Exercises on Thermal Comfort, Load and Energy Calculations
(Solutions)

1. (a) Briefly describe the heat balance equation for assessing thermal comfort and its parameters. Apart from heat balance, what is the other condition necessary to ensure thermal comfort?

Answer:

The heat balance equation for thermal comfort is:

$$S = M - W - E - (R + C)$$

- S = Rate of heat storage; proportional to rate of change in mean body temp.; normally, S is zero; adjusted by the thermo-regulatory system of the body
- M = Metabolic rate; heat released from human body per unit skin area, depends on muscular activities, environment, body sizes, etc.; 1 met = 58.2 W/m^2 (seated quiet person)
- W = Mechanical work, energy in human body transformed into external mechanical work
- E = Evaporative heat loss; release of latent heat energy from evaporation of body fluid respired vapour loss; E_{res} (respiration heat losses: latent E_{rel} and sensible E_{rec}) and evaporative heat loss from skin E_{sk} (include skin diffusion E_{dif} and regulatory sweating E_{rsw})
- R + C = Dry heat exchange, through convective and radiative heat transfer; heat loss by radiation if skin temp. > temp. of surrounding surfaces; heat loss by convection if skin temp. > dry bulb temp.

The other condition necessary to ensure thermal comfort is: sense of thermal neutrality (depends on actual combination of skin temperature and the body's core temp, and the absence of local discomfort conditions).

(b) Explain the meaning of the following environmental indices commonly used for evaluating the perception of thermal comfort.

i) Mean radiant temperature

ii) Operative temperature

iii) Effective temperature

iv) Equivalent temperature

Answer:

i) Mean radiant temperature = uniform temp. of an imaginary black enclosure which result in the same heat loss by radiation as the actual enclosure

ii) Operative temperature = uniform temp. of an imaginary enclosure with the same dry heat by R + C as in the actual environment (integrate dry-bulb and MRT)

$$t_o = \frac{h_r \cdot t_r + h_c \cdot t_{db}}{h_r + h_c}$$

iii) Effective temperature = temp of an environment at 50%RH that results in the same total heat loss from the skin as for the actual environment (combine temp. & humidity effect)

iv) Equivalent temperature = temp. that integrates the effect of dry-bulb, MRT and air velocity, also called wind-chill temperature

2. (a) Briefly explain the meaning of the following terms for cooling load principles.

i) Space heat gain
ii) Space cooling load
iii) Space heat extraction rate
iv) Cooling coil load

What are the major components of space cooling load? Which components could have a latent part?

Answer:

Meaning of the following terms:

i) Space heat gain: instantaneous rate of heat gain that enters into or is generated within a space.

ii) Space cooling load: the rate at which heat must be removed from the space to maintain a constant space air temperature.

iii) Space heat extraction rate: the actual rate of heat removal when the space air temp. may swing.

iv) Cooling coil load: the rate at which energy is removed at a cooling coil serving the space.

Major components of space cooling load:

External

1. Heat gain through exterior walls and roofs
2. Solar heat gain through fenestrations (windows)
3. Conductive heat gain through fenestrations
4. Heat gain through partitions & interior doors

Internal

1. People
2. Electric lights
3. Equipment & appliances

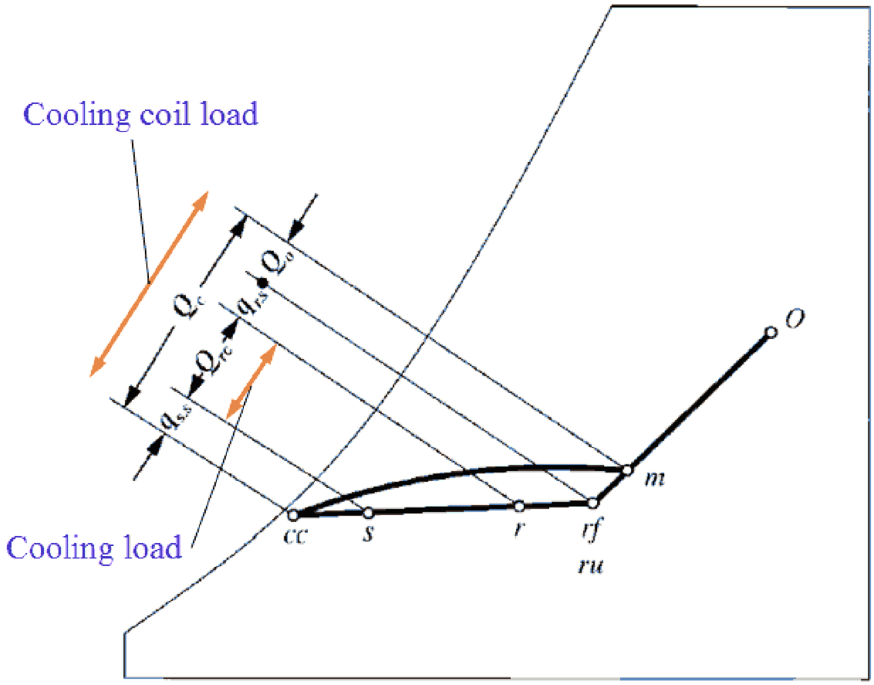
People and equipment & appliances could have a latent part.

(b) Draw a summer air conditioning cycle on a psychrometric chart using the following conditions. Illustrate on the chart the important components of the cooling coil load. What is the sensible heat ratio of the space cooling process?

- Outdoor air at dry-bulb temperature 33 ^{o}C and wet-bulb temperature 28 ^{o}C
- Room air at dry-bulb temperature 25 ^{o}C and relative humidity 50%
- Supply air at dry-bulb temperature 14 ^{o}C and relative humidity 85%
- Supply fan and duct heat gain is assumed 1.5 ^{o}C
- Return plenum and duct heat gain is assumed 1.5 ^{o}C
- Outdoor air flow rate = 20 l/s and return air flow rate = 80 l/s

Answer:

Sample of the A/C cycle:



Important components of the cooling coil load are:

- Space cooling load
- Supply system heat gain
- Return system heat gain
- Ventilation load

Sensible heat ratio of the space cooling process (s-r) as obtained from the chart is = 0.75

3. (a) Briefly explain the meaning of "sol-air temperature" and the equation to express and calculate it.

What are the <u>three</u> components of Transfer Function Method (TFM)? Show them on a simple diagram of cooling load principles.

Answer:

<u>Sol-air temperature</u>: A fictitious outdoor air temperature that gives the rate of heat entering the outer surface of walls and roofs due to the combined effect of incident solar radiation, radiative heat exchange with the sky vault and surroundings, and convective heat exchange with the outdoor air.

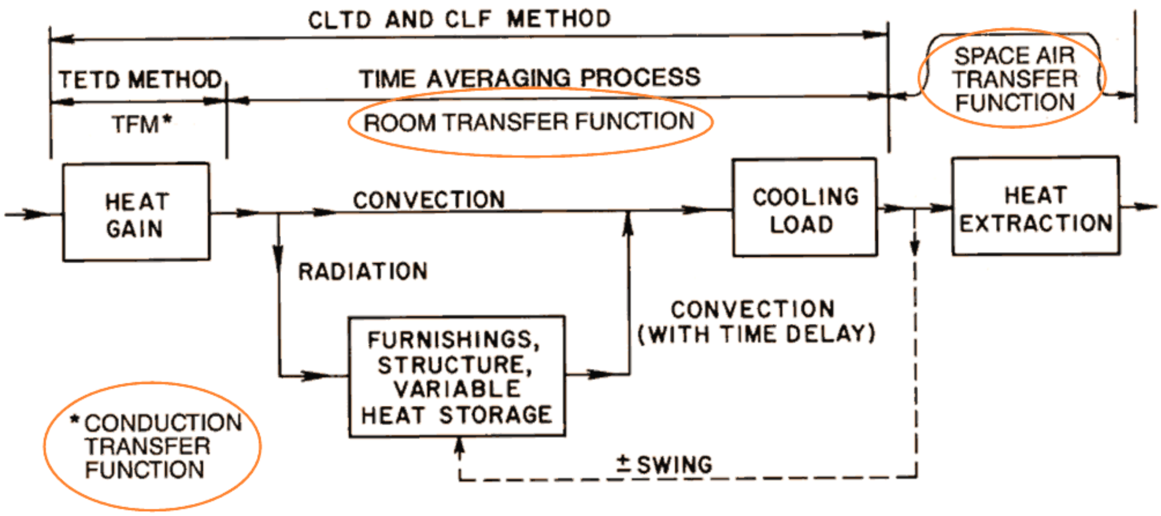
$$t_e = t_o + \frac{\alpha E_t}{h_o} - \frac{\varepsilon \Delta R}{h_o}$$

where

α = absorptance of surface for solar radiation
E_t = total solar radiation incident on surface, $W/(m^2 \cdot K)$
h_o = coefficient of heat transfer by long-wave radiation and convection at outer surface, $W/(m^2 \cdot K)$
t_o = outdoor air temperature, °C
t_s = surface temperature, °C
ε = hemispherical emittance of surface
ΔR = difference between long-wave radiation incident on surface from sky and surroundings and radiation emitted by blackbody at outdoor air temperature, W/m^2

Three components of Transfer Function Method (TFM):

- Conduction transfer function (CTF)
- Room transfer function (RTF)
- Space air transfer function (SATF)



(b) Load and energy calculations were performed for an office building using a building energy simulation program. The annual energy use for a reference case and a low-energy case is shown on Figure 1.

If the total floor area of the building is 500 m^2, determine the followings:

i) Annual energy saving of the low energy case (in kWh).

ii) Amount of the energy saving obtained from "cooling" and "lights", respectively (in kWh).

The load estimation indicates that the peak design cooling loads for reference case and low-energy case are 44 kW and 28 kW, respectively. Calculate the load density (in m^2/kW) of the peak design cooling loads for each case.

The 24-hour cooling load profiles of the two cases have also been analysed. Briefly explain the important factors affecting the characteristics of the load profiles. If the HVAC system of the building is shut down at night time, what could happen to the cooling load when the system starts to operate in the morning of the next day.

Answer:

i) Amount of the energy saving obtained from

- "cooling" = (111.4 – 46.2) x 500 = 32,600 kWh
- "lights" = (72.7 – 25.7) x 500 = 23,500 kWh

ii) Density of the peak design cooling loads:

- Reference case = 500 / 44 = 11.36 m^2/kW
- Low-energy case = 500 / 28 = 17.86 m^2/kW

iii) Important factors affecting the characteristics of the load profiles:

- Heat storage effect (thermal capacity of building fabric)
- Operation schedule of building and HVAC system

iv)When HVAC system starts to operate in the morning of the next day: (brief description)

- Need to cool or warm the building fabric
- Cool-down or warm-up period