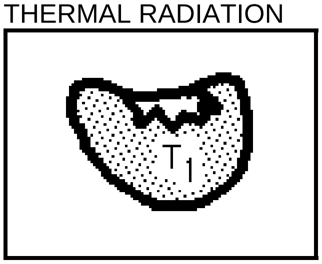
Radiative Heat Transfer

Objectives:
To understand the basics of radiative heat transfer.
To utilize radiative properties in design of energy efficient structures

RADIATION
All materials at temperatures above 0 Absolute emit radiation of an electromagnetic nature;
WAVELENGTH λ FREQUENCY υ

As temperature of solid increases the frequency will increase and wavelength decrease.

THERMAL RADIATION



$\alpha + \rho + \tau = 1$

α =
ρ =
τ =

Black Body -- a body which absorbs all radiation incident upon it

Grey Body -- objects which partially reflect and partially absorb radiation
Lamp black α = ρ =

Absolute magnitude of α,ρ,τ depends on the nature of incoming radiation
e.g. wall of a house is opaque to visible light but transparent to radio waves.

Actual amount of heat transfer to an object by radiation is the difference between what it receives from other sources and what it reradiates back to its own environment

Stefan-Boltzmann's Law

$q_b = \sigma A T^4$

where
T = absolute temperature
q_b = maximum rate of heat which can be radiated at temperature T
$\sigma = 5.669 \times 10^{-8}\ W/m^2K^4$

$q = \varepsilon \sigma AT^4$

Mathematically it can be shown that numerical value of $\alpha = \varepsilon$

ε depends on wavelength and temperature

RADIATION BETWEEN TWO BODIES

Rate of radiative heat transfer from (1)

But rate of heat transfer from (1) to (2) depends upon how much of heat radiated from (1) is absorbed by (2) i.e. it depends on the geometry of system

therefore

where F_{12} is called view factor

Similarly the rate of radiaton from (2) to (1) is

$$q_{21} = F_{21}\,\sigma\, T_2^4 A_2$$

The net rate of radiation from (1) to (2) is

$$q_{net} = \sigma T_1^4 A_1 F_{12} - \sigma T_2^4 A_2 F_{21}$$

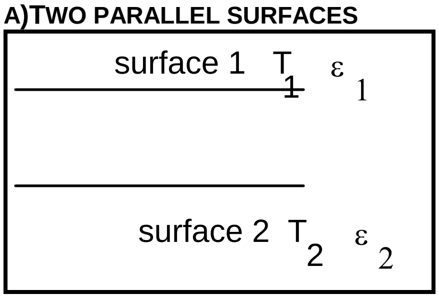
For black or gray bodies

$$A_1 F_{12} = A_2 F_{21}$$

therefore $q_{net} = \sigma A_1 F_{12}(T_1^4 - T_2^4)$

TWO SPECIAL CASES

A)TWO PARALLEL SURFACES

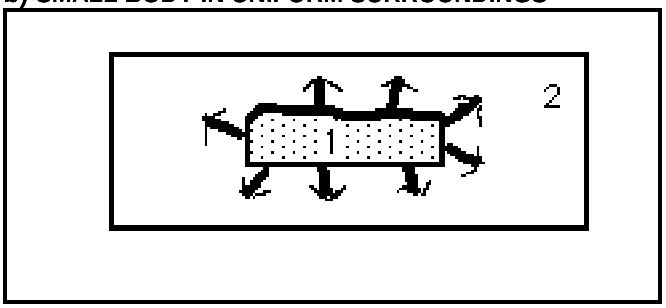


Each surface must intercept the energy emitted by the other

$A_1 = A_2$

and $\frac{1}{F_{12}} = \frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1$

b) SMALL BODY IN UNIFORM SURROUNDINGS

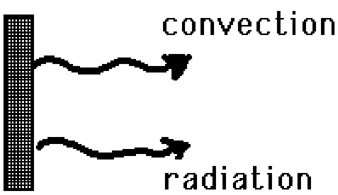


All of the radiation leaving (1) is absorbed by (2)
surface (2) acts like a black body

$F_{12} = \varepsilon_1$

$q_{net} = A_1 \ \varepsilon_1 \sigma \ (T_2^4 - T_1^4)$

EQUIVALENT HEAT TRANSFER COEFFICIENT



Radiation and convection heat transfer often occur in parallel, therefore we can write the following expression

$q_r = h_r A_1 \ (t_1 - t_2)$

$= \ \sigma \ (T_1^4 - T_2^4) \ A_1 \ F_{12}$ (1)

Two ways to find h_r

a) $T_1^4 - T_2^4 = (T_1^2 + T_2^2) \ (T_1^2 - T_2^2)$

$= \ (T_1^2 + T_2^2)(T_1 + T_2)(T_1 - T_2)$

From eqn(1)
therefore

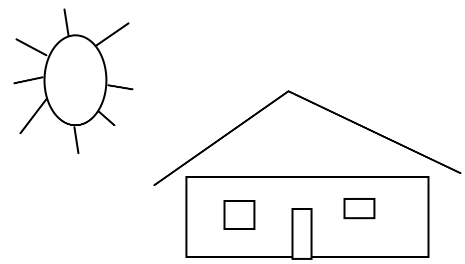
$h_r / F_{12} = \ (T_1^2 + T_2^2)(T_1 + T_2)$

b) If T_1 and T_2 differ by less than 100 C

$h_r = F_{12} \, 4 \, \sigma \, T_{avg}^3$

where $T_{avg} = (T_1 + T_2) / 2$

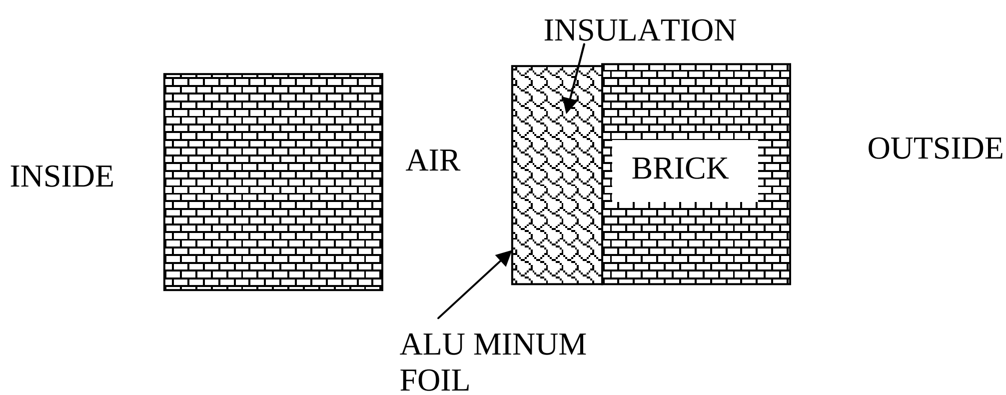
EXAMPLES



What paint should be used for minimum heat gain during summer ?
White Paint
ε short wave = = α short wave
Of the total amount of short wave radiation
radiation absorbed = %
radiation reflected = %

For long wave at 40 C
ε long wave =
it absorbs 95 % of long wave radiation incident on it
If the surface was at 40 C, it will emit 95 % of what a black body will emit at 40 C

Compare with black paint
ε long wave =
ε short wave =



Polished Iron
ε long wave =
ε short wave =

During summer
outside wall surface will receive heat
insulation will eventually heat
but aluminum foil emits very little 6 %

During winter
inner wall is heated
aluminum foil absorbs very little 6 %
reflects 94 % long wave radiation back to inside wall