



# Air-Conditioning & Refrigeration

BSc

Lecture 13

Course weekly Outline &

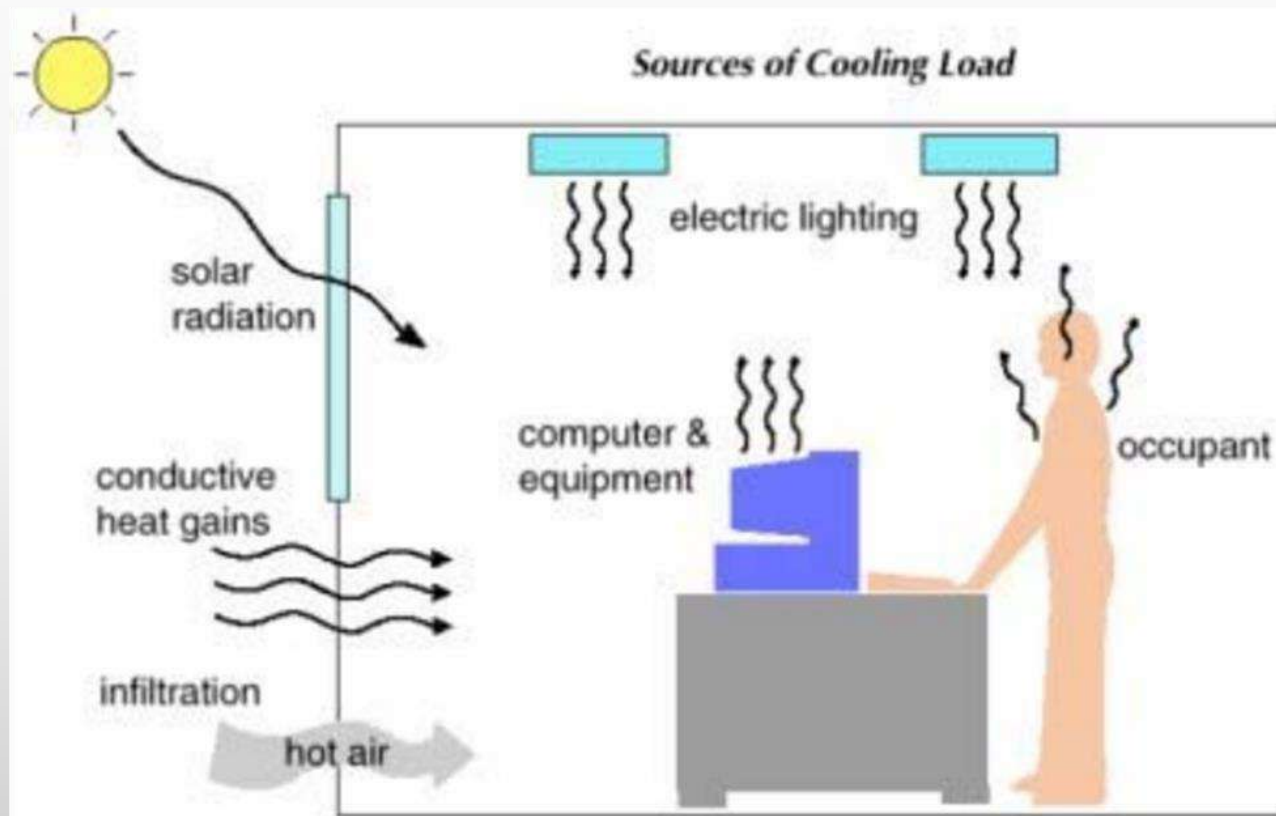
Ch.1 (Introduction to Air conditioning & Refrigeration)

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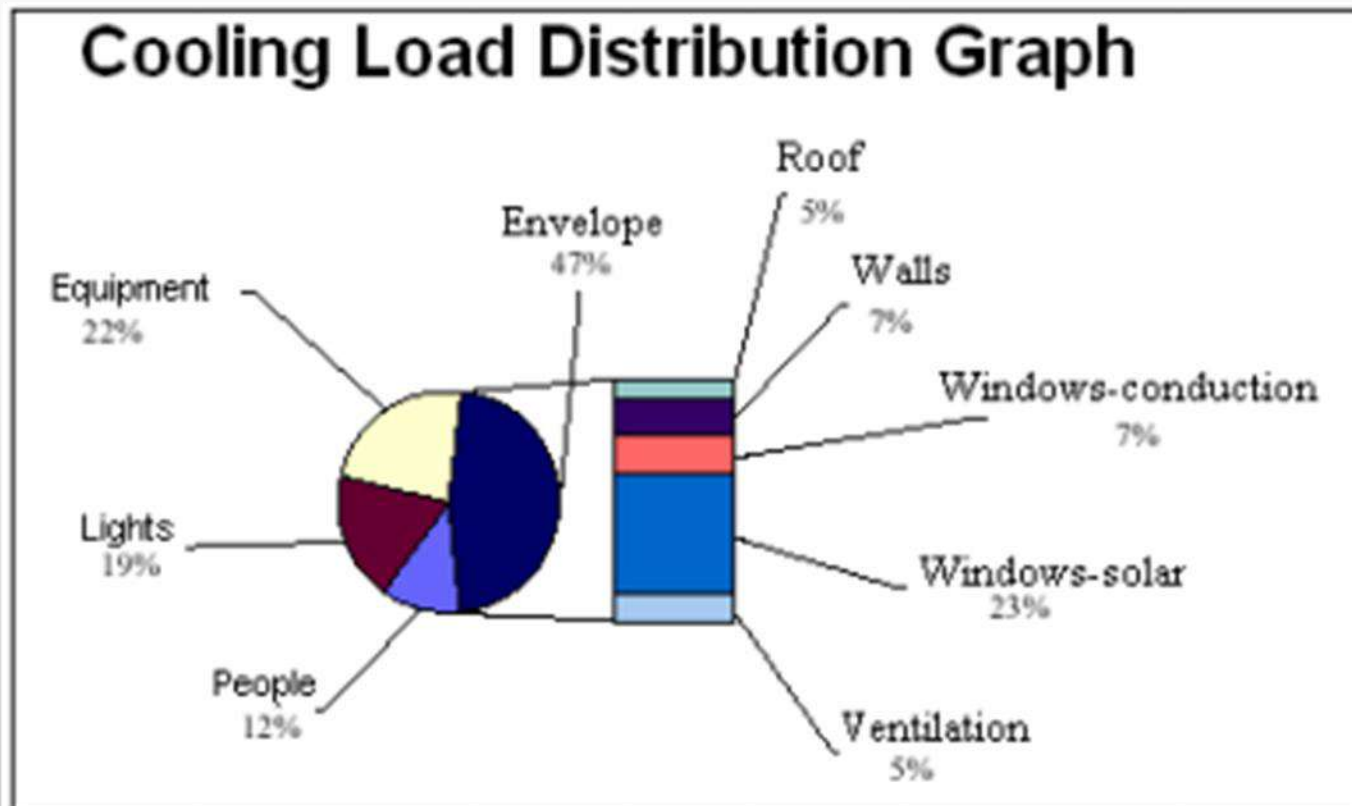
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The total building cooling load consists of heat transferred through the building envelope (walls, roof, floor, windows, doors etc.) and heat generated by occupants, equipment, and lights. The load due to heat transfer through the envelope is called 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 then used to size the HVAC equipment. HVAC equipment is rated in Btu/h, 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 .

$$Q = U A ( CLTD ) \quad \text{where :}$$

U : overall heat transfer coefficient

A : area of wall ,roof ,or glass

CLTD : cooling load 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:-

$Q = A \text{ SHG SF CLF}$  , 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 :

$Q = U A (T_o - T_i)$  where  $\Delta T_o$  is the adjacent space temperature given by  
 $\Delta T = \frac{1}{2} (T_o - T_r)$  Summer

4.4 : Cooling load due to ventilation and infiltration :

$Q_s = \rho \cdot V \cdot c_p (T_o - T_i) = 1.22 \dot{V}_{flow} (T_o - T_r)$   
 $Q_l = 2500 \rho V_{flow} (W_o - W_i) = 2940 \dot{V}_{flow} (W_o - W_r)$   
 $Q_{total} = \rho V_{flow} (h_o - h_i) = 1.2 \dot{V}_{flow} (h_o - h_r)$

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

Where :  $V_{flow}$  is the ventilation requirements from standard tables .

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

People :

$Q = 70 \text{ W/person}$  or from tables according to activities .

$Q_s = N * (\text{sensible heat gain}) * CLF$

$Q_l = N * (\text{latent heat gain})$

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

Lights :

$Q_{clc} = W F_u F_s CLF$  , 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 :

$Q_s = \text{sensible heat gain} * F_u$

$Q_l = \text{latent heat gain} * F_u$

Load of Partitions

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

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

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

Examples

## 4.6 Applications

Six examples. lecture (9 & 10/11)

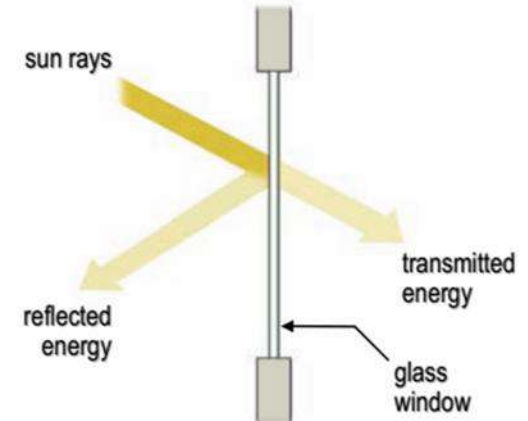


# U-factors for Windows

fixed frames, vertical installation

	aluminum without thermal break	aluminum with thermal break	wood/vinyl
<b>single glazing</b>			
1/8 in. [3.2 mm] glass	1.13 [6.42]	1.07 [6.07]	0.98 [5.55]
<b>double glazing</b>			
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]
<b>triple glazing</b>			
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 1/4-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<sup>2</sup> • °F [3.56 W/m<sup>2</sup> • °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<sup>2</sup>

	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	
	<u>operable</u>	<u>fixed</u>	<u>operable</u>	<u>fixed</u>
<b>uncoated single glazing</b>				
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
<b>reflective single glazing</b>				
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
<b>uncoated double glazing</b>				
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
<b>reflective double glazing</b>				
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 *			WINTER*	
							D.B. °C	R.H. %	DAILY RANGE °C	D.B. °C	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'	272.6	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	AMA	MIDDLE	34° 28'	33	41° 57'	138.5	43	21	17.6	1	68
7	KHAKAQDN		34° 18'		45° 26'	202.2	45	15	18.4	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° 11'	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	53
15	AMARA		31° 51'		47° 10'	7.5	45	15	19	4.5	50
15	SAMAWA		31° 18'		45° 15'	6	45	14	13.5	4.5	65
17	NASIRIYA		31° 05'		46° 14'	3	45	18	18.4	4.5	79
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:

$$Q_S = \text{number of people} \times \text{sensible heat gain/person} \times \text{CLF}$$

$$Q_L = \text{number of people} \times \text{latent heat gain/person}$$

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

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

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

## 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

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

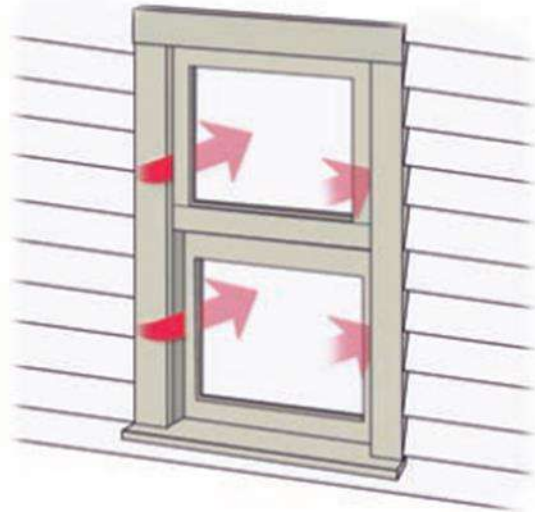
$$[ Q = \text{watts} \times \text{ballast factor} \times \text{CLF } ] \quad [ Q_{\text{lights}} = 5,400 \times 1.2 \times 1.0 = 6,480 \text{ W } ]$$

## 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:

$$\text{infiltration airflow} = (\text{volume of space} \times \text{air change rate}) \div 60$$

$$[\text{infiltration airflow} = (\text{volume of space} \times \text{air change rate}) \div 3,600]$$

where,

- Infiltration airflow = quantity of air infiltrating into the space, cfm [ $\text{m}^3/\text{s}$ ]
- Volume of space = length  $\times$  width  $\times$  height of space,  $\text{ft}^3$  [ $\text{m}^3$ ]
- 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

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$$\text{Volume} = [13.7 \text{ m} \times 18.3 \text{ m} \times 3.7 \text{ m} = 927.6 \text{ m}^3]$$

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

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

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