# Air-Conditioning & Refrigeration

BSc

**Lecture 13**

**Course weekly Outline &**

**Ch.1 (Introduction to Air conditioning & Refrigeration)**

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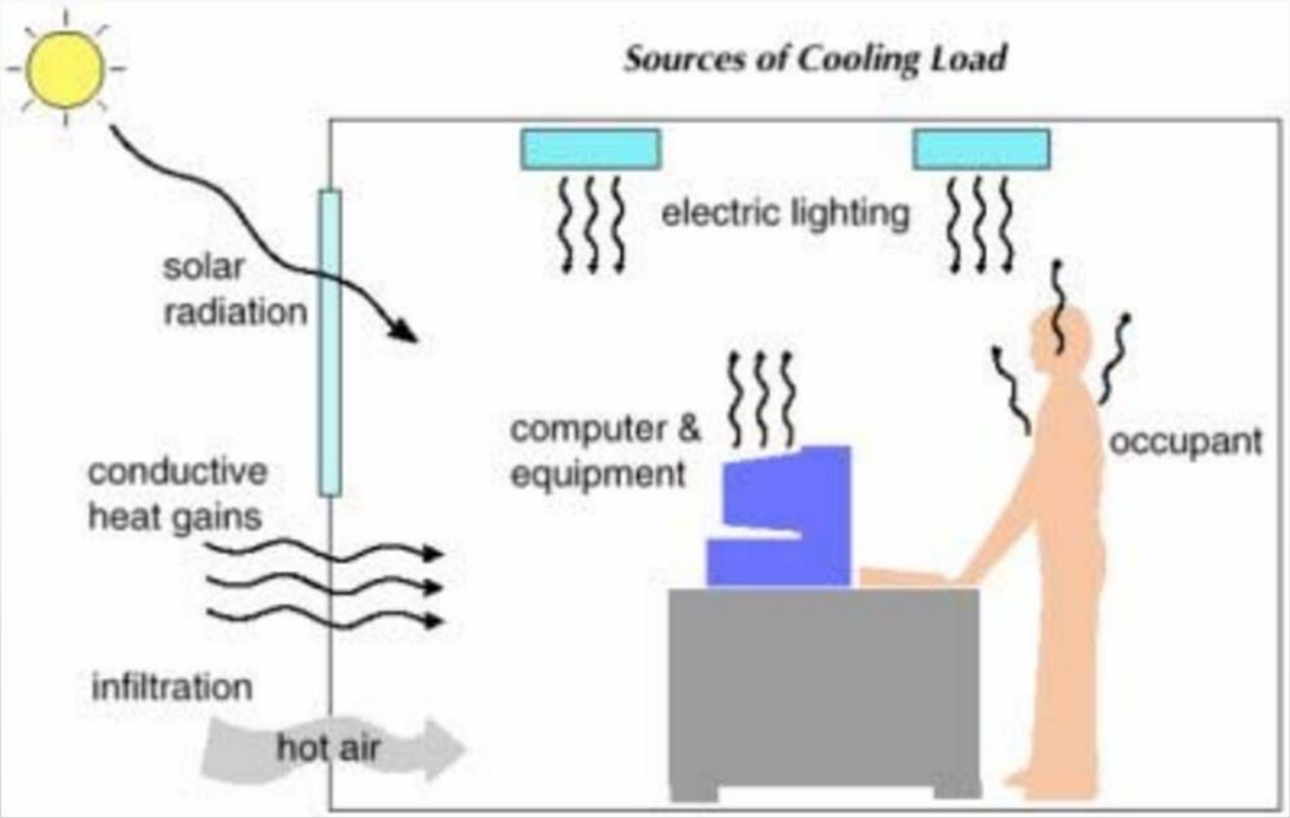
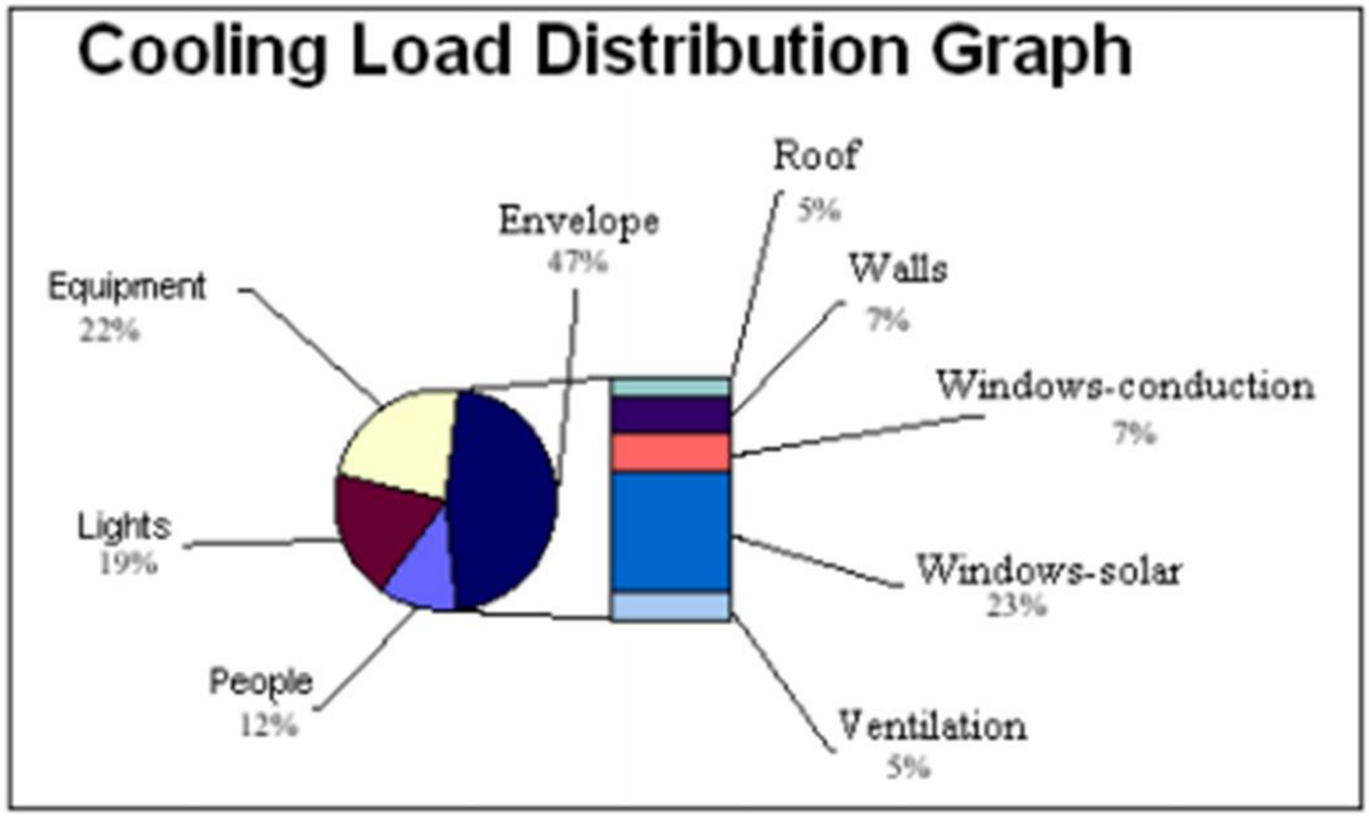
The total building cooling load consists of heat transferred through the building envelope (walls, roof, floor, windows, doors etc.) and heat generated by occupants, equipment, and lights. The load due to heat transfer through the envelope is called as **external load**, while all other loads are called as **internal loads**. The percentage of external versus internal load varies with building type, site climate, and building design. The total cooling load on any building consists of both **sensible** as well as **latent** load components. The sensible load affects the dry bulb temperature, while the latent load affects the moisture content of the conditioned space.



The total load is the summation of external and internal load or both sensible and latent loads. Usually 10% safety margin is added but it all depends on how accurate are the inputs. The final load is than used to size the HVAC equipment. HVAC equipment is rated in Btuh, but is commonly expressed in tonnage. A Btu (British thermal unit) is the amount of heat needed to raise one pound of water one degree Fahrenheit. A "Ton" of cooling load is actually 12,000 Btu per hour heat extraction equipment. The term ton comes from the amount of cooling provided by two thousand pounds or one ton of ice.



Cooling load is the rate at which heat must be removed to maintain the temperature and humidity required at design values through :
Structural components ,
Windows ,
Infiltration ,
Occupants and appliances .

## 4.1 : Cooling load through structural components ;

The Cooling Load Temperature Difference (CLTD) method will be used to calculate the structural components load .This method combine the effect of the temperature difference between indoor and outdoor , solar radiation and considered thermal capacity of the enclosure .

$Q = U A ( CLTD )$ where :

U : overall heat transfer coefficient
A : area of wall ,roof ,or glass
CLTD : cooling laod temperature difference given in tables for walls ,roofs and glass

**Table 2. CLTDs for Sunlit Walls (40° North Latitude, July 21), °C**

| | Wall Type 9 | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Hour | | | | | | | | | | | | | | | | | | | | | | | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| N | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 2 | 2 | 3 | 4 | 4 | 6 | 7 | 8 | 9 | 11 | 12 | 12 | 13 | 13 | 12 | 11 |
| NE | 10 | 8 | 7 | 6 | 5 | 4 | 3 | 3 | 3 | 6 | 9 | 11 | 13 | 14 | 14 | 15 | 15 | 16 | 16 | 15 | 14 | 14 | 13 | 11 |
| E | 11 | 9 | 8 | 7 | 6 | 4 | 3 | 3 | 4 | 7 | 11 | 14 | 18 | 20 | 21 | 21 | 21 | 20 | 19 | 18 | 17 | 16 | 14 | 13 |
| SE | 11 | 9 | 8 | 7 | 6 | 4 | 3 | 3 | 3 | 5 | 7 | 11 | 14 | 17 | 19 | 20 | 21 | 20 | 19 | 19 | 18 | 16 | 14 | 13 |
| S | 12 | 10 | 8 | 7 | 6 | 4 | 3 | 3 | 2 | 2 | 2 | 3 | 6 | 8 | 11 | 14 | 16 | 18 | 19 | 19 | 18 | 17 | 15 | 13 |
| SW | 17 | 14 | 12 | 10 | 8 | 7 | 5 | 4 | 3 | 3 | 3 | 3 | 4 | 6 | 8 | 11 | 14 | 18 | 22 | 24 | 25 | 24 | 22 | 20 |
| W | 19 | 17 | 14 | 12 | 9 | 8 | 6 | 4 | 4 | 3 | 3 | 4 | 4 | 6 | 7 | 9 | 12 | 17 | 21 | 24 | 27 | 27 | 25 | 23 |
| NW | 16 | 14 | 12 | 9 | 8 | 6 | 5 | 4 | 3 | 3 | 3 | 3 | 4 | 5 | 6 | 8 | 10 | 12 | 16 | 19 | 21 | 21 | 20 | 18 |

**Table 4. CLTDs for Flat Roofs (40° North Latitude, July 21), °C**

| | Hour | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Roof Type | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| 1 | 0 | -1 | -2 | -3 | -3 | -3 | 0 | 7 | 16 | 25 | 33 | 41 | 46 | 49 | 49 | 46 | 41 | 33 | 24 | 14 | 8 | 5 | 3 | 1 |
| 2 | 1 | 0 | -1 | -2 | -3 | -3 | -2 | 2 | 9 | 18 | 27 | 34 | 41 | 46 | 48 | 47 | 44 | 39 | 31 | 22 | 14 | 8 | 5 | 3 |
| 3 | 7 | 4 | 3 | 1 | 0 | -1 | 0 | 3 | 7 | 13 | 19 | 26 | 32 | 37 | 40 | 41 | 41 | 37 | 33 | 27 | 21 | 17 | 13 | 9 |
| 4 | 9 | 6 | 4 | 2 | 1 | -1 | -2 | -2 | 0 | 4 | 9 | 16 | 23 | 30 | 36 | 41 | 43 | 43 | 41 | 37 | 31 | 25 | 19 | 13 |
| 5 | 12 | 9 | 7 | 4 | 3 | 2 | 1 | 1 | 3 | 7 | 12 | 17 | 23 | 28 | 33 | 37 | 38 | 38 | 36 | 33 | 28 | 23 | 19 | 15 |

4.2 : Cooling loads through windows:

$Q = A\ SHG\ SF\ CLF$ , where :

Solar Heat Gain ( SHG ) includes effects of both transmission and solar radiation ,
SF is the shade factor ,
CLF is the cooling load factor.

4.3 : Cooling load through partitions ,ceiling , and floor :

$Q = U\ A\ \Delta T$ (~~$T_b - T_i$~~) where $\Delta T$ is ~~the adjacent space temperature~~ given by

$\Delta T = \frac{2}{3}(T_o - T_r)$ summer

4.4 : Cooling load due to ventilation and infiltration :

$Qs = \rho . V . c_p ( T_o - T_i ) = 1.22\ \dot{V}_{flow} ( T_o - T_r )$
$Ql = 2500\ \rho\ V_{flow} ( W_o - W_i ) = 2940\ \dot{V}_{flow} ( W_o - W_r )$
$Qtotal = \rho\ V_{flow} (h_o - h_i ) = 1.2\ \dot{V}_{flow} ( h_o - h_r )$
Where : $V_{flow}$ is the ventilation requirements from standard tables .

$\dot{V}_{flow} = \dot{V}_{out}$

4.5: Internal cooling load due to occupants , lights and appliances :

People :
Q = 70 W/person or from tables according to activities .
Qs =N * ( sensible heat gain ) * CLF
Ql = N * (latent heat gain )

Where N is the number of people in the space and , CLF is cooling load factor .

Lights :

$Q_{elc} = W F_u F_s CLF$ , where : W is the watts input of the light , $F_u$ is lighting use factor , $F_s$ is special allowance factor.

Power :

$Q_p = P\ E_f\ CLF$ where P is power rating , $E_f$ is efficiency factor .

Appliances :
Q = 470 W for both kitchen and laundry for single family
Q = 350 W for multi-family
For latent cooling load calculate for individual components or estimate as 30% $Q_s$ .
OR :
Qs = sensible heat gain * $F_u$
Ql = latent heat gain * $F_u$

Load of Partitions

$Q = U_p \cdot A_p * \Delta T$

$\Delta T = \frac{2}{3}(T_o - T_r)$ for summer

$\Delta T = \frac{1}{2}(T_r - T_o)$ for Winter

~~Examples~~

4.6 Applications

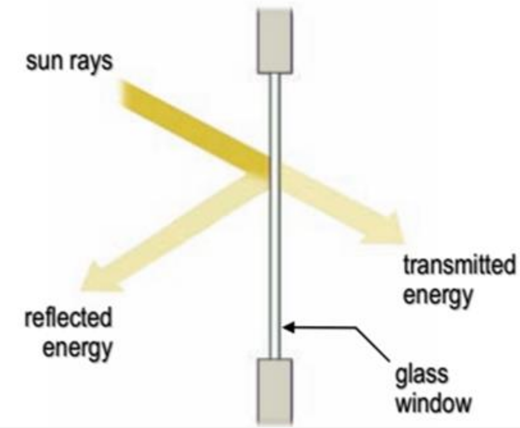
Six examples. lecture (9 & 10 & 11)

# U-factors for Windows

fixed frames, vertical installation

| | aluminum without thermal break | aluminum with thermal break | wood/vinyl |
|---|---|---|---|
| **single glazing** | | | |
| 1/8 in. [3.2 mm] glass | 1.13 [6.42] | 1.07 [6.07] | 0.98 [5.55] |
| **double glazing** | | | |
| 1/4 in. [6.4 mm] air space | 0.69 [3.94] | 0.63 [3.56] | 0.56 [3.17] |
| 1/2 in. [12.8 mm] air space | 0.64 [3.61] | 0.57 [3.22] | 0.50 [2.84] |
| 1/4 in. [6.4 mm] argon space | 0.66 [3.75] | 0.59 [3.37] | 0.52 [2.98] |
| 1/2 in. [12.8 mm] argon space | 0.61 [3.47] | 0.54 [3.08] | 0.48 [2.70] |
| **triple glazing** | | | |
| 1/4 in. [6.4 mm] air spaces | 0.55 [3.10] | 0.48 [2.73] | 0.41 [2.33] |
| 1/2 in. [12.8 mm] air spaces | 0.49 [2.76] | 0.42 [2.39] | 0.35 [2.01] |
| 1/4 in. [6.4 mm] argon spaces | 0.51 [2.90] | 0.45 [2.54] | 0.38 [2.15] |
| 1/2 in. [12.8 mm] argon spaces | 0.47 [2.66] | 0.40 [2.30] | 0.34 [1.91] |

## Solar Radiation through Glass




The windows in our example are double-pane windows with a ¼-inch [6.4 mm] air space between the panes. Assuming that the windows are fixed (not operable), with aluminum frames and a thermal break, the U-factor is 0.63 Btu/hr • $ft^2$ • °F [3.56 W/$m^2$ • °K].

**Table 6. CLTDs for Glass, °C**

| Hour | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| 1 | 0 | -1 | -1 | -1 | -1 | -1 | 0 | 1 | 2 | 4 | 5 | 7 | 7 | 8 | 8 | 7 | 7 | 6 | 4 | 3 | 2 | 2 | 1 |

# SHG CLF for Sunlit Glass (40° North Latitude, July 21), W/m$^2$

| | Space Type A | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Hour | | | | | | | | | | | | | | | | | | | | | | | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| N | 0 | 0 | 0 | 0 | 3 | 79 | 85 | 88 | 101 | 110 | 120 | 126 | 126 | 123 | 113 | 98 | 98 | 113 | 38 | 19 | 9 | 3 | 3 | 0 |
| NE | 0 | 0 | 0 | 0 | 6 | 268 | 406 | 422 | 353 | 236 | 173 | 151 | 139 | 126 | 117 | 101 | 82 | 57 | 22 | 9 | 6 | 3 | 0 | 0 |
| E | 0 | 0 | 0 | 0 | 6 | 293 | 495 | 583 | 576 | 485 | 334 | 211 | 167 | 142 | 123 | 104 | 82 | 57 | 22 | 9 | 6 | 3 | 0 | 0 |
| SE | 0 | 0 | 0 | 0 | 3 | 148 | 299 | 413 | 473 | 473 | 413 | 306 | 198 | 154 | 129 | 107 | 85 | 57 | 22 | 9 | 6 | 3 | 0 | 0 |
| S | 0 | 0 | 0 | 0 | 0 | 28 | 54 | 79 | 129 | 202 | 268 | 306 | 302 | 265 | 198 | 132 | 98 | 63 | 25 | 13 | 6 | 3 | 0 | 0 |
| SW | 0 | 0 | 0 | 0 | 0 | 28 | 54 | 76 | 95 | 110 | 123 | 202 | 318 | 419 | 476 | 479 | 419 | 293 | 110 | 54 | 25 | 13 | 6 | 3 |
| W | 3 | 0 | 0 | 0 | 0 | 28 | 54 | 76 | 95 | 110 | 120 | 126 | 205 | 359 | 498 | 589 | 605 | 491 | 180 | 85 | 41 | 19 | 9 | 6 |
| NW | 3 | 0 | 0 | 0 | 0 | 28 | 54 | 76 | 95 | 110 | 120 | 126 | 126 | 158 | 265 | 381 | 450 | 410 | 145 | 69 | 35 | 16 | 9 | 3 |
| HOR | 0 | 0 | 0 | 0 | 0 | 76 | 217 | 378 | 532 | 665 | 759 | 810 | 816 | 772 | 684 | 554 | 394 | 221 | 91 | 44 | 22 | 9 | 6 | 3 |

The **shading coefficient (SC)** is an expression used to define how much of the radiant solar energy, that strikes the outer surface of the window, is actually transmitted through the window and into the space. The shading coefficient for a particular window is determined by comparing its reflective properties to a standard reference window. The table on this slide includes shading coefficients for common window systems. When the value for the shading coefficient decreases, more of the sun's rays are reflected by the outer surface of the glass.

shading coefficient at normal incidence

| | aluminum frame | | other frames | |
|---|---|---|---|---|
| | operable | fixed | operable | fixed |
| **uncoated single glazing** | | | | |
| 1/4 in. [6.4 mm] clear | 0.82 | 0.85 | 0.69 | 0.82 |
| 1/4 in. [6.4 mm] green | 0.59 | 0.61 | 0.49 | 0.59 |
| **reflective single glazing** | | | | |
| 1/4 in. [6.4 mm] SS on clear | 0.26 | 0.28 | 0.22 | 0.25 |
| 1/4 in. [6.4 mm] SS on green | 0.26 | 0.28 | 0.22 | 0.25 |
| **uncoated double glazing** | | | | |
| 1/4 in. [6.4 mm] clear - clear | 0.70 | 0.74 | 0.60 | 0.70 |
| 1/4 in. [6.4 mm] green - clear | 0.48 | 0.49 | 0.40 | 0.47 |
| **reflective double glazing** | | | | |
| 1/4 in. [6.4 mm] SS on clear - clear | 0.20 | 0.18 | 0.15 | 0.17 |
| 1/4 in. [6.4 mm] SS on green - clear | 0.18 | 0.18 | 0.15 | 0.16 |

# OUT SIDE DESIGN CONDITION DATA FOR IRAQ

(MECHANICAL SEC.)

| No. | CITIES | LOCATION | ACTUAL LATITUDE °N° | APPROX. LATITUDE °N° | LONGITUDE °E° | ELEVATION ABOVE MSL* °M° | SUMMER * D.B. °C | SUMMER * R.H. % | SUMMER * DAILY RANGE °C | WINTER * D.B. °C | WINTER * R.H. % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | SALAHADDIN | NORTH | 36° 23′ | 35° | 44° 13′ | 1088 | 37.5 | 23 | 11.4 | -0.5 | 50 |
| 2 | SINJAR | | 36° 19′ | | 41° 50′ | 538 | 39.5 | 17 | 12.5 | 1.5 | 78 |
| 3 | MOUSLE | | 36° 19′ | | 43° 09′ | 222.6 | 44 | 18.5 | 21.2 | 0.5 | 92 |
| 4 | SULAIMANIYA | | 35° 33′ | | 45° 27′ | 853 | 40 | 15 | 15 | -1.5 | 77 |
| 5 | KIRKUK | | 35° 28′ | | 44° 24′ | 330.8 | 44 | 14 | 16 | 3 | 81 |
| 6 | AKA | MIDDLE | 34° 28′ | 33° | 41° 57′ | 138.5 | 43 | 21 | 17.6 | 1 | 68 |
| 7 | KHANAQIN | | 34° 18′ | | 45° 26′ | 202.2 | 45 | 15 | 16.4 | 3 | 81 |
| 8 | HADITHA | | 34° 04′ | | 42° 22′ | 108 | 43.5 | 15 | 18 | 1 | 93 |
| 9 | HABBANIYA | | 33° 22′ | | 43° 34′ | 43.6 | 44 | 17 | 18.3 | 2.5 | 85 |
| 10 | BAGHDAD | | 33° 14′ | | 44° 14′ | 34.1 | 45 | 15 | 18.7 | 1.5 | 84 |
| 11 | RUTBA | | 33° 02′ | | 40° 47′ | 615.5 | 40 | 15 | 17.3 | 0.5 | 82 |
| 12 | HAI | | 32° 10′ | | 46° 03′ | 14.9 | 45 | 18.5 | 17.9 | 4 | 64 |
| 13 | NAJAF | SOUTH | 32° 01′ | 31° | 44° 19′ | 50 | 45.5 | 14 | 17 | 4 | 62 |
| 14 | DIWANIYA | | 31° 59′ | | 44° 59′ | 20.4 | 44.5 | 19.5 | 19.3 | 3.5 | 80 |
| 15 | AMARA | | 31° 51′ | | 47° 10′ | 7.5 | 46 | 16 | 19 | 4.5 | 50 |
| 16 | SAMAWA | | 31° 18′ | | 45° 16′ | 6 | 45 | 14 | 13.5 | 4.5 | 66 |
| 17 | NASIRIYA | | 31° 05′ | | 46° 14′ | 3 | 45 | 18 | 18.4 | 4.5 | 70 |
| 18 | BASRAH | | 30° 34′ | | 47° 47′ | 2.4 | 43 | 38 | 15 | 5.5 | 89 |

*: MEAN-SEA LEVEL    * °F = $\frac{9}{5}$ °C + 32°

As mentioned in Period One, people generate more heat than is needed to maintain body temperature. This surplus heat is dissipated to the surrounding air in the form of sensible and latent heat. The amount of heat released by the body varies with age, physical size, gender, type of clothing, and level of physical activity. This table is an excerpt from the *1997 ASHRAE Handbook—Fundamentals*. It includes typical sensible and latent heat gains per person, based on the level of physical activity. The heat gains are adjusted to account for the normal percentages of men, women, and children in each type of space.

The equations used to predict the sensible and latent heat gains from people in the space are:

$Q_S$ = number of people × sensible heat gain/person × CLF

$Q_L$ = number of people × latent heat gain/person

where,

- $Q_S$ = sensible heat gain from people, Btu/hr [W]
- $Q_L$ = latent heat gain from people, Btu/hr [W]
- CLF = cooling load factor, dimensionless

$[\ Q_{sensible} = 18 \times 75 \times 1.0 = 1{,}350\ W\ ]$

$[\ Q_{latent} = 18 \times 55 = 990\ W\ ]$

## Heat Generated by People

| level of activity | sensible heat gain | latent heat gain |
|---|---|---|
| moderately active work (office) | 250 Btu/h [75 W] | 200 Btu/h [55 W] |
| standing, light work, or walking (store) | 250 Btu/h [75 W] | 200 Btu/h [55 W] |
| light bench work (factory) | 275 Btu/h [80 W] | 475 Btu/h [140 W] |
| heavy work (factory) | 580 Btu/h [170 W] | 870 Btu/h [255 W] |
| athletics (gymnasium) | 710 Btu/h [210 W] | 1,090 Btu/h [315 W] |

## CLF Factors for People

| total hours in space | hours after people enter space | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 2 | 0.65 | 0.74 | 0.16 | 0.11 | 0.08 | 0.06 | 0.05 | 0.04 | 0.03 | 0.02 | 0.02 | 0.01 |
| 4 | 0.65 | 0.75 | 0.81 | 0.85 | 0.24 | 0.17 | 0.13 | 0.10 | 0.07 | 0.06 | 0.04 | 0.03 |
| 6 | 0.65 | 0.75 | 0.81 | 0.85 | 0.89 | 0.91 | 0.29 | 0.20 | 0.15 | 0.12 | 0.09 | 0.07 |
| 8 | 0.65 | 0.75 | 0.81 | 0.85 | 0.89 | 0.91 | 0.93 | 0.95 | 0.31 | 0.22 | 0.17 | 0.13 |
| 10 | 0.65 | 0.75 | 0.81 | 0.85 | 0.89 | 0.91 | 0.93 | 0.95 | 0.96 | 0.97 | 0.33 | 0.24 |

## Heat Gain from Lighting

$$[Q = \text{watts} \times \text{ballast factor} \times \text{CLF}]$$

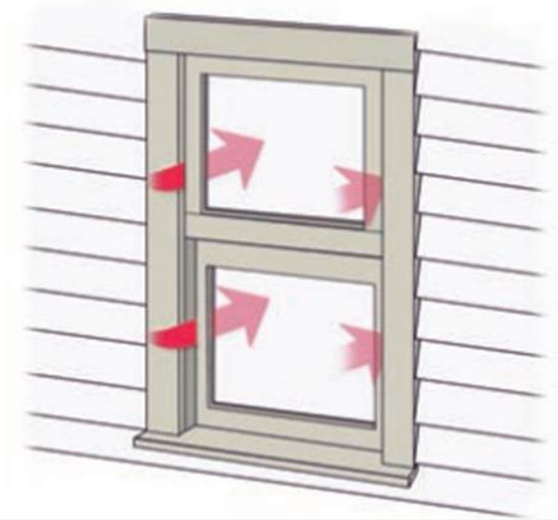
$$[\, Q = \text{watts} \times \text{ballast factor} \times \text{CLF} \,] \qquad [\, Q_{lights} = 5{,}400 \times 1.2 \times 1.0 = 6{,}480 \text{ W} \,]$$

## Heat Generated by Equipment

| equipment | sensible heat gain | latent heat gain |
|---|---|---|
| coffee maker | 3,580 Btu/h [1,050 W] | 1,540 Btu/h [450 W] |
| printer (letter quality) | 1,000 Btu/h [292 W] | |
| typewriter | 230 Btu/h [67 W] | |

**Infiltration**

In a typical building, air leaks into or out of a space through doors, windows, and small cracks in the building envelope. Air leaking **into** a space is called **infiltration**. During the cooling season, when air leaks into a conditioned space from outdoors, it can contribute to both the sensible and latent heat gain in the space because the outdoor air is typically warmer and more humid than the indoor air.



## Methods of Estimating Infiltration

- Air change method
- Crack method
- Effective leakage-area method

The **crack method** is a little more complex and is based upon the average quantity of air known to enter through cracks around windows and doors when the wind velocity is constant. The **effective leakage-area method** takes wind speed, shielding, and "stack effect" into account, and requires a very detailed calculation.

The **air change method** is the easiest, but may be the least accurate of these methods. It involves estimating the number of air changes per hour that can be expected in spaces of a certain construction quality. Using this method, the quantity of infiltration air is estimated using the equation:

infiltration airflow = (volume of space × air change rate) ÷ 60

[infiltration airflow = (volume of space × air change rate) ÷ 3,600]

where,

- Infiltration airflow = quantity of air infiltrating into the space, cfm [$m^3/s$]
- Volume of space = length × width × height of space, $ft^3$ [$m^3$]
- Air change rate = air changes per hour
- 60 = conversion from hours to minutes
- 3,600 = conversion from hours to seconds

The table below includes estimates for infiltration using the air change method. Assuming that the space in our example is of average construction and kept at a positive pressure relative to the outdoors, we estimate 0.3 air changes/hr of infiltration.

**Table 9. Estimates of Infiltration Airflow, Air Changes Per Hour**

| | |
|---|---|
| Neutral pressure, poor construction | 1.0 |
| Neutral pressure, average construction | 0.6 |
| Neutral pressure, tight construction | 0.3 |
| Pressurized, poor construction | 0.5 |
| Pressurized, average construction | 0.3 |
| Pressurized, tight construction | 0.0 |





**Volume=** [13.7 m × 18.3 m × 3.7 m = 927.6 $m^3$]

$$\left[\text{infiltration airflow} = \frac{927.6 \times 0.3}{3{,}600} = 0.077\ m^3/s\right]$$

$$[Q_{sensible} = 1{,}210 \times \text{airflow} \times \Delta T]\ [Q_S = 1{,}210 \times 0.077 \times (35 - 25.6) = 876\ W]$$

$$[Q_{latent} = 3{,}010 \times \text{airflow} \times \Delta W]\ [Q_L = 3{,}010 \times 0.077 \times (15 - 10) = 1{,}159\ W]$$