



Carnegie Mellon University

Thermodynamics (Part I)

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Agenda

1. Fundamentals in heat transfer
2. Impact of the outdoor environment on the indoor of buildings
3. Mitigation strategies through passive design

References

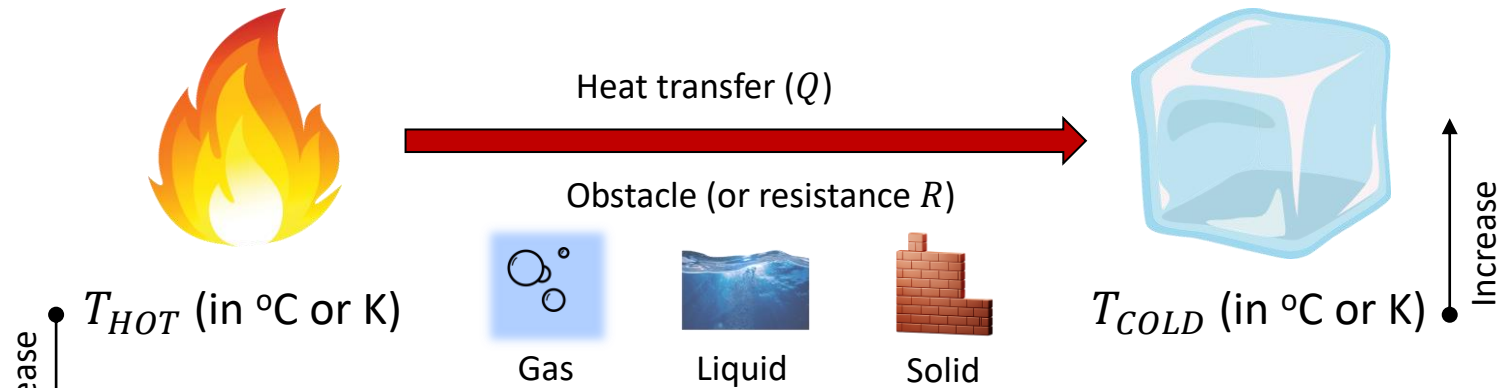
Hens H. S. L., "**Building Physics -- Heat, Air and Moisture: Fundamentals and Engineering Methods with Examples and Exercises**". 2nd Edition. Newark: Ernst Sohn, (2008).

Elaouzy, Y., and A. El Fadar. "**Energy, economic and environmental benefits of integrating passive design strategies into buildings: A review.**" *Renewable and sustainable energy reviews* 167 (2022): 112828.

**What are the important notions of heat transfer
in building science?**

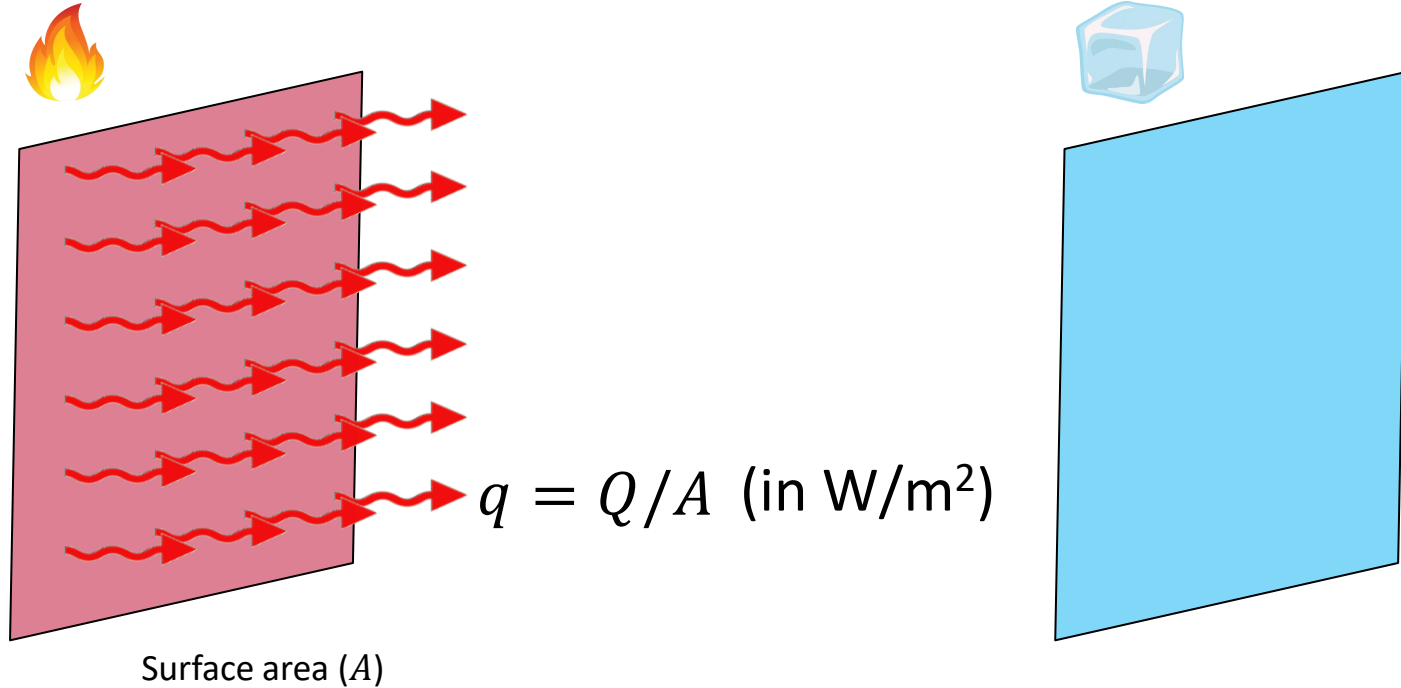
Heat transfer

= rate at which energy is transferred from one hot body to a cold one



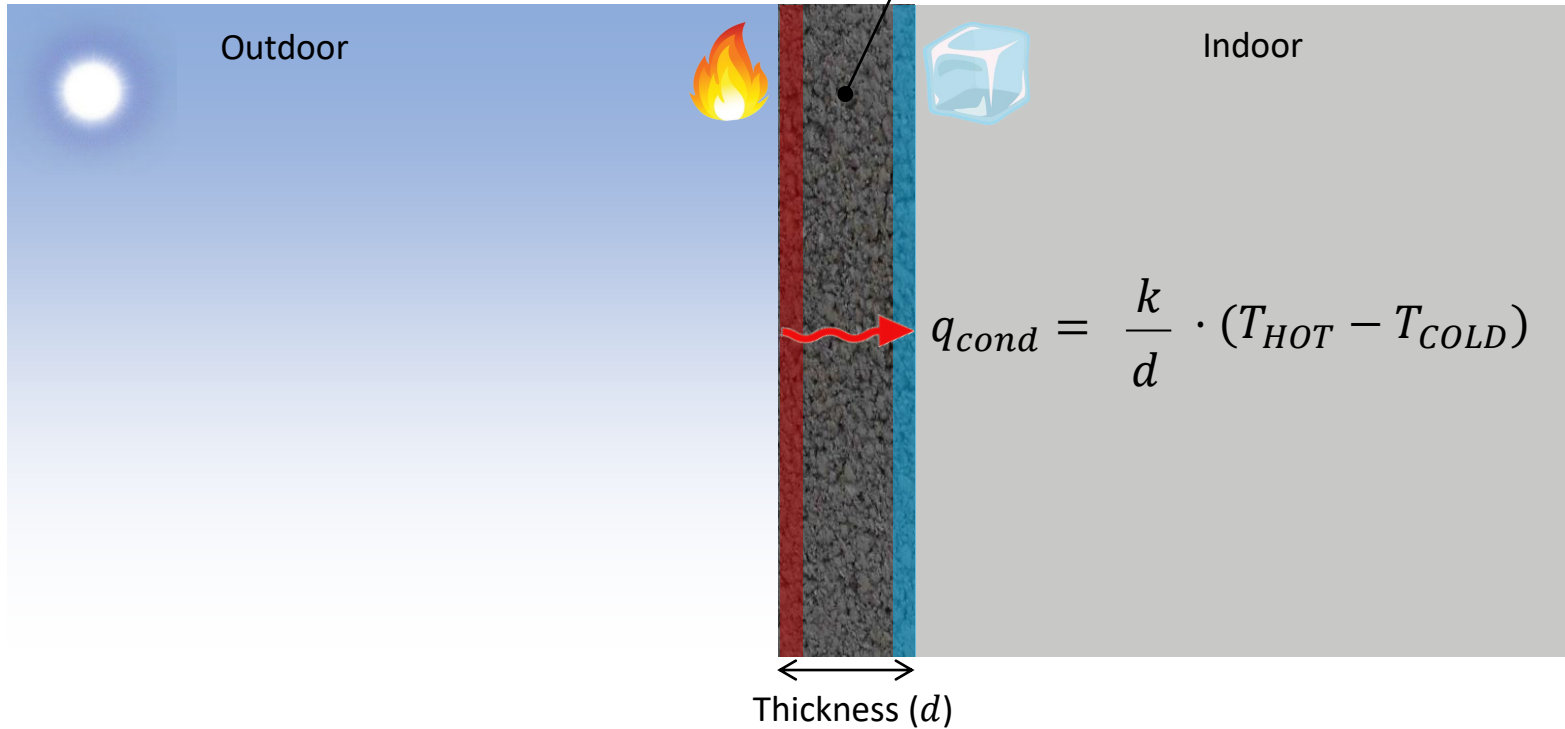
$$Q = \frac{T_{HOT} - T_{COLD}}{R} \quad (\text{in J/s or W})$$

Heat flux



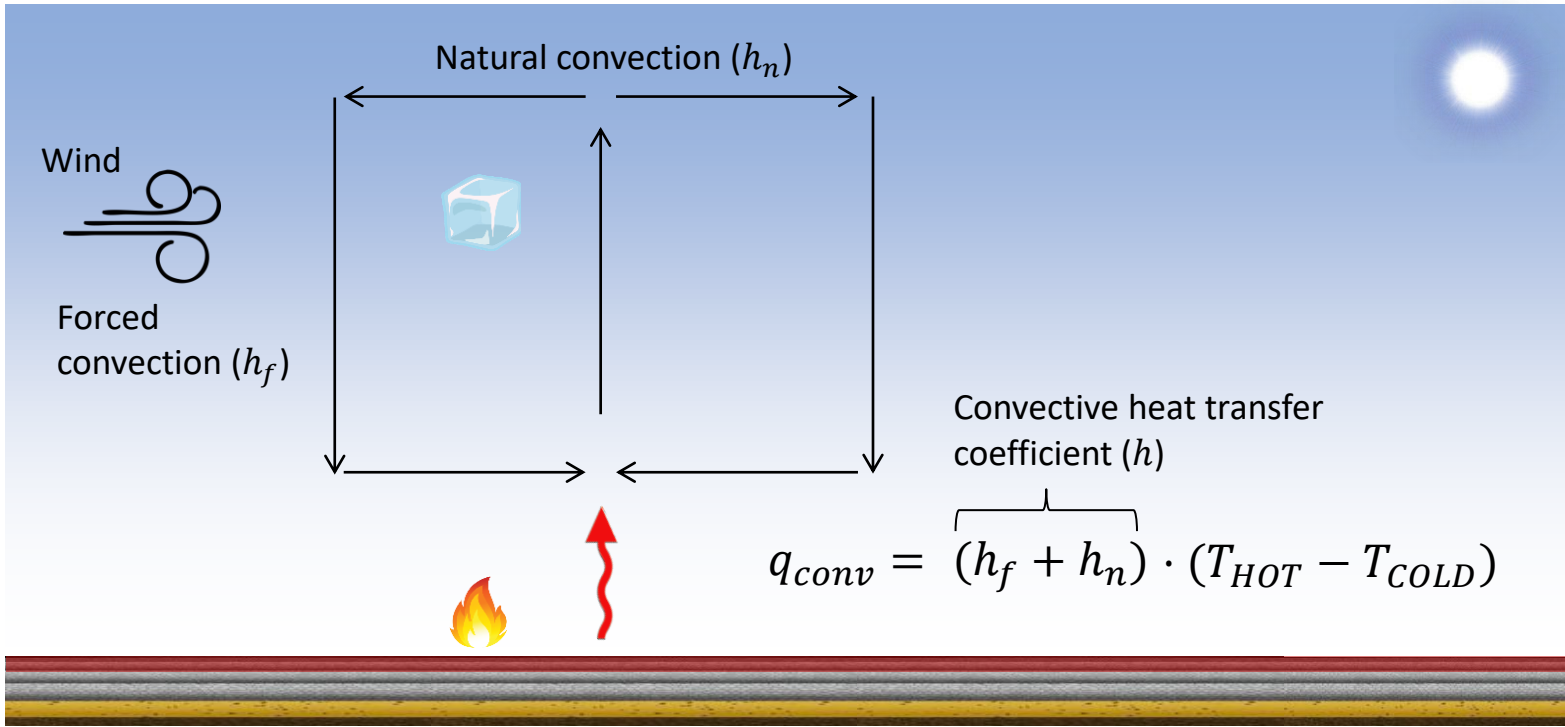
Conduction

= heat transferred through a solid



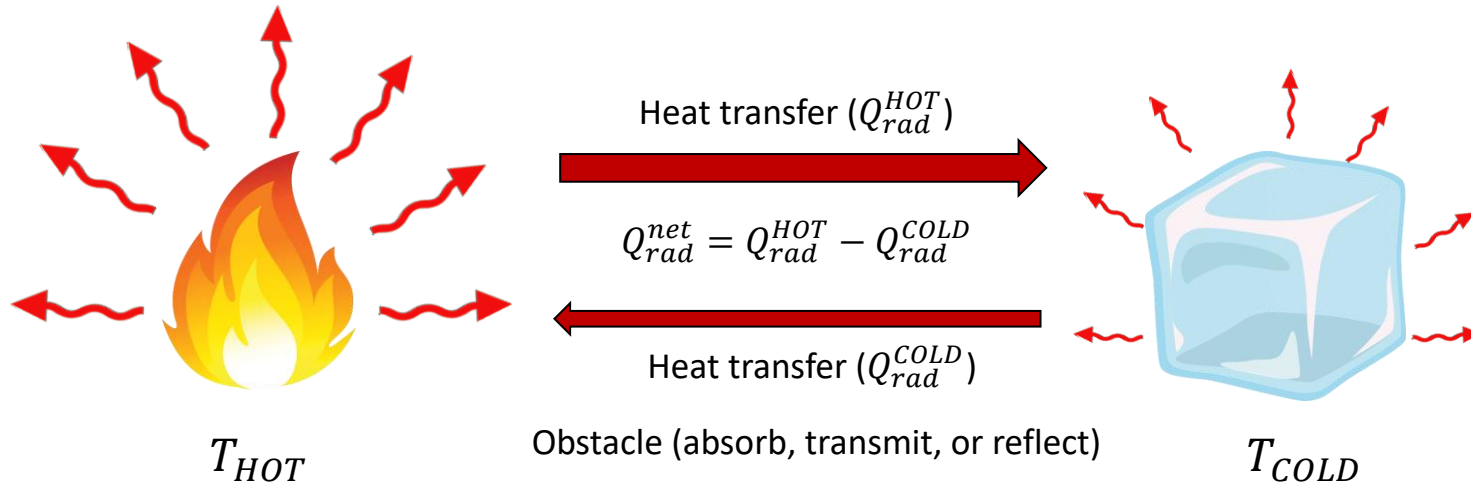
Convection

= heat transferred between a solid surface and a gas or liquid



Radiation

$$\text{Emissivity } (\varepsilon = q_{rad}/(\sigma \cdot T^4))$$



$$q_{rad} = \varepsilon \cdot \underbrace{\sigma \cdot T^4}_{\text{Black body}}$$

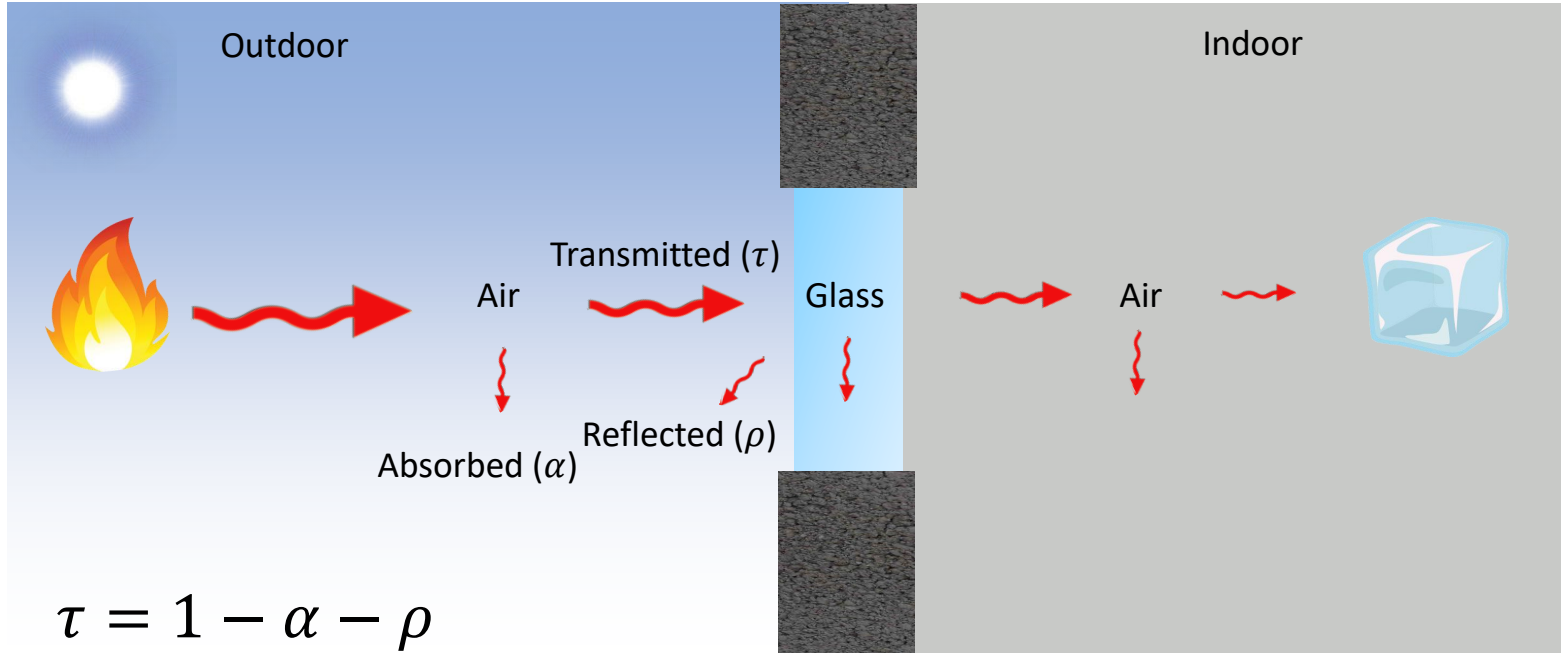


Gas

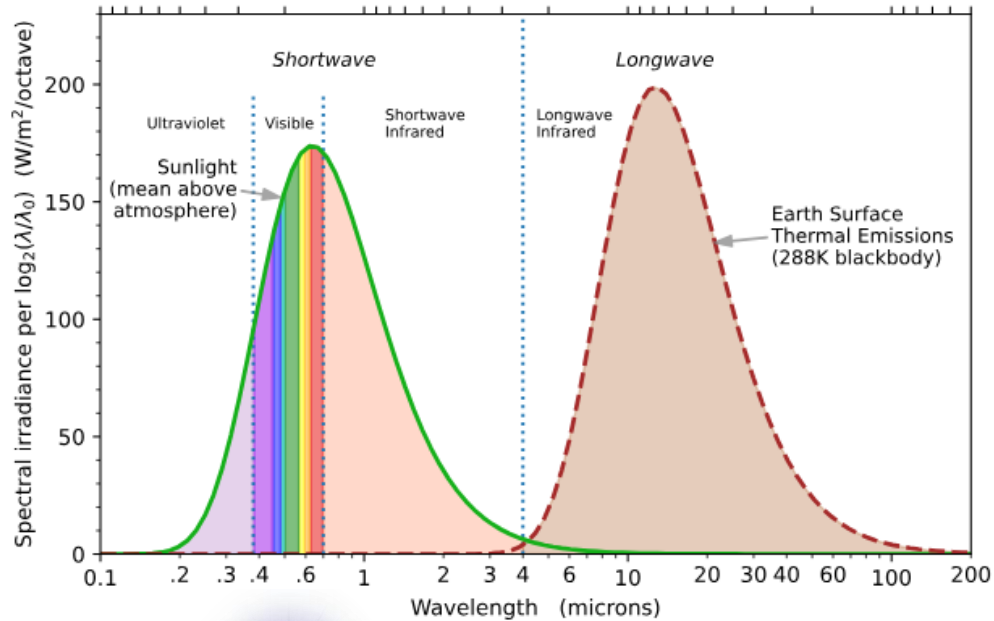


Transparent
solid

Heat transfer by radiation



Shortwave and longwave radiation



Sun



Tree

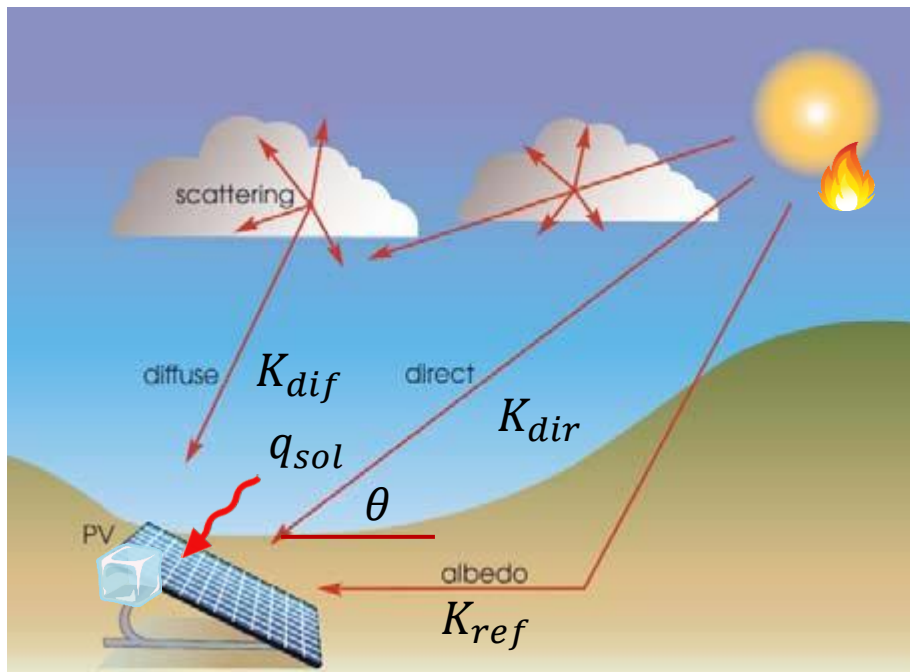


Building



Humans

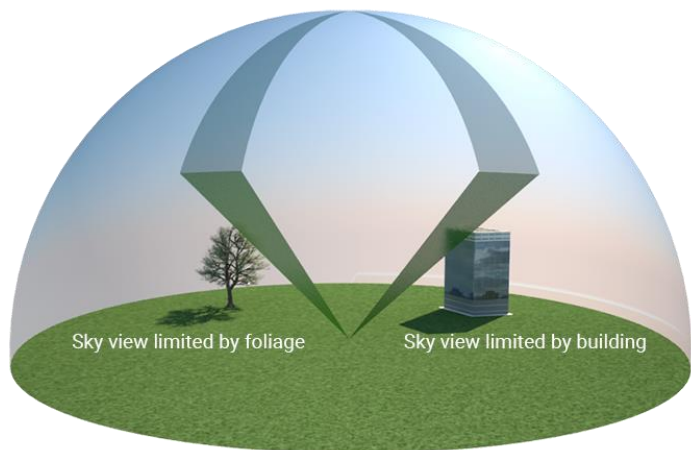
Incident shortwave radiation



$$q_{sol} = (1 - \cos \theta)K_{dir} + F_{sky}K_{dir} + K_{ref}$$

↓
Sky view factor

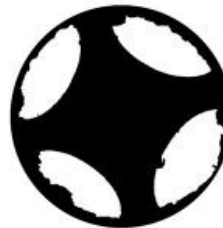
Sky view factor



Golden Gate Bridge
San Francisco (US)
(37,81008°, -122,47643°)
SVF = 0.87



Eiffel Tower
Paris (FR)
(48,85283°, 2,34940°)
SVF = 0.42



Time Square
New York (US)
(40,75734°, -73,98831°)
SVF = 0.37

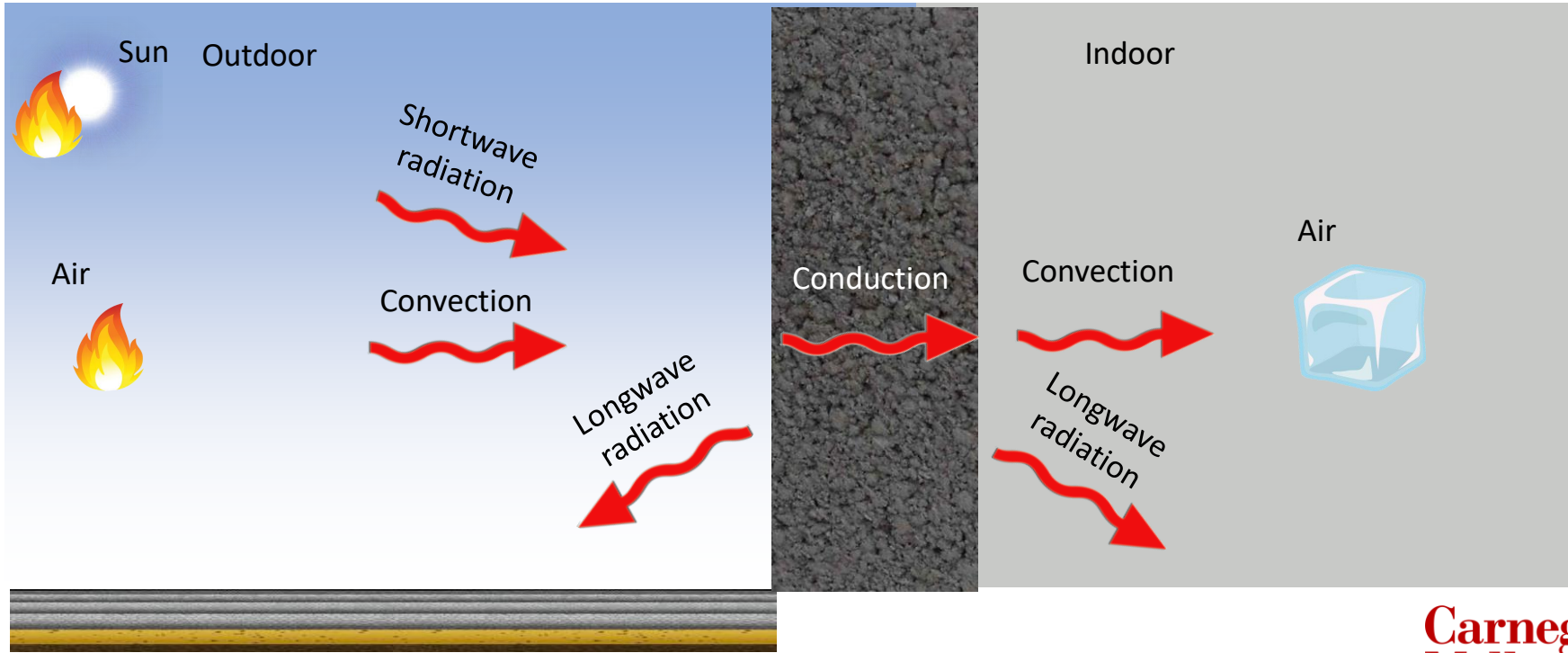


Singapore Zoo
Singapore (Asia)
(1,40290°, 103,79545°)
SVF = 0.19



How is heat transferred into a building?

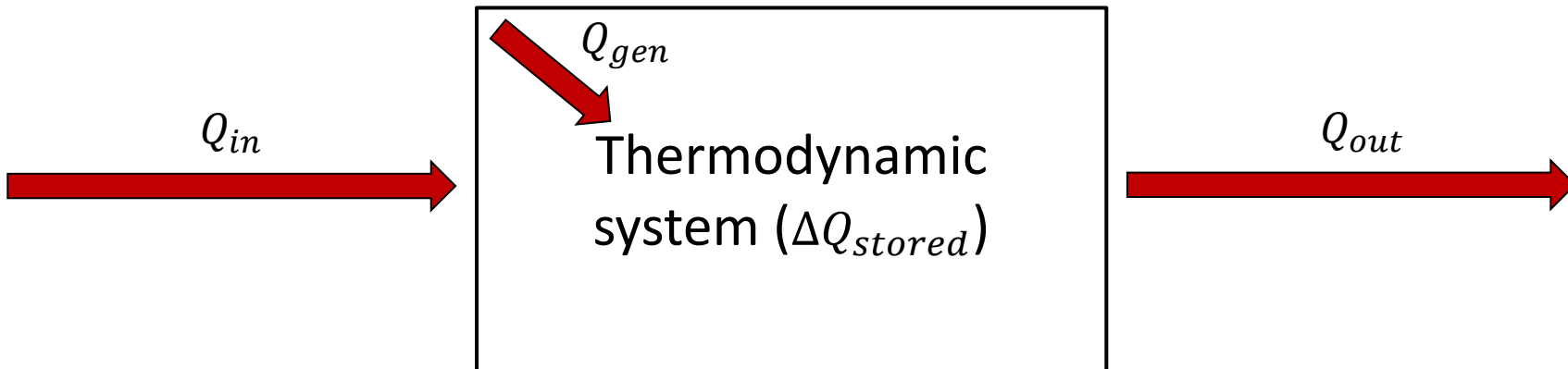
Heat transfer through walls or roofs



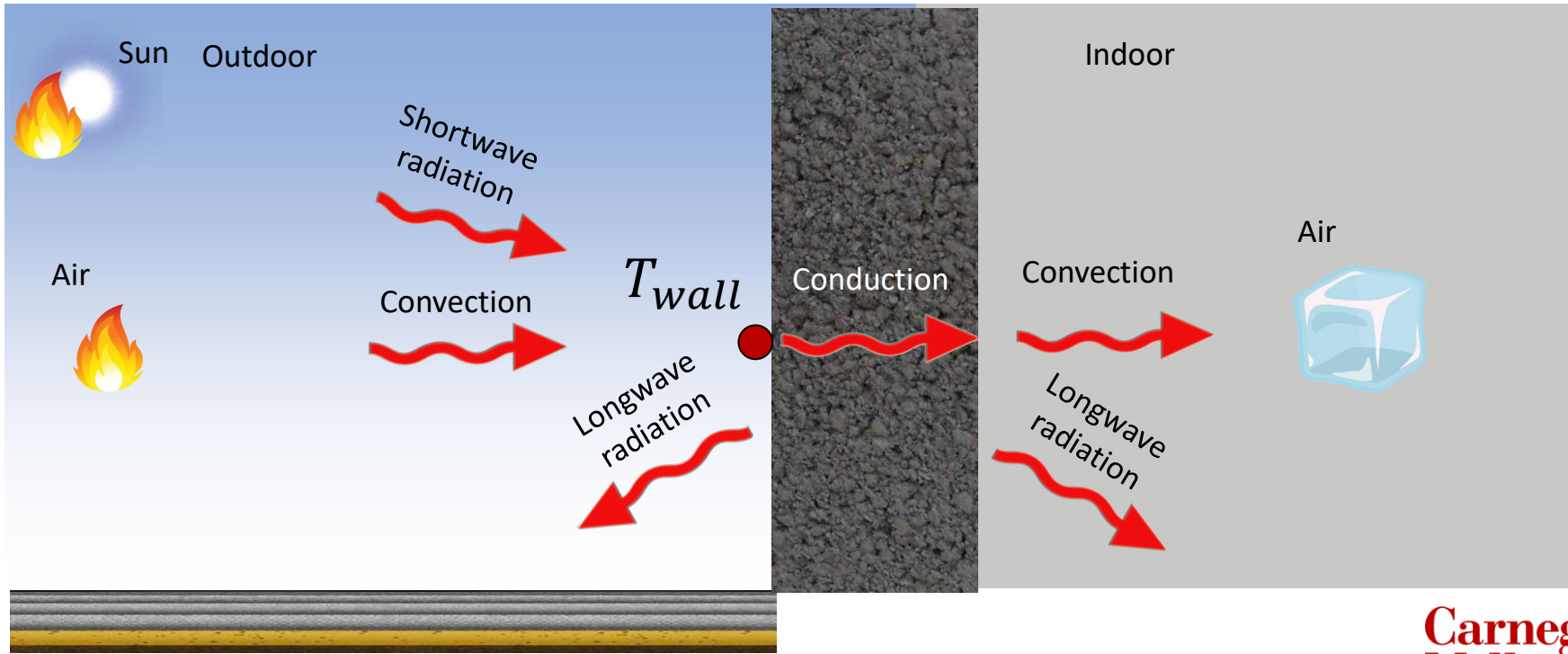
Heat balance

$$\Delta Q_{stored} = Q_{gen} + Q_{in} - Q_{out}$$

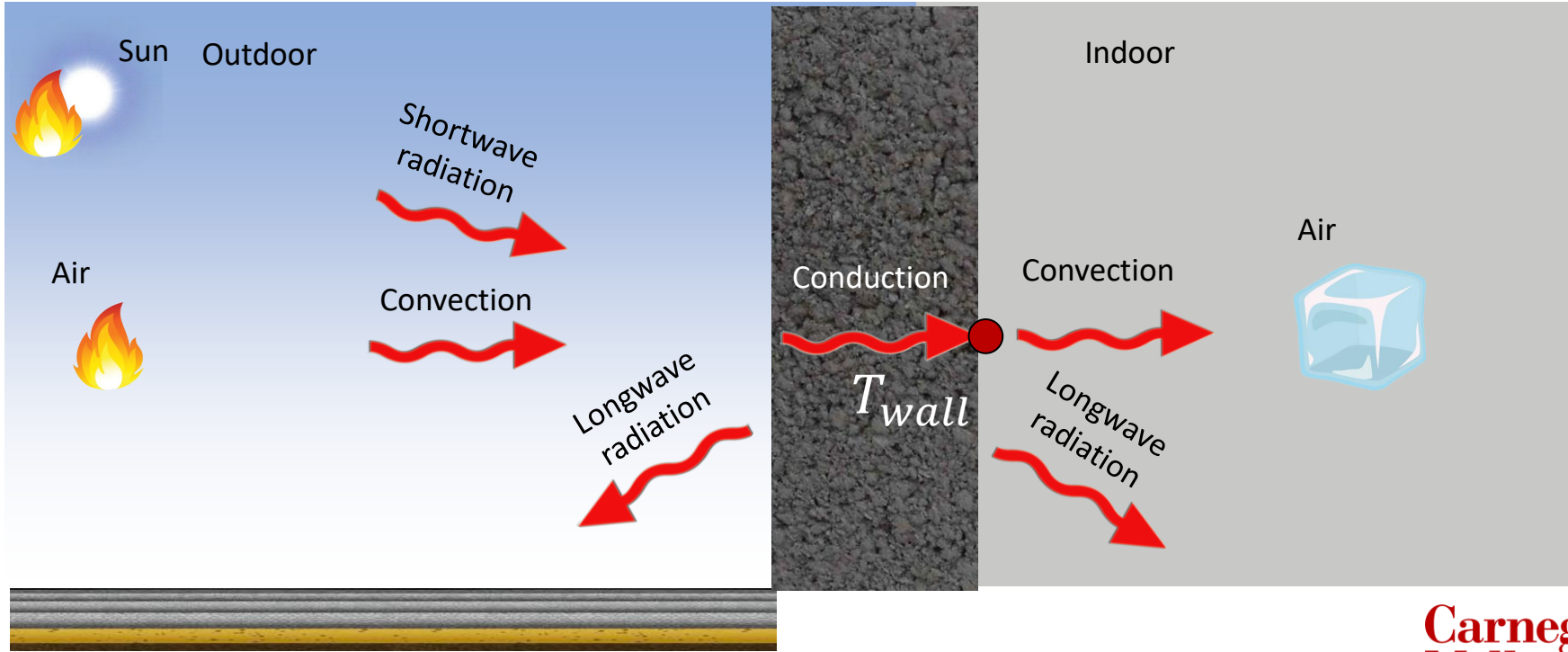
Surrounding



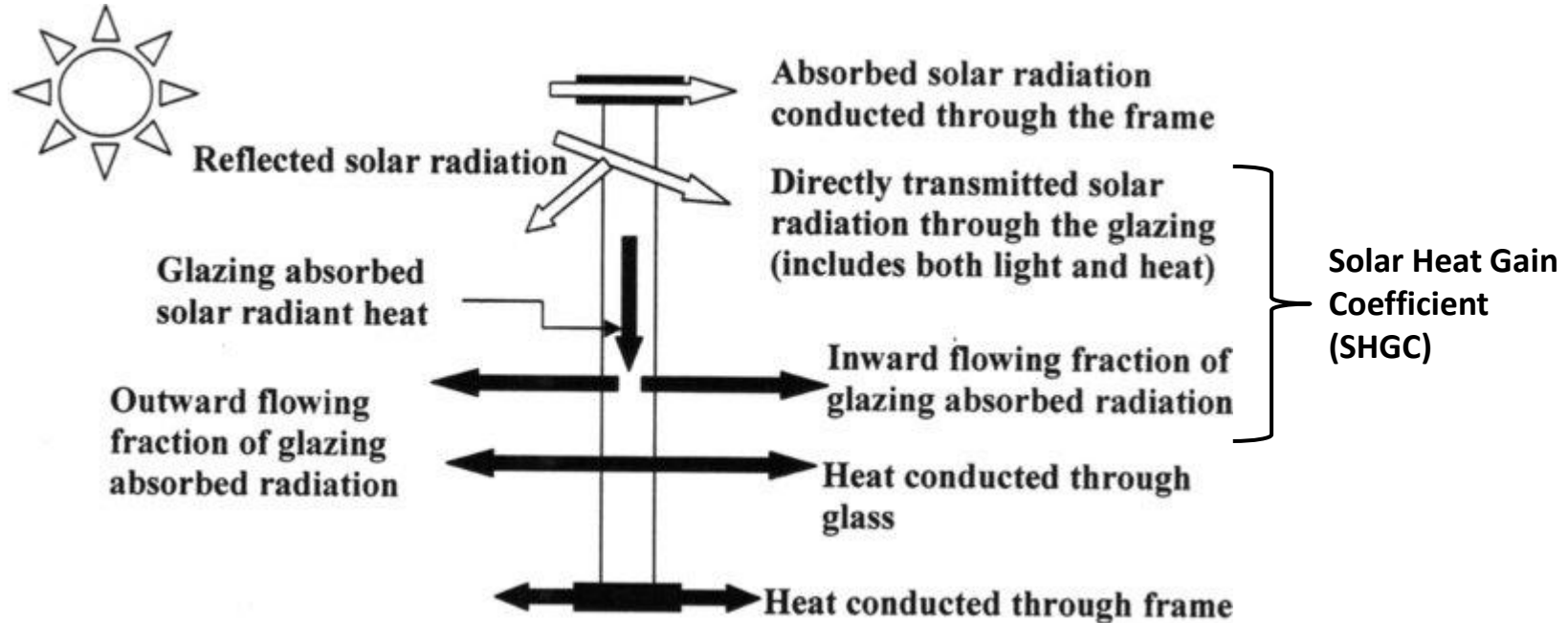
Outdoor heat balance



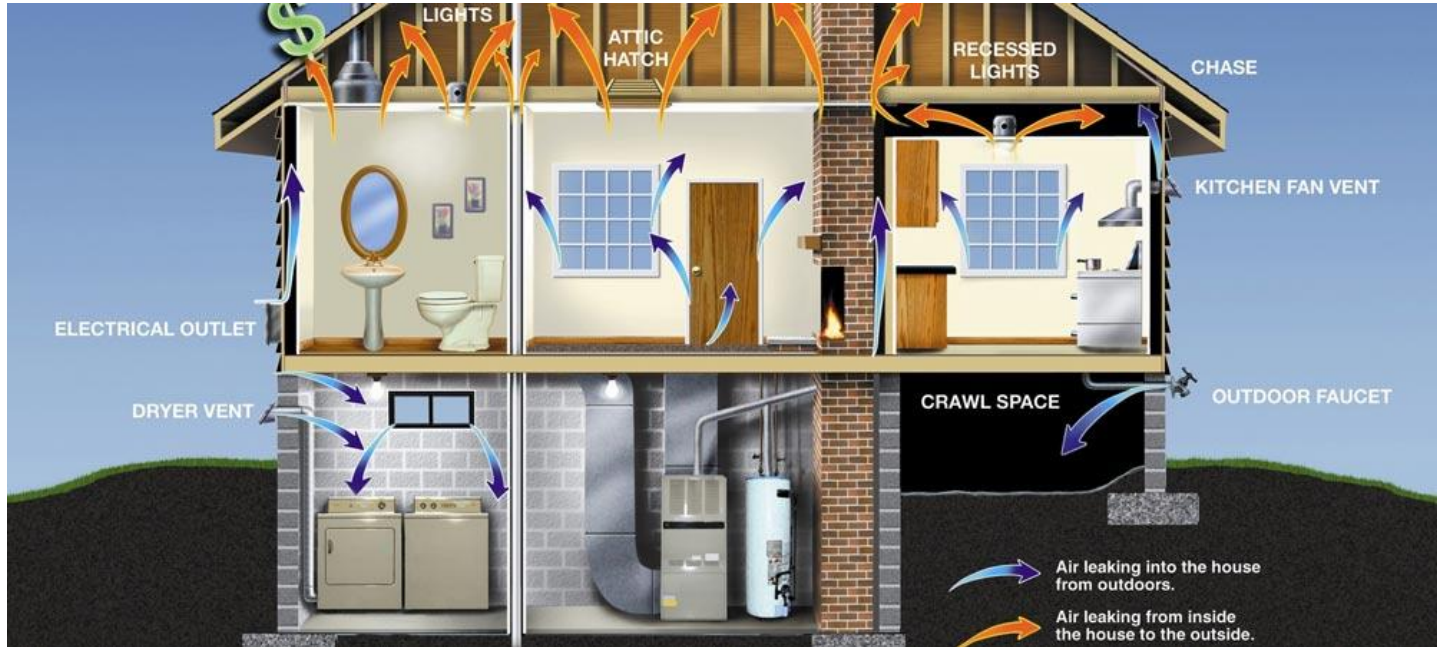
Indoor heat balance



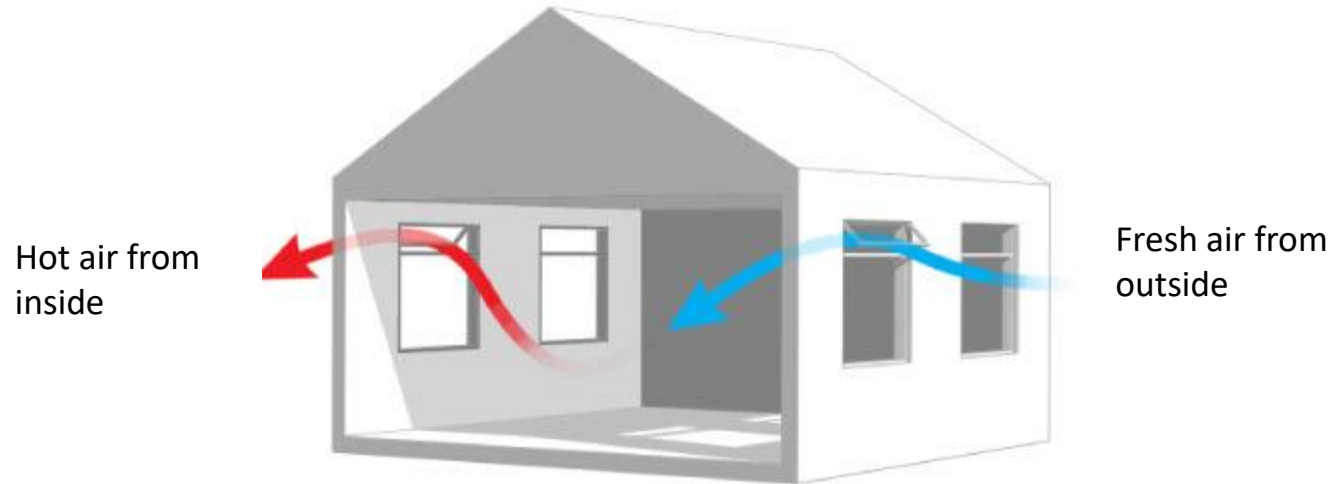
Heat transfer through windows



Infiltration

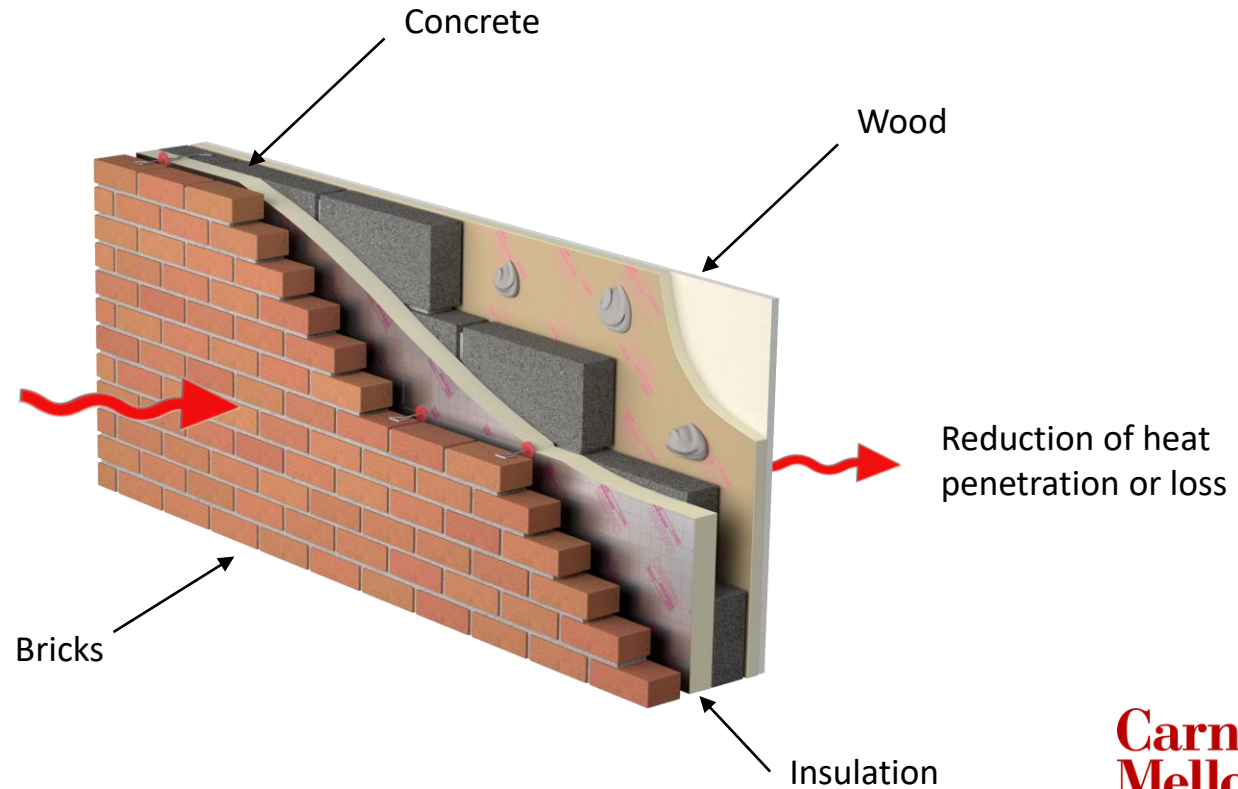


Natural ventilation



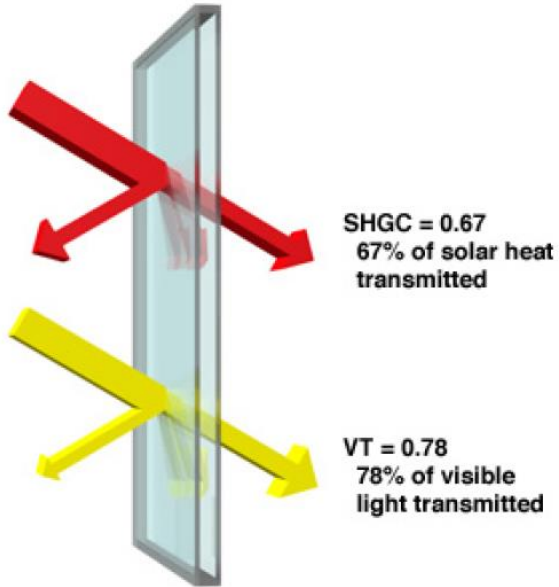
How do some passive design strategies work?

Insulated wall

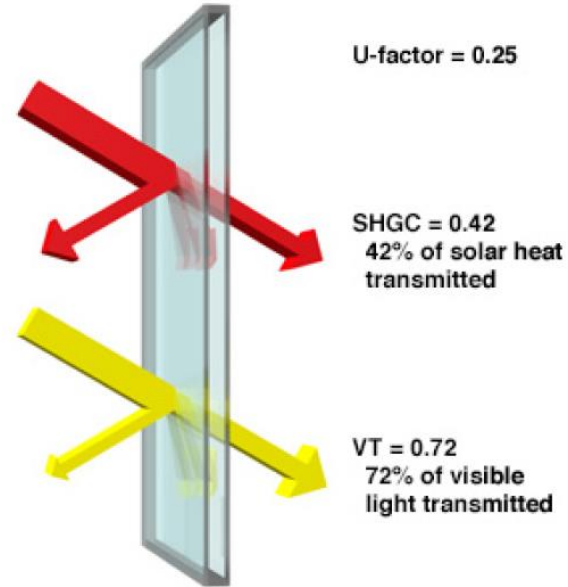


Low-e glass

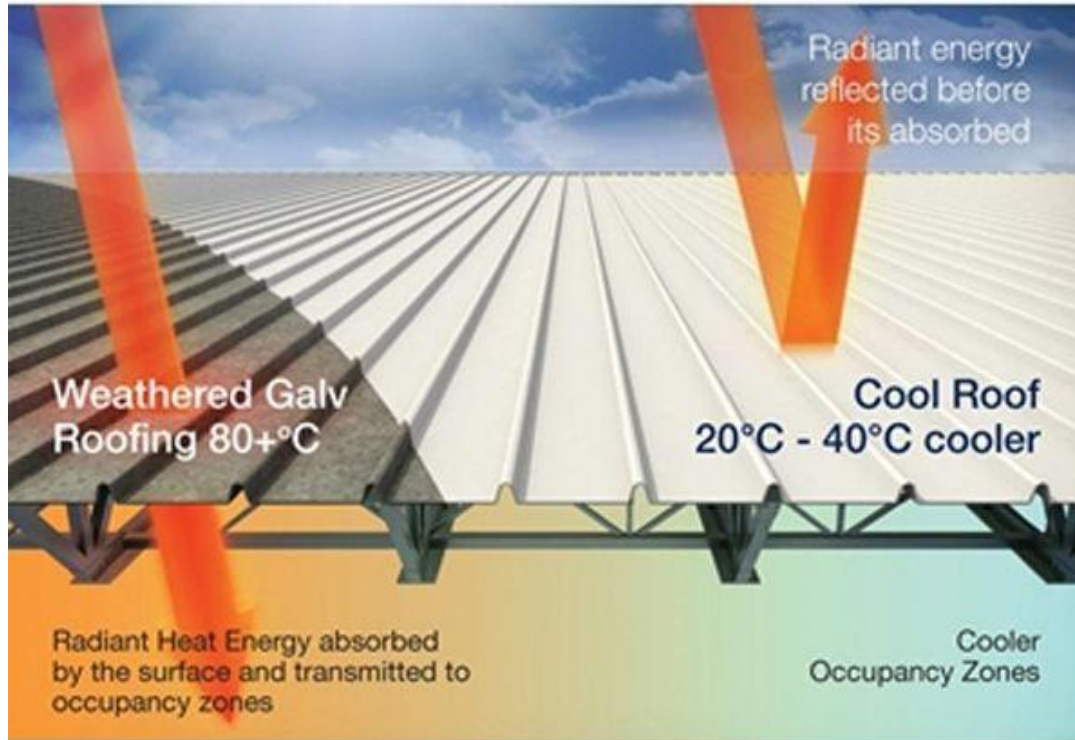
Double glazed



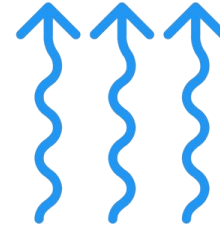
Low-e glass



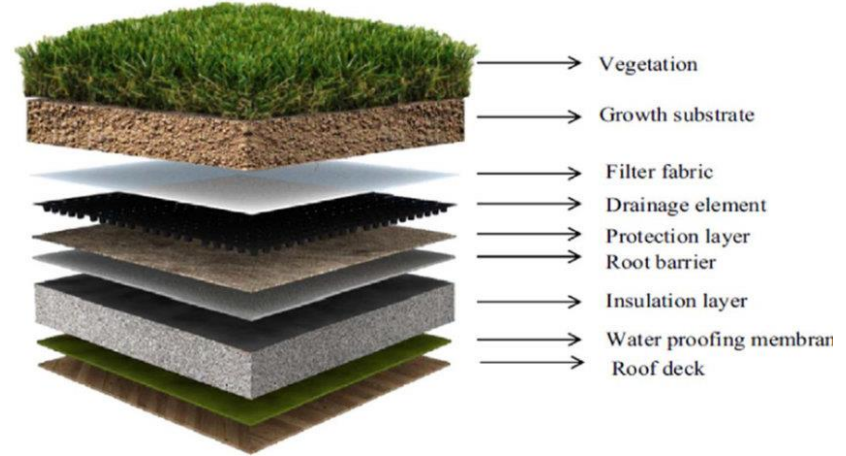
Cool roof



Green roof



Evapotranspiration
(Cooling effect)



Retro-reflective facades

