**CHAPTER 3**

**Ac Cooling /Heating Load Calculation**

**Introduction**

Heat gains from the sun can lead to increases in internal temperatures beyond the limits of **comfort**.This is usually above 24oC dry bulb temperature.

A software programme such as is often used to determine the internal summertime temperatures for a building.

It is therefore necessary to determine the amount of solar radiation that is transmitted into buildings through; windows, walls, roof, floor and by admitting external air into the building.Several measures can be adopted to reduce solar radiation in buildings.

These are external and internal shading and by careful building design.Natural vegetation such as tall trees can also reduce solar heat gains.

Window areas can be reduced although natural day lighting is important in northern latitudes in winter so there is a limit to glass reduction.

Buildings can be orientated so that there is less window area facing directly south. These are just some of the ways to reduce solar radiation.



**Calculating Heat Gains**

The load on an air-conditioning system can be divided into the following sections:

1. Sensible Transmission through glass.

2. Solar Gain through glass.

1. Internal Heat gains

4. Heat gain through walls.

5. Heat gain through roof.

6. Ventilation and/ or infiltration gains.

The heat gain through the glass windows is divided into **two** parts since there is a heat gain due to temperature difference between outside and inside and another gain due to solar radiation shining through windows.

Heat gains through solid ground floors are minimal and can be neglected.

**1.0 Sensible Transmission Through Glass**

This is the Solar Gain due to differences between inside and outside temperatures. In very warm countries this can be quite significant.

This gain only applies to materials of negligible thermal capacity i.e. glass.

Qg = Ag . Ug (To- Tr) ........ eqn. 1

Where;

Qg = Sensible heat gain through glass (W)

Ag = Surface area of glass (m2)

Ug = 'U' value for glass (W/m2 oC)

To = outside air temperature (oC)..

Tr = room air temperature (oC)

**2.0 Solar Gain Through Windows**

This gain is when the sun shines though windows.

The cooling loads per metre squared window area have been tabulated in stanadrds. for various; locations, times, dates and orientations.

These figures are then multiplied by correction factors for; shading and air node correction factor.

Heat load is found from;

Qsg = Fc . Fs . qsg . Ag ........ eqn. 2

where Qsg = Actual cooling load (W)

qsg = Tabulated cooling load (W/m2)

Fc = Air node correction factor from Table below.

Fs = Shading factor.

Ag  = Area of glass (m2)

The Air point control factors (Fc) and Shading factors (Fs) are given in the Table below for various types of glass, building weights and for open and closed blinds.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Air node correction factors (Fc)** | | | | | |
|  | Building Weight | Single Glazing | | Double glazing | |
| Horizontal blind | | Horizontal blind | |
| Light | 0.91 | | 0.91 | |
| Heavy | 0.83 | | 0.90 | |
| **Shading factors (Fs)** | | | | | |
| Type of glass | Building Weight | Single Glazing | | Double glazing | |
|  | Open horizontal blind | Closed horizontal blind | Open horizonta blind | Closed horizontal blind |
| Clear 6mm | Light | 1.00 | 0.77 | 0.95 | 0.74 |
| Heavy | 0.97 | 0.77 | 0.94 | 0.76 |
| Bronze tinted 6mm | Light | 0.86 | 0.77 | 0.66 | 0.55 |
| Heavy | 0.85 | 0.77 | 0.66 | 0.57 |
| Bronze tinted 10mm | Light | 0.78 | 0.73 | 0.54 | 0.47 |
| Heavy | 0.77 | 0.73 | 0.53 | 0.48 |
| Reflecting | Light | 0.64 | 0.57 | 0.48 | 0.41 |
| Heavy | 0.62 | 0.57 | 0.47 | 0.41 |

Aa slightly different formula as follows;

Qsg = S . qsg . Ag

where Qsg = Actual cooling load (W)

qsg = Tabulated cooling load (W/m2)

S = Mean solar gain factor

Ag  = Area of glass (m2)

**3.0 Internal Heat Gains -**

Internal gains can account for most heat gain in buildings in the U.K.

These gains are from occupants, lights, equipment and machinery, as detailed below.

OCCUPANTS - Sensible and latent heat gains can be obtained from CIBSE Guide A (2006) - Table 6.3.

Typical gains are shown below.

|  |  |  |  |
| --- | --- | --- | --- |
| **Conditions** | **Typical building** | **Sensible Heat Gain (Watts)** | **Latent Heat Gain (Watts)** |
| Seated very light work | Offices, hotels, apartments | **70** | 45 |
| Moderate office work | Offices, hotels, apartments | **75** | 55 |
| Standing, light work; walking | Department store, retail store | **75** | 55 |
| Walking standing | Bank | **75** | 70 |
| Sedentary work | Restaurant | **80** | 80 |
| Light bench work | Factory | **80** | 140 |
| Athletics | Gymnasium | **210** | 315 |

LIGHTING – Average power density from.

ELECTRICAL EQUIPMENT - PC’s and Monitors

Laser Printers and Photocopiers –

Electric Motors

Lift Motors

Cooking equipment

Heat load is found from;

Q int. = Heat from Occupants + Heat from Lighting + Heat from Electrical Equipment + Heat from Cooking

**4.0 Heat Gain Through Walls**

This is the unsteady-state heat flow through a wall due to the varying intensity of solar radiation on the outer surface.

**4.1 Sol-Air Temperature**

In the calculation of this heat flow use is made of the concept of **sol-air** **temperature**, which is defined as;

the value of the outside air temperature which would, in the absence of all radiation exchanges, give the same rate of heat flow into the outer surface of the wall as the actual combination of temperature difference and radiation exchanges.

SOL-AIR TEMP,

|  |
| --- |
|  . I . cos a . cos n +  Is |

|  |
| --- |
| hso |

Teo = Ta + ( ) ........ eqn. 4.1

**where**

**Teo = sol-air Temperature (oC)**

**Ta = outside air temperature (oC)**

** = absorption coefficient of surface**

**I =intensity of direct solar radiation on a surface at right angles to the rays of the sun. (W/m2)**

**a = solar altitude (degrees)**

**n = wall-solar azimuth angle (degrees)**

**Is = intensity of scattered radiation normal to a surface (W/m2)**

**hso = external surface heat transfer coefficient (W/m2oC)**

**4.2 Thermal Capacity**

The heat flow through a wall is complicated by the presence of thermal capacity, so that some of the heat passing through it is stored, being released at a later time.

Thick heavy walls with a high thermal capacity will damp temperature swings considerably, whereas thin light walls with a small thermal capacity will have little damping effect, and fluctuations in outside surface temperature will be apparent almost immediately.

The thermal capacity will not affect the **daily mean solar gain** but will affect the solar gain at a particular time. The particular time  of a solar gain is normally the time of the maximum gain.The heat gain arrives at the inside of a thick wall some time after the sun hits the outside surface of the wall.This time lag is .

The calculation is, therefore, again split into two components.

**1. Mean gain through wall,**

Q = A . U ( Tem - Tr) ........ eqn. 4.2

where, Q = heat gain through wall at time 

A = area of wall (m2)

U = overall thermal transmittance (W/m2 oC)

Tem = 24 hour mean sol-air temperature (oC)

Tr = constant dry resultant temperature (oC). dry bulb is used.

**2.** The **variation from the mean** solar gain is subject to both a decrement factor and time lag.

Q = f ( Teo - Tem) ........ eqn. 4.3

where Q = Heat gain through wall at time ()

 = time lag in hours

teo = sol-air temperature at time ( (oC)

tem = 24 hour mean sol-air temperature (oC)

f = decrement factor (

Therefore the Solar Gain through a wall at time () is;

Q = A . U [( Tem - Tr) + f ( Teo - Tem)] ........ eqn. 4.4

where, Q = heat gain through wall at time  (Watts)

 = time lag in hours (

A = area of wall (m2)

U = overall thermal transmittance (W/m2 oC) (

Tem = 24 hour mean sol-air temperature (oC)

Tr = constant dry resultant temperature (oC) room dry bulb is used.

f = decrement factor for typical wall constructions.

teo = Sol-air temperature at time () (oC)

**5.0 Heat Gain Through Roof**

The heat gain through a roof uses the same equation as for a wall as shown below.

**Q+Roof = A U [( Tem - Tr) + f ( Teo - Tem)]** ........ eqn. 5

**6.0 Ventilation and/or Infiltration Gains**

Heat load is found from;

Qsi = n . V (To- Tr) / 3 ........ eqn. 6

where Qsi = Sensible heat gain (W)

n = number of air changes per hour (h-1) (see note below)

V = volume of room (m3)

To = outside air temperature (oC)

Tr = room air temperature (oC)

Infiltration gains should be added to the room heat gains.

Recommended infiltration rates are 1/2 air change per hour for most air-conditioning cases.

Ventilation or fresh air supply loads can be added to either the room **or** central plant loads but should only be accounted for once.

**Total Room Load From Heat Gains**

**Q total = Qg + Qsg + Qint. + Q+Wall + Q +Roof + Qsi**

Q total = Ag . Ug (To - Tr) 1. Sensible Glass

+ Fc . Fs . qsg . Ag 2. Solar Glass.

+ Qint. 3. Internal

+A.U [( Tem - Tr) + f ( Teo - Tem)] 4. Walls

+A.U [( Tem - Tr) + f ( Teo - Tem)] 5. Roof

+ n . V (To - Tr) / 3 6. Ventilation

........ eqn. 7

In the majority of cases, by far the greatest external fluctuating component is the solar heat gain through the **windows**.Therefore, it will be this gain which determines when the total heat gain to the room is a **maximum**.

Heat gains may be calculated and displayed in table form as shown below.

|  |  |  |
| --- | --- | --- |
| **Heat Gain from** | **Watts** | **%** |
| 1. Sensible transmission through glass |  |  |
| 2. Solar gain through glass |  |  |
| 3. Internal |  |  |
| 4. External walls |  |  |
| 5. Roof |  |  |
| 6. Ventilation |  |  |
| Total |  | 100% |
| Heat gain per m2 floor area = |  | |
| Heat gain per m3 space = |

**Latent Gains**

Latent heat gains are calculated so that the Total heat gain can be determined to complete a psychrometric chart.

Total heat gain = Sensible heat gain + Latent heat gains

Also Latent heat gains are required to size Chillers.

Latent heat gains are comprised of latent gain from occupants and from natural infiltration fresh air.Latent heat gains from occupants can be obtained from standrads.

The following formula gives the infiltration latent heat gain.

Qli = 0.8 . n . V ( mso –msr )

Where;

Qli = Infiltration latent heat gain (W)

n = Number of air changes per hour (h-1)

V = Room volume (m3)

mso = Moisture content of outside air (g/kg d.a.) from psychrometric chart.

msr = Moisture content of room air (g/kg d.a.) from psychrometric chart.

**Example 1**

The room shown below is to be maintained at a constant environmental temperature of 21oC for a plant operation of 12 hours per day.

The room is on the intermediate floor of an Library located in London latitute 51.7oN.

The internal construction is lightweight demountable partitions, lightweight slab floors and suspended acoustically treated ceilings, shading is intermittent.

Calculate the maximum sensible cooling load in the room in **July**

The outside air temperature (to) may be found from forJuly 4t).The maximum value ocurrs at 16.00 hrs. and is 25.4oC.

DATA:

Occupants = 100

Infiltration = 0.5 air changes per hour

Building classification = lightweight,

Building response = fast.

External wall 'U' value = 0.45 W/m2oC, internal insulation, neglect time lag

through wall.

External wall colour = light.

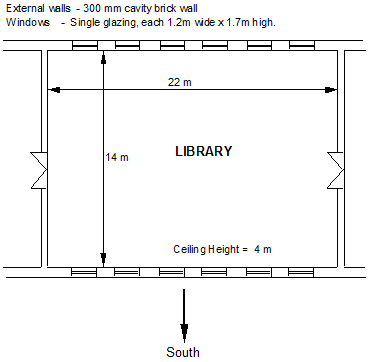
External wall decrement factor f = 0.65

Glass type & 'U' value = clear 6mm, double glazing, U = 2.80 W/m2oC

Window blinds = internal blind.

Lighting = 30 Watts / m2 floor area

Heat gain from machinery and equipment = 4000 Watts



NOTE: It should be noted that this total heat gain is used to size central plant items such as Chillers, Condensers and Cooling Towers.

Cooling coils are sized usually with a pschrometric chart.

Answer

Areas:

Area of window = 1.2 x 1.7 = 2.04 m2.

Total area of glass = 2.04 x 12No. windows = 24.48 m2.

Area of glass facing South = 12.24 m2.

Area of wall facing South = 22.0 m x 4.0 m high = 88 m2 less glass

= 88 - 12.24 = 75.76 m2.

Floor area = 22 x 14 = 308m2.

Room volume = 308 x 4 = 1232 m3.

Gains:

1. Sensible transmission through glass Qg = Ag Ug (To - Tr)

Qg = 24.48 x 2.8 (25.4 – 21)

Qg = 301.6 Watts

2. Solar Gain through glass Qsg = Fc Fs qsg Ag

where:

Qsg = Actual cooling load (W)

Fc = Air node correction factor from forinternal blind, fast response - 0.91.

Fs = Shading factor from Table in page 2 - for blind/clear/clear, fast response – 0.95.

qsg = Tabulated cooling load for July 4th , orientation South, 12.30 hours gives maximum

of 238 W/m2

Ag  = Area of glass facing South (m2)

(Maximum is at 12.30 hrs) Qsg = 0.91 x 0.95 x 238 x 12.24

Qsg = 2,518.4 Watts

3. Internal Qint. = Qint.

Qint. = Lights (30 W/m2 x 308) + 4000 W + People (100 x 100)

Qint. = 9,240 + 4,000 + 10,000

Qint. = 23,240.0 Watts

4. External wall Q Wall  = A U [( Tem - Tr) + f ( Teo - Tem)]

where,

Q = heat gain through wall at time q+f (Watts)

A = area of wall facing South (m2)

U = overall thermal transmittance given in question as 0.45 W/m2 oC.

Ttem = 24 hour mean sol-air temperature (oC) at 12.30 hrs, light wall facing

South – 22.6oC

Tr = constant dry resultant temperature (oC). Room dry bulb of 21oC is given.

f = decrement factor for wall is given as 0.65.

Tteo = sol-air temperature when Tabulated cooling load (qsg) is at 13.00 hrs. light wall, South facing gives 38.8oC.

Q+Wall  = 75.76 x 0.45 [( 22.6 – 21) + 0.65 ( 38.8 – 22.6)]

Q+Wall  = 34.092 [ 1.6 + 10.53 ]

Q+Wall  = 413.5 Watts

5. Roof Q+Roof = Nil for intermediate floor.

6. Ventilation Qsi = n V (to - tr) / 3

Qsi = 0.5 x 1232 (25.4 – 21) / 3

Qsi = 903.5 Watts

7. Q total = Qg + Qsg + Qint. + Q+Wall + Q +Roof + Qsi

Q total = 301.6 + 2,518.4 + 23,240.0 + 413.5 + 0 + 903.5

Q total = **27,377 Watts**

The results are shown in the table below.

|  |  |  |
| --- | --- | --- |
| **Heat Gain from** | **Watts** | **%** |
| 1. Sensible transmission through glass | 301.6 | 1.1 |
| 2. Solar gain through glass | 2,518.4 | 9.2 |
| 3. Internal | 23,240.0 | 84.9 |
| 4. External walls | 413.5 | 1.5 |
| 5. Roof | 0 | 0 |
| 6. Ventilation | 903.5 | 3.3 |
| Total | **27,377** | 100% |
| Heat gain per m2 floor area = 88.9 W/m2 |  | |
| Heat gain per m3 space = 22.2 W/m3 |

**Example 3**

The Restaurant shown below is to be maintained at a constant environmental temperature of 22oC for a plant operation of 12 hours per day.

The Restaurant area is on the ground floor of an Single storey building located at 51.7oN.

The internal construction is lightweight partitions, concrete hollow slab floors and suspended ceilings.

Calculate the maximum sensible cooling load in the Restaurant area in July.

DATA:

Occupants = 70

Lighting = 22 Watts / m2 floor area

Infiltration = 1.0 air changes per hour

Outside air temperature (to) = 28oC.

Building classification = lightweight, fast response building.

External wall surface texture = dark.

External wall - use information from standard Brick, internal 50mm EPS insulation, 100mm lightweight aggregate concrete block, 13mm dense plaster, cavity wall.

Windows - Double glazed internal shade, clear 6mm glass, light slatted

blinds, intermittent shading.

Roof - use information in standards

Heat gain from equipment = 2000 Watts

s

|  |
| --- |
| **14.0 m** |

|  |
| --- |
| **7.7 m** |

|  |
| --- |
| **9.5 m** |

|  |
| --- |
| Female Toilet |

|  |
| --- |
| Male Toilet |

|  |
| --- |
| Reception |

|  |
| --- |
| Entrance |

|  |
| --- |
| **10.0 m** |

|  |
| --- |
| Lobby |

|  |
| --- |
| **Restaurant** |

|  |
| --- |
| **3.5 m** |

|  |
| --- |
| Kitchen |

|  |
| --- |
| **2.7m** |

|  |
| --- |
| Cold Store |

|  |
| --- |
| Prep. Room |

|  |
| --- |
| **PLAN**  **Scale: 1:100** |

|  |
| --- |
| South |

|  |
| --- |
| All Restaurant Windows  1.4 m wide x 2.0 m high, double glazed. |

|  |
| --- |
| Height of wall to eaves  = 3.0 metres. |

|  |
| --- |
| Height of ceiling at ridge = 5.9 metres. |

|  |
| --- |
| Roof pitch = 300 |

|  |
| --- |
| South |

Answer

Areas:

Area of window = 1.4 x 2.0 = 2.8 m2.

Total area of glass = 2.8 x 10No. windows = 28.0 m2.

Area of glass facing South = 14.0 m2.

Area of wall facing South = 14.0 m x 3.0 m high = 42 m2 less glass = 42 - 14 = 28.0 m2.

Floor area = 14 x 10 = 140 m2.

Ceiling area = Length x 2(Rafter length inside)

Rafter length inside = 0.5 x room width / cos roof pitch

= Rafter length inside = 0.5 x 5 / cos 300.

= Rafter length inside = 0.5 x 5 / 0.866 = 5.774 metres

Ceiling area = 14 x 2 (5.774) = 161.7 m2.

Room volume = 140m2 x 3 + ( 14 x 5 x 2.9 ) = 623 m3.

Gains:

1. Sensible transmission through glass Qg = Ag Ug (to - tr)

Qg = 28.0 x 2.8 (28 – 22)

Qg = 470 Watts

2. Solar Gain through glass Qsg = Fc Fs qsg Ag

where:

Qsg = Actual cooling load (W)

Fc = Air node correction factor from Table in page 2 – internal blind, fast response - 0.91.

Fs = Shading factor from Table in page 2 - for blind/clear/clear, fast response – 0.95.

qsg = Tabulated cooling load from Intermittent shading for July 4th , orientation South,

12.30 hours gives maximum of 238 W/m2

Ag  = Area of glass facing South (m2)

(Maximum is at 12.30 hrs) Qsg = 0.91 x 0.95 x 238 x 14.0

Qsg = 2,880 Watts

3. Internal Qint. = Qint.

Qint. = Lights (22 W/m2 x 140) + 2000 W + People (70 x 100)

Qint. = 3080 + 2,000 + 7,000

Qint. = 12,080 Watts

1. External wall

Find information from standard the decrement factor is 0.42, time lag  is 8.8 hours, ‘U’ value 0.52 W/m2oC.

If the maximum solar heat gain is at 12.30 pm and the time lag is 8.8 hours then the time of the relevant sol air temperature is;

12.50 - 8.8 = 3.7 say  is at 4.00 am.

Teo = sol-air temperature when Tabulated cooling load (qsg) is at 04.00 hrs dark wall, South facing gives 10.4 oC.

A correction can be applied to this since we are using outside air temperature (To) of 28oC.

The tabulated maximum outside air temperature (To) (July 4th) ocurrs at 16.00 hrs.

and is 25.40C.

The difference in outside temperatures is; 28 – 25.4 = 2.6 oC.

The actual sol air temperature (teo) to use in this example is;

2.6 oC + 10.4 oC = 12.8 oC

External wall Q+Wall  = A U [(Tem - Tr) + f ( Teo - Tem)]

Therefore the Solar Gain through a wall at time () is;

Q  = heat gain through wall at time  (Watts)

 = time lag in hours

A = area of wall facing South (m2)

U = overall thermal transmittance given in = 0.52 W/m2 oC.

Tem = 24 hour mean sol-air temperature (oC) CIBSE Guide J (2002) - Table 5.36 at 13.00 hrs, dark wall facing South – 25.8oC

Tr = constant dry resultant temperature (oC). Room dry bulb of 21oC is given.

f = decrement factor for wall = 0.42.

Teo = sol-air temperature at time () (oC) from above is 12.8oC.

(dark façade) Q  Wall  = A U [( tem - tr) + f ( teo - tem)]

Q  Wall  = 28 x 0.52 [( 25.8 – 22) + 0.42 ( 12.8 – 25.8)]

Q  Wall  = 14.56 [ 3.8 + - 5.5 ] - this - 5.5 is a heat loss since it happens so early in the morning and will be neglected.

Q  Wall  = 14.56 [ 3.8 ]

Q  Wall  = 55 Watts

1. Roof

Find decrement factor (f)

The decrement factor is 0.88, time lag is 3.0 hours, ‘U’ value 0.23 W/m2oC.

If the maximum solar heat gain is at 12.30 pm and the time lag is 3.0 hours then the time of the relevant sol air temperature is;

 is at 12.30 hrs - 3.0 = 9.30 hrs

Teo = sol-air temperature when Tabulated cooling load (qsg) is at 10.00 hrs. dark wall, South facing gives 40.4 oC.

A correction can be applied to this since we are using outside air temperature (To) of 28oC.

The tabulated maximum outside air temperature (to) from CIBSE Guide J (2002) - Table 5.36 page A6-127 (July 4th) ocurrs at 16.00 hrs. and is 25.40C.

The difference in outside temperatures is; 28 – 25.4 = 2.6 oC.

The actual sol air temperature (teo) to use in this example is; 2.6 oC + 40.4 oC = 43 oC

Q  Roof = A U [( Tem - Tr) + f ( Teo - Tem)]

Q  Roof = 161.7 x 0.23 [(25.8 – 22) + 0.88 (43 – 25.8 )]

Q  Roof = 37.19 [ ( 3.8 + 15.1 ) ]

Q  Roof = 703 Watts

6. Ventilation Qsi = n V (To - Tr) / 3

Qsi = 1.0 x 623 (28 – 22) / 3

Qsi = 1,246 Watts

7. Q total = Qg + Qsg + Qint. + Q  Wall + Q  Roof + Qsi

Q total = 470 + 2,880 + 12,080 + 55 + 703 + 1,246

Q total = **17,434 Watts**

The results are shown in the table below.

|  |  |  |
| --- | --- | --- |
| **Heat Gain from** | **Watts** | **%** |
| 1. Sensible transmission through glass | 470 | 2.7 |
| 2. Solar gain through glass | 2,880 | 16.5 |
| 3. Internal | 12,080 | 69.3 |
| 4. External walls | 55 | 0.3 |
| 5. Roof | 703 | 4.0 |
| 6. Ventilation | 1,246 | 7.2 |
| Total | **17,434** | 100% |
| Heat gain per m2 floor area = 125 W/m2 |  | |
| Heat gain per m3 space = 28 W/m3 |