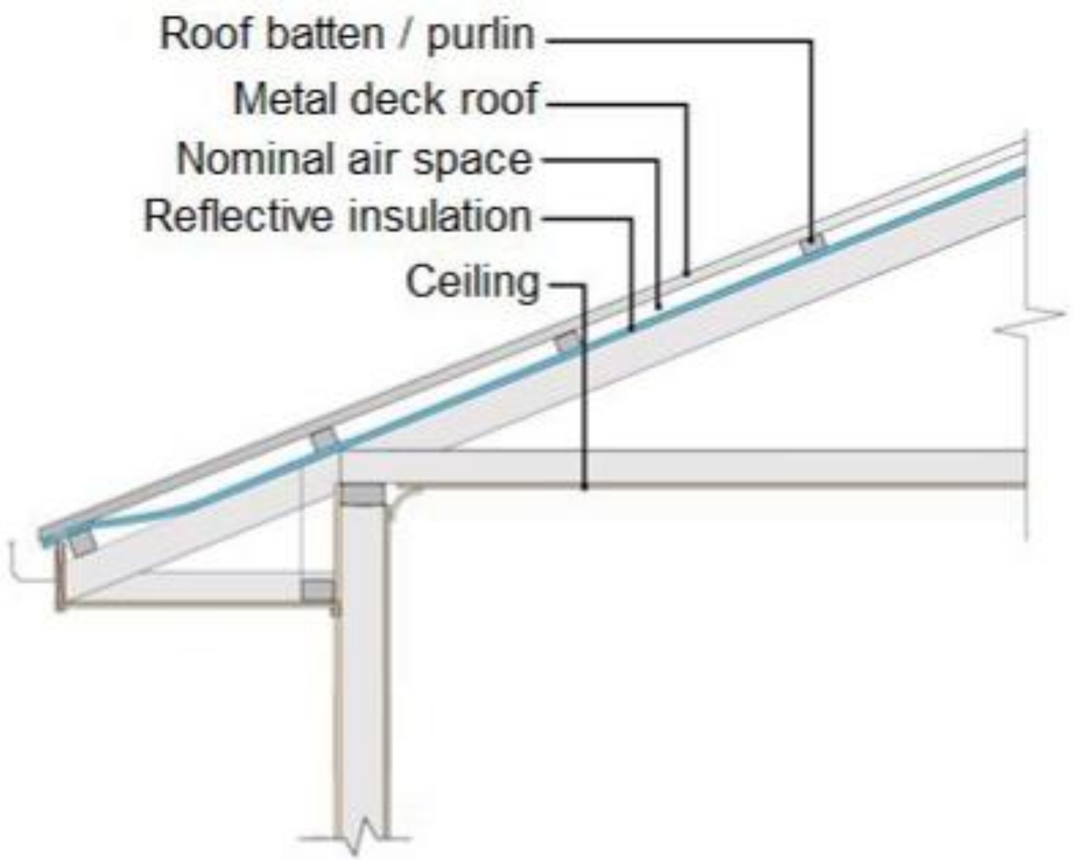
Definition of Radiant Barrier & Reflective Insulation

- **Radiant barrier**

A material with low emittance surface. When its facing an open air space is defined as radiant barrier system

- **Reflective insulation**

Reflective insulation is a thermal insulation system consisting of one or more low emittance surfaces, bounding one or more enclosed air spaces with a measurable R-value.

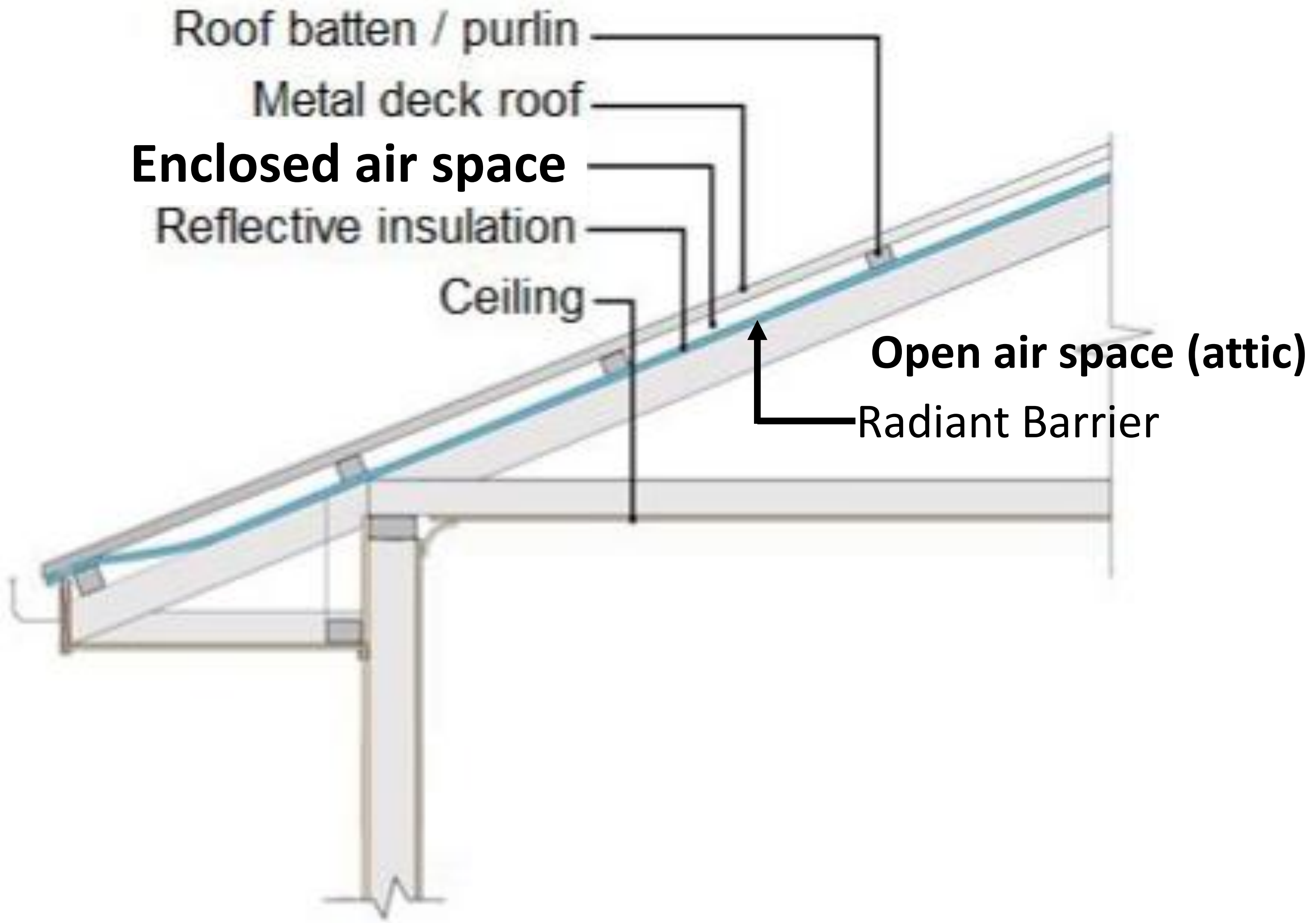


Source: MS 2095 Radiant Barrier and Reflective Insulation Materials

ASHRAE HANDBOOK - FUNDAMENTALS
on reflective air gaps

Table 3 Thermal Resistances of Plane Air Spaces[a,b,c], (m²·K)/W

Position of Air Space	Direction of Heat Flow	Air Space: Mean Temp.[d], °C	Air Space: Temp. Diff.[d], °C	13 mm Air Space[c] — Effective Emittance ε_{eff}[d,e]: 0.03	0.05	0.2	0.5	0.82	20 mm Air Space[c] — Effective Emittance ε_{eff}[d,e]: 0.03	0.05	0.2	0.5	0.82
Horiz.	Up	32.2	5.6	0.37	0.36	0.27	0.17	0.13	0.41	0.39	0.28	0.18	0.13
		10.0	16.7	0.29	0.28	0.23	0.17	0.13	0.30	0.29	0.24	0.17	0.14
		10.0	5.6	0.37	0.36	0.28	0.20	0.15	0.40	0.39	0.30	0.20	0.15
		−17.8	11.1	0.30	0.30	0.26	0.20	0.16	0.32	0.32	0.27	0.20	0.16
		−17.8	5.6	0.37	0.36	0.30	0.22	0.18	0.39	0.38	0.31	0.23	0.18
		−45.6	11.1	0.30	0.29	0.26	0.22	0.18	0.31	0.31	0.27	0.22	0.19
		−45.6	5.6	0.36	0.35	0.31	0.25	0.20	0.38	0.37	0.32	0.26	0.21
45° Slope	Up	32.2	5.6	0.43	0.41	0.29	0.19	0.13	0.52	0.49	0.33	0.20	0.14
		10.0	16.7	0.36	0.35	0.27	0.19	0.15	0.35	0.34	0.27	0.19	0.14
		10.0	5.6	0.45	0.43	0.32	0.21	0.16	0.51	0.48	0.35	0.23	0.17
		−17.8	11.1	0.39	0.38	0.31	0.23	0.18	0.37	0.36	0.30	0.23	0.18
		−17.8	5.6	0.46	0.45	0.36	0.25	0.19	0.48	0.46	0.37	0.26	0.20
		−45.6	11.1	0.37	0.36	0.31	0.25	0.21	0.36	0.35	0.31	0.25	0.20
		−45.6	5.6	0.46	0.45	0.38	0.29	0.23	0.45	0.43	0.37	0.29	0.23
Vertical	Horiz.	32.2	5.6	0.43	0.41	0.29	0.19	0.14	0.62	0.57	0.37	0.21	0.15
		10.0	16.7	0.45	0.43	0.32	0.22	0.16	0.51	0.49	0.35	0.23	0.17
		10.0	5.6	0.47	0.45	0.33	0.22	0.16	0.65	0.61	0.41	0.25	0.18
		−17.8	11.1	0.50	0.48	0.38	0.26	0.20	0.55	0.53	0.41	0.28	0.21
		−17.8	5.6	0.52	0.50	0.39	0.27	0.20	0.66	0.63	0.46	0.30	0.22
		−45.6	11.1	0.51	0.50	0.41	0.31	0.24	0.51	0.50	0.42	0.31	0.24
		−45.6	5.6	0.56	0.55	0.45	0.33	0.26	0.65	0.63	0.51	0.36	0.27
45° Slope	Down	32.2	5.6	0.44	0.41	0.29	0.19	0.14	0.62	0.58	0.37	0.21	0.15
		10.0	16.7	0.46	0.44	0.33	0.22	0.16	0.60	0.57	0.39	0.24	0.17
		10.0	5.6	0.47	0.45	0.33	0.22	0.16	0.67	0.63	0.42	0.26	0.18
		−17.8	11.1	0.51	0.49	0.39	0.27	0.20	0.66	0.63	0.46	0.30	0.22
		−17.8	5.6	0.52	0.50	0.39	0.27	0.20	0.73	0.69	0.49	0.32	0.23
		−45.6	11.1	0.56	0.54	0.44	0.33	0.25	0.67	0.64	0.51	0.36	0.28
		−45.6	5.6	0.57	0.56	0.45	0.33	0.26	0.77	0.74	0.57	0.39	0.29
Horiz.	Down	32.2	5.6	0.44	0.41	0.29	0.19	0.14	0.62	0.58	0.37	0.21	0.15
		10.0	16.7	0.47	0.45	0.33	0.22	0.16	0.66	0.62	0.42	0.25	0.18
		10.0	5.6	0.47	0.45	0.33	0.22	0.16	0.68	0.63	0.42	0.26	0.18
		−17.8	11.1	0.52	0.50	0.39	0.27	0.20	0.74	0.70	0.50	0.32	0.23
		−17.8	5.6	0.52	0.50	0.39	0.27	0.20	0.75	0.71	0.51	0.32	0.23
		−45.6	11.1	0.57	0.55	0.45	0.33	0.26	0.81	0.78	0.59	0.40	0.30
		−45.6	5.6	0.58	0.56	0.46	0.33	0.26	0.83	0.79	0.60	0.40	0.30


Roof batten / purlin
Metal deck roof
Enclosed air space
Reflective insulation
Ceiling
Open air space (attic)
Radiant Barrier

HOW TO GAUGE THE PERFORMANCE OF THE REFLECTIVE INSULATION?

Thermal Resistance calculation

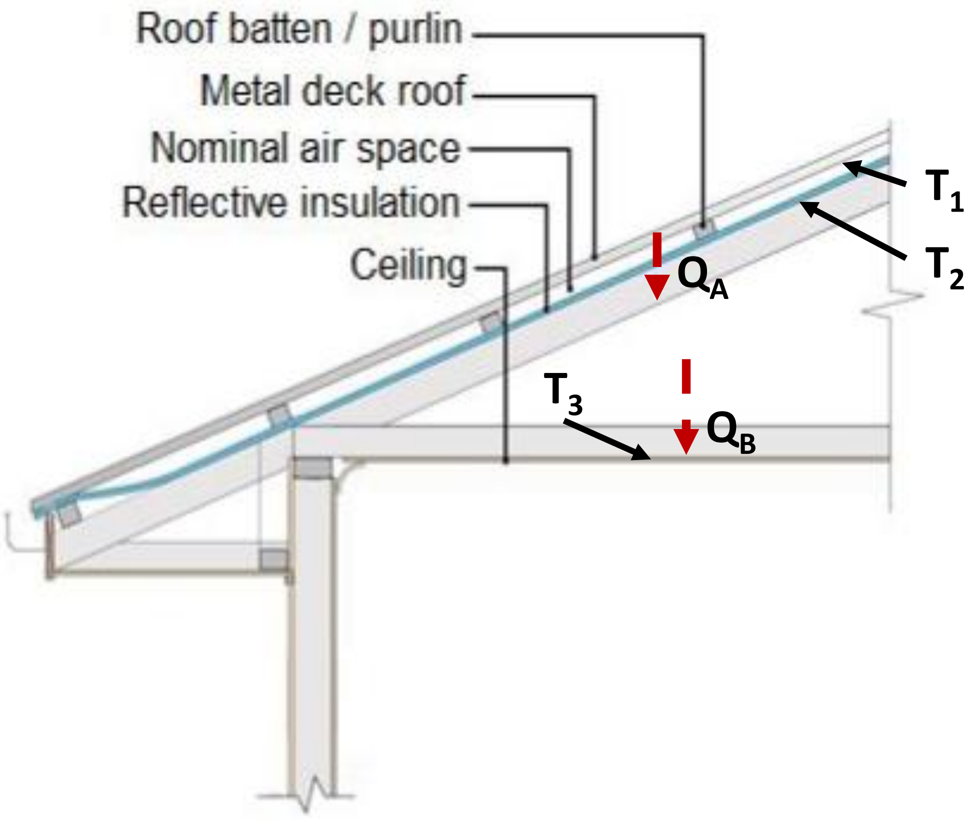
Equations used to calculate RSI or R-value:

ʽYʺYٍʺQة ةﺗﺨﺢ ة ﺗ ﺘ ﺔ ﻭﺍ٩ﺍﻭ / ﺉ   ʽYʺYٍʺQة ﺧﺪ ﺓ ﺗ ﻰﺍ٩ﺍﻭ / ﺉ

ʽYʺYٍʺQا ﺧﺪ ﺓ ﺟ ʽYʺYٍʺQة ةﺗﺨﺢ ة ﺗ ʽYʺYٍʺQة ﺧﺪ ﺓ ﺗ

Key parameters obtained from the CFD simulation:

1. The average surface temperature of the roof, T_1.
2. The average surface temperature of the reflective foil, T_2.
3. The average surface temperature of the top of the ceiling, T_3.
4. The average heat flux across the reflective air space, Q_A.
5. The average heat flux across the attic, Q_B.



Solar Reflectance Index (SRI) as defines by US Green Building Council (USGBC) as a measure of the constructed surface's ability to stay cool in the sun by reflecting solar radiation and emitting thermal radiation.

The procedure defines a Solar Reflectance Index (SRI) that measures the relative "steady state surface temperature" of a surface with respect to the standard white (SRI=100) and the standard black (SRI=0) under the standard solar and ambient conditions.

The calculation of the Solar Reflectance Index (SRI) are performed in compliance with the **ASTM Standard Test Method E1980** from the measured values of **Solar Reflectance and Thermal Emittance**. The program used for the calculations was provided by Lawrence Berkeley Laboratory California.

The Solar reflectance values are measured according to ASTM Standard Test Method E903 Hemispherical spectral reflectance measurement using PerkinElmer Model UV/VIS, NIR Lambda 950 Spectrophotometer utilizing an integrating sphere and the Thermal Emittance values are measured according to ASTM Standard Test Method C1371 using an emissometer.

- **Solar Reflectance** is the fraction of the incident solar energy which is reflected by the surface. The best standard technique for its determination uses spectrophotometric measurements, with an integrating sphere to determine the reflectance at each different wavelength. The average reflectance is then determined by an averaging process, using a standard solar spectrum. This method is documented by **ASTM (Amer. Soc. for Testing and Materials) as Standards E903 and E892.**

UV-VIS-NIR SPECTROPHOTOMETER

SRI CALCULATION USING ASTM E 1980

To compute solar reflectance index (SRI) and roof surface temperature based on solar reflectance (R) and thermal emittance (E) using ASTM standard E 1980:

1. Input R and E in blue and green cells.
2. Click on the red button to compute SRI and roof surface temperature.

Ambient conditions and reference-surface properties specified in next worksheet.

Tool coded by Ronnen Levinson, Heat Island Group, Lawrence Berkeley National Laboratory (http://HeatIsland.LBL.gov).
For assistance, contact Hashem Akbari at H_Akbari@LBL.gov or Ronnen Levinson at RMLevinson@LBL.gov .

Test surface properties

Solar reflectance (0-1)	R	0.70
Thermal emittance (0-1)	E	0.80

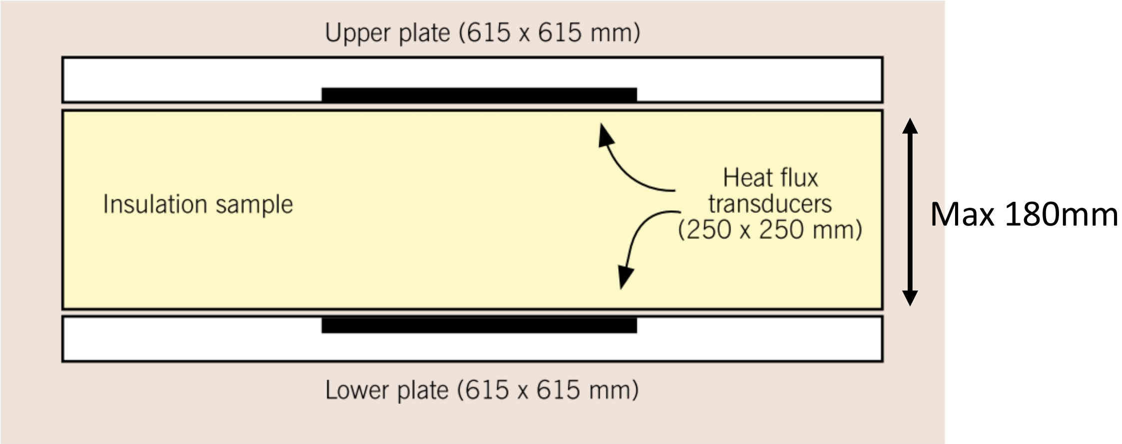
Click to update SRI

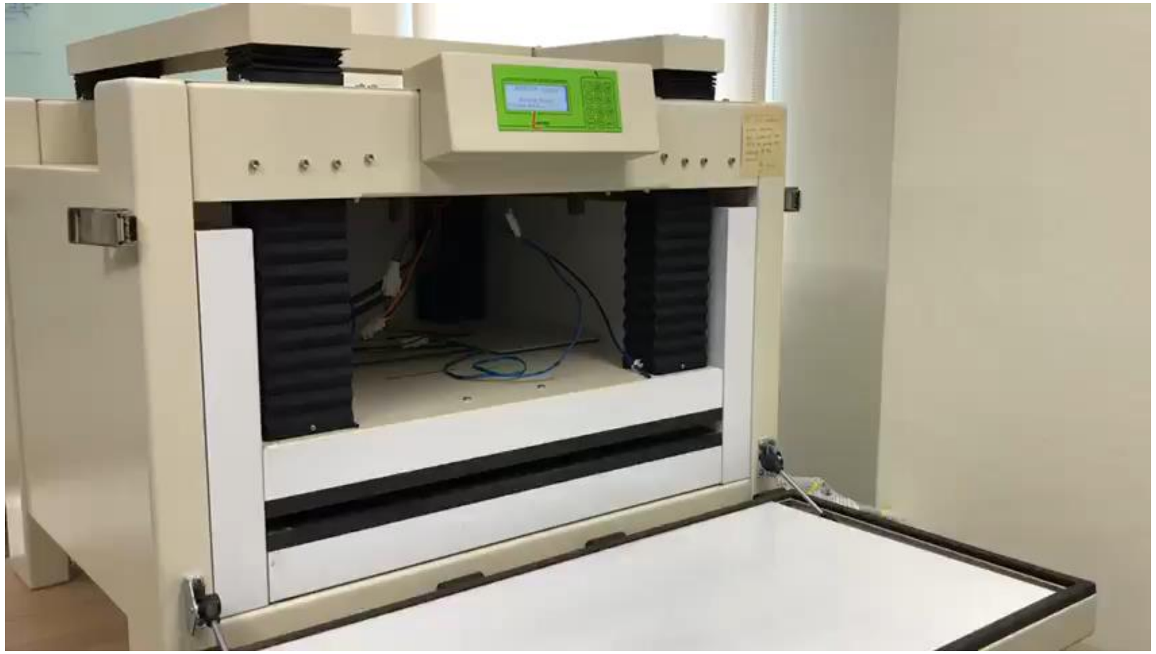
SRI= 84

Methods of radiant barrier & reflective insulation investigation

Laboratory Measurement	Field Measurement	CFD Simulation
• **Hot box** only measures the heat transfer through the **center of the test panels** which contains the insulation material which may results in **inaccurate result**. • **Heat flow meter** only evaluates the thermal resistance of insulation material, **not the whole roof assembly** • **Solar simulator to measure the roof assembly R-value** • **Steady-state** measurement • Results **may not represent real environment** • Led to the need to conduct field measurements under **dynamic and transient conditions**	• Measurements give a more **realistic and accurate results** • **Limited roof configurations** can be tested due **to time constraints and it can be costly** • Essential to **provide high quality data** for the development of **computer simulation model**	• Yarbrough (2011) expresses the need of using computer simulation • Need to be **validated** against field measurements • Important method especially in **parametric analysis** in which **wider range of environmental and building parameters** can be studied in a shorter period of time

Heat Flow Meter: Thermal Conductivity, R-Value & U-Value





INTERNATIONAL STANDARD

ISO 8301

First edition
1991-08-01

AMENDMENT 1
2010-08-15

Thermal insulation — Determination of steady-state thermal resistance and related properties — Heat flow meter apparatus

AMENDMENT 1

Isolation thermique — Détermination de la résistance thermique et des propriétés connexes en régime stationnaire — Méthode fluxmétrique

AMENDEMENT 1

Reference number
ISO 8301:1991/Amd.1:2010(E)

MALAYSIAN STANDARD

MS 2095:2014

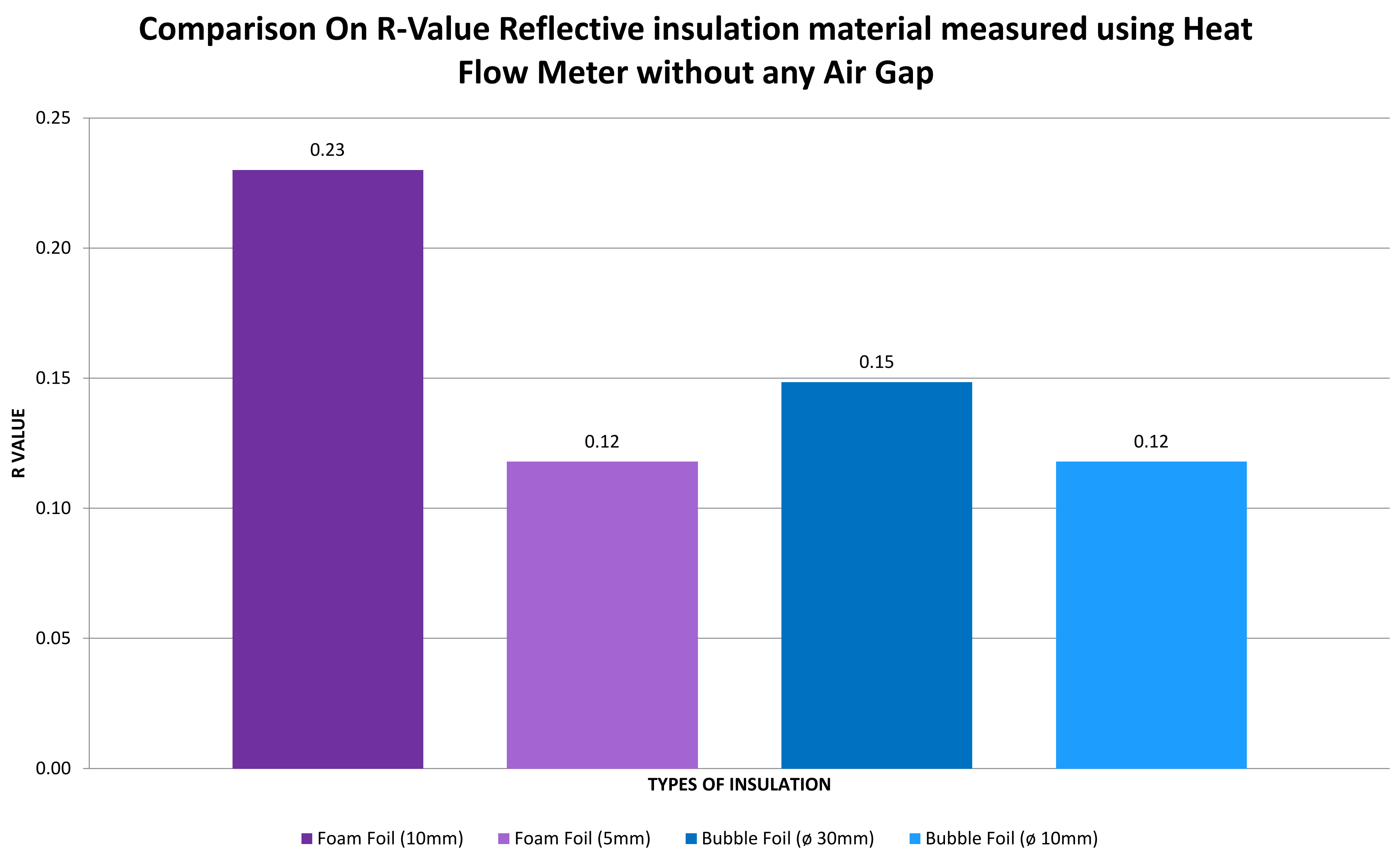
Radiant barrier and reflective insulation building materials - Specification (First revision)

ICS: 91.120.10

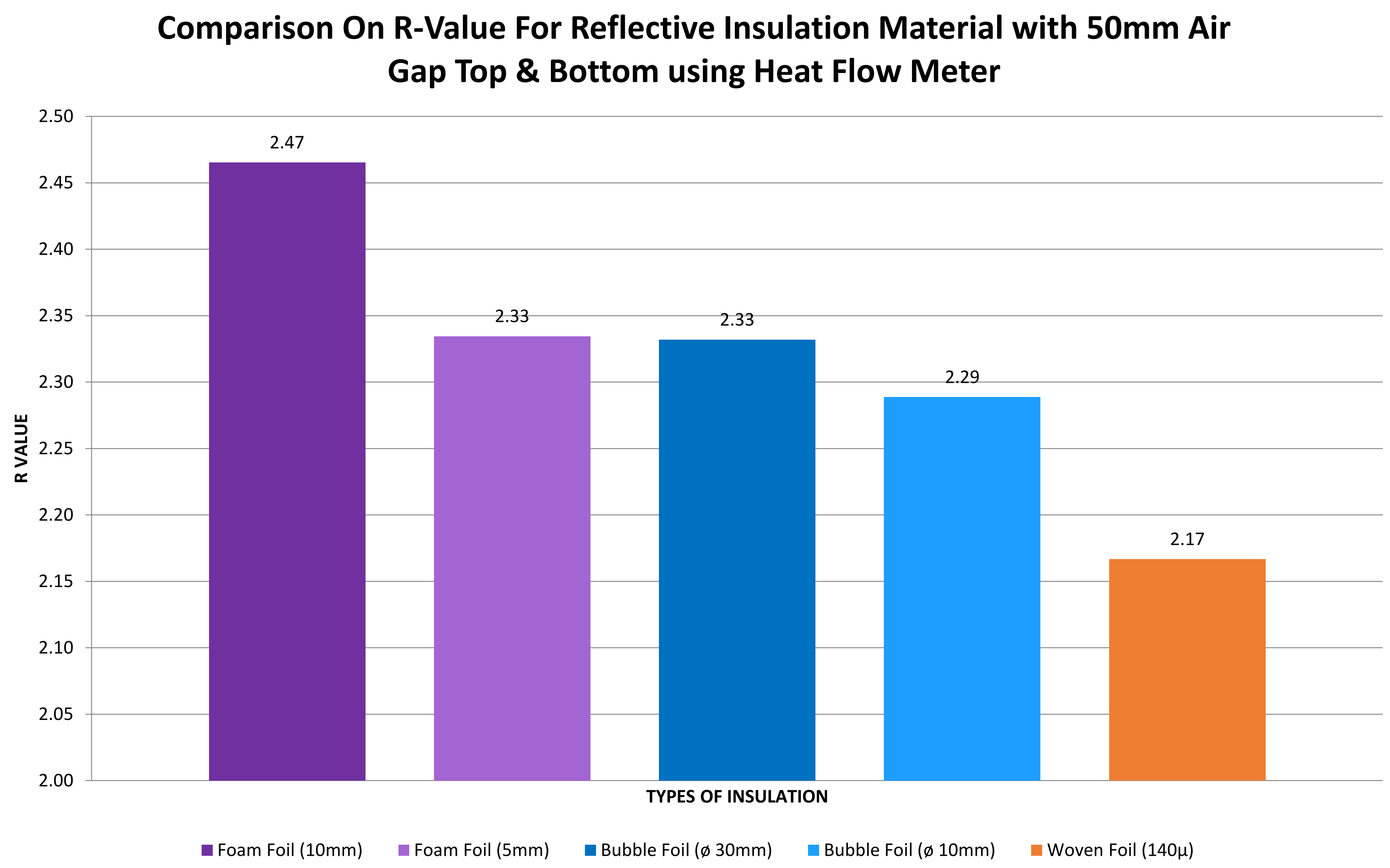
Descriptors: radiant barrier, reflective insulation, application, properties, classification, allowable usage, marking and roll labelling

DEPARTMENT OF STANDARDS MALAYSIA

d) the temperature of hot and cool plate shall be 35 °C and 20 °C, with the temperature difference of 15 °C;



Comparison On R-Value Reflective insulation material measured using Heat Flow Meter without any Air Gap
0.25
0.20
0.15
0.10
0.05
0.00
R VALUE
0.23
0.12
0.15
0.12
TYPES OF INSULATION
Foam Foil (10mm)
Foam Foil (5mm)
Bubble Foil (ø 30mm)
Bubble Foil (ø 10mm)


Comparison On R-Value For Reflective Insulation Material with 50mm Air Gap Top & Bottom using Heat Flow Meter
R VALUE
2.50
2.45
2.40
2.35
2.30
2.25
2.20
2.15
2.10
2.05
2.00
2.47
2.33
2.33
2.29
2.17
TYPES OF INSULATION
Foam Foil (10mm)
Foam Foil (5mm)
Bubble Foil (ø 30mm)
Bubble Foil (ø 10mm)
Woven Foil (140µ)

METHOD: INDOOR SOLAR SIMULATOR

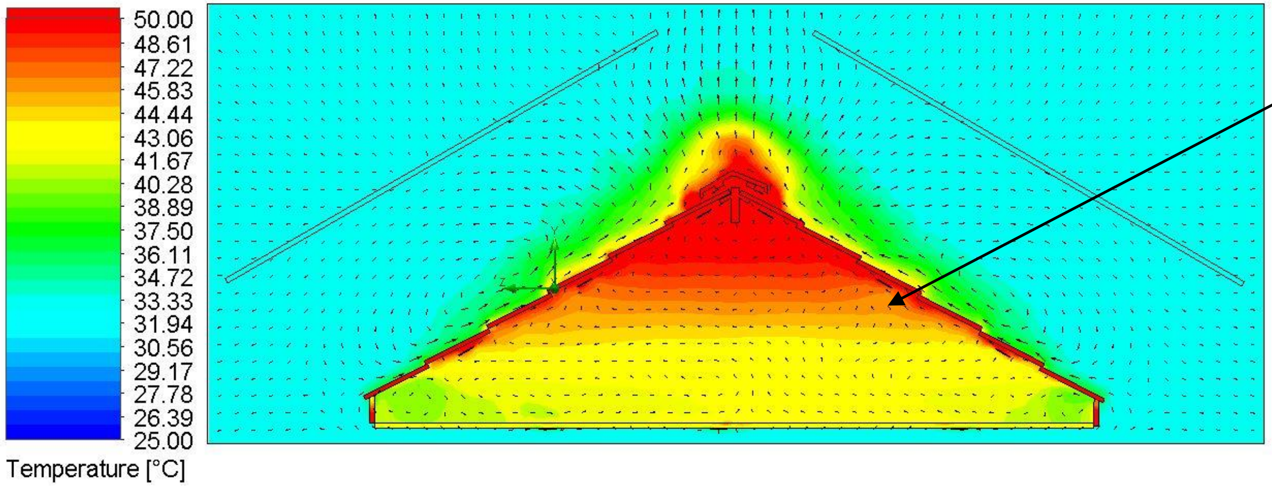
- To measure the whole roof assembly or system
- Actual roof configurations

3D Computational Fluid Dynamics Simulation for reflective insulation in a roof attic

Boundary conditions:

Hot and humid condition
Ambient temperature: 33ÁC
Relative humidity: 80%
Solar radiation: 600 – 1000 W/m²

1. Without reflective foil

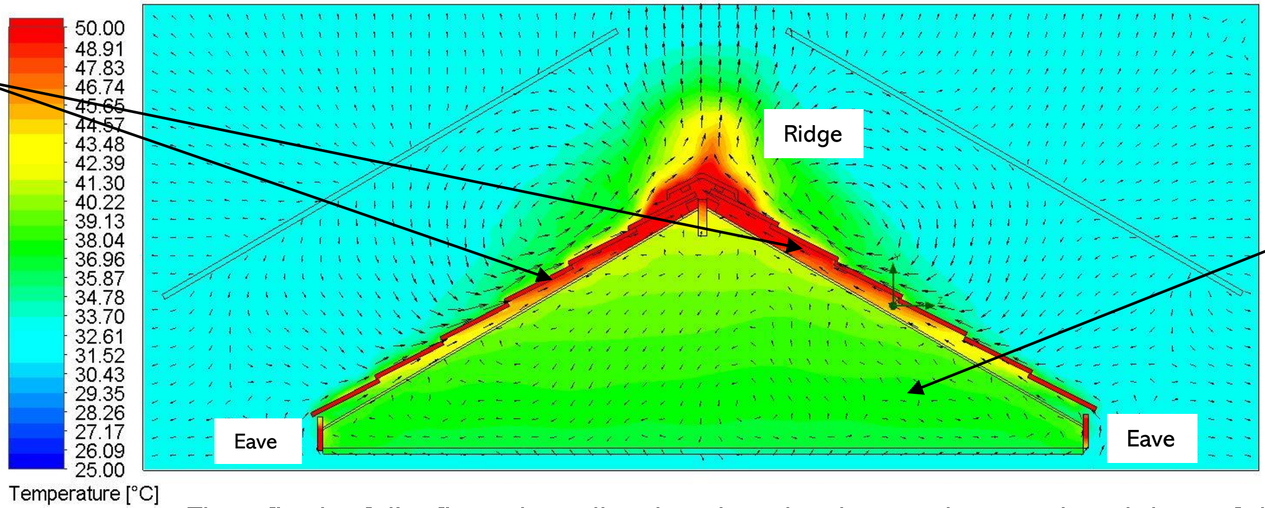


Heat is radiated into the attic in the absence of reflective foil

Without reflective foil, the underside of the roof tiles radiates all the heat directly into the attic.
The attic overheats and causes the house to become warmer during hot days.

2. With reflective foil

Heat is reflected by the reflective foil



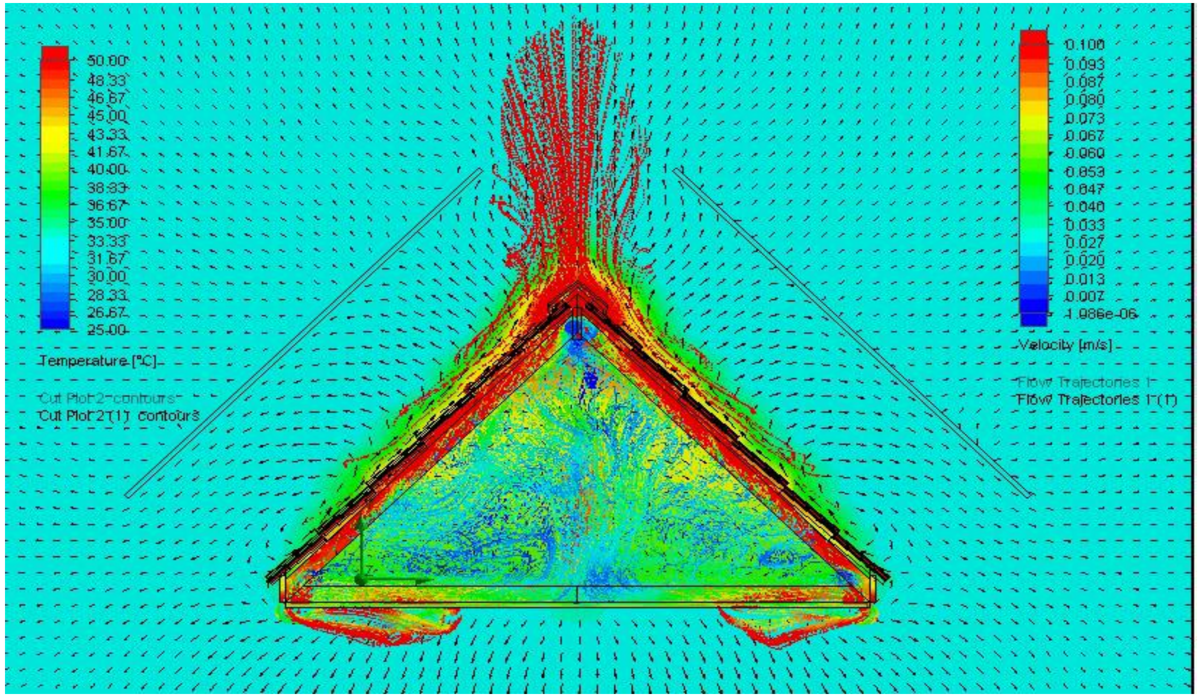
Temperature in attic is reduced by 10ÁC

Heat flux is reduced by 80%

The reflective foil reflects the radiant heat into the air space between it and the roof tiles
The heat flows from the eaves of the roof and escapes through the ridge
It keeps the attic space cooler and leads to cooler indoor environment

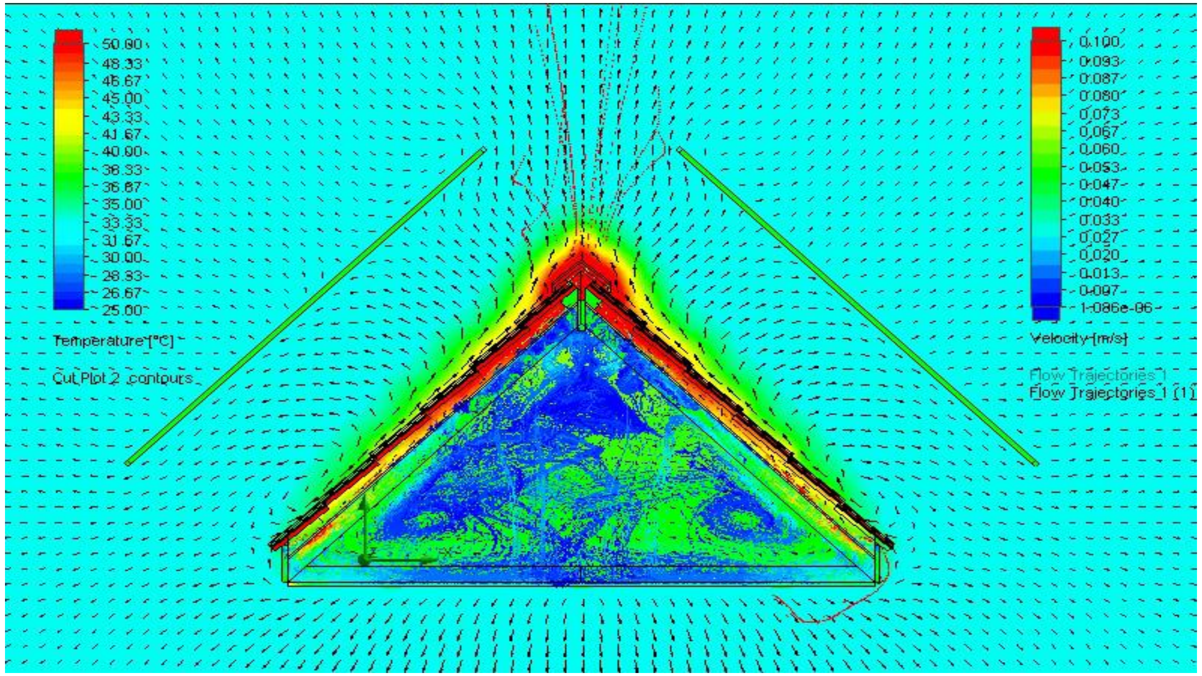
CFD ANIMATION

Without reflective insulation
@45deg pitch



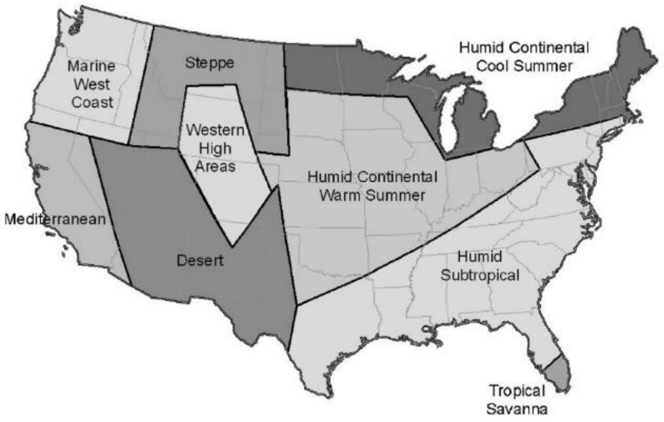
With reflective insulation
@45deg pitch with
75mm air space

- Cooler temperature at the attic space
- Convective heat is lesser (vortices lesser)
- Air velocities decreases in the attic



A perspective on the effect of climate and local environmental variables on the performance of attic radiant barriers in the United States

Mario A. Medina*, Bryan Young



Techno-economic evaluation of roof thermal insulation for a hypermarket in equatorial climate: Malaysia

Sau Wai Lee, Chin Haw Lim
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Bangi, Selangor, Malaysia

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Greenbuildingindex Sdn Bhd
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Ivan Loo
Terreal Malaysia Sdn Bhd
Selangor, Malaysia

Location: Selangor, Malaysia
Climate: Tropical hot and humid
Ambient temperature: 32ÁC
Relative Humidity: 75%

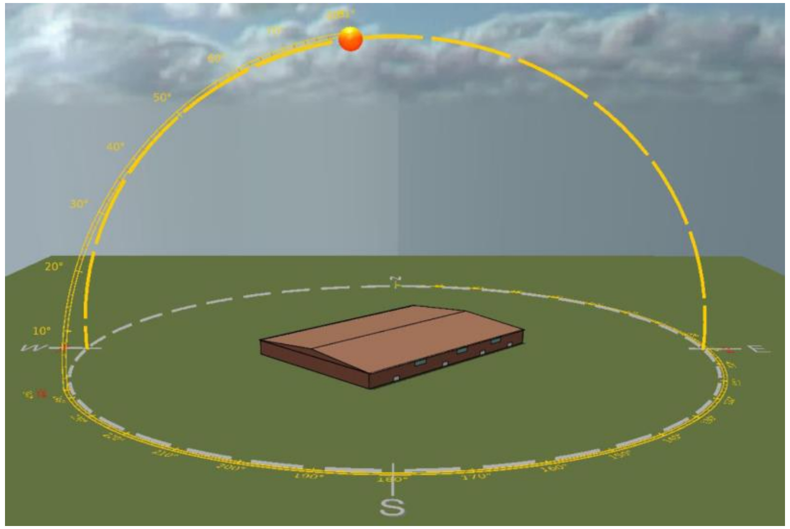


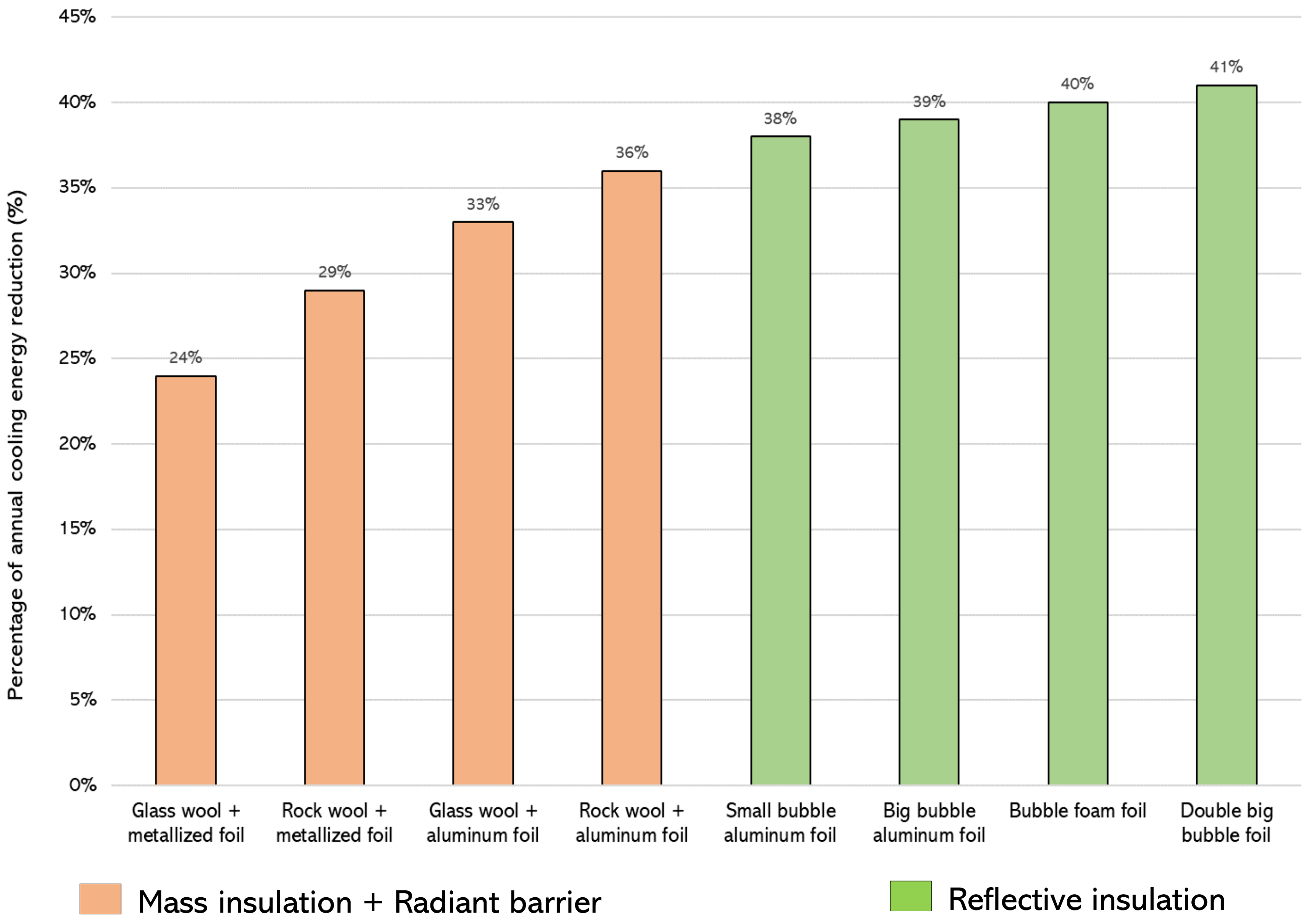
Figure: Hypermarket located in Klang Valley, modelled in IESVE

Simulation profile:

1. Metal deck roof
2. Simulation under Malaysia's weather condition
3. Operation for one year, 7 days a week
4. Maximum A/C and lighting usage during operational hours
5. Shoppers occupancy at 100%
    1. 3 hours during weekdays
    2. 6 hours during weekends

Aim: Investigate the annual cooling energy reduction for each insulation as compared to Base case (non-insulated roof)

	Case	Insulation materials	Insulation system
	0	Base case (non-insulated roof)	Air gap of 80mm
Mass insulation + Radiant barrier	1	Glass wool + metallized foil	Glasswool Metallized foil 0.16mm 50mm lower air gap
	2	Rock wool + metallized foil	Rockwool Metallized foil 0.16 mm 50mm lower air gap
	3	Glass wool + aluminium foil	Glasswool Aluminium foil 0.16 mm 50mm lower air gap
	4	Rock wool + aluminium foil	Rockwool Aluminium foil 0.16 mm 50mm lower air gap
Reflective Insulation	5	Small bubble aluminum foil	30mm upper air gap Small bubble aluminium foil 4 mm 50mm lower air gap
	6	Big bubble aluminum foil	30mm upper air gap Big bubble aluminum foil 8mm 50mm lower air gap
	7	Bubble + foam foil	30mm upper air gap Bubble + foam foil 9 mm 50mm lower air gap
	8	Double big bubble foil	30mm upper air gap Double big bubble foil 16 mm 50mm lower air gap



Location: Selangor, Malaysia
Climate: Tropical hot and humid
Ambient temperature: 32ÁC
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Source: S.W. Lee, C.H. Lim, Elias Salleh, Reflective thermal insulation systems in building: A review on radiant barrier and reflective insulation, Renew. Sustain. Energy Rev. 65 (2016) 643–661. doi:10.1016/j.rser.2016.07.002.

Conclusion

- Climatic conditions such as **solar radiation**, **ambient temperature** and **relative humidity** have direct effect on the performance of roof insulations.

- Reflective foil is more effective in tropical countries that experience **high ambient temperature** or **tropical climate with hot and humid condition** all year round

    - The **high reflectivity and low emissivity** characteristics of reflective foil is effective in reducing radiative heat gain and thus reduces the cooling energy usage

- Mass insulation is highly beneficial for countries that experience **cold winter with extreme low ambient temperature**

    - The **high R-value** of mass insulation is effective at reducing heat loss and thus reduces the heating energy usage

APPLICATIONS OF ROOF THERMAL INSULATION IN TROPICAL CLIMATE

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- National Evaluator for UNIDO
- Head of first Authorized Training Centre for building performance simulation software in UKM (IESVE)
- Expert for Malaysia Sustainable Energy Development Authority (SEDA)
- Board member of Malaysia Green Building Council (MGBC) between 2017-2018
- Expert panel for working group of selected Malaysian Standards

Accolades

- ASEAN Energy Awards (2004, 2014, and 2015)

DIALOGUE SESSION

Photo by **Tima Miroshnichenko** from **Pexels**

Consideration on the practicality of a reflective air-gap

Shouldn't the reflective air-space be ventilated?

How to differentiate Radiant Barrier & Reflective Insulation?

Challenge in influencing building design with research outcomes

ASK US ANYTHING!

SUMMARY

Photo by Luca Nardone from Pexels