Chapter 4

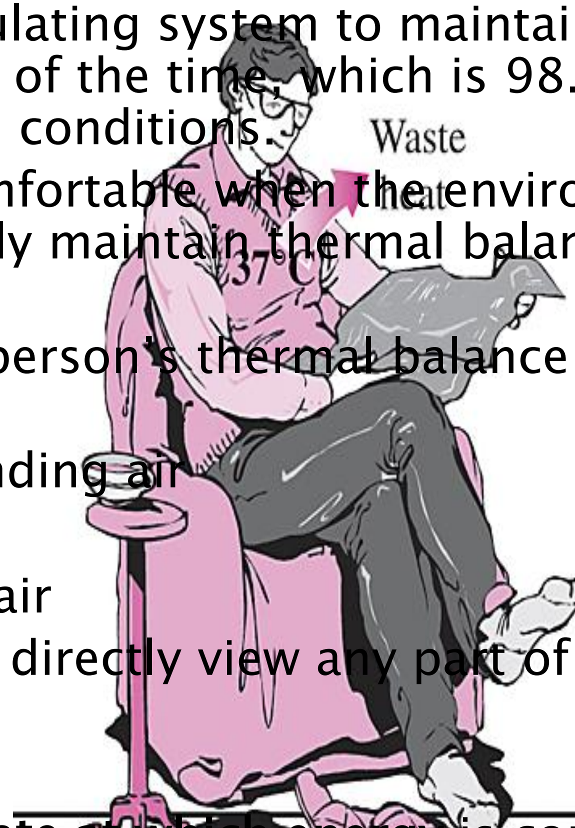
Comfort and health-Indoor air quality

Comfort-Physiological Consideration

- The human body has a complicated regulating system to maintain the human body temperature constant most of the time, which is 98.6 F (36.9 C) regardless of the environmental conditions.
- A normal, healthy person feels most comfortable when the environment is at conditions where the body can easily maintain thermal balance with that environment.
- The environmental factors that affect a person's thermal balance and influence thermal comfort are:

1. The dry bulb temperature of the surrounding air
2. The humidity of the surrounding air
3. The relative velocity of the surrounding air
4. The temperature of any surface that can directly view any part of the body and thus exchange radiation
5. Personal activity and clothing.

- The body temperature is controlled by **rate at which energy** is converted from chemical to thermal form within the body. The blood circulation controls the rate at which the thermal energy is carried to the surface of the skin.



- A unite to express the metabolic rate per unite of body surface area **is met, defined as the metabolic rate of a sedentary person (quite): 1 met=18.4 Btu/(hr-ft^2) (58.2 w/ m^2).** *ASHRAE handbook (1)* gives the average heat generation for various categories of persons
- Type and amount of clothing that a person is wearing affects his/her comfort and it is measured by degree of insulation and it is described as single equivalent uniform layer over the whole body. The insulating value is given in terms of **clo units: 1 clo= 0.88 (F-ft^2 -hr)/Btu [0.155 (m^2 - C)/W].** *ASHRAE handbook (1)* gives typical insulation values for clothing.

Environmental Comfort Indices

- There are some environmental factors that affect human comfort, which are:

1. Temperature (dry bulb, wet bulb and dew point)
2. Humidity, both relative and humidity ratio
3. Air motion
4. Radiation

- Computations involves the angle factor or configuration factor used in radiation heat transfer calculations. The basic index used to describe the radiative conditions in space is the mean radiant temperature and it is measured by Vernon's globe thermometer.
- Measurements of the glob thermometer can be combined to estimate the mean radiant temperature as given in equation (4-1).

$$T_{mrt}^4 = T_g^4 + C\bar{V}^{1/2}(T_g - T_a)$$

where

T_{mrt} = mean radiant temperature, R or K

T_g = globe temperature, R or K

T_a = ambient air temperature, R or K

$\bar{V}$ = air velocity, fpm or m/s

$C = 0.103 \times 10^9$ (English units) $= 0.247 \times 10^9$ (SI units)

- Other indices have been developed to simplify the environmental factors controlling human comfort. These indices have two categories, depending on how they were developed. 1- Rational indices, which depend on theoretical concepts already developed and they have the least direct use in design 2- Empirical indices, which are based on measurements with subjects or relations that do not necessarily follow theory.
- ET^* : the effective temperature of an environment at 50% relative humidity that results in the same total heat loss from skin as in the actual environment, it combines temperature and humidity into single index. ET depends on both clothing and activity, so it is not possible to generate a universal chart and its calculations are tedious.
- SET: standard effective temperature, which has been defined for typical indoor conditions. These conditions are: clothing insulation= 0.6 clo, moisture permeability index = 0.4, metabolic activity level= 1 met, air velocity less than 20 fpm and ambient temperature = mean radiant temperature.
- The operative temperature: is the average of the mean radiant and ambient air temperatures depends on their heat transfer coefficient. It is sometimes called the adjusted dry bulb temperature. The ET and the operative temperature are used in comfort design by ASHRAE standard 55-1992 (2).

- The humid operative temperature : is the temperature of a uniform environment at 100% relative humidity in which a person loses the same total amount of heat from skin as in the actual environment. It takes into account the convective, conductive and radiative heat transfer from the body as well as mass transfer. A similar index is the adiabatic equivalent temperature
- The heat stress index: is the ratio of the total evaporative heat loss required for thermal equilibrium to the maximum evaporative heat loss possible for environment, multiplied by 100, for steady-state conditions and with the skin temperature held constant at 95 F.
- The skin wettedness is similar to the heat stress index. It is the ratio of observed skin sweating to the maximum possible sweating for the environment. Skin wettedness is a measure of thermal discomfort.
- The wet globe temperature t_{wbg} is and environmental heat stress index that combines the dry bulb temperature t_{db} , a naturally ventilated wet bulb temperature t_{nwb} and the globe temperature t_g .
- Equations (4-2) and (4-3) defines this index. Equation 4-2 is used when the solar radiation is significant.

$$t_{wbg} = 0.7_{nwb} + 0.2\ t_g + 0.1\ t_{db}$$

Equation 4-2 is usually used where solar radiation is significant. In enclosed en
ments the index is calculated from

$$t_{wbg} = 0.7\ t_{nwb} + 0.3\ t_g$$

Comfort Conditions

- ASHRAE standard 55-1992 gives the conditions for an acceptable thermal environment.
- Most comfort studies involve use of the ASHRAE thermal sensation scale, which relates thermal sensation felt by a participant to a corresponding number.
- These scales are:

+3 hot

+2 warm

+1 slightly warm

0 neutral

-1 Slightly cool

-2 cool

-3 cold

- Energy balance equations have been developed that use a predicted mean vote (PMV) index, which gives the mean response of a large group of people according to ASHRAE thermal sensation scale.

- The ranges based on a 10 % dissatisfaction criterion, which is described as general thermal comfort.
- Local thermal comfort describes the effect of thermal radiation asymmetry, drafts, vertical air temperature distribution and floor surface temperatures.
- In selecting indoor design conditions it is important to avoid condensation on building surfaces and materials by adjusting indoor dew point.

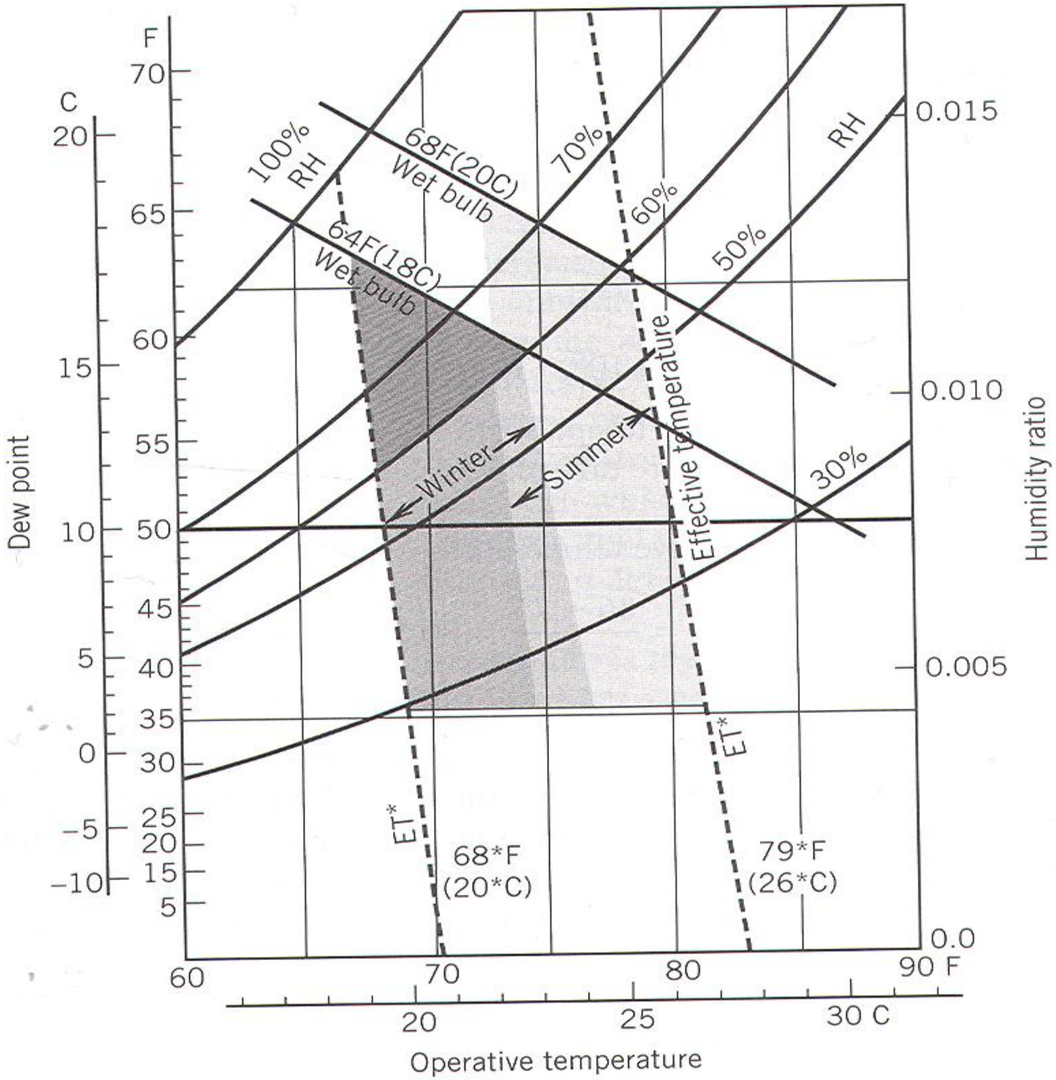


Figure 4-1 Acceptable ranges of operative temperature and humidity for people in typical summer and winter clothing during light and primarily sedentary activity (≤ 1.2 met). (Reprinted by permission from ASHRAE Standard 55-1992.)

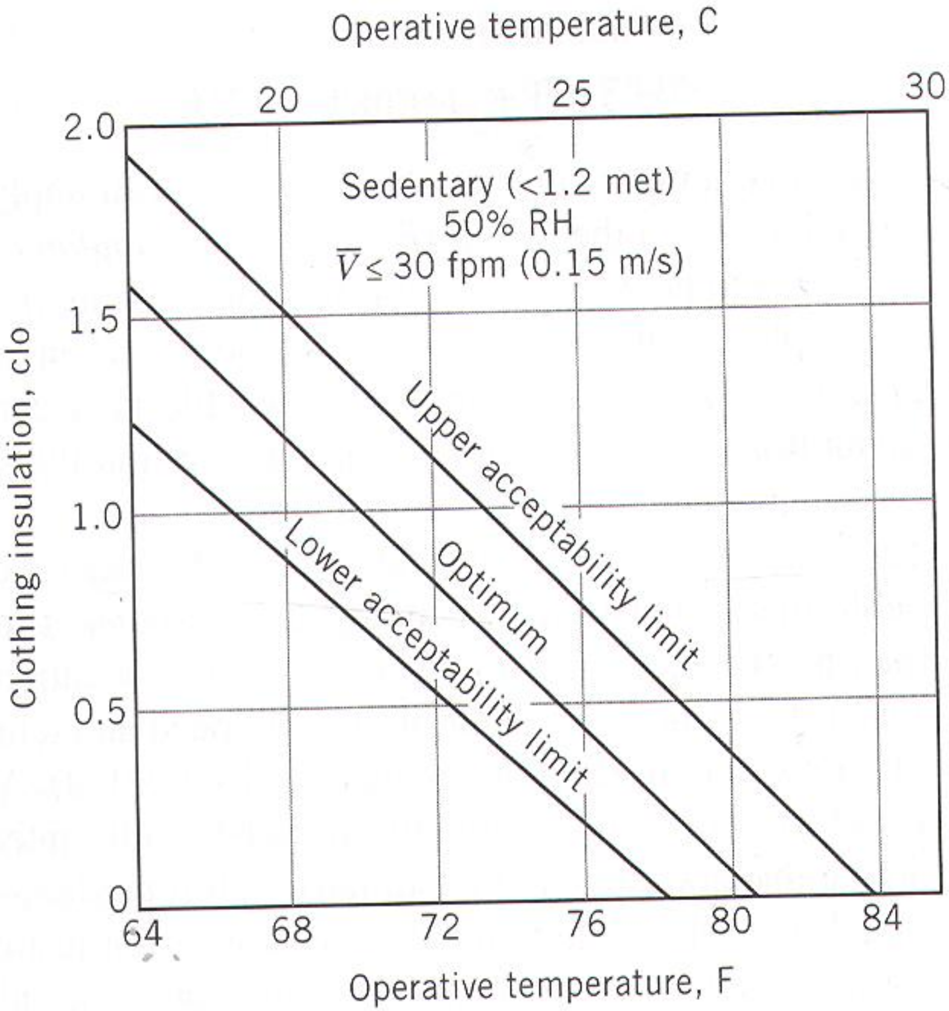


Figure 4-2 Clothing insulation for various levels of comfort at a given temperature during light and primarily sedentary activities (≤ 1.2 met). (Reprinted by permission from ASHRAE Standard 55-1992.)

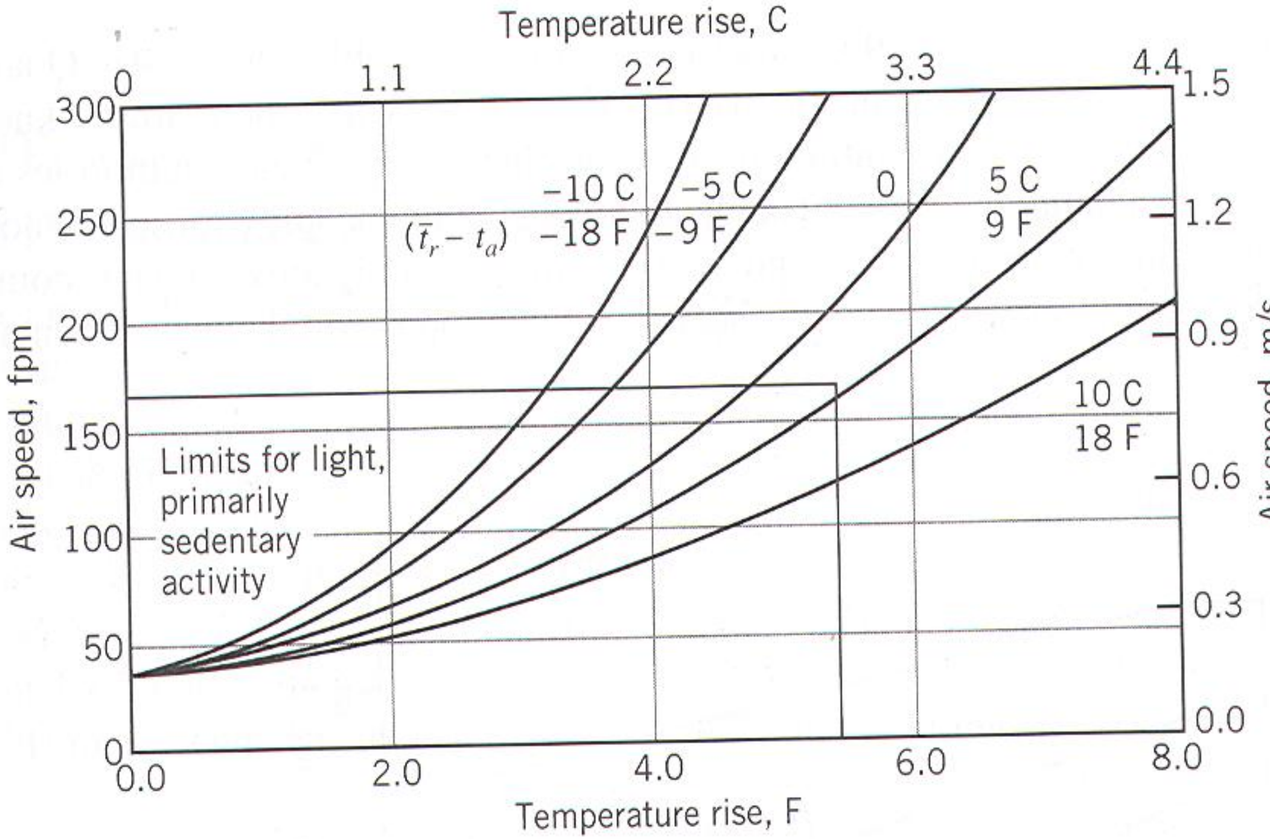


Figure 4-3 Air speed required to offset increased temperature. (Reprinted by permission from ASHRAE Standard 55-1992.)

Acceptable operative temperatures for active persons can be calculated (for 1.2 < met < 3) in degrees Fahrenheit from:

$$t_{o,active} = t_{o,sedentary} - 5.4(1 + clo)(met - 1.2)\,F \tag{4-4a}$$

The Basic Concerns of IAQ

- ASHRAE Standard 62-1999 “ Ventilation for Acceptable Indoor Air Quality” (6), defines IAQ as: air in which there are no known contaminates at harmful consent rations and with which a substantial majority (80%) of occupant are not having any kind of dissatisfaction.
- Maintaining good indoor quality includes keeping gaseous and particulate contaminants below some acceptable level in the indoor environment.
- Sick building syndrome: buildings with an unusual number of suffering occupants.

Methods to Control Humidity

- Why it is important to control the humidity?
- Indoor spaces with relative humidity of 50% are shown to be the most convenient atmosphere health wise.
- Moister is removed during cooling and is added during heating.
- In cooling process a problem of fungus and mold growing appears when:

1. Liquid is blown from the coil by the airstream and into the supply duct.
2. If the drain pan is poorly drained
3. If the refrigeration unit is cycling on and off in short periods due to low load

- Ultraviolet (UV) lamps and especially treated surfaces are used in preventing mold growth.
- Humidity can be lowered by reducing the air speed (fan speed), or by passing some of the air around the coil under special circumstances

- Chemical treatment to remove excess water is a way to remove humidity from makeup air (outside door air) by using desiccants.
- Desiccant is a sorbent material that has a particular affinity for water and they are used in the HVAC systems when:

1. There is a high latent to sensible load ratio
2. The cost of energy to regenerate the desiccant is low relative to the cost of energy used for refrigeration cycle for dehumidification
3. Air might have to be chilled below the freezing point in an attempt to dehumidify it by refrigeration
4. Air must be delivered continuously at subfreezing temperatures

- In the heating cycle when water is sprayed to humidify the air some water may evaporate and blow with the airstream into the supply duct, this liquid build-up may cause mold growing.
- Humidification by steam is more advantageous than water in avoiding mold problems.

Methods to Control Contaminants

- Methods to control contaminants:

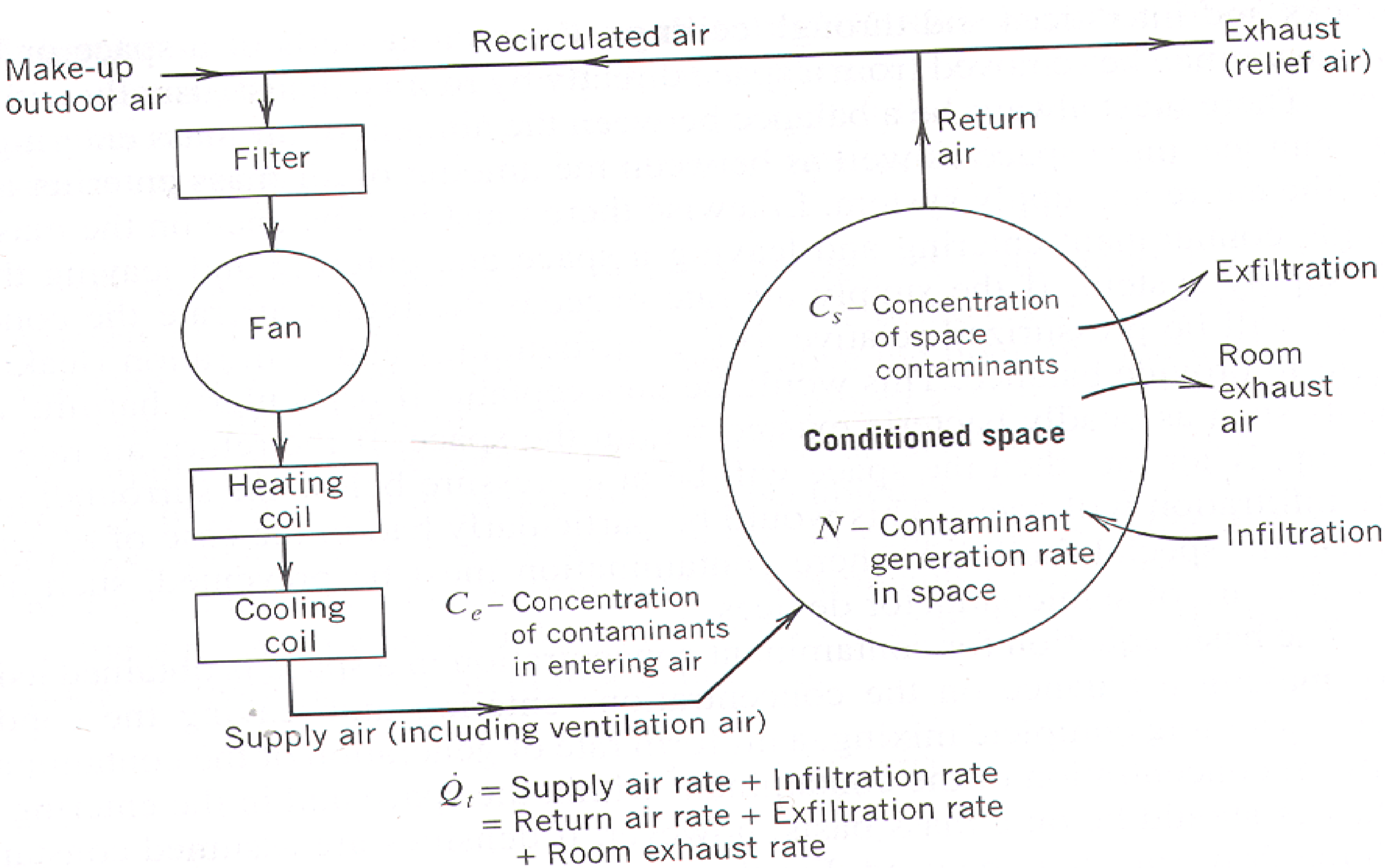
1. Source elimination or modification
2. Use of outdoor air
3. Space air distribution
4. Air cleaning

Source Elimination or Modification

- Elimination is mainly for new buildings.
- Modification is for already existed buildings.

Use of Outdoor Air

- Supply air: is the air delivered to the conditioned space for ventilation, heating cooling, etc.
- Outdoor air is used to dilute contaminants within a space.
- Ventilation air: is a portion of air that is outdoor air and recirculated tread air are mixed to maintain good IAQ.
- Outdoor air is air taken from external atmosphere and thus have not been circulated before.
- Infiltration: the entrance of outdoor air through windows, doors and cracks and it happens also when the return airflow is more than the supply.
- Recirculated air: is the air recirculated from the conditioned space, and it is only differs from return air in that some of return air is exhausted outside through dampers of fans.
- Exfiltration is air leakage to the outer atmosphere and it happens when the supply air is more than the return air.
- Mass balance of different flow rates is required, as well as mass of any contaminant entering and leaving.


Recirculated air
Make-up
outdoor air
Exhaust
(relief air)
Filter
Return
air
Fan
Exfiltration
C_s – Concentration
of space
contaminants
Room
exhaust
air
Conditioned space
Heating
coil
N – Contaminant
generation rate
in space
Infiltration
Cooling
coil
C_e – Concentration
of contaminants
in entering air
Supply air (including ventilation air)
$\dot{Q}_t$ = Supply air rate + Infiltration rate
= Return air rate + Exfiltration rate
+ Room exhaust rate

The basic equation for contaminant concentration in a space is obtained using Fig. 4-6, making a balance on the concentrations entering and leaving the conditioned space assuming complete mixing, a uniform rate of generation of the contaminant, and uniform concentration of the contaminant within the space and in the entering air. All balances should be on a mass basis; however, if densities are assumed constant, then volume flow rates may be used. For the steady state case,

$$\dot{Q}_t C_e + \dot{N} = \dot{Q}_t C_s \tag{4-5}$$

where:

$\dot{Q}_t$ = rate at which air enters or leaves the space
C_s = average concentration of a contaminant within the space
$\dot{N}$ = rate of contaminant generation within the space
C_e = concentration of the contaminant of interest in the entering air

Equation 4-5 can be solved for the concentration level in the space C_s or for the necessary rate $\dot{Q}_t$ at which air must enter the space to maintain the desired concentration level of a contaminant within the space. This fundamental equation may be used as the basis for deriving more complex equations for more realistic cases.

EXAMPLE 4-2

A person breathes out carbon dioxide at the rate of 0.30 L/min. The concentration of CO_2 in the incoming ventilation air is 300 ppm (0.03 percent). It is desired to hold the concentration in the room below 1000 ppm (0.1 percent). Assuming that the air in the room is perfectly mixed, what is the minimum rate of air flow required to maintain the desired level?

SOLUTION

Solving Eq. 4-5 for $\dot{Q}_t$:

$$\dot{Q}_t = \frac{\dot{N}}{C_s - C_e} = \frac{0.30 \text{ L/min}}{(0.001 - 0.0003)(60 \text{ s/min})}$$
$$= 7.1 \text{ L/s} = 15 \text{ cfm}$$

- In most HVAC systems emphasis is placed on maintaining the occupied zone at a nearly uniform condition.
- Occupied zone: is the region within an occupied space between the floor and 72 in.(180 cm) above the floor and more than 2 ft (60 cm) from the wall or fixed AC equipment.
- Some fraction S of the supply rate Q_s bypass and does not enter the occupied zone. In result some of the outdoor air in the room supply air leaves without doing anything.
- The effectiveness E_{oa} with which outdoor is used can be expressed as the fraction of the outdoor air entering the system that is utilized:
- Stratification factor S: occupied zone bypass factor.

$$E_{oa} = \frac{\dot{Q}_o - \dot{Q}_{oe}}{\dot{Q}_o} \tag{4-6}$$

where:

$\dot{Q}_o$ = rate at which outdoor air is taken in
$\dot{Q}_{oe}$ = rate at which unused outdoor air is exhausted

From Fig. 4-7, with R equal to the fraction of return air $\dot{Q}_r$ that is recirculated, the rate at which outdoor air is supplied to the space $\dot{Q}_{os}$ is

$$\dot{Q}_{os} = \dot{Q}_o + RS\dot{Q}_{os} \tag{4-7}$$

The amount of unused outdoor air that is exhausted $\dot{Q}_{oe}$ is

$$\dot{Q}_{oe} = (1 - R)S\dot{Q}_{os} \tag{4-8}$$

Combining Eqs. 4-6, 4-7, and 4-8 yields

$$E_{oa} = \frac{1 - S}{1 - RS} \tag{4-9}$$

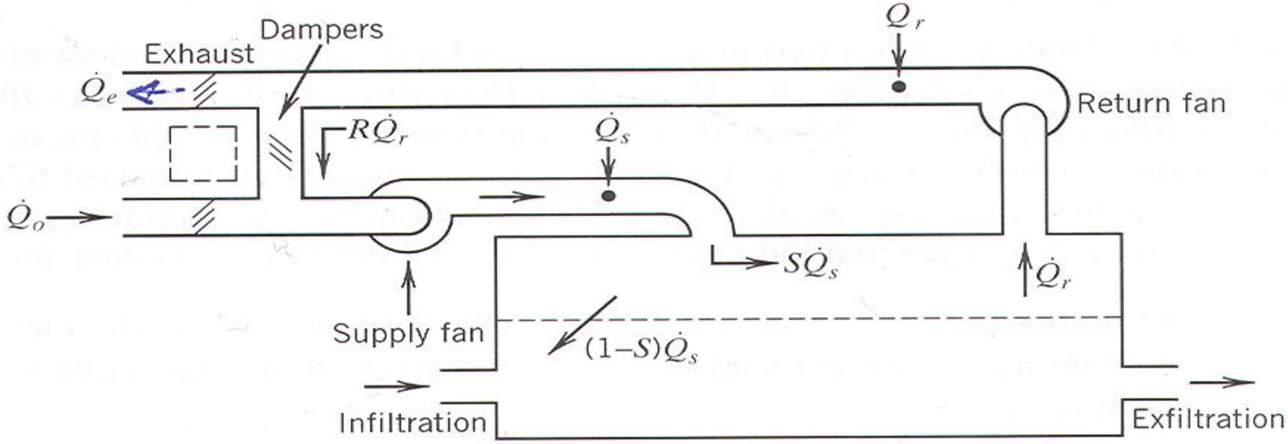


Figure 4-7 Typical air distribution system. (ASHRAE Standard 62-1999 © 1999, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.)

Ventilation Rate Procedure

- The ventilation rate procedure, prescribes the rate at which outdoor air must be delivered to different types of conditioned spaces and various means to condition that air.
- The ventilation rate procedure prescribes:

1. The outdoor air quality acceptable for ventilation or treated when necessary
2. Ventilation rates for residential, commercial, institutional, vehicular and industrial spaces.
3. Criteria for reduction of outdoor air quantities when recirculated air is treated
4. Criteria for variable ventilation when the air volume in the space can be used as a reservoir to dilute contaminants.

- Outdoor air treatment is prescribed where the technology is available and feasible for any concentrations exceeding the values recommended