

# HVAC ME472

Taibah University - Yanbu Branch  
College of Engineering at Yanbu  
**Mechanical Engineering Department**

**Heating, Ventilating, and Air Conditioning**

**HVAC ME472**

**Part 4**

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# Comfort and Health – Indoor Environment Quality

- ❑ **Comfort** is a major concern of the **HVAC** industry.
- ❑ **Comfort** involves control of **temperature**, **humidity**, **air motion**, and **radiant sources** interacting with the occupants.
- ❑ **Odor**, **dust** (particulate matter), **noise**, and **vibration** are additional **factors** that may cause one to feel **uncomfortable**.
- ❑ A well-designed **HVAC** system manages to keep these variables within **specified limits** that have been set by the **customer**, **building codes**, and **good engineering judgment**.
- ❑ **Nonenvironmental factors** such as **dress** and the **activity level** of the occupants must be **considered**.
- ❑ There are more conscious of the need for good **indoor air quality** (IAQ) or a more general concept, good **indoor environmental quality** (IEQ).

# Comfort – Physiological Considerations

- ❑ The amount of **heat generated** and **dissipated** by the human body varies considerably with **activity**, **age**, **size**, and **gender**.
- ❑ The human body has a **complex** regulating system acting to maintain the deep body temperature of about **98.6 °F (36.9 °C)** regardless of the environmental conditions.
- ❑ The environmental **factors** that affect a person's **thermal balance** and therefore influence **thermal comfort** are:
  - ✓ The **dry bulb** temperature of the surrounding air
  - ✓ The **humidity** of the surrounding air
  - ✓ The **relative velocity** of the surrounding air
  - ✓ The **temperature** of any surfaces that can directly view any part of the body and thus **exchange radiation**

# Comfort – Physiological Considerations

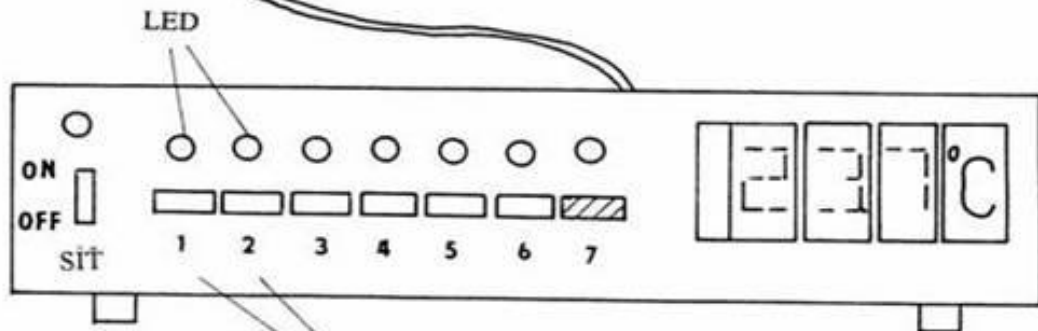
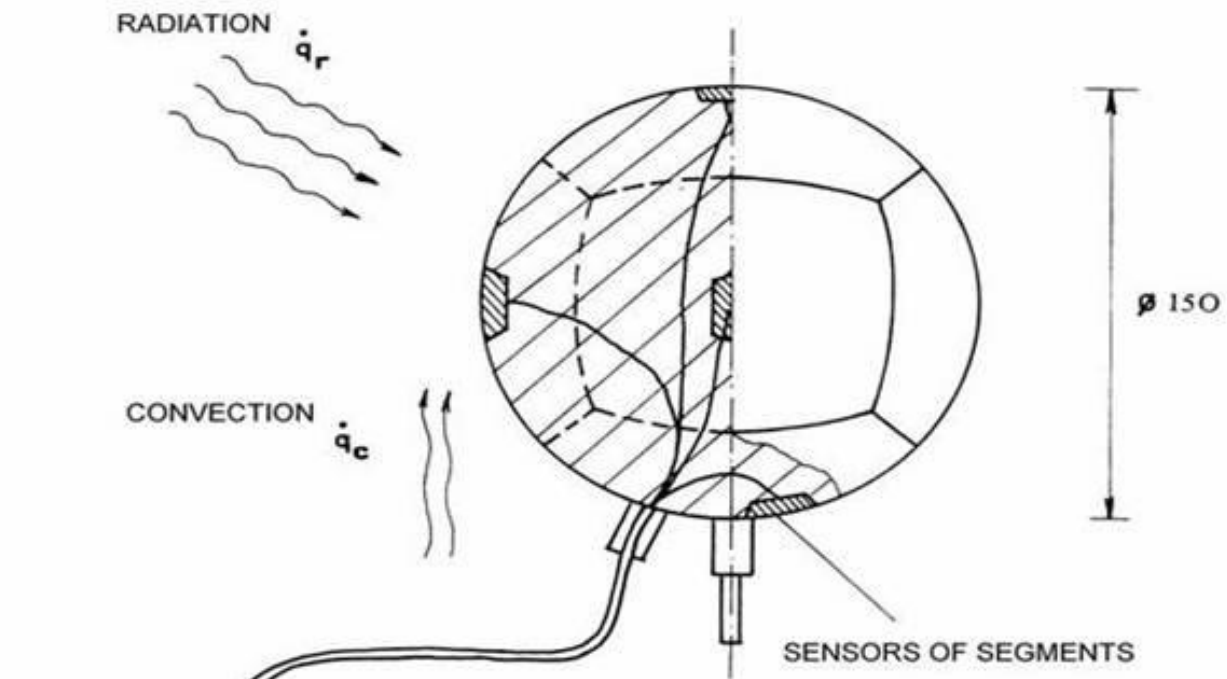
- ❑ the amount of **radiant exchange** between a **person** and the **surroundings**. Cold walls or windows may cause a person to feel cold even though the surrounding air may be at a comfortable level. Likewise, sunlight or warm surfaces such as stoves or fireplaces or ceilings may cause a person to
- ❑ feel warmer than the surrounding air temperature would indicate.
- ❑ In addition the **personal variables** that influence thermal comfort are **activity** and **clothing**.
- ❑ **Animal** and **human** body temperatures are essentially **controlled** by a heat balance that involves **metabolism**, **blood circulation** near the surface of the skin, **respiration**, and **heat** and **mass** transfer from the skin.
- ❑ **Metabolism** determines the rate at which **energy** is converted from **chemical** to **thermal** form within the body
- ❑ Heat transfer from the skin may be by **conduction**, **convection**, or **radiation**.
- ❑ **Sweating** and the accompanying mass transfer play a very important role in the rate at which energy can be carried away from the skin by air.

# Comfort – Physiological Considerations

- ❑ A unit to express the **metabolic** rate per unit of body surface area is the **met**, defined as the metabolic rate of a **sedentary** person (seated, quiet):
  - ❑ 1 met = 18.4 Btu/(hr-ft<sup>2</sup>) (58.2 W/m<sup>2</sup>).
  - ❑ The average adult is assumed to have an **effective surface area** for heat transfer of 19.6 ft<sup>2</sup> (1.82 m<sup>2</sup>) and will therefore **dissipate** approximately 360 Btu/hr (106 W) when functioning in a quiet seated manner.
  - ❑ Comfort is a **subjective** matter, depending upon the **opinion** or **judgment** of those affected.

# Environmental Comfort Indices

- ❑ The basic index used to describe the radiative conditions in a space is the mean radiant temperature, the mean temperature of individual exposed surfaces in the environment.
- ❑ The most commonly used instrument to determine the mean radiant temperature is Vernon's globe thermometer which consists of a hollow sphere 6 in. in diameter, flat black paint coating and a thermocouple or thermometer bulb at its center.
- ❑ The equilibrium temperature assumed by the globe (the globe temperature) results from a balance in the convective and radiative heat exchanges between the globe and its surroundings.
- ❑ Measurements of the globe thermometer, air temperature, and air velocity can be combined as a practical way to estimate values of the mean radiant temperature.



1 - 6 SWITCHES OF SELECTED SEGMENTS  
7 GLOBE TEMPERATURE



# Environmental Comfort Indices

## □ The mean radiant temperature:

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

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)

□ **Rational indices:** depend on theoretical concepts already developed.

□ **Empirical indices** are based on measurements with subjects or on simplified relationships that do not necessarily follow theory.

□ **The effective temperature ET\*** is the temperature of an environment at  $\phi = 50\%$  relative humidity that result in the same total heat loss from the skin as in the actual environment. It combines temperature and humidity into a single index. So **two** environments with the **same** ET\* should produce the **same thermal response** even though the  $T$  and  $\phi$  are **different**.

# Environmental Comfort Indices

❑ Standard effective temperature (SET), defined for typical indoor temperature

- ✓ Clothing insulation = 0.6 clo,
- ✓ Moisture permeability index = 0.4,
- ✓ Metabolic activity level = 1.0 met,
- ✓ Air velocity < 20 fpm,
- ✓ Ambient temperature = mean radiant temperature.

➤ 1 clo = 0.880 (F-ft<sup>2</sup>-hr)/Btu [0.155 (m<sup>2</sup>-C)/W], which is the unit of the cloth insulating value

❑ The operative temperature is the average of the mean radiant and ambient air temperatures, weighted by their respective heat transfer coefficient.

❑ The humid operative temperature is the temperature of a uniform environment at  $\phi = 100\%$  in which a person **loses** the same total amount of heat from the skin as in the actual environment.

# Environmental Comfort Indices

- ❑ The **adiabatic equivalent temperature**, the temperature of a uniform environment at  **$\phi = 0\%$**  in which a person loses the same total amount of heat from the skin as in the actual environment.
- ❑ 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 the environment**, multiplied by 100, for steady-state conditions, and with **the skin temperature** held constant at **95 F**.
- ❑ **The wet bulb globe temperature  $t_{wbg}$**  is an environmental **heat Stress index** that combines the  $t_{db}$ , a naturally ventilated  $t_{wb}$  and the **globe temperature  $t_g$**

$$t_{wbg} = 0.7 t_{nwb} + 0.2 t_g + 0.1 t_{db} \quad (4-2)$$

- Equation 4-2 is usually used where **solar radiation is significant**.
- In **enclosed environments the index** is calculated from:

$$t_{wbg} = 0.7 t_{nwb} + 0.3 t_g \quad (4-3)$$

## Environmental Comfort Indices (Example 4-1)

Determine the operative temperature for a workstation in a room near a large window where the dry bulb and globe temperatures are measured to be 75 F and 81 F, respectively. The air velocity is estimated to be 30 ft/min at the station.

The operative temperature depends on the mean radiant temperature, which is given by Eq. 4-1:

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

or

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

$$T_{mrt} = [(81 + 460)^4 + (0.103 \times 10^9) (30)^{1/2} (81 - 75)]^{1/4} = 546 \text{ R} = 86 \text{ F}$$

Notice that in Eq. 4-1 absolute temperature must be used in the terms involving the fourth power, but that temperature differences can be expressed in absolute or non-absolute units.

A good estimate of the operative temperature is

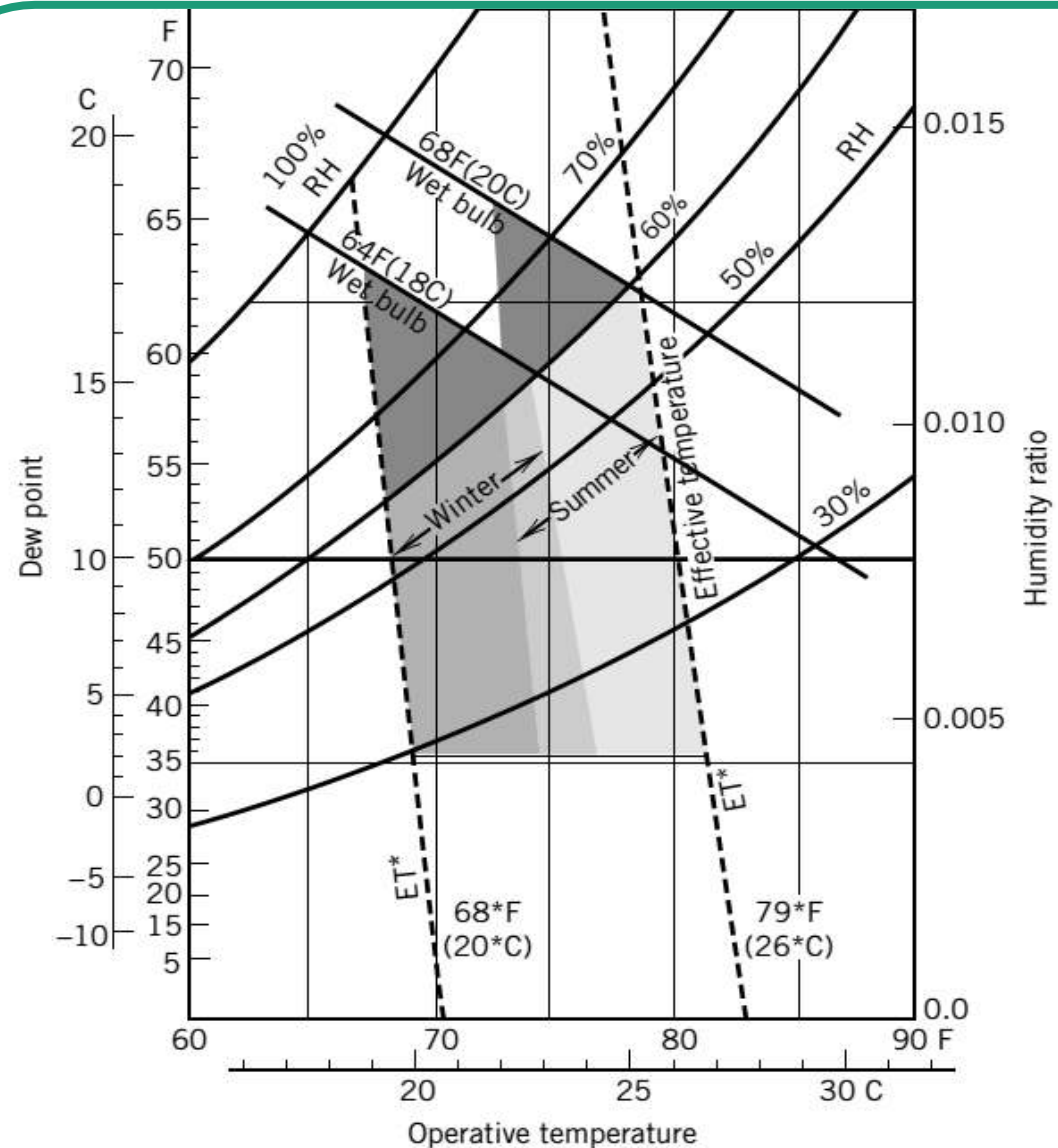
$$t_o = \frac{t_{mrt} + t_a}{2} = \frac{86 + 75}{2} = 80.5, \quad t_o = 81 \text{ F}$$

# Comfort Conditions

- ❑ Most comfort studies involve use of the ASHRAE **thermal sensation scale**.
- ❑ This scale relates words describing **thermal sensations** felt by a participant to a corresponding number. The scale is:
  - +3 hot
  - +2 warm
  - +1 slightly warm
  - 0 neutral
  - 1 slightly cool
  - 2 cool
  - 3 cold

# Comfort Conditions

- ❑ Acceptable range of operative temperature and humidify for people in typical summer and winter clothing during light and primarily sedentary activity ( $\leq 1.2$  met)
- ❑ In selecting indoor design condition, care must be taken to avoid condensation on building surfaces and materials by adjusting the indoor dew points and by controlling the critical surface temperature.



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

## THE BASIC CONCERNS OF IAQ

□ Acceptable **indoor air quality** (IAQ) is that at which there are **no** known contaminants at **harmful concentrations** as determined by **cognizant authorities** and with which a substantial majority **(80 % or more)** of the people exposed do **not** express **dissatisfaction**, with acceptable **odors** air quality, not only are **occupants** comfortable but their environment is **free** of bothersome odors and **harmful** levels of contaminants.

# THE BASIC CONCERNS OF IAQ

- ❑ HVAC systems, in addition to maintaining **thermal** comfort, must also **provide** a **clean, healthy, and odor-free** indoor environment.
- ❑ Maintaining good **indoor air quality** involves keeping **gaseous and particulate** contaminants below some acceptable level in the indoor environment.
- ❑ **Emphasis** on **comfort** and **health** in the workplace and increased litigation place a great **responsibility** on contractors, building owners, employers, and HVAC engineers to be well **informed**, technically **competent**, and totally **ethical** in any actions affecting **indoor air quality**.

# COMMON CONTAMINANTS

## Carbon Dioxide and Other Common Gases

- ❑ Carbon dioxide (CO<sub>2</sub>) is an exhaled by-product of human (and all mammal) metabolism.
- ❑ CO<sub>2</sub> levels are typically higher in occupied interior spaces than for outdoor air.
- ❑ CO<sub>2</sub> is an easily measurable indicator of the effectiveness of ventilation of the space and gives an indication of unacceptable levels of more harmful gases.
- ❑ The Environmental Protection Agency (EPA) recommends a maximum level of 1000 ppm (1.8 g/m<sup>3</sup>) for continuous CO<sub>2</sub> exposure specifically for school and residential occupancy, and as a guideline for other building types.

# COMMON CONTAMINANTS

## Carbon Dioxide and Other Common Gases

- ❑ Incomplete combustion of hydrocarbon fuels and tobacco smoking are two significant sources of carbon monoxide which is highly toxic.
- ❑ Buildings with internal or nearby parking garages and loading docks are more likely to have high levels of CO.
- ❑ HVAC outdoor air intakes at ground level where heavy street traffic occurs can also draw unacceptable levels of CO into the building's air system.
- ❑ Improperly vented or leaking furnaces, chimneys, and water heaters are often the source of difficulty.
- ❑ CO levels near 15 ppm are harmful and can significantly affect body chemistry.
- ❑ Headaches and nausea are common symptoms in those exposed to quantities of CO above their tolerance.

# COMMON CONTAMINANTS

## Carbon Dioxide and Other Common Gases

- ❑ Sulfur oxides are the result of combustion of fuels containing sulfur and may enter a building through outdoor air intakes or from leaks in combustion systems within the building.
  
- ❑ Nitrous oxides are produced by combustion of fuel with air at high temperatures
  - ✓ These contaminants brought in with outdoor contaminated air
  - ✓ Indoor combustion sources frequently contribute significant amounts of nitrous oxides

# COMMON CONTAMINANTS

## Volatile متقلبة Organic Compounds (VOCs)

- ❑ A variety of **organic** chemical **species** occur in a typical modern indoor environment, resulting from **combustion sources**, **pesticides**, مبيدات الآفات **building materials** and **finishes**, cleaning agents and solvents, and **plants** and **animals**.
- ❑ **Formaldehyde** gas, one of the more common **VOC**, can be **irritating** to the eye and the **mucous** membranes and cause a variety of problems such as **asthmatic** and is considered to be a **potential cancer hazard**.
  - ✓ **Acceptable** limits are in the range of 1 ppm as a time-weighted 8-hour average,
  - ✓ **For homes**, levels of 0.1 ppm seem to be a more prudent upper limit.

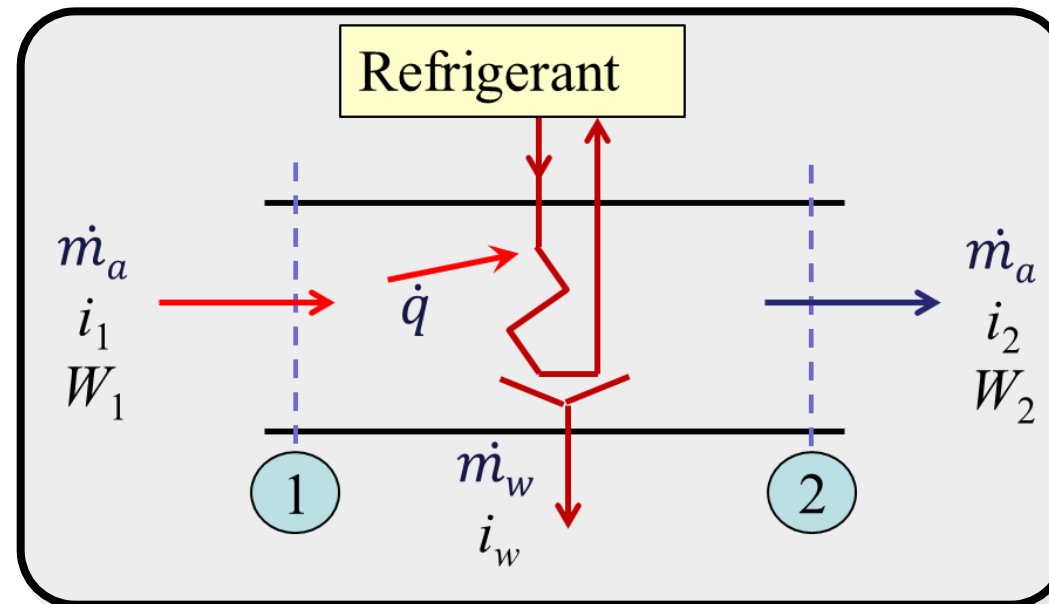
# COMMON CONTAMINANTS

## Particulate Matter

- ❑ A typical sample of outdoor air might contain soot and smoke, silica, clay, decayed **التهاوي** animal and vegetable matter, lint and plant fibers, metallic fragments, bacteria, plant pollens, and other living material.
- ❑ Their size may range from less than 0.01  $\mu\text{m}$  to the size of leaves and insects.
- ❑ When particles are suspended in the air, the mixture is called an aerosol. **الهباء الجوي**
- ❑ Some particulate material may be created in the indoor environment by human or animal activities.
- ❑ Environmental tobacco smoke (ETS) has been one of the major problems in maintaining good indoor air quality, and concern has been heightened by increased evidence of its role in lung diseases, particularly cancer.
- ❑ Allergies are a common problem in a modern society, and the indoor environment may contain many of the particulates found outdoors.

# METHODS TO CONTROL HUMIDITY

- ❑ In order to keep space-relative humidities within acceptable limits in temperate climates, some moisture must be removed from all or part of the supply air when cooling and moisture must generally be added when heating.
- ❑ The most common method of dehumidification of an airstream occurs in the cooling coil, where moisture is condensed from the airstream on the cold fin and coil surfaces when at least part of those surfaces are below the dew point temperature.

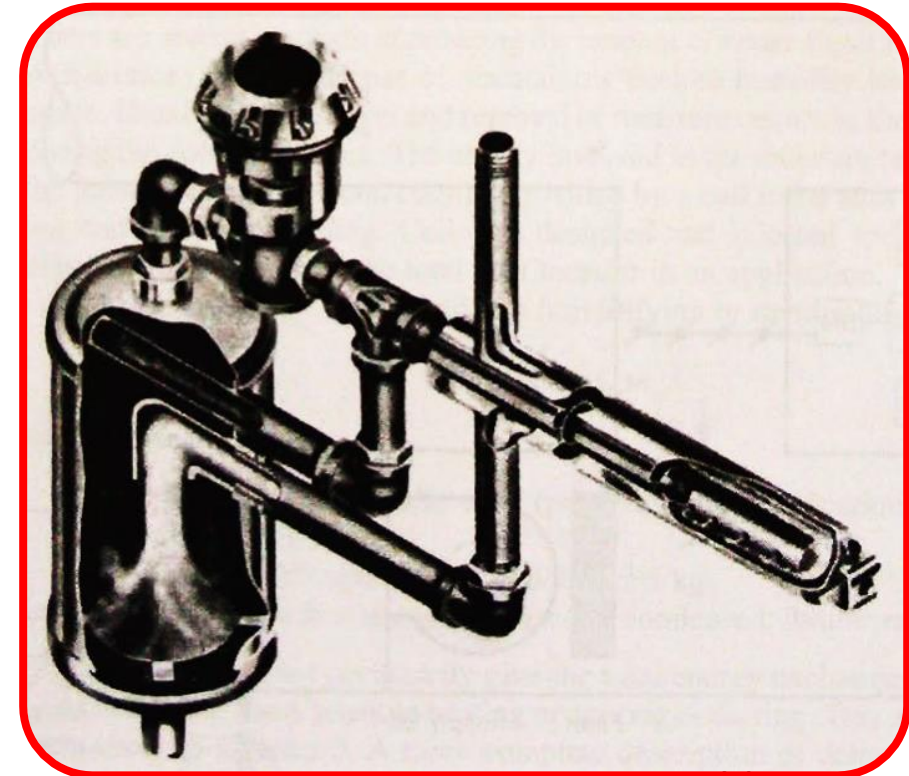


# METHODS TO CONTROL HUMIDITY

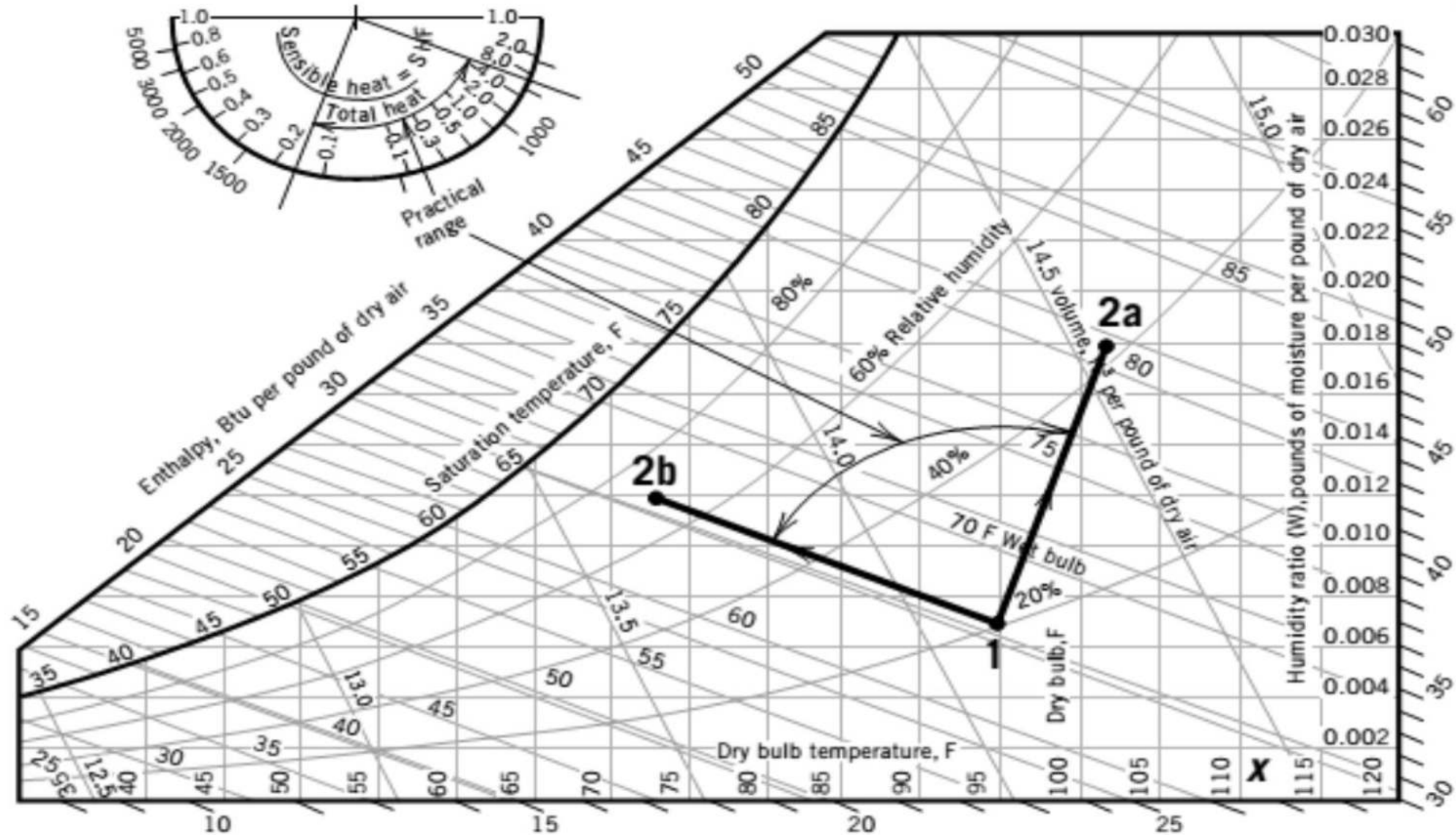
- ❑ Cooling coils are typically designed and selected to provide **adequate** latent cooling.
- ❑ Extremely humid outdoor conditions, or **large** requirements for outdoor air, or **high ratios** of internal latent to **sensible** loads (such as with an indoor swimming pool) may require special dehumidification processes.
- ❑ One common process is to simply lower the supply air to a temperature low enough to remove the required amount of moisture and then to reheat that air back up to a temperature required to meet the space cooling load.
- ❑ **Humidity** can also be lowered by reduced fan speed (reduced air flow) or by **bypassing** some of the air around the coil under **special circumstances**.

# METHODS TO CONTROL HUMIDITY

- ❑ In the **heating cycle**, where **humidification** is most usually required, water **spray** systems may be used.
- ❑ Some of **the water sprayed into the airstream** may fail to evaporate and be blown into the **ductwork** downstream where, over time, the liquid build up creates **mold** problems.
- ❑ **Humidification** by **injecting steam** into the **airstream** offers some **distinct** advantages over water injection in terms of **avoiding** liquid build up.



# METHODS TO CONTROL HUMIDITY



**Figure 3-8** Practical range of adiabatic humidifying processes.

# Methods to Control Contaminants

□ There are **four** basic methods to **control** **gaseous** or **particulate** contaminants in order to maintain **good** IAQ in buildings:

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

# Methods to Control Contaminants

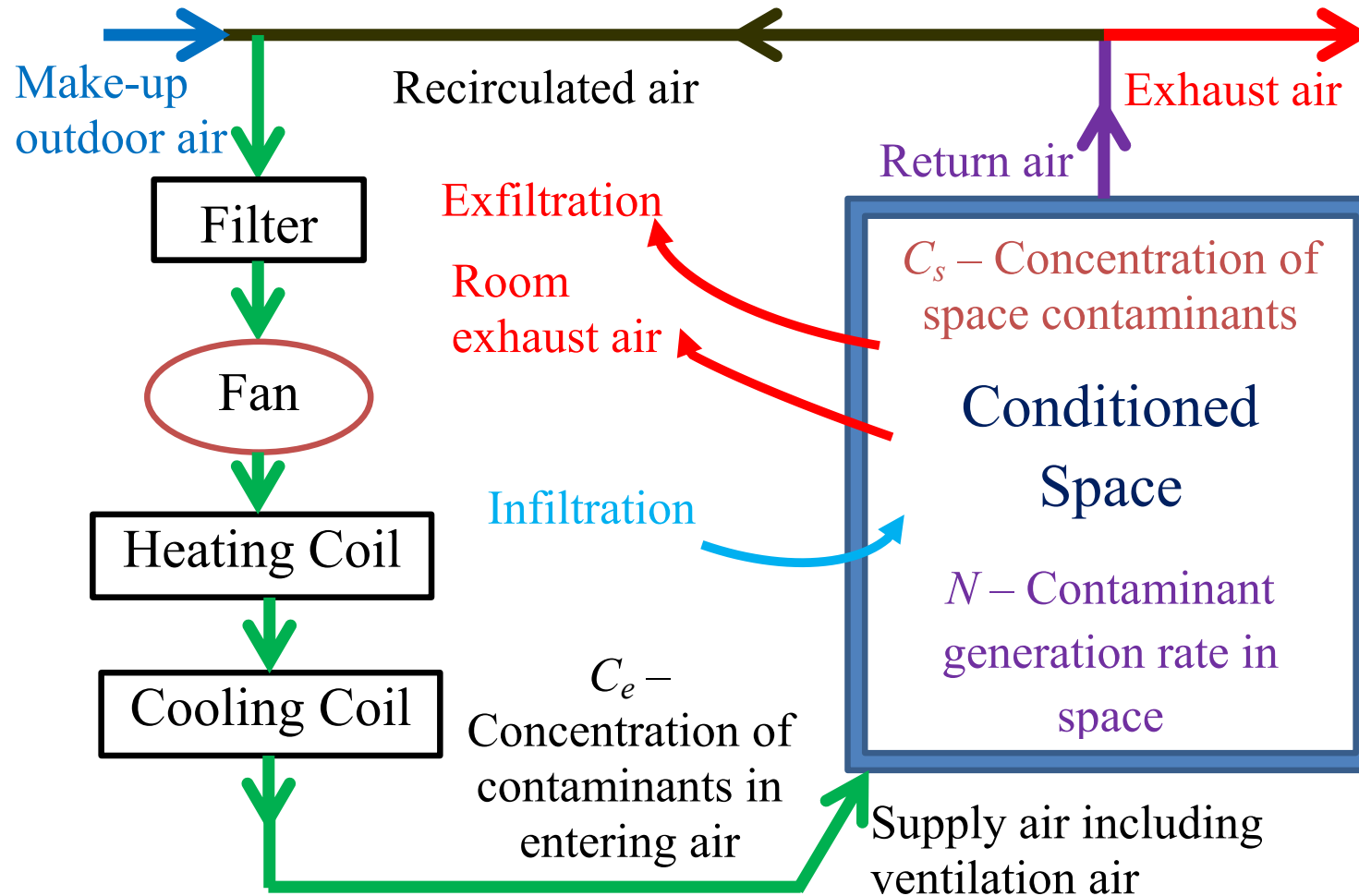
## 1. Source Elimination or Modification

- ❑ This is the **most effective** method to **control** contaminants **because** it operates **directly** on the source.
- ❑ It **specifies** what **materials** and **furnishings** are to be **allowed** in new and retrofitting buildings.
- ❑ Eliminating of **smoking** within a building is an acceptable approach to **improving** IAQ in public and private buildings.
- ❑ Removal of **paints**, **solvents**, **cleaners**, **insecticides**, and **VOCs** is necessary to make the indoor environment **acceptable**.
- ❑ The source of **mold** due to **moisture** should be **cleaned** and **eliminated**.
- ❑ Contaminated **materials** should be **removed** and in **extreme cases**, entire buildings should be **abandoned** when the problem is **beyond** solution.

# Methods to Control Contaminants

## 2. Use Outdoor Air

□ Outdoor air is used to dilute contaminants within a space.



$$\begin{aligned}\dot{Q}_t &= \text{Supply air rate} + \text{Infiltration rate} \\ &= \text{Return air rate} + \text{Exfiltration rate} + \text{Room exhaust rate}\end{aligned}$$

# Methods to Control Contaminants

## 2. Use Outdoor Air

- ❑ **Supply air** is the air delivered to the conditioned space and used for ventilation, heating, cooling, humidification, or dehumidification.
- ❑ **Ventilation air** is a portion of supply air that is outdoor air plus any recirculated air that has been treated for the purpose of maintaining acceptable IAQ.
- ❖ It takes energy to condition outdoor air; therefore, economy in operation usually requires the use of a minimum amount of outdoor air to meet the air quality requirements.
- ❑ **Outdoor air** is air taken from the external atmosphere and therefore not previously circulated through the system.
- ❖ Some outdoor air may enter a space by infiltration through cracks and interstices and through ceilings, floors and wall of a space or building.

# Methods to Control Contaminants

## 2. Use Outdoor Air

- ❖ It is usually assumed that the outdoor air is **free** of **contaminants** which is **not true** in some locations.
- ❖ The Ambient-Air quality standard is shown in the table below as published by EPA (Environmental Protection Agency, USA)

Contaminants	Long-Term Concentration			Short-Term Concentration		
	$\mu\text{g}/\text{m}^3$	ppm	Averaging	$\mu\text{g}/\text{m}^3$	ppm	Averaging
Sulfur dioxide	80	0.03	1 year	365	0.14	24 hours
Particles	50	—	1 year	150	—	24 hours
Carbon monoxide				40,000	35	1 hour
Carbon dioxide				10,000	9	8 hours
Oxidants (ozone)				235	0.12	1 hour
Nitrogen dioxide	100	0.055	1 year			
Lead	1.5	—	3 months			

# Methods to Control Contaminants

## 2. Use Outdoor Air

- ❑ **Recirculated air** is the air removed from the conditioned space and intended for reuse as supply air. It differs from return air only in that some of the return air may be exhausted or relieved through damper or by fan.
- ❑ **Makeup air** is outdoor air supplied to replace exhaust air and exfiltration.
- ❑ **Exfiltration** is air leakage outward through cracks and interstices الفجوات and through ceilings, floors and wall of a space or building.
- ❖ There must always be a balance between the amount of air mass entering and leaving a space and the entire air supply system.
- ❖ If the supply air rate exceeds the return air rate, the conditioned space will be pressurized relative to the surroundings and exfiltration (leaking) will occur to provide balance.
- ❖ If the return air rate exceeds the supply air rate then the space will be at a pressure below the surrounding spaces and infiltration will occur.

# Methods to Control Contaminants

## 2. Use Outdoor Air

- The basic equation for contamination concentration in a space for the steady state

$$\dot{Q}_t C_e + \dot{N} = \dot{Q}_t C_s \quad (4-5)$$

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

- **Example 4-2:** A person breathes out carbon dioxide at the rate of 0.30 L/min. The concentration of CO<sub>2</sub> in the incoming ventilation is 300 ppm. It is desired to hold the concentration in the room below 1000 ppm. Assuming that the air in the room is perfectly mixed, what is the minimum rate of air flow required to maintain the desired level

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

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

# Methods to Control Contaminants

## 2.1. Ventilation Rate Procedure (Table 4-2 in the Text Book)

- ✓ The outdoor air **quality acceptable** for ventilation or **treated** when necessary.
- ✓ Ventilation **rates** for **residential**, **commercial institutional**, **vehicular** and **industrial** spaces.
- ✓ Criteria for **reduction** of outdoor air **quantities** when **recirculated** air is treated.
- ❑ Indoor air quality is considered **acceptable** by the **Ventilation Rate Procedure** if the required rates of acceptable outdoor air listed in **Table 4-2** are provided for the **occupied** space.
- ❑ Rooms provided with **exhaust air systems**, such as **toilet rooms** and **bathrooms**, **kitchens**, and **smoking lounges** may be furnished with **makeup air** from **adjacent** occupiable spaces provided the **quantity** of air supplied **meets** the requirements of **Table 4-2**.

# Methods to Control Contaminants

## 2.2. Indoor Air Quality Procedure (Table 4-2 in the Text Book)

- ❑ It provides a **direct solution** to **acceptable** IAQ by **restricting** the concentration of all known **contaminants** of concern to some specified **acceptable** levels.
- ❑ Both **quantitative** and **subjective** evaluations are involved.
- ❑ The **quantitative evaluation** involves the use of **acceptable** indoor contaminant levels from a **variety** of sources.
- ❑ The **subjective evaluation** involves the **response** of **impartial observers** to odors that might be **present** in **the indoor environment**.
- ❑ Because **the Indoor Air Quality Procedure** is **difficult** to implement and can be fully **verified** only **after** the building is finished, most designers have followed the **Ventilation Rate Procedure**. This is in spite of the fact that the **large** quantities of outdoor air required can lead to **high operating costs**.

# Methods to Control Contaminants

## 3. Space Air Distribution

- ❑ Where contaminants **exist** in only a **small portion** of the conditioned space, it is **desirable** to **minimize** mixing of **air** within the **occupied zone**.
- ❑ This may be **accomplished** by **displacement ventilation**, where air only slightly lower in **temperature** than the **desired** occupied space temperature, is **supplied at low velocity** from outlets near **floor** level.
- ❑ Returns are **located** in or near the **ceiling**.
- ❑ The movement of the air is **essentially vertical** in the occupied (lower) zone.
- ❑ A **vertical temperature gradient** exists in the occupied zone, but good design of the system should hold the temperature difference **below** 5 F (3 C).
- ❑ Localized ventilation is sometimes **utilized** to provide **heating** or **cooling** and/or contaminant **removal** where a **special need** exists.
- ❑ Where contaminants sources can be **localized**, the offending gas can be **removed** from the conditioned space **before** it spreads into the **occupied zone**.

# Methods to Control Contaminants

## 4. Air Cleaning

- ❑ Design of a proper system for **gas cleaning** is often the **final step** in assuring that an HVAC system will **provide** a **healthy** and **clean** indoor environment.
- ❑ In many cases it is **desirable** to **clean** or **filter** the incoming outdoor air to **replenish** the **oxygen** required for **breathing** and to **dilute** the carbon dioxide and other **wastes** produced by the occupants .
- ❑ Cleaning or filtration of the **recirculated** air can often **provide** a cost-effective approach to the **control** of indoor air contaminants.

# Methods to Control Contaminants

## 4. 1. Gas Removal

- ❑ Contaminants may be removed from an air stream by
  - ❖ absorption,
  - ❖ physical adsorption,
  - ❖ chemisorption,
  - ❖ catalysis,
  - ❖ Combustion
- ❑ Absorption, Both solid and liquid absorbers may be used to reduce carbon dioxide and carbon monoxide to carbon, returning the oxygen to the conditioned space.
- ✓ Air washers used to control temperature and humidity can remove contaminant gases and particles from an airstream by absorption.

# Methods to Control Contaminants

## 4. 1. Gas Removal

- ❑ **Adsorption** is the **adhesion** of **molecules** to the surface of a **solid**.
- ✓ **Good adsorbents** must have **large** surface areas **exposed** to the gas being adsorbed and therefore typically have **porous** surfaces.
- ✓ Activated **charcoal** الفحم النباتي is the most widely used **adsorbent** because of its **superior** adsorbing properties.
- ❑ **Catalysis** is closely related to **chemisorption** in that chemical reactions occur at the **surface** of the **catalyst**; however, the gaseous pollutant does not react with the catalyst itself.
- ✓ This method of air **purification** has the **potential** for **longer life** than with adsorbents or chemisorbers, where an unharmed product is created in the reaction.
- ❑ **Combustion**: Catalytic combustion permits the burning of offending gas at **T lower** than with unassisted combustion and is widely used in automobiles to reduce urban air pollution.

# Methods to Control Contaminants

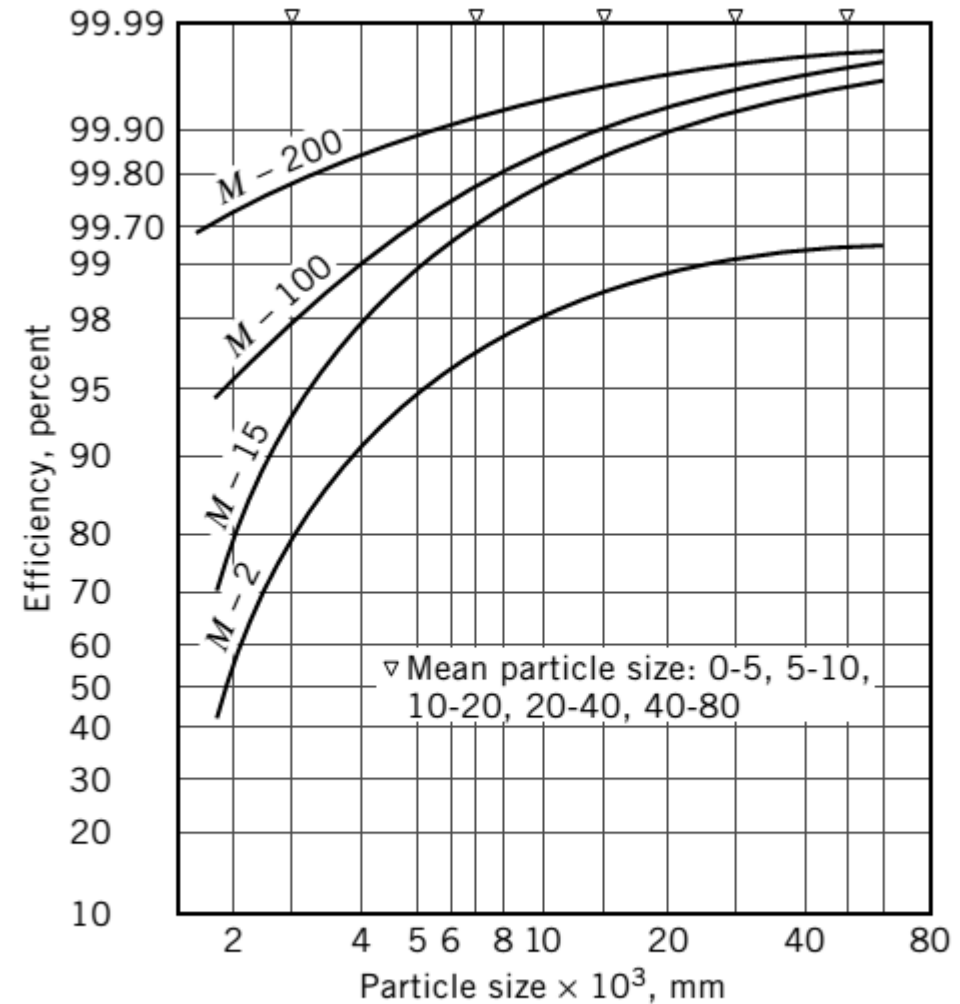
## 4. 2. Particulate Removal (Filtering)

- ❑ It is **impossible** to design **one type** of air particulate **cleaner** (filter) that would be **suitable** for **all applications** due to the **wide** variety of **suspended** particles in both the **outdoor** and **indoor** environments.
- ❑ For example, clean rooms in an **electronic** assembly process require **entirely** different particulate **removal systems** than an **office** or a **hospital**.
- ❑ The **most important characteristics** of the aerosol affecting the **performance** of a particulate **air cleaner** include the particle's
  - Size and shape
  - Specific gravity
  - Concentration
  - Electrical properties

# Methods to Control Contaminants

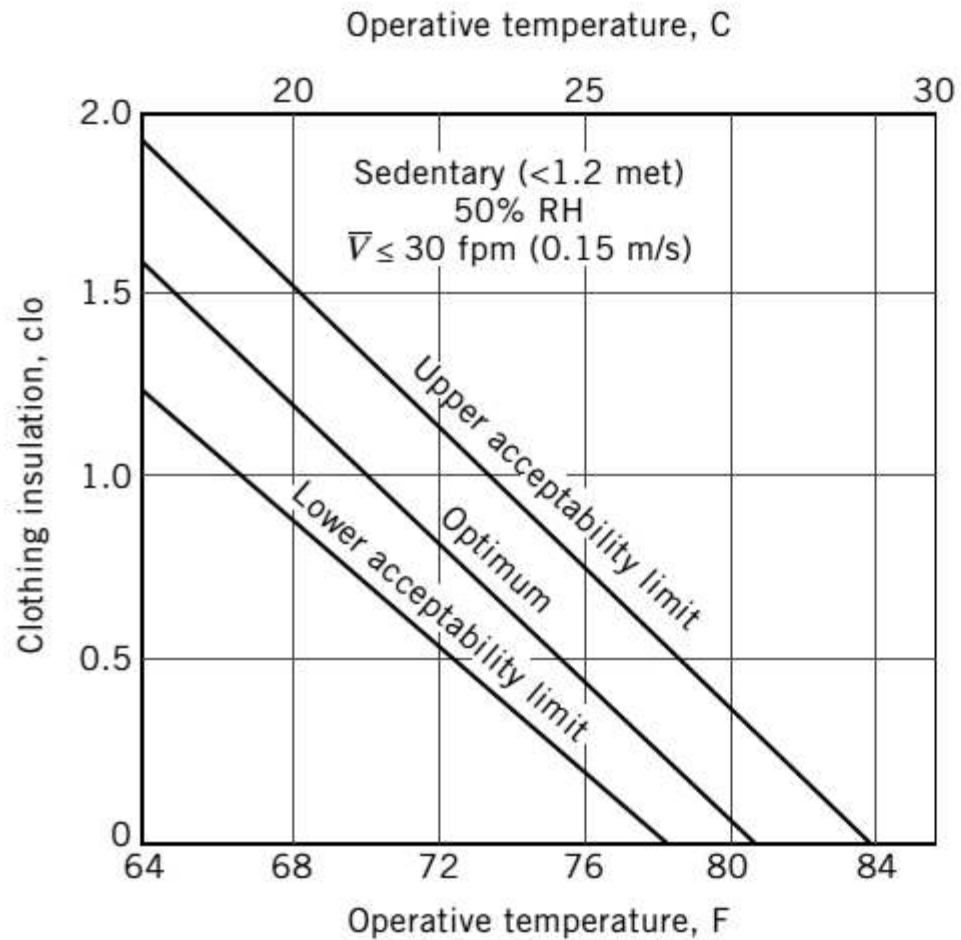
## 4. 2. Particulate Removal (Filtering)

- The **three** operating characteristics that can be **used** to **compare** various types of particulate air cleaners are
  - Efficiency
  - Air-flow resistance
  - Dust-holding capacity
- Typical **engineering data** (physical size, flow rate at a stated pressure drop) for the four filters shown are given in Table 4-3.

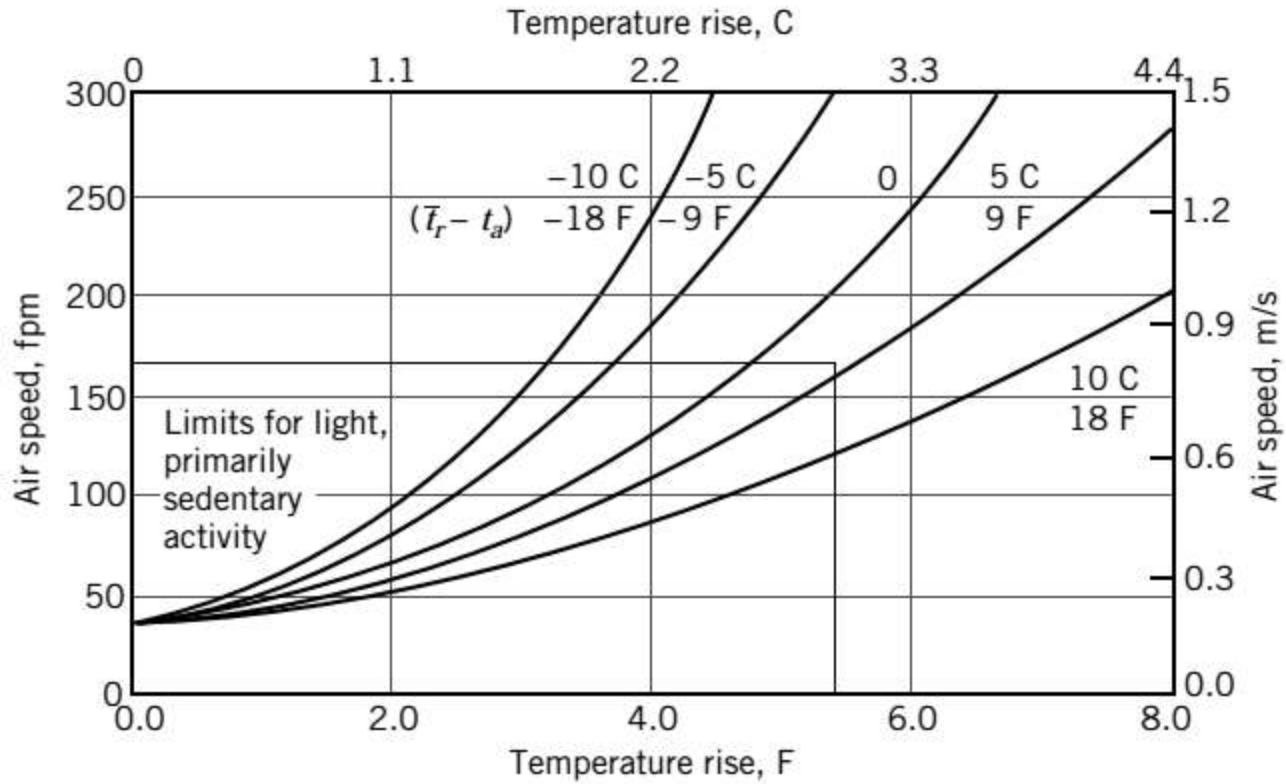


**Figure 4-8** Gravimetric efficiency of high-performance dry-media filters.

Efficiency of high-performance dry-media filters.



**Figure 4-2** Clothing insulation for various levels of comfort at a given temperature during light and primarily sedentary activities ( $\leq 1.2$  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.)

# Methods to Control Contaminants

## 4. 2. Particulate Removal (Filtering)

**Table 4-3** Engineering Data—High-Performance Dry-Media Filters (Corresponds to Efficiency Data of Fig. 4-8)

Standard Size Rated Capacity <sup>a</sup>	Meter: Inch:	0.3 × 0.6 × 0.2		0.3 × 0.6 × 0.3		0.6 × 0.6 × 0.2		0.6 × 0.6 × 0.3		Pressure Loss	
		12 × 24 × 8		12 × 24 × 12		24 × 24 × 8		24 × 24 × 12		Inches of	
		ft <sup>3</sup> /min	m <sup>3</sup> /s	ft <sup>3</sup> /min	m <sup>3</sup> /s	ft <sup>3</sup> /min	m <sup>3</sup> /s	ft <sup>3</sup> /min	m <sup>3</sup> /s	Water	Pa
Media	M-2 <sup>b</sup>	900	0.42	1025	0.48	1725	0.81	2000	0.94	0.15	37.4
Type	M-15	900	0.42	1025	0.48	1725	0.81	2000	0.94	0.35	87.2
	M-100	650	0.30	875	0.41	1325	0.62	1700	0.80	0.40	100.0
	M-200	450	0.21	630	0.29	920	0.43	1200	0.56	0.40	100.0
Effective filtering area (all media types):		14.5 ft <sup>2</sup>	1.35 m <sup>2</sup>	20.8 ft <sup>2</sup>	1.93 m <sup>2</sup>	29.0 ft <sup>2</sup>	2.69 m <sup>2</sup>	41.7 ft <sup>2</sup>	3.87 m <sup>2</sup>		

<sup>a</sup>Filters may be operated from 50 to 120 percent of the rated capacities with corresponding changes in pressure drop.

<sup>b</sup>The M-2 is available in 2-in. thickness and standard sizes with a nominal rating of 0.28 in. wg at 500 fpm face velocity.

- ❑ The **pressure loss** across a **filter** element is assumed to be **proportional** to the square of the **flow rate**.
- ❑ Thus, letting the **subscript** *r* stand for **rated** conditions, the **pressure loss** at any required rate of flow  $\dot{Q}$  can be determined by

$$\Delta p = \Delta p_r \left( \frac{\dot{Q}}{\dot{Q}_r} \right)^2 \quad (4-10)$$

**EXAMPLE 4-6:** Assume that the office in Example 4-5 is occupied by 70 persons and that a suitably efficient filter was the M-15 filter of Fig. 4-8 and Table 4-3. Using this filter, design a system that has a pressure loss of no more than 0.30 in. wg in the clean condition.

Table 4-3 gives the application data needed. There are four sizes of M-15 filters to choose from, and the rated cfm at 0.35 in. wg pressure loss is given for each size. We must choose an integer number of filter elements. The total supply cfm required for 70 persons is

$$\dot{Q}_s = (123 + 20 \text{ cfm/person})(70 \text{ persons}) = 10,000 \text{ cfm}$$

It is desirable for the complete filter unit to have a reasonable geometric shape and be as compact as possible. Therefore, choose the  $24 \times 24 \times 12$  elements for a trial design. The rated cfm will first be adjusted to obtain a pressure loss of 0.30 in. wg using Eq. 4-10:

$$\dot{Q}_n = \dot{Q}_r (\Delta p_n / \Delta p_r)^{1/2} = 2000(0.3/0.35)^{1/2} = 1852 \text{ cfm/element}$$

Then the required number of elements is

$$n = \dot{Q}_s / \dot{Q}_n = 10,000 / 1852 = 5.40 \text{ elements}$$

Since  $n$  must be an integer, use 6 elements and the complete filter unit will have dimensions of  $48 \times 72$  in., a reasonable shape. The filter unit will have a pressure loss less than the specified 0.30 in. wg. Again, using Eq. 4-10 the actual pressure loss will be approximately

$$\Delta p = \Delta p_r [\dot{Q} / \dot{Q}_r]^2 = 0.35 [(10,000 / 6) / 2000]^2 = 0.24 \text{ in.wg}$$

This is not an undesirable result and can be taken into account in the design of the air distribution system.

**4.2 Using Fig. 4-1**, draw a conclusion about the comfort of a mixed group of men and women in typical seasonal clothing, with sedentary activity for the following cases:

- (a) Summer, operative temperature 24 C, wb 18 C    (b) Winter, operative temperature 24 C, wb 18 C  
(c) Summer, operative temperature 23 C, dp 10 C    (d) Winter, operative temperature 22 C, dp 1 C

(a) comfortable (b) too warm (c) comfortable (d) too dry

**4.9 What do you think is the best thermostat setting (air dry bulb temperature) in a shop where the workmen are standing, walking, lifting, and performing various machining tasks? Assume that a globe temperature measurement reads 72 F (22 C), the relative humidity will be in the 45 percent range, and air motion will likely be around 30 ft/min (0.15 m/s). The men are dressed in typical summer garments (clo =0.5). Calculate the answer in F or C.**

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

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

Use Eq. 4-4 to estimate a value of the operative temperature

$t_o$ , active, assuming  $t_o$  for sedentary activities is 78 F (25.6 C)

with  $\text{met} = 2.0$ .  $t_o$ , active =  $78 - 5.4 (1 + 0.5) (2 - 1.2) = 71.5 \text{ F}, (22\text{C})$

As an approximation

$$T_{\text{mrt}} = 2T_o - T_a \text{ and } T_{\text{mrt}}^4 = T_g^4 + C\bar{V}^{1/2}(T_g - T_a) \quad \text{Eq. (4-1)}$$

eliminating  $T_{\text{mrt}}$  between the 2 equations

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

where all temperatures are absolute

Solve by trial and error with  $T_g = 72 + 460 = 532 \text{ R}$

and  $T_o = (71.5 + 460) = 531.5 \text{ R}$ ,  $C = 0.103 \times 10^9$ ,  $\bar{V} = 30$

$$\underline{\underline{t_a = 85 \text{ F (30C)}}}$$

Cold surroundings require high ambient air temperature

for comfort, even with high activity level.

**4.16 A classroom in a school is designed for 100 people. (a) What is the minimum amount of clean outdoor air required? (b) The floor area is 1500 ft<sup>2</sup>. What is the outdoor air ventilation requirement on the basis of floor area (see Table 4-5)?**

Use Table 4-2.

(a) cfm / person = 15 cfm/person = (15)(100) = 1,500 cfm

(b) Estimated maximum occupancy = 50 persons / 1000 ft<sup>2</sup>

No. of Occupants = 75 people = (15)(75) = 1,125 cfm

**How many people could occupy a room where the concentration level of carbon dioxide is to be kept below 1000 ppm if air with a concentration of 300 ppm CO<sub>2</sub> is being supplied to the room at the rate of 3.00 m<sup>3</sup>/s (6400 cfm)? Assume that each person is producing carbon dioxide at the average rate of 5.00 mL/s (0.0107 cfm) and that the incoming air is completely mixed with the room air.**

**Solution: SI units**

$Q_t = 3.00 \text{ m}^3/\text{s} = 3000 \text{ L/s}$

$C_s = 300 \text{ ppm} = 0.0003$

$C_e = 1000 \text{ ppm} = 0.0010$

$N = Q_t \cdot (C_s - C_e) = 3000(0.0003 - 0.0010)$

$= -2100 \text{ mL/s}$

No. of people = (2100 mL/s) / (5.00 mL/s) =

420 people

$$\dot{Q}_t C_e + \dot{N} = \dot{Q}_t C_s$$

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

**4.18** Each person in a room is assumed to be producing carbon dioxide at the average rate of 0.0107 cfm (5.0 ml/s) and air with a CO<sub>2</sub> concentration of 280 ppm is being supplied to the room at the rate of 6000 cfm (2.8 m<sup>3</sup>/s). It is desired to keep the concentration level of CO<sub>2</sub> in the space below 1000 ppm. Assuming complete mixing, determine how many persons could occupy the room and not exceed the desired CO<sub>2</sub> level.

$n$  = number of people to occupy a room

$$\dot{N} = n (5.0 \text{ ml/s})$$

Solving Eq. 4-5 for  $\dot{N}$

$$\dot{N} = \dot{Q}_t (C_s - C_e) = n (5.0) \text{ ml/s-person}$$

$$n = \dot{Q}_t (C_s - C_e) / (5.0)$$

$$= 2.8 (1000 - 280) / 5.0$$

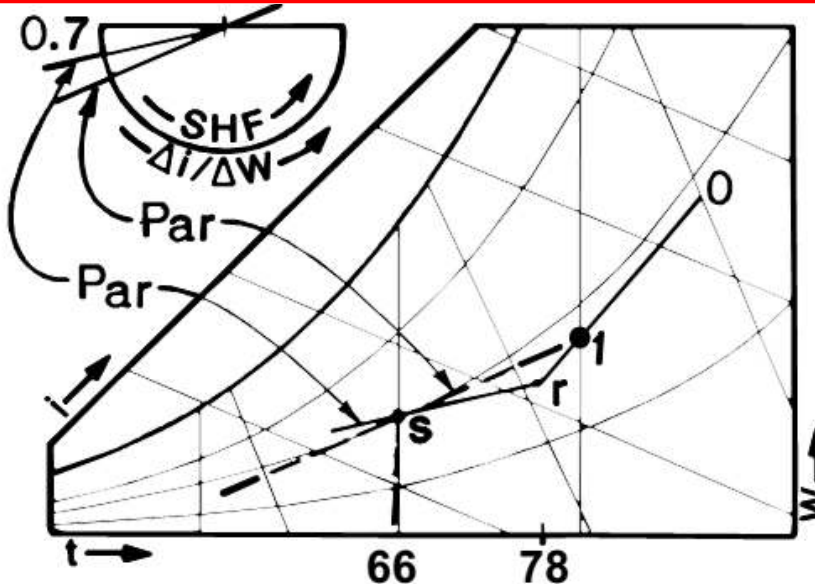
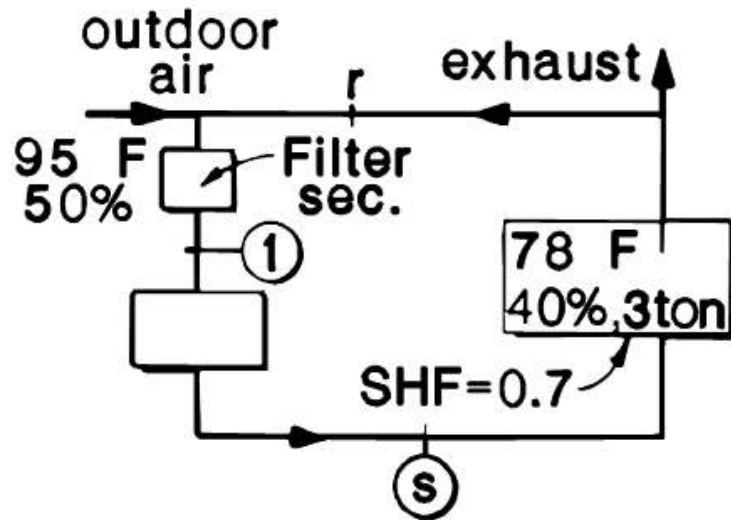
$$n = 403 \text{ persons or } 0.0069 \text{ m}^3 / \text{s} - \text{person}$$

For English Units:

$$n = 6000 (1000 - 280 \times 10^{-6}) / 0.0107$$

$$= 404 \text{ persons or } 14.8 \text{ cfm/person}$$

Work Problem 4-24 but replace the 100 % outdoor air requirement with 25 % outdoor air and use high-performance filters for the return air. Gravimetric efficiency must be at least 99 percent in the  $0-5 \times 10^{-6}$  meter particle range. (a) Find required air flow and (b) design the filter system so that the maximum pressure loss with clean filters is less than 0.125 in. wg.



$\dot{m}_0 = 0.25 \dot{m}_s$ ; Locate point 1 on psychrometric Chart at 82.4 F db and 66.8 F wb

$i_1 = 31.4 \text{ Btu / lbm}$  and  $v_1 = 13.9 \text{ ft}^3 / \text{lbm}$

investigate feasibility of using 100 % outdoor in the cooling & dehumidifying of a laboratory whose computed heat gain is 3 tons and whose SHF is 0.7. The indoor design conditions are 78 F db and 40 % relative humidity. The outdoor design conditions are 95 F db and 50 % relative humidity. The direct expansion equipment to be used for cooling has a fixed air-flow rate of 350 cfm per ton.

$$\dot{q}_{1s} = \dot{m}_1 (i_1 - i_s) = \dot{Q}_1 / V_1 (60) (i_1 - i_s)$$

$$\dot{Q}_1 = 350 / 12,000 \dot{q}_{1s} ; = (350 / 12,000) (60 / v_1) (i_1 - i_s)$$

$$i_s = 31.4 - \frac{12,000 (13.9)}{60 (350)} = 23.46 \text{ Btu / lbm}$$

Locate on psychrometric Chart:  $t_s = 65.6 \text{ F db}, 55.5 \text{ F wb}$

$$\dot{q}_{sr} = \dot{m}_s (i_r - i_s) = 36,000; i_r = 27.6 \text{ Btu / lbm}$$

$$\dot{m}_s = \dot{m}_1 = \frac{36,000}{(27.6 - 23.46)} = 8695.7 \text{ lb / hr}$$

$$\dot{Q}_s = \dot{m}_s (v_s) = \frac{8695.7}{60} (13.4) = 1940 \text{ cfm}$$

$$\dot{q}_{1s} = 8695.7 (31.4 - 23.46) = 69,000 \text{ Btu / hr} = 5.75 \text{ tons}$$

$$\dot{Q}_1 = 5.75 (350) = 2014 \text{ cfm}$$

(c) Design filters for 2014 cfm, use M-200 media of fig 4-8.

Try the 24x24x8 units of table 4-3. 920 cfm @ 0.4 in. wg.

For max.  $\Delta P$  of 0.125 in.wat.

$$\dot{Q} = 920 [0.125 / 0.40]^{1/2} = 514 \text{ cfm / module};$$

$$n = 2014 / 514 = 3.92, \text{ use 4 modules}$$

**4.19:** Select a filter system that will have a gravimetric efficiency of at least 95 percent in the particle size range of  $0 - 5 \times 10^{-3}$  mm. The system must handle 2200 cfm, and the maximum pressure drop across the filters must be less than or equal to 0.25 in. of water. Space limits the depth of the filters to 8 in.

Fig. 4-9, use M-15, try 12 x 24 x 8 in, = 900 cfm, = 0.35 in. w.g. = 760.6 cfm( cfm x efficiency)

Required number of elements, =  $2200 \text{ cfm} / 900 \text{ cfm} = 2.44$  use 3

Use 3 elements, 24 in x 36 in filter unit.

Actual = 0.232 in w.g.

**4.13** Air motion is a parameter that may be adjusted to improve comfort when space temperature are fixed. Discuss the general effect of increased or decreased air motion when the space temperature is low in winter and high in summer.

**Answer:**

1. When the space temperature is low in winter, an increase in air motion will feel uncomfortable and a decrease in temperature will feel comfortable as shown in Fig. 4.3 and 4.2.
2. When the space temperature is high in summer, an increase in air motion will feel comfortable and a decrease in temperature will feel uncomfortable as shown in Fig. 4.3 and 4.2.

4-13 Too much air motion in the cold winter months tends to cause drafts and make people uncomfortable. Air velocity just sufficient to prevent large temperature gradients from floor to ceiling is best for winter. The opposite is true for hot summer months. Higher air velocity tends to compensate for high temperature and humidity.

**4.14 A method of saving energy in large, chilled water cooling systems is to increase the temperature of the water circulating in the system. (a) How will this affect the space comfort conditions? (b) Would there be certain periods of time when this would be feasible? Discuss.**

**Answer:**

**(a) When the chilled water cooling system increase the temperature of the water circulating in the system it will affect the space comfort conditions if it increases the room temperature outside the comfort condition at normal air motion.**

**(b) Yes, by increasing air motion.**