Some Thermal Resistance Values

Assuming constant thickness of given material

Substance	R (1 inch) (imperial units)	R (1cm) (metric units)
Air (non-convecting)	6	0.42
Copper	3.7×10^{-4}	2.6×10^{-5}
Plywood	1.25	8.6×10^{-2}
Glass	0.18	1.3×10^{-2}
Brick	0.11	7.7×10^{-3}
Concrete	0.14	1.0×10^{-2}
Fiberglass batts	3.6	0.25
Polyurethane foam	6.3	0.43

McFarland pg 16-8

To obtain actual R value, multiply by number of inches/cm of thickness

Typical R values for various structures

Structure	R value $ft^2 hr°F/Btu$	R value m^2K/W
2x4 wall with fiberglass insulation	11	1.94
2x4 wall with polyurethane foam insulation	22	3.87
Ceiling with 11 in. fiberglass batts	38	6.87
Ceiling with 14 in. fiberglass batts	49	8.63

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Example (imperial units)

A homeowner has a total ceiling area of (50 ft)x(20 ft) = 1000 ft^2

Currently the attic is insulated with fiberglass insulation having an R value of 8 (“R8”)

Question: If the winter temperature is 32°F and the house interior is at 72°F, how much heat is lost through the ceiling assuming **no air leakage** (just conduction)

From $\Delta T = \left(\frac{Q}{At}\right)R$ we have $\frac{Q}{t} = \frac{1}{R}A\Delta T = \frac{1}{8}(1000)(40) = 5000\frac{Btu}{hr}$

Convert to kW: $\left(5000\frac{Btu}{hr}\right)\left(\frac{1055J}{1Btu}\right)\left(\frac{1hr}{3600s}\right) = 1465W = 1.47kW$

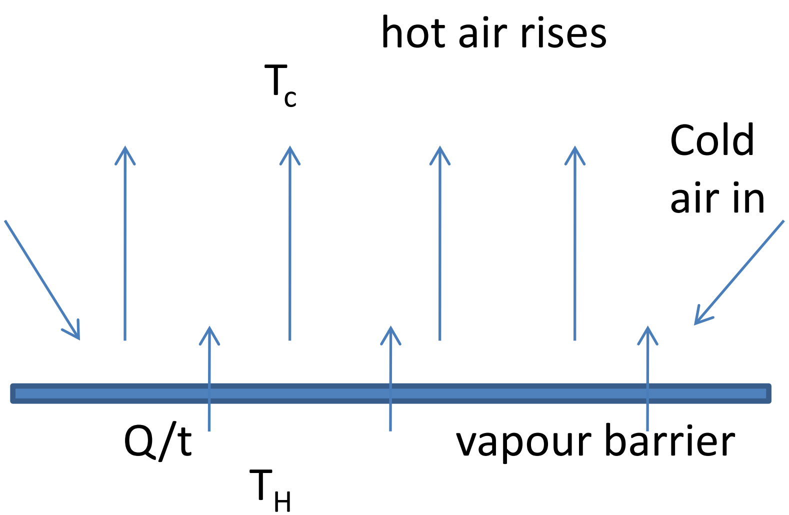
Question: If the homeowner increases to R38 insulation, by what fraction will the heat loss decrease?

Heat loss is proportional to 1/R value, therefore the loss will decrease by a fraction (1/38)/(1/8)= 0.21

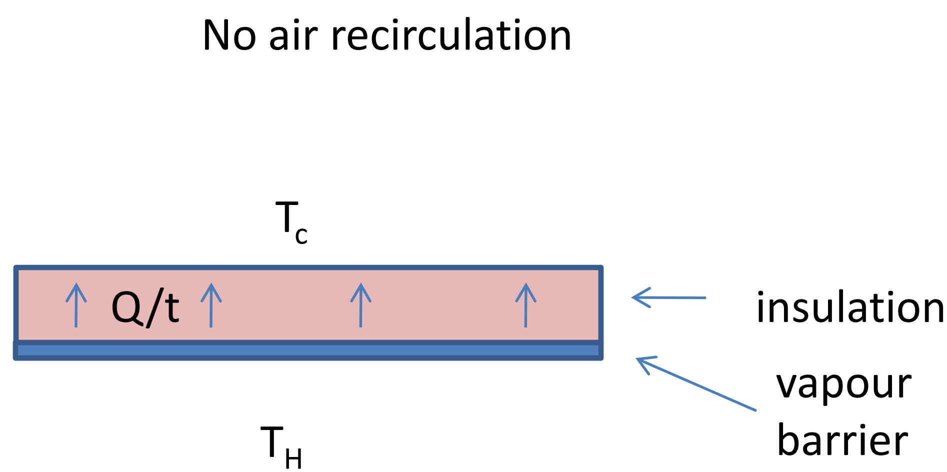
Role of Fiberglass insulation e.g. in house ceiling

Air is a good insulator, but we need to suppress convection

Uninsulated ceiling:



Insulated ceiling:



Uninsulated ceiling:

Warm ceiling transfers heat to air space, hot air rises, and is replaced with cold air in a continuous cycle.

Note: this is not the same as direct air leakage (to be discussed)

Insulated ceiling:

Insulation suppresses physical flow of warm air (convection)

Heat transfer is primarily through conduction which is very slow for air.

Closed cell foams (e.g. polyurethane) are more effective than fiber based insulators.

Heat Loss by Air Leakage (Convection)

- In older homes, a large fraction of the heat is lost through leakiness in the building envelope. This is a form of convection (direct transfer of heat by loss of warm air).

- Heat can escape directly by flow of air through holes in the building sheathing. Because hot air rises, the highest loss is through the roof.

- This is the purpose of the vapour barrier installed in most homes since the late 60s: to prevent the direct flow of hot air to the outside.

- A plastic film is placed all around the house on the warm side of the insulation in order to prevent direct loss of heat via convection (leakage of air).

- Complete sealing is very difficult, since there are so many openings (electrical outlets, door frames, ceiling fans etc.)

- In addition there are adverse health consequences to completely sealing the house: humidity, internal pollutants, spores, etc. can build up.

Air Changes Per Hour (Convection)

Important quantity:
N=number of times in one hour that the air is completely replaced due to leakage

If V = volume of house, then the total loss of air is given by VN (m^3/hr or ft^3/hr)

This hot air is replaced with cold air which has to be heated.

From before we had $Q=C\Delta T$ where ΔT = the temperature difference

Heat capacity C is usually measured in J/K/kg or J/K/mole, however for these calculations it is convenient to quote it as J/K/m^3 or Btu/°F/ft^3.

Specific heat of air: 0.24 Btu/lb/°F
Density of air: 0.074 lb/ft^3
Volume specific heat of air:

$$C = \left(0.24\frac{Btu}{lb \cdot {}^oF}\right)\left(0.074\frac{lb}{ft^3}\right) = 0.018\frac{Btu}{ft^3 \cdot {}^oF}$$

(In SI units: C=<u>1.2kJ/m³/K)</u>

Heat loss rate is then: **Q/t=*NVCΔT***

Heat loss rate Q/t = $VN \times 0.018 \mathrm{x} \Delta T$ (US units (Btu/hr)
=$VN\ \Delta T/3$ (SI units: kW)

(N in hr^{-1})

Sample Calculation

A single story house is 30 ft wide and 50 feet long. The ceiling height is 8 ft. The air is changed at rate of $N=5\ hr^{-1}$ (typical of an older poorly insulated home).

Calculate the rate of heat loss in Btu/hr if the inside temperature is 72°F and the outside temperature is 32°F

Total interior volume = (30ftx50ftx8ft)=12000 ft^3

Total heat loss = $NVC\ \Delta T$= ($5\ hr^{-1}$)($12000\ ft^3$)($0.018\ Btu/ft^3/°F$)(40°F)=

43,000 Btu/hr (12.6kW)

For a high efficiency R2000* home the maximum leakage specification is $N=1.5hr^{-1}$.

This would reduce the heat loss from leakage by a factor of 1.5/5=0.3 to:

12,960 Btu/hr (3.8kW)

(Conversion factor 1kW=3414 Btu/hr)

*http://r2000.chba.ca/

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Windows

Estimate the R value of a single glass window of thickness ¼ inch (6 mm)

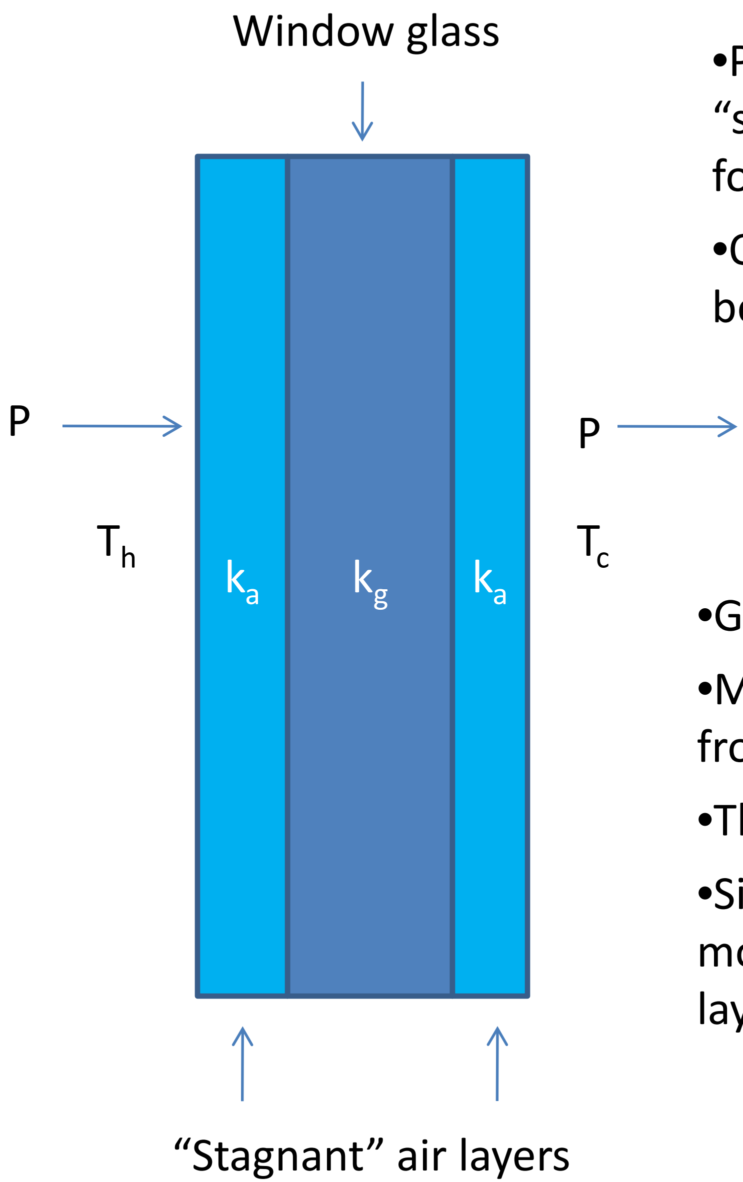
From before: 1 inch of glass has an R value of 0.18

Therefore ¼ inch has an R value of 0.18/4= 0.045 (British units) Very low!!!

Compare this to R=11 for standard insulated wall with 2x4 construction

But something is wrong with this calculation:

Windows: Convective/conductive layer



- Provided the air is not too windy, a thin layer of “stagnant” air called the convective/conductive layer forms at the inside and outside surfaces
- Outside of this layer the temperature is assumed to be constant (either T_h or T_c) due to convection

- Glass is actually a reasonable good conductor of heat
- Most of the insulating effect of glass windows comes from .the conductive-convective layer
- This layer is thickest for still air.
- Since outside air is generally more turbulent (in winter) most of the insulating effect comes from the inside air layer, which tends to be thicker.

Windows

	R value (ft^2-°F-hr/Btu)	R value (RSI) (m^2K/W)
Inside air film alone	0.68	0.120
Single pane (including inside air film)	0.91	0.160
Single pane with storm window	2.00	0.352
Double pane, 1/4" air space	1.69	0.298
Double pane, 1/2" air space	2.04	0.359
Double pane, 1/2" air space, low E glass	3.13	0.551
Triple pane, 1/4" air space	2.56	0.451
Standard 2x4 wall, fiberglass insulation	11	1.94

Conversion factor: R (RSI)=Rx0.176

http://www.coloradoenergy.org/procorner/stuff/r-values.htm

Note how much lower these numbers are than the wall and ceiling numbers. Fortunately window area is a small fraction of the total area, but still a big fraction of the heat loss

Double Glazed Windows

We can increase the insulating properties of the window by adding an extra pane of glass with an air gap between.

Thus we get an additional air layer, which cannot be disrupted by outside air flow.

The air gap can be replaced by an inert gas such as Ar or Kr having higher thermal conductivity

We can also coat the glass with so called “high emissivity” coatings which are designed to reflect heat back into the house.