AL - MUSTAQBAL UNIVERSITY COLLEGE
Iraq – Babylon

Refrigeration and Air conditioning Engineering.
3rd year – refrigeration and Air conditioning Course

Lecture - 3 - Heat gain through wall part-2

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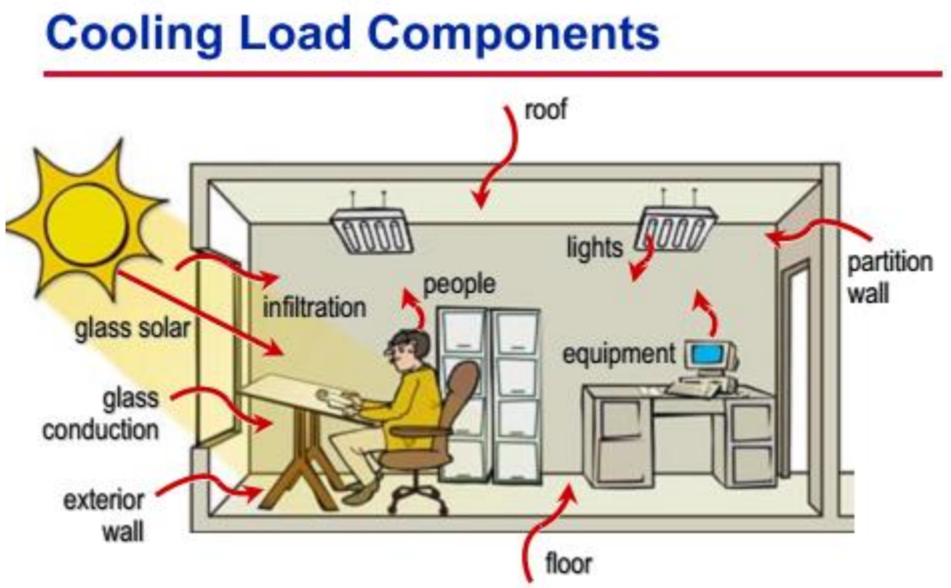
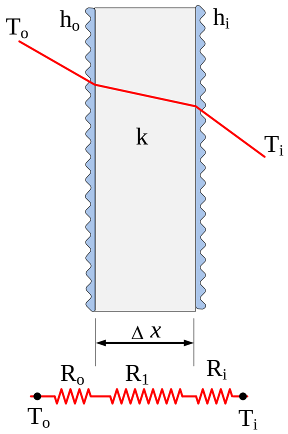


1.4 Heat Transfer Topics

1.4.1 Single layered wall

The overall heat transfer coefficient for single layered wall can be calculated as follows:



$R_o = \frac{1}{h_o}$, $R_i = \frac{1}{h_i}$, $R_1 = \frac{\Delta x}{k}$

$$R_t = R_o + R_1 + R_i$$

$$U_o = \frac{1}{R_t} = \frac{1}{R_o + R_1 + R_i} = \frac{1}{\frac{1}{h_i} + \frac{\Delta x}{k} + \frac{1}{h_o}}$$

Where:

ho: Outdoor heat transfer coefficient W/m^2 K

outdoor heat transfer coefficient for summer is 17 W/(m^2·K),and 29.7 W/m^2 K for winter

: Indoor heat transfer coefficient W/m^{2}K.

indoor coefficient 8.3 W/(m^2·K)

: wall thickness m

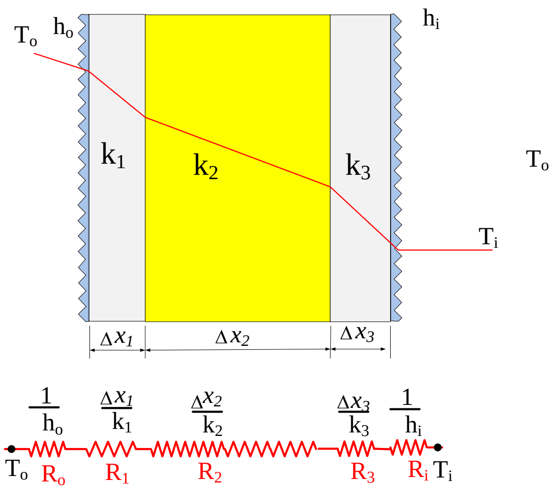
: thermal conductivity W/m K

: Overall heat transfer coefficient W/m^2 K

: Thermal resistance m^2 K/W

1.4.2 Multi layered wall:

If the wall consist of more than one layer, the heat transfer coefficient can be calculated as follows:



$$R_o = \frac{1}{h_o}\ , \quad R_i = \frac{1}{h_i}\ , \qquad R_1 = \frac{\Delta x_1}{k_1}, \quad R_2 = \frac{\Delta x_2}{k_2}, \quad R_3 = \frac{\Delta x_3}{k_3}$$

$$R_t = R_o + R_1 + R_2 + R_3 + R_i$$

$$U_o = \frac{1}{R_t} = \frac{1}{R_o + R_1 + R_2 + R_3 + R_i} = \frac{1}{\frac{1}{h_i} + \frac{\Delta x_1}{k_1} + \frac{\Delta x_2}{k_2} + \frac{\Delta x_3}{k_3} + \frac{1}{h_o}}$$

Example 1:

Find the overall heat transfer coefficient for outdoor wall in summer, the wall consist of 5 mm cement plaster, 24 cm common brick and 10 mm gypsum plaster.

Solution:

From table 19

R_{gypsum}	R_{cement}	K_{Brick}	h_i	h_o
0.026 m^2 K/W	0.05 m2 K/W	0.727 W/m K	8.3 W/m^2 K	17 W/m^2 K

Ro=1/ho=1/17=0.059 m2 K/W

Ri=1/hi=1/8.3=0.121 m2 K/W

R1=R gypsum * (dx/dx)=0.026x(10/20)=0.013 m2 K/W

$R_2 = \frac{\Delta x_2}{k_2} = \frac{0.24}{0.72} = 0.333 \frac{m^2 K}{W}$, R1=R cement * (dx/dx)=0.05x(5/13)=0.0192 m2 K/W

$R_t = R_o + R_1 + R_2 + R_3 + R_i =$ 0.059+0.013+0.333+0.0192+0.121

$R_t = 0.545 \quad \frac{m^2 K}{W}$

$U_o = \frac{1}{R_t} = \frac{1}{0.545} = 1.83 \frac{W}{m^2\,K}$

1.5 Heat gain through wall

The heat gain through a wall is the sum of the relatively steady-state flow that occurs because the inside air temperature is less than that outside, and the unsteady-state gain resulting from the varying intensity of solar radiation on the outer surface of the wall. The phenomenon of unsteady-state heat flow through a wall is complicated by the fact that a wall has a thermal capacity, and so a certain amount of the heat passing through it is stored, being released to the interior (or exterior) at some later time. Two environmental factors are to be considered when assessing the amount of heat entering the outer surface of a wall:

1. the diurnal variation of air temperature, and
2. the sinusoidal-type variation of solar intensity.

Figure 3 presents a simplified picture.

At (a), under steady-state conditions, the graph of temperature through the wall is a straight line. The calculation of heat gain under such circumstance is exactly the same as for the more familiar case of steady-state loss.

At (b) the effect of raising the outer surface temperature. The temperature at the point (Pb) is greater than that at point (Pa). Such an increase could be caused by the outer wall surface receiving solar radiation. Heat flows away from (Pb) in both directions because its temperature is higher than both the air and the material of the wall in its vicinity.

If the intensity of solar radiation then diminishes, the situation in Figure (3c) arises. Since heat flowed away from (Pb), the value of the temperature at (Pc) is now less than it was at (Pb).

When the surface temperature rises again, the situation is as shown at (d). It can be seen that the crest of the wave, represented by points (Pa), (Pb), (Pc), (Pd) etc., is travelling to the right and that its magnitude is reducing. The wave will reach the inner surface of the wall and will produce similar fluctuations in surface temperature. The inner surface temperature will have a succession of values corresponding to the point (Pr) as it rises and falls. Thick walls with a large thermal capacity will damp the temperature wave considerably, whereas thin walls of small capacity will have little damping effect, and fluctuations in outside surface temperature will be apparent, almost immediately, as similar changes in inner surface temperature. It is possible for the inner surface temperatures to be less than room air temperatures, at certain times of the day, for walls of sufficiently heavy construction. A wide diurnal range of temperature can give this result. This outside surface temperature falls at night, by radiation to the black vault of the sky, and the effect of this is felt as a low inside surface temperature at some time later. At such a time, the air conditioning load will be reduced because of the heat lost into the wall from the room. Figure 7.15 presents a simplified picture of this.

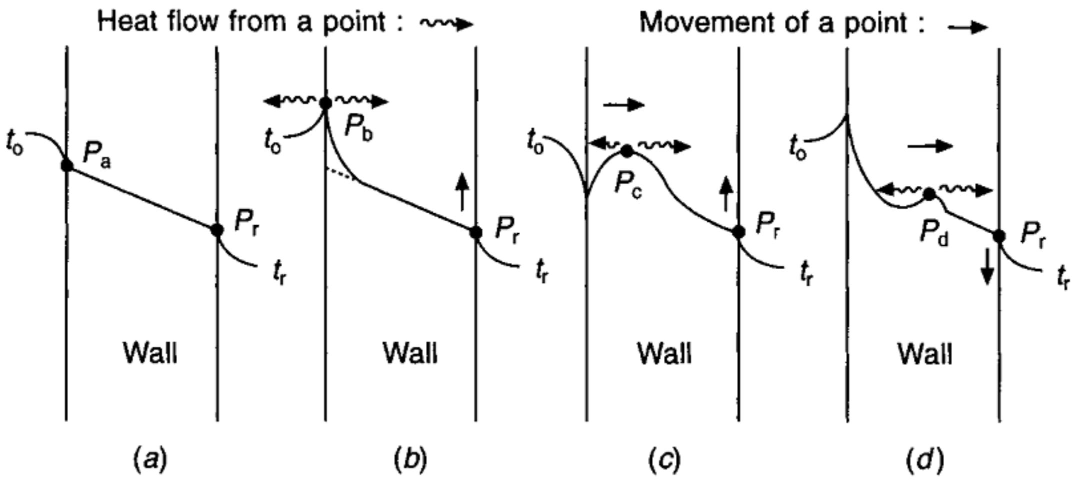


Fig. 3 Temperature gradients in a wall subjected to an unsteady heat input on the outside.

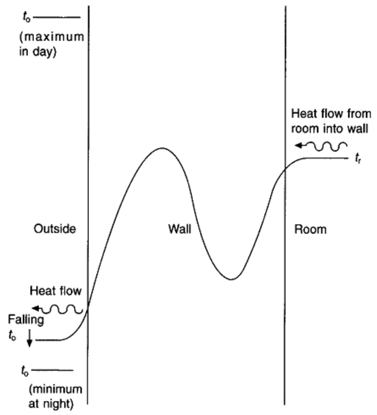


Fig. 4 Temperature gradient in a wall showing the possibility of heat flow outwards under unsteady state conditions.

1.6 Equivalent Temperature Difference:

Equivalent temperature difference takes into account the combined effects of solar radiation, the outside temperature and the flywheel effect of heat storage in the wall or roof.

Basis of Tables 15 and 16

- Equivalent Temperature Difference for Sunlit and Shaded Walls and Roofs

Table 15 and 16 are based on the following conditions:

1. Solar heat in July at 40° North latitude.
2. Outdoor daily range of dry-bulb temperatures, 11°C.
3. Maximum outdoor temperature of 35 °C db and a design indoor temperature of 26.5 °C, i.e. a design difference of 8.5°C
4. 4. Dark color walls and roofs with absorptivity of 0.90. For light color, absorptivity is 0.50; for medium color, 0.70.
5. 5. Sun time. The specific heat of most construction materials is approximately 0.9 kJ/kg K; the thermal capacity of typical walls or roofs is proportional to the weight m^2; this permits easy interpolation.

To calculate the equivalent temperature difference for any wall or roof at any orientation, the following procedures must be considered:

1. Calculate the weight of wall or roof per m^2 (Tables 19)
2. Select the equivalent temperature difference depending on orientation, weight of wall and day time.(Table 15)
3. Select the outdoor design conditions for summer (Table 1)
4. Select the outdoor design conditions for winter (Table 1)
5. Find the yearly range (Step 3 –step 4).
6. Find the daily range (Table 1).
7. Find the difference between (outdoor design condition for month at 3P.M.) – Room design condition .
8. Find the correction of equivalent temp. diff. (Table 16 A)
9. Find the equivalent temperature difference for wall or roof exposed to the sun for desired time of day for the given wall from the following equation:

   $$\Delta t_{em} = (Step\ 2 + step\ 8)$$

10. Find equivalent temperature difference for same wall or roof in shade Δt_{es} at desired time of day.

    $$\Delta t_{es} = equiv.temp.diff.(Table\ 15\ at\ north\ shade) + step\ (8)$$

11. Find the maximum solar radiation maximum solar heat gain through glass for wall facing or horizontal for roofs, for month and latitude desired R_s (Table 12A)
12. Find the maximum solar heat gain through glass for wall facing or horizontal for roofs, for July at 40 North latitude R_m, Table (12B).
13. The correct equivalent temperature difference is:
    a- For light color walls and roofs

$$\Delta t_e = 0.55\frac{R_s}{R_m}.\Delta t_{em} + (1-0.55)\frac{R_s}{R_m}.\Delta t_{es}$$

b- For medium color walls and roofs

$$\Delta t_e = 0.78\frac{R_s}{R_m}.\Delta t_{em} + (1-0.78)\frac{R_s}{R_m}.\Delta t_{es}$$

Example:2

Find the equivalent temperature difference for the wall in example(1), if light colored wall facing south at Baghdad city.

1- Calculate the weight of wall From Table (19)

Material	Thickness (m)		Weight (kg/m^2)
Gypsum	0.01	W=W* (dx/dx)=30.4*(10/20)	15.37
Brick	0.24	W=W* (dx/dx)=390.4x(240/200)	468.48
Cement	0.005	W=W* (dx/dx)=105.6x(5/13)	40.6
Weight of wall			524.5

2- Select the equivalent temperature difference depending on orientation, weight of wall and day time.(Table 15), at south orientation at 488 kg/m^2 and 3 PM, $\Delta t_e = 8.3$ ^oC

EXPOSURE	Weight of wall kg/m^2	SUN TIME											
		PM											
		1	2	3	4	5	6	7	8	9	10	11	12
South	98	15.0	16.7	15.6	14.4	11.1	8.3	6.7	5.6	3.9	3.3	1.7	1.1
	293	11.1	13.3	13.9	14.4	12.8	11.1	8.3	6.7	5.6	4.4	3.3	2.2
	488	4.4	6.7	8.3	8.9	10.0	10.0	8.3	7.8	6.1	5.6	4.4	4.4
	683	2.2	2.2	3.9	5.6	7.2	7.8	8.3	8.9	8.9	7.8	6.7	5.6

3- Select the outdoor design conditions for summer (Table 1) DBT=45 ^oC
4- Select the outdoor design conditions for winter (Table 1) DBT=1.5 ^oC
5- Find the yearly range (Step 3 –step 4). Yearly range = 45-1.5=43.5 ^oC
6- Find the daily range (Table 1). Daily range = 18.7^oC
7- Find the difference between (outdoor design condition for month at 3P.M.) – Room design condition . (Indoor deign condition from Table (2) equals 25 ^oC.

Difference= 45-25= 20 ^oC

8- From Table 16A, the interpolation between Difference and daily range is as follows

FOR MONTH AT 3 P.M. MINUS ROOM TEMP	Daily Range oC												
	8.9	10.0	11.1	12.2	13.3	14.4	15.6	16.7	17.8	18.9	20.0	21.1	22.2
19.4	12.2	11.7	11.1	10.6	10.0	9.4	8.9	8.3	7.8	7.2	6.7	6.1	5.6
22.2	15.0	14.4	13.9	13.3	12.8	12.2	11.7	11.1	10.6	10.0	9.4	8.9	8.3

Tc=7.2

9- Find the equivalent temperature difference for wall or roof exposed to the sun Δt_{em} for desired time of day for the given wall from the following equation:

$\Delta t_{em} = (Step\ 2 + step\ 8)$=8.3+7.2=15.5 °C

10- Find equivalent temperature difference for same wall or roof in shade Δt_{es} at desired time of day.

$\Delta t_{es} = equiv.temp.diff.(Table\ 15\ at\ north\ shade) + step\ (8)$=1.7+7.2=8.9 °C

11- Find the maximum solar radiation maximum solar heat gain through glass for wall facing or horizontal for roofs, for month and latitude desired R_s (Table 12A) Rs=95 W/m²

12- Find the maximum solar heat gain through glass for wall facing or horizontal for roofs, for July at 40 North latitude R_m, Table 12B. Rm=322 W/m²

14. The correct equivalent temperature difference is:

c- For light color walls and roofs

$$\Delta t_e = 0.55\frac{R_s}{R_m}.\Delta t_{em} + (1 - 0.55)\frac{R_s}{R_m}.\Delta t_{es}$$

$$= 0.55\frac{95}{322}.(15.5) + (1 - 0.55)\frac{95}{322}.\,8.9$$

$$= 3.7\ ^{\circ}C$$

Homework:

Find the equivalent temperature difference for the wall mentioned in example 3 for the orientation West, North, east and (Roof) horizontal.