A typical installation with underdeck insulation

Underdeck Thermal Insulation for Building Envelope

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Introduction

In a tropical country like India, the ambient conditions vary from summer to monsoon to winter season. They also vary from region to region. During the summer and monsoon seasons, relative humidity is very high. During the summer season, the combination of high temperature and high relative humidity makes the inside conditions uncomfortable in building envelopes.

Radiation, conduction and convection are modes of heat transfer. Surface temperature is greatly affected by these parameters. In the summer season, heat is transferred by conduction, convection and radiation, or by a combination of these three parameters, but the most significant mode is by conduction through the roof and walls. On the other hand, during the winter season, conductive and convective heat losses are more important factors and the contribution of radiation heat losses is less important. The inside temperature in the building envelope gets affected due to conductive and convective heat transfer.

In this scenario, there is a need to retard and obstruct this overall heat transfer. The method of retarding the flow of heat or cold is termed thermal insulation.

About the Author

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Importance of Thermal Insulation

Thermal insulation is an essential part of a building and performs many functions:

1. To reduce the rate of heat flow by conduction, convection and radiation.
2. To reduce the heating/cooling load, leading to energy conservation.
3. To improve human comfort, thereby increasing the efficiency of workmen.
4. To maintain inside conditions or to prevent excessive temperature drop during the winter.
5. To prevent condensation.

6. To protect people and the installation in case of fire.
7. To reduce noise levels.

Due to space limitations, the scope of this article is restricted to Underdeck Insulation. Overdeck insulation, insulation on hot surfaces, and insulation on cold surfaces for tanks, vessels, pipes and ducts shall be covered in separate articles.

Underdeck Roof Insulation

Photo 1: Installation with underdeck insulation with ducting running in the conditioned area

Underdeck insulation is a treatment provided to the inner surface of the roof. The performance of a building envelope significantly affects indoor energy consumption, thermal comfort of occupants, and condensation. Considering these factors, the selection of insulation material plays a significant role.

Definitions

It is necessary to define certain technical terms to be able to calculate heat losses and understand the factors involved.

Thermal Conductivity

Thermal conductivity is the ability of a material to conduct heat. Material with lower conductivity is more suitable for insulation. Thermal conductivity is also known as 'K' or 'λ' value at mean temperature. Its unit is W/m.°C or BTU.in/ft^2.hr.°F.

Thermal conductivity values are dependent on application workmanship, density, structural limitation, exposure to atmospheric condition, movement of air, state of insulation surface, and manufacturer's performance data. Maximum specified thermal conductivity values are mentioned in various standard specifications. However, the designer should ensure that proper design values have been taken to satisfy the specific requirement of the user.

Thermal Resistance

Thermal resistance or 'R' value is a measure of the resistance offered to heat flow by a material of a given thickness. It is expressed in m^2.°C/W or hr.ft^2.°F/BTU.

In simple terms R= T/K

Where:

R= Thermal resistance

T= Thickness of insulating material

K= Thermal conductivity

'R' value is widely used in practice to describe the thermal resistance of insulation materials. Increasing the thickness of an insulation layer increases its thermal resistance. Heat transfer of the material is linearly related to its thickness.

In practice, for compressible materials such as rock wool and glass wool, thermal properties change when they are compressed, i.e., compressing fiber glass or rock wool reduces its 'R' value as its thickness decreases.

For multilayer insulation, one cannot multiply the 'R' value of insulation by the number of layers, as there is heat loss due to air leakage from between the layers.

Reflective foils have high thermal conductivity and would function poorly as conductive insulators. Their effectiveness, when employed to resist heat gain, is limited due to their high reflectivity, i.e. low emissivity. Hence, in practice, one needs to select insulation material with aluminum foil facing the room and not the roof.

Overall thermal resistance can be calculated from the following equation:

$$R = \frac{1}{F_o} + \frac{t_1}{K_1} + \frac{t_2}{K_2} + \frac{1}{F_i}$$

Where

R = Overall thermal resistance of insulation

F_o = Thermal conductivity of air film on outer side (BTU.in/ft^2.hr.°F)

F_i = Thermal conductivity of air film on inner side (BTU.in/ft^2.hr.°F)

K_1 = Thermal conductivity of concrete roof slab (BTU.in/ft^2.hr.°F)

K_2 = Thermal conductivity of insulation material (BTU.in/ft^2.hr.°F)

t_1 = Thickness of homogeneous material (in)

t_2 = Insulating material thickness (in)

To increase the thermal resistance, consideration should be given to the use of multiple layers of roof insulation

Coefficient of Heat Transmission

The symbol 'U' designates the overall coefficient of heat transmission. It is defined as the reciprocal (U = 1/R) of the sums of the resistance of the component parts of the structure or composite material. It is expressed in W/m^2.K or BTU/ft^2.hr.°F.

A low 'U' value indicates a high level of insulation, leading to energy saving.

'U' value forms the basis of design in heat load calculation and is the governing factor in the selection of insulating material.

Energy Saving through use of Phenolic Foam Underdeck Insulation

Case Study 1: G.I. Sheet Roofing

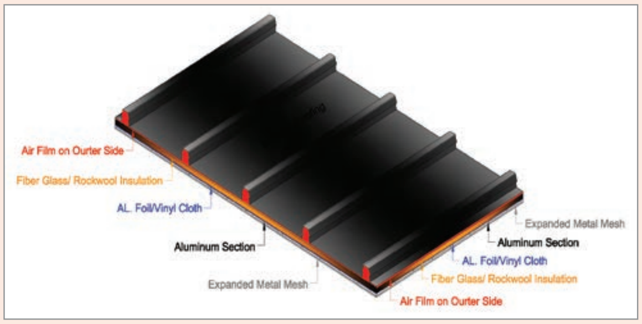

Figure 1: Underdeck insulation with fiber glass / rockwool insulation for metallic roofing

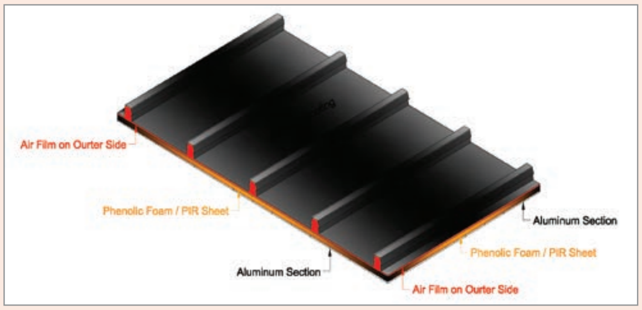

Figure 2: Underdeck insulation with phenolic foam / PIR sheet for metallic roofing

Sample calculations with the assumptions considered:

t_1 = 0.6mm (0.02362") G.I. sheet

t_2 = 2.36" (60mm) phenolic foam insulation material *(Figure 2)*

K_1 = 423 BTU.in/ft2.hr.°F (thermal conductivity of G.I. roofing sheet)

K_2 = 0.194 BTU.in/ft2.hr.°F (thermal conductivity of phenolic foam insulation)

F_o = 4.16 BTU. in/ft2.hr.°F (thermal conductivity of air film at higher temperature)

F_i = 1.73 BTU.in/ft2.hr.°F (thermal conductivity of air film at lower temperature)

Overall thermal resistance of G.I. sheet roofing with insulation:

$$R_{oi} = \frac{1}{F_o} + \frac{t_1}{K_1} + \frac{t_2}{K_2} + \frac{1}{F_i}$$

$$= \frac{1}{4.16} + \frac{0.02362}{423} + \frac{2.36}{0.194} + \frac{1}{1.73}$$

= 12.97˚F.ft².hr/BTU

Overall coefficient of heat transmission U_{oi} with insulation:

$U_{oi} = 1/R_{oi}$

= 1/12.98

= 0.077 BTU/ft².hr.˚F

Overall thermal resistance of G.I. sheet roofing without insulation:

$$R_{ow} = \frac{1}{F_o} + \frac{t_1}{K_1} + \frac{1}{F_i}$$

$$= \frac{1}{4.16} + \frac{0.02362}{423} + \frac{1}{1.73}$$

= 0.81˚F.ft².hr/BTU

Overall coefficient of heat transmission 'U_{ow}' without insulation:

$U_{ow} = 1/R_{ow}$

=1/0.81

= 1.23 BTU/ft².hr.˚F

To calculate the air conditioning load from the above U values, the following data is considered:

Exposed roof area:	10,000 ft²
Ambient temperature:	42˚C (107.6˚F)
Inside room temperature:	24˚C (75.2˚F)
Temperature difference ΔT:	107.6˚F-75.2˚F = 32.4˚F

Air conditioning load with insulated G.I. roofing:

Load = Exposed surface area x solar temperature difference x U value of insulated G.I. roofing

= 10,000 x 32.4 x 0.077

= 24,948 BTU/hr (12,000 BTU/hr = 1 TR)

= 2.079 TR

Air conditioning load with uninsulated G.I. roofing:

Load = Exposed surface area x solar temperature difference x U value of uninsulated G.I. roofing

= 10.000 x 32.4 x 1.23

= 3,98,520 BTU/hr

= 33.21 TR

Hence, saving in AC load due to underdeck roof insulation

= 33.21–2.079 TR

= 31.131 TR

Saving in Capex @ Rs. 40, 000 per TR

= Rs. 40, 000 x 31.131 TR

= Rs. 12,45,240

To calculate saving in Opex, the following data is considered:

1.2 kW/TR: Electrical consumption of AC plant including chiller, pumps, cooling tower, etc.

Rs. 10 per unit (kWhr): Cost of electricity

8 hours: Operating hours per day

25 days: Operating days per month

9 months: Operating months in a year

0.7: Utilization factor

Operating cost saving of AC plant per annum with underdeck insulation for 31.131 TR lower capacity

= TR x electrical consumption x operating hours x operating days x operating months x cost of electricity x utilization factor

= 31.131 x 1.2 x 8 x 25 x 9 x 10 x 0.7

= Rs. 4,70,701 per annum

However, to achieve this cost saving, the user will have to bear the cost of underdeck insulation.

Case Study 2 : Concrete Roof Slab

Sample calculations with assumptions considered:

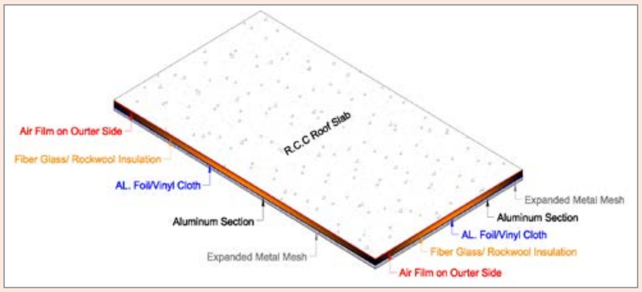

Figure 3: Underdeck insulation with fiber glass / rockwool insulation for R.C.C. roof slab

t_1 = 6" (150mm) thick roof slab with plaster on both outer and inner surface

t_2 = 2.36" (60mm) thick phenolic foam insulation material *(Figure 4)*

K_1 = 7.5 BTU.in/ft².hr.°F (thermal conductivity of roof slab concrete)

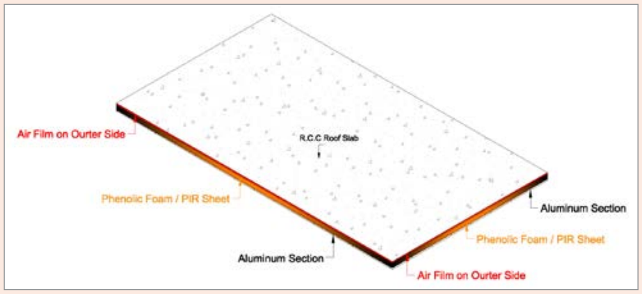

Figure 4: Underdeck insulation with phenolic foam / PIR sheet for R.C.C. roof slab

K_2 = 0.194 BTU.in/ft².hr.°F (thermal conductivity of phenolic foam insulation material)

F_o = 4.16 BTU.in/ft².hr.°F (thermal conductivity of air film at higher temperature)

F_i = 1.73 BTU.in/ft².hr.°F (thermal conductivity of air film at lower temperature)

Ambient temperature: 42˚C (107.6˚F)

Inside room temperature: 24˚C (75.2˚F)

With these assumptions, the designer can calculate the overall coefficient of heat transmission of roof slab with insulation, without insulation and total cost saving (refer the sample calculation in *Case Study 1).*

Table 1: Physical properties and values of insulating materials

Sr. No.	Insulation Material	Thermal Conductivity (K)		Thermal Resistance (R=T/K)		Coefficient of heat transmission (U=1/R)	Density	Thickness
		W/m.K	BTU.in/ft².hr. °F	m².K/W	˚F.ft². hr/BTU	BTU/ft². hr.˚F	Kg/m³	mm
1	Polyurethane foam (PUF) board with foil	0.022	0.152	2.27	12.89	0.077	45±2	50
2	Polyisocyanurate foam (PIR) board with foil	0.023	0.159	2.17	12.32	0.083	45±2	50
3	Phenolic foam board with foil	0.028	0.194	2.14	12.15	0.082	60±5	60
4	Resin bonded fiberglass wool insulation board with foil	0.033	0.228	1.51	8.57	0.116	32	50
5	Rock wool rigid slab with foil	0.033	0.228	2.57	14.59	0.068	48	85
6	Expanded polystyrene (EPS) slab	0.033	0.228	1.51	8.57	0.116	40	50
7	Close cell elastomeric EPDM/ nitrile rubber sheet	0.035	0.242	1.42	8.06	0.124	35±2	50

Note: These 'K' Values are at 10°C mean temperature. They are approximate and based on the average of available figures; therefore, the designer should consider reasonable tolerances to calculate the heat loss.

Conversion Factors

i. Conductivity:

a. Multiply 'K' value in Metric System (W/m.K) by 6.9348 to get 'K' value in English System (BTU.in/ft².hr.°F)

b. Multiply 'K' value in English System (BTU.in/ft².hr.°F) by 0.1442 to get 'K' value in Metric System (W/m.K)

ii. Thermal Resistance

a. Multiply 'R' value in Metric System (m².K/W) by 5.6786 to get 'R' value in English System (˚F.ft². hr/ BTU)

b. Multiply 'R' value in English System (˚F.ft².hr/BTU) by 0.1761 to get 'R' value in Metric System (m². K/W)

Technical Limitations of Insulation Materials

Polyurethane Foam (PUF) and Polyisocyanurate Foam (PIR) Board

i. The structure of these foam boards is 90% close-cell.

ii. These boards have very low water vapour diffusion resistance coefficient (μ value), i.e. ≤60. This increases moistening, which in turn increases thermal conductivity.

iii. CFC or HCFC gases diffuse out of foam board; this gap is replaced by air, thus reducing its 'R' value. This aging effect may start after 5-6 years.

Phenolic Foam Board

i. The structure of phenolic foam board is 95% close-cell.

ii. Phenolic boards have very low water vapor diffusion resistance coefficient (μ value), i.e. ≤50. This increases moistening, which in turn increases thermal conductivity.

iii. This material is environment friendly and manufactured without the use of CFCs or HCFCs, and has zero ODP.

Resin Bonded Fiber Glass Wool and Rock Wool Rigid Slab

Fiber glass and rock wool rigid slabs have relatively high 'R' values for their thickness, and low thermal conductivity. However, their main technical limitations are:

i. Their structure is open cell.
ii. Poor structural strength.
iii. Their μ value is around 1.0, which is very low. Due to this, water content inside the insulation leads to poor thermal efficiency.

Expanded Polystyrene (EPS) Slab

i. Its structure is close-cell, but it performs like open cell. The slab is hard and brittle.
ii. Its μ value is ≥60.
iii. It degrades when exposed to direct sun light.
iv. 'R' value varies by slab density.
v. The material reacts with all solvents.

Close-cell Elastomeric EPDM/ Nitrile Rubber Sheet

i. These sheets are close-cell in structure, which effectively retards the flow of moisture vapour, so ingress and egress of water vapour are negligible.
ii. Their μ value is ≥7000, which allows their use in areas with space limitation.
iii. They are free from CFC or HCFC gases.

Guidelines

1. The thermal conductivity values indicated in *Table 1* are at 10˚C mean temperature.
2. Mean temperature is the average of two temperatures: air in the conditioned area, and ambient air. Mean temperature can be defined as:

Mean temperature (T_m) = [Grille temperature in conditioned area (T_{in}) + ambient temperature (T_{am})]/2

3. In practice, thermal conductivity values should be selected at +24˚C mean temperature.
4. Insulating material should meet Energy Conservation Building Code ECBC-2007.
5. To avoid condensation in the conditioned area, the designer should select insulating material thickness considering the surrounding relative humidity. If the surrounding relative humidity is high, the required thickness of insulating material should be high.
6. User should provide mechanical forced ventilation to reduce attic air.

Acknowledgement

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References

ASHRAE Handbook
Carrier HVAC Handbook