PDHonline Course M272 (4 PDH)

Indoor Air Quality (IAQ) Engineering

Instructor: Lance D. LaRue, PE, FPE, CIAQP

2020

PDH Online | PDH Center

5272 Meadow Estates Drive
Fairfax, VA 22030-6658
Phone: 703-988-0088
www.PDHonline.com

An Approved Continuing Education Provider

Indoor Air Quality (IAQ) Engineering

Lance D. LaRue P.E., FPE, CIAQP

Course Content

1. ENGINEERING & INDOOR AIR QUALITY (IAQ)

It has been said that the HVAC system is the heart of a building. This analogy can be extended to say that the HVAC system is the heart of a building's indoor air quality. Throughout our lives we spend countless hours within buildings and we desire to have good indoor air quality within these buildings. When we combine these two ideas we can come to the conclusion that the HVAC system within these building has a large impact on us (the general public) and it is worth our time to get it right.

As engineers and other professionals we have made it part of our life's work to serve the public in this or another arena. In the design, construction, operation, and maintenance of built facilities we have an established role to play – this role should not be taken lightly, abused, or given over to others with different qualifications. There exists a minimum standard of care that an engineering professional in the IAQ industry must operate within. The information contained herein is intended to help the engineering professional lay a firm foundation in this pursuit. It is the responsibility of the individual engineering professional to pursue these things with great diligence.

2. IAQ: COMFORT, HEALTH, & PRODUCTIVITY

The quality of our indoor air impacts many things in our lives. Of these, we will focus our attention on three particular items – comfort, health, and productivity. Human comfort is closely related to temperature and humidity. Since the inception of the HVAC industry there has been a large amount of research and information developed relating

human comfort, temperature, and humidity. We will explore this relationship in more detail later in this course.

The need for healthy indoor air is self-evident to most people. In recent years, there has been a great deal of attention given to this topic in the media. As engineers and design professionals, we are responsible for applying science and technology in a reasonable and responsible fashion, this is especially important when public health is at question. Later in this course we will explore this issue from an engineering point of view.

The last of these three items is the least concrete. We can measure temperature and relative humidity and we can test for contaminants or biological organisms, but we can not easily perform similar measurements for productivity. So we must resort to experts in other fields to help us make our case. A quick internet search will return as much information on this topic as an individual will care to review. After even the shortest of such reviews an individual could make the following conclusions – 1) no one person wants to work within an uncomfortable and unhealthy environment and if they do they will not be as productive as if the circumstances were ideal; 2) every resource that reports on the annual economic impact of poor indoor air quality states the cost to our economy is in the billions of dollars.

3. BUILDING SYSTEM DESIGN & IAQ

Building system design can affect indoor air quality in many ways. Engineers, architects, and other design professionals should take special care in making sure that their designs are not contributing to any adverse situations. Each designer should develop a design checklist to help prevent any of these situations. Following are items that each designer should consider when developing such a checklist.

Indoor air quality design considerations should include:
A. Thermal Comfort – what temperature and humidity conditions are required for the building occupants to be comfortable?

B. Ventilation – what amount of ventilation is required? Does it meet the applicable minimum code requirements? Does the prescribed amount of outside air maintain the indoor CO_2 below reasonable levels?

C. Exhaust – what amount is required by code or by application?

D. System Controls – are the system controls of the proper type to help maintain proper indoor air quality? If the design includes water features, large amounts of outside air, unique building envelope configurations, etc… then the designer will need to consider more than simple thermostats in order to control the indoor air quality.

E. Pollutants – are there any chemicals or potential pollutants that the design should take into consideration? For example, are cleaning chemicals kept in a central location? If they are then exhaust should be provided for them. Also, is there a large copy or reproduction facility included in the design? Most applicable building codes require exhaust for this application?

F. Construction Management Practices – your first question might be "how does this relate to indoor air quality?" This issue is getting a lot of attention these days, especially when "green" designs are being considered. Two important factors related to indoor air quality and construction management are control of pollutants/dust during construction and the impact of construction materials during and shortly after initial building occupancy. Control of construction dust is especially important if the work is going on within an occupied building. Guidelines have been developed on how to mitigate these issues, see SMACNA – IAQ Guidelines for Occupied Buildings under Construction. After their initial installation some building materials can give off pollutants in either particle or gaseous form. Where this might be a concern the design team should consider low-emitting building materials.

4. ENGINEERING DEISGN: TEMPERATURE & HUMIDITY

Proper temperature and humidity are paramount for having acceptable indoor air quality. This is another way of stating that the proper thermal comfort environment

contributes to acceptable indoor air quality. To best understand this relationship we need to define thermal comfort. The industry's standard of care for thermal comfort is ASHRAE Standard 55 - Thermal Environmental Conditions for Human Occupancy (hereafter known as ASHRAE Standard 55).

The following definitions are taken from ASHRAE Standard 55:

Thermal comfort – the condition of mind that expresses satisfaction with the thermal environment - this requires subjective evaluation.

Acceptable thermal environment – an environment that at least 80% of the occupants would find thermally acceptable.

A designer could ask, why 80% satisfaction – why not another number. Because of human physiology variations and differences in human clothing levels it is improbable that 100% of building occupants would be satisfied at any given time. ASHRAE Standard 55 was developed with this consideration in mind. Statistically an 80% satisfaction rate was considered to be the most realistic. As a safety factor or cushion, ASHRAE Standard 55 specifies temperature and humidity ranges for summertime and wintertime based upon a general 10% dissatisfaction criterion. The ranges are shown in the adjacent figure. This figure is taken from the 2001 ASHRAE HANDBOOK FUNDAMENTALS I-P Edition, Page 8.12. ASHRAE Standard 55 and this figure give designers a range of indoor design temperatures for both summer and winter time operation. Within the range presented in ASHRAE Standard 55, it is common to use 75°F db & 50% RH for summer and 70 °F db & 40% RH for winter indoor design conditions.
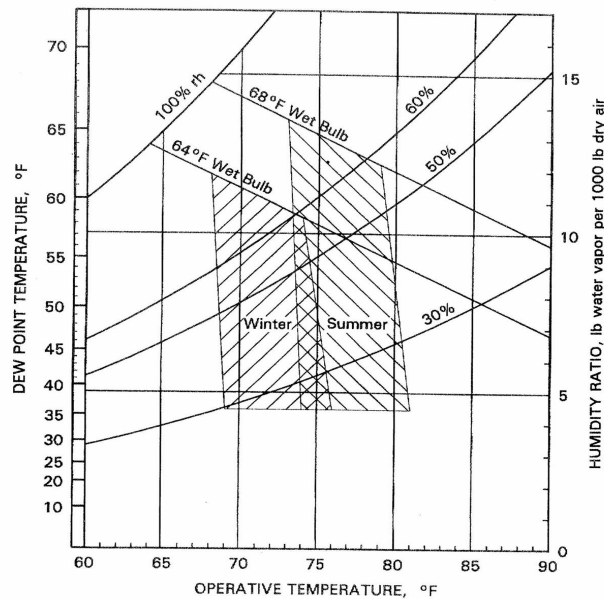
Excerpt from: 2001 ASHRAE Handbook Fundamentals IP Edition, Page 8.12; Atlanta, GA

In order to better understand the relationship between temperature and humidity we must discuss psychrometry. In general terms, psychrometry is the measurement of the heat (temperature) and water vapor (humidity) properties of air. For most applications, we discuss psychrometry in the context of standard atmospheric pressure. If your specific application varies from standard atmospheric pressure, then you should refer to a psychrometric chart developed for your application pressure. The preceding

Retrieved May 8, 2007, from "EngineeringToolbox.com" website,
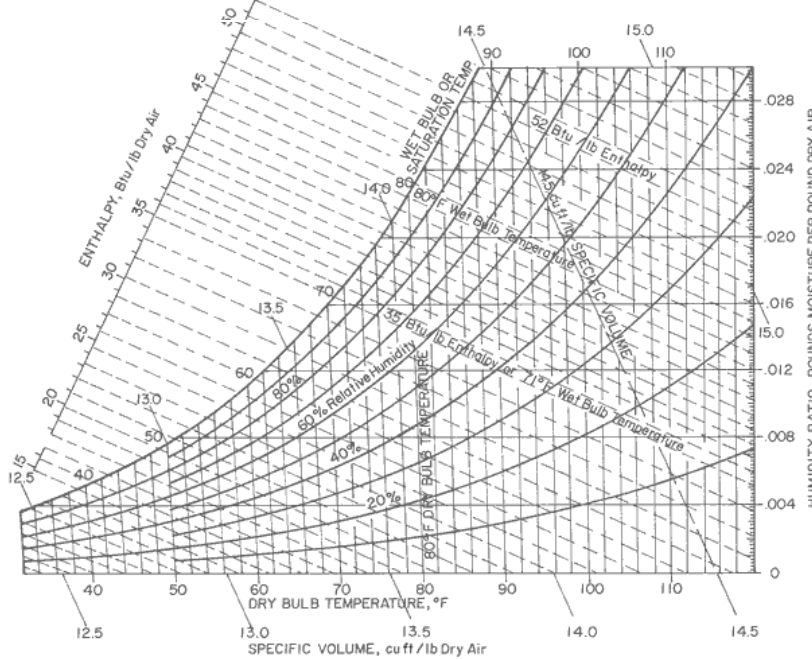http://www.engineeringtoolbox.com/psyhcrometric-charts-d_514.html

figure from ASHRAE Standard 55 is a small subset of a larger psychrometric chart. The figure to the left is a representation of the general structure of a psychrometric chart. Psychrometric charts come in many variations, electronic versions are even available online or via a

desktop download to be used on your personal computer. No matter what version of

psychrometric chart or psychrometric software you should make yourself comfortable with the data. At a minimum the designer should understand the relationship between different property states and what processes can

A—Humidifying Only
B—Heating & Humidifying
C—Sensible Heating Only
D—Chemical Dehumidifying
E—Dehumidifying Only
F—Cooling & Dehumidifying
G—Sensible Cooling Only
H—Evaporative Cooling Only
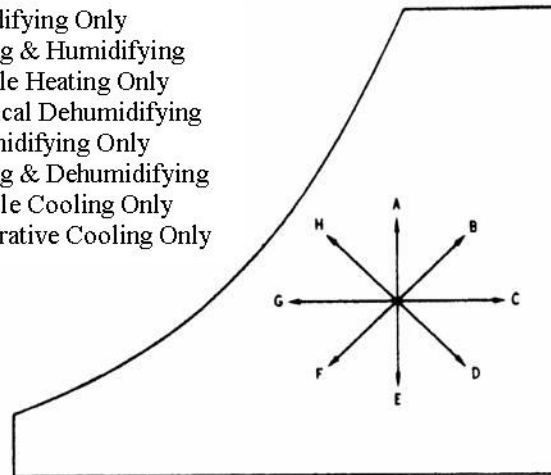
Excerpt from: Directions for using the Trane Psychrometric Chart, Trane Psychrometrtic Chart, 1960, The Trane Company, La Crosse, Wisconsin.

be represented via psychrometric data. The figure to the right graphically portrays these processes over-layed on a psychrometric chart.

The practical use of all of this information culminates in heat and moisture load calculations. These load calculations are what engineers should use in sizing new equipment or systems and in analyzing existing systems. Heat load calculations are also referred to as heat gain/loss calculations or heating & cooling load calculations. Moisture load calculations are also known as humidification & dehumidification load calculations. Each load calculation is a balance or accounting of the forces acting upon and within the building envelope. The resultant loads are a balance between 1) temperature and moisture interactions through the building envelope, 2) internal generation of heat and moisture within the envelope, and 3) airflow into and out of the envelope. Following are the general equations for reference for the different loads.

Heat Load Equations

A. Heat transmission through building material:

$H = U \bullet A \bullet \Delta T$; U-Conductance of material or assembly, A-Area of Heat Transfer, ΔT-Temperature difference across material or assembly.

B. Heat radiation through transparent material:

$H = A \bullet SlrF \bullet ShdF$; A-Area of exposure; SlrF-Solar Factor, ShdF-Shading Factor.

C. Heat due to people, equipment, or processes: Refer to data tables from ASHRAE HANDBOOK FUNDAMENTALS Chapter 29.

D. Heat due to airflow into or out of the envelope:

1. Ventilation:

Sensible Heat (Btu/Hr) / $Hs = 1.08 \bullet CFM \bullet \Delta T$

Latent Heat (Btu/Hr) / $Hl = 0.68 \bullet CFM \bullet \Delta T$

2. Infiltration:

Sensible Heat (Btu/Hr) / $Hs = V \bullet 0.018 \bullet ACH \bullet \Delta T$

Latent Heat (Btu/Hr) / $Hl = V \bullet 0.011 \bullet ACH \bullet \Delta T$

[CFM-Airflow in cubic feet per minute, ΔT-Change in temperature in °F,

V-Volume in cubic feet, ACH-Air changes/hour]

Moisture Load Equations

E. Moisture transmission through building material:

$G = \sum \left((Pi - Pe)/N \bullet \sum_i (\mu i \bullet si) \bullet A \right)$; G (kg/s)-Diffusion of water

vapor from inside to outside, A (m^2)-Surface area of wall element, Pi

(Pa)- Vapor pressure inside, Pe (Pa)-Vapor pressure outside, N (Pa m s /

kg)- Coefficient of resistance to diffusion of water vapor into air, μ-Factor

of resistance of water vapor to air for a specific wall element, s (m)-

Thickness of a specific wall element.

F. Moisture due to people, equipment, processes, or material: Refer to ASHRAE

HANDBOOKS or manufacturer's data for more detail.

G. Moisture due to airflow into or out of the envelope:

$G = V \bullet \rho(Xi - Xe)$; G (kg/s)-Water vapor flowrate transferred to the

outside, V (m^3/s)-Ventilation flowrate, ρ (kg/m^3)-Density of air, Xi

(kg/kg)-Specific humidity inside, Xe (kg/kg)-Specific humidity outside.

5. ENGINEERING DESIGN: VENTILATION

The proper engineering design of ventilation systems is as critical to acceptable
indoor air quality as temperature and humidity. Proper ventilation is credited with a large
portion of achieving and maintaining acceptable indoor air quality. The relationship
between ventilation and indoor air quality is best defined by the industry standard of care
– ASHRAE Standard 62.1 - Ventilation for Acceptable Indoor Air Quality (hereafter
known as ASHRAE Standard 62.1). ASHRAE Standard 62.1 defines acceptable indoor
air quality as air in 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.

ASHRAE Standard 62.1 specifies two different design procedures for determining the proper amount of ventilation. The two methods are the Indoor Air Quality Procedure and the Ventilation Rate Procedure. The Indoor Air Quality Procedure is an intense analysis of the projects potential contaminant sources, contaminant concentration targets, and perceived acceptability targets. This procedure requires a good deal more effort, but it does allow for lessened airflows under the proper circumstances. The Ventilation Rate Procedure is a more common and a more prescriptive type of approach. The Ventilation Rate Procedure is closely in line with the standard ventilation requirements of most mechanical codes. Also, the Ventilation Rate Procedure is designed to meet most typical applications – if a project falls outside of the general guidelines, then the IAQ Procedure should be investigated. The goal of both procedures is to have an effective and efficient ventilation system. The following equations comprise the Ventilation Rate Procedure. The ventilation effectiveness and efficiency are also determined using the following equations. Equations for a single zone system are presented here - see AHSRAE 62.1 / Appendix A for other system types.

A. $Vbz = Rp \bullet Pz + Ra \bullet Az$; Vbz (CFM)-Breathing zone outdoor airflow, Rp (CFM/person)-Outdoor airflow required per person, Pz (# of people)-Zone population, Ra (CFM/ft^2)-Outdoor airflow required per unit area, Az (ft^2)-Zone floor area. Selected occupancy types are listed the table below. Refer to Table 6.1 in ASHRAE Standard 62.1-2004 for more details.

Selected Occupancy Category	People Outdoor Air R_p		Area Outdoor Air R_a		Default Values		
						Combined Outdoor Air Rate (see note 5)	
	cfm/person	L/s*person	cfm/ft^2	L/s*m^2	#/1000 ft^2 (#/100	cfm/person	L/s*person
Lecture classroom	7.5	3.8	0.06	0.3	65	8	4.3
Science laboratories	10	5	0.18	0.9	25	17	8.6
Computer lab	10	5	0.12	0.6	25	15	7.4
Multi-use assembly	7.5	3.8	0.06	0.3	100	8	4.1
Restaurant dining	7.5	3.8	0.18	0.9	70	10	5.1
Conference/meeting	5	2.5	0.06	0.3	50	6	3.1
Barracks sleeping areas	5	2.5	0.06	0.3	20	8	4.0
Office space	5	2.5	0.06	0.3	5	17	8.5
Reception areas	5	2.5	0.06	0.3	30	7	3.5
Main entry lobbies	5	2.5	0.06	0.3	10	11	5.5
Shipping/receiving	-	-	0.12	0.6	-		
Warehouses	-	-	0.06	0.3	-		
Auditorium seating	5	2.5	0.06	0.3	150	5	2.7
Places of religious worship	5	2.5	0.06	0.3	120	6	2.8
Libraries	5	2.5	0.12	0.6	10	17	8.5
Sales (except as below)	7.5	3.8	0.12	0.6	15	16	7.8
Mall common areas	7.5	3.8	0.06	0.3	40	9	4.6
Supermarket	7.5	3.8	0.06	0.3	8	15	7.6
Gym, stadium (play area)	-	-	0.3	1.5	30		
Spectator areas	7.5	3.8	0.06	0.3	150	8	4
Swimming (pool and deck)	-	-	0.48	2.4	-		
Bowling alley (seating)	10	5	0.12	0.6	40	13	6.5
Gambling casinos	7.5	3.8	0.18	0.9	120	9	4.6

Excerpt from: Table 6-1 Minimum Ventilation Rates in Breathing Zone, ASHRAE Standard 62.1-2004 Ventilation for Acceptable Indoor Air Quality, 2004, Atlanta, GA

B. Ez – Zone air distribution effectiveness. See Table 6-2 in ASHRAE Standard 62.1.

C. $Voz = Vbz / Ez$; Voz – Zone Outdoor Airflow (outdoor air to the zone from air distribution system).

D. $Vot = Voz$ (single-zone system only); Vot – Outdoor air intake flow, for single-zone systems the zone outdoor airflow equals the system outdoor airflow.

E. Ev – System ventilation efficiency (measure of how efficiently the outdoor air gets from the intake to the breathing zone), for single-zone systems Ev=1 (Vot=Voz), for other system types refer to Appendix A of ASHRAE 62.1.

The preceding calculations prescribe the amount of outside air required to each zone. Another important factor for proper ventilation that is frequently over-looked and misunderstood is the quality of the outside air. ASHRAE Standard 62.1 makes several requirements dealing with the quality of outside air. The first requirement is that the quality of the outside air must not exceed the maximum limits of the National Ambient Air Quality Standard (NAAQS).

Excerpt from National Ambient Air Quality Standard (NAAQS), Retrieved May 10, 2007, from "www.EPA.gov" website, http://epa.gov/air/criteria.html

	NATIONAL AMBIENT AIR QUALITY STANDARDS					
	LONG TERM			SHORT TERM		
	CONCENTRATION		AVERAGING	CONCENTRATION		AVERAGING
CONTAMINANTS	μg/m^3	ppm		μg/m^3	ppm	
Sulfur Dioxide	80	0.03	1 year	365	0.14	24 hours
Particles (PM10)	50	-	1 year	150	-	24 hours
Carbon Monoxide	-	-	-	40,000/10,000	35/9	1 hour/8 hour
Oxidants/Ozone	-	-	-	235	0.12	1 hour
Nitrogen Dioxide	100	0.055	1 year	-	-	-
Lead	1.5	-	3 months	-	-	-

The NAAQS requirements are listed in the adjacent table. When the minimum requirements of NAAQS are not met, then the outside air must be treated by filtration or cleaning. ASHRAE Standard 62.1 provides detailed guidance on how filtration and cleaning of outside air should be performed. ASHRAE Standard 62.1 also provides guidance on how outside air intakes should be located in order to minimize or eliminate the effects of poor quality outside air.

With the updated release of ASHRAE Standard 62.1-2004 from 62.1-2001 a new provision was added – air classification and recirculation. ASHRAE Standard 62.1-2004 introduced the classification of air space types and provided guidelines for air recirculation into and out of these spaces. The air classification and recirculation provisions were added to help minimize the affects of cross-contamination from a "dirty"

Excerpt from: Section 5.17.1 Classification, ASHRAE Standard 62.1-2004 Ventilation for Acceptable Indoor Air Quality, 2004, Atlanta, GA

CLASS 1	low contaminant concentration, low sensory-irritation intensity, inoffensive odor
CLASS 2	moderate contaminant concentration, mild sensory-irritation intensity, mildly offensive odors, not necessarily harmful or objectionable
CLASS 3	significant contaminant concentration, significant sensory-irritation intensity, offensive odor
CLASS 4	highly-objectionable fumes or gases, potentially dangerous particles, bio-aerosols or gases at high concentrations.

area to a "clean" area. Air space types are placed into one of four classes. The adjacent figure outlines these different classifications. For detailed descriptions of each air space type refer to Tables 5-2 and 5-3 of ASHRAE Standard 62.1. ASHRAE Standard 62.1 requires that air from a higher class not be recirculated to a space of a lower class. The standard does however make provisions for cleaning recirculated air from Class 2 to Class 1.

Carbon dioxide would normally be addressed in the ventilation section of similar presentations. This is because ASHRAE Standard 62.1 addresses carbon dioxide in occupied spaces and the HVAC and indoor air quality industries have been impacted by these provisions. For this presentation carbon dioxide is addressed in a later section on contaminants and control.

6. ENGINEERING DESIGN: AIR DISTRIBUTION

Properly engineered air distribution systems are another key ingredient to acceptable indoor air quality. Air distribution systems can be considered to be the vehicle that delivers the proper thermal and ventilation conditions to the building occupants. The engineering goal for air distribution systems is to relate local temperatures and air velocities in the occupied space to the occupants thermal comfort requirements. In the previous section on thermal comfort - temperature and relative humidity guidelines were discussed. Here we will further that discussion and add a couple more guidelines related to acceptable indoor air quality. Following are common ranges for indoor comfort:

A. Summer / Cooling:

80% Satisfaction Guidelines: 73-77°F & 45-55% RH, Local Air Velocities (Drafts) < 50 FPM with a vertical temperature difference from ankle to neck of 2-3°F.

B. Winter / Heating

80% Satisfaction Guidelines: 70-74°F & 30-50% RH, Local Air Velocities (Drafts) < 20-30 FPM with a vertical temperature difference from ankle to neck of 4°F.

C. Year-round

80% Satisfaction Guidelines: Zone Air Distribution Effectiveness and System Ventilation Efficiency in accordance with ASHRAE Standard 62.1 Chapter 6.
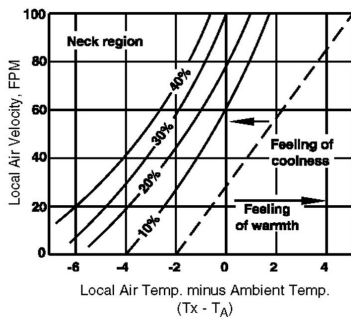
Air distribution system design includes two critical parameters, the selection of air devices & the layout of air devices. Air devices can be selected based upon several factors. The most common factors that affect selection are local air velocities and noise. We will explore air device selection & layout based upon these two factors as well as the proximity of air devices to one another and the localized affects of air devices. When air device noise is not considered during the design, it will probably get a lot of attention

after it is installed. We will explore equipment noise in more depth in a later section, but for the purposes of this section – the designer should heavily consider noise requirements in all but the least likely circumstances.

Local Velocity fpm	Temperature °F	$(T_x - T_A)$	Percentage Objecting
80	75	0	20%
60	74	-1	20%
40	73	-2	20%
15	71	-4	20%
60	75	0	10%
40	75	0	5%
30	75	0	Neutral
15	75	3	Warm

3 Charts - Excerpts from: 2007 Titus Engineering Guidelines; Richardson, TX

Local air velocities are responsible for much of the success or failure of an air distribution system. There has been a great deal of research done on the connections between comfort, temperature, and local air velocities. For in depth presentations on this subject see 2001 ASHRAE Fundamentals Handbook, Chapter 32. Also, see the Engineering Guides from either Titus (www.titus-hvac.com) or Price (www.price-hvac.com). Any of these resources will give a designer a

comprehensive review of most air distribution topics. The research indicates that an acceptable number of people ($\geq$80%) are
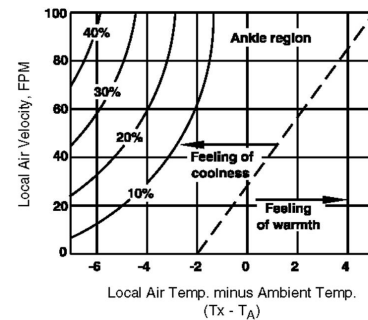
comfortable in an environment where the draft temperature difference is between -3°F & +2°F and the local air velocities are less than 50-70 FPM. The table to the right summarizes the results of this research. For the visual people in the audience, below are two charts that represent comfort, temperature differences, and local air velocities. These two charts also present the fact that the main areas of discomfort that are affected are the neck and ankles. These areas are the focus of our work in preventing excessive local air velocities. One common method for the proper selection of air devices is referred to as Air Diffusion Performance Index (ADPI). A comprehensive presentation of ADPI is given in the references mentioned at the beginning of this paragraph. ADPI is a statistical representation of the number of points within a space that satisfy the temperature and velocity conditions presented in the previous table. An ADPI of $\geq$ 80 is normally considered acceptable. ADPI does have limitations and these should be considered when using this method. ADPI was developed for cooling scenarios and it is not directly

applicable to heating scenarios. When taking this into account the designer should select the air device mid-range for a given ADPI. This will help to ensure that the air device will operate as well as possible under cooling and heating modes. The other limitation to ADPI is related to the room load, when the room load falls outside of the given ranges then the designer will need to select the air device based upon the throw and drop of each device for cooling and heating operations.

The ADPI method and data are presented for a selected few types of air devices in the following table. The Room Load and the Characteristic Length from the space are required. For the air device, once the device type is selected then T50 can be obtained based upon the required airflow. Using the Room Load, Characteristic Length, and T50 with the referenced chart then the ADPI can be obtained. Recall from above that a minimum ADPI of 80 is desired for acceptability.

Selected Air Diffusion Performance Indices (ADPI)					
Terminal Device	Room Load Btu/h-ft^2	T50/L for max ADPI	Max ADPI	For ADPI >	Range of T50/L
High Sidewall Grilles	80	1.8	68	-	-
	60	1.8	72	70	1.5-2.2
	40	1.6	78	70	1.2-2.3
	20	1.5	85	80	1.0-1.9
Circular Ceiling Diffusers	80	0.8	76	70	0.7-1.3
	60	0.8	83	80	0.7-1.2
	40	0.8	88	80	0.5-1.5
	20	0.8	93	90	0.7-1.3
Perforated, Louvered Ceiling Diffusers	11-50	2	96	90	1.4-2.7
				80	1.0-3.4

Characteristic Room Length for Several Diffusers	
Diffuser Type	Characteristic Length, L
High Sidewall Grille	Distance to wall perpindicular to jet.
Circular Ceiling Diffuser	Distance to closest wall or intersecting air jet.
Perforated, Louvered Ceiling Diffuser	Distance to wall or midplane between outlets.

Excerpt from: 2007 Titus Engineering Guidelines; Richardson, TX

Other factors that affect air distribution system design are the proximity of air devices to one another and the localized affects of air devices. The most critical issue for air devices in proximity to one another is to understand how the airflow patterns are affecting one another. For example, if two louvered ceiling diffusers are placed close to one another then the airflow at their common side would collide at midpoint and be pushed toward the floor possibly creating a draft. Another problem with air devices in proximity to each other is short-circuiting. This most frequently occurs when a return or exhaust air device is placed too close to a supply air device. This results in the conditioned supply air being taken back into the ductwork before it has a chance to interact with the environment as it was designed. Short-circuiting leads us to the issue of localized affects for air devices. There are two local effects of particular interest – airflow around return & exhaust air devices and Surface Effect (Coanda Effect). Return & exhaust air devices have little effect on airflow outside of their immediate vicinity. One could ask why then the explanation on short-circuiting – the answer is two-fold, 1) short-circuiting affects both return and exhaust air devices and 2) return air devices may not draw in air well outside of their local area, but a supply air device pointed directly at a return air device will short-circuit enough air to impact the system in a negative way. Surface Effect occurs when air that is discharged from an air device at relatively high velocities clings to the ceiling due to a low pressure region between the air mass and ceiling. Proper use of this surface effect can be helpful in preventing drafts and providing good air distribution. See the selected resources mentioned previously for full details.

<div align="center">Excerpt from: 2007 Titus Engineering Guidelines; Richardson, TX</div>

The figure to the right portrays a round ceiling diffuser in operation for both cooling and heating modes. The details of this picture or a similar one should be in the designers mind when
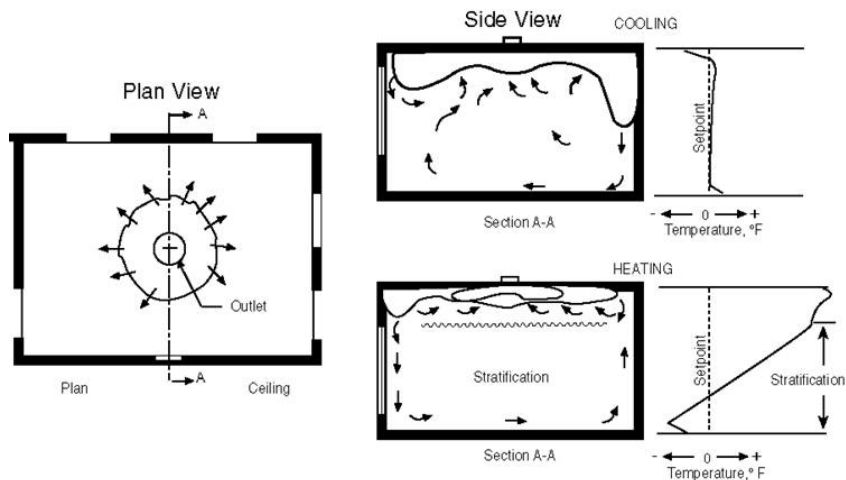
selecting and laying out air devices for an air distribution system.

7. ENGINEERING DESIGN: CONTAMINANTS & CONTROL

Understanding contaminants and how they are controlled is fundamental to proper engineering design for acceptable indoor air quality. Contaminants and their control can be very in-depth and challenging. Over the past decades there has been a great deal of scientific resources expended on this topic. Every designer should have a good understanding of how and why this topic is important. In this section we will explore the basics of contaminants and controls and we will work to lay a firm foundation for the designer's understanding. This section contains a large amount of information and there is no easy way to present all of the required items – graphics have been provided where available to make it as palatable as possible.

For the purposes of this presentation a good definition of a contaminant is necessary. A contaminant is an unwanted airborne constituent that may reduce the acceptability of the air. Contaminants in air are separated into two major categories – particulate contaminants and gaseous contaminants. For both categories, the contaminants of primary concern are the ones that are capable of being taken in by breathing, this is also known as inhalable and/or respirable – depending upon the resource. Particulate contaminants are categorized as solid, liquid, or complex particles. Solid particles are comprised of dusts, fumes, and bio-aerosols. Liquid particles are comprised of mists and fogs. Complex particles are comprised of environmental

Excerpt from: Engineering Cookbook – A Handbook for the Mechanical Designer, Loren Cook Co., 1999

Relative Size Chart of Common Air Contaminants
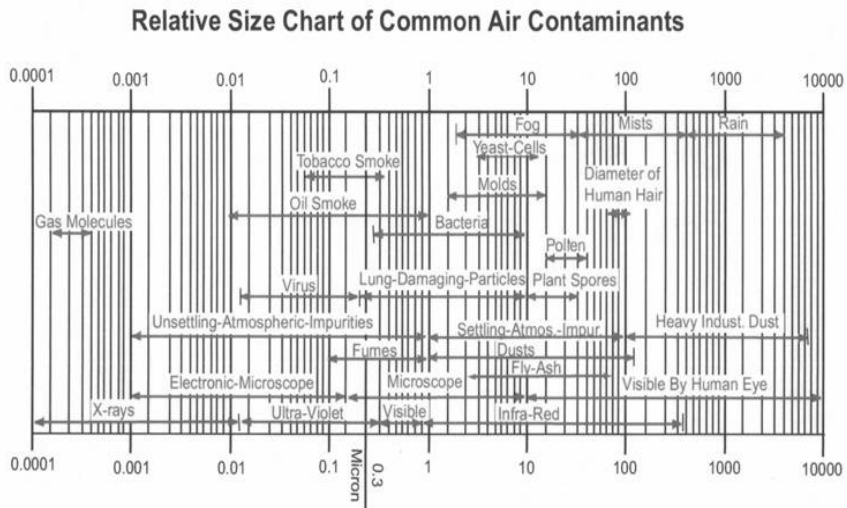
tobacco smoke (ETS) and other smokes. Gaseous contaminants are categorized as organic and inorganic substances.

Most indoor air contaminants can be classified into one of the before mentioned categories. Also as mentioned before, these contaminants are part of a larger group referred to as inhalable and/or respirable particles. Respirable contaminant is the most fitting term for this discussion because it has direct implications to health and indoor air quality. The physical property that best classifies when a contaminant is capable of being taken in by breathing is the average particle size (diameter). The size of the particle also determines where in the respiratory system that particle will eventually be deposited. Particle diameter is measured in microns (μm). For reference, 1 μm = 1/1,000,000 m = 1/25,400 in. For clarification, the use of the term inhalable does well describe the capability of a contaminant of being taken in by breathing, but respirable better describes the process for our discussion because respirable refers to the contaminant being taken into the deeper parts of the lungs.

Particle size classifications are broken down in different ways for different reasons. The first breakdown is simple in form and relates to particles as large, medium, and small. Large particles (>100 μm) tend to fall out of the air quickly. Depending upon the conditions, large particles can fall out of the air in minutes. Medium particles (<100 μm & >25 μm) tend to fall out slower but still settle out after time. Depending upon the conditions, medium particles can fall out of the air in hours. Small particles (<25 μm) tend to take very long periods of time to settle out of the air. Depending upon conditions, some small particles can remain suspended for indefinite periods of time. All of these particles would be considered inhalable and the small particles would be considered respirable.

The second classification breakdown deals with inhalable and respirable particles, but this breakdown further defines the contaminant because it locates within the body where the particles are likely to be deposited. This classification of particles consists of medium & small particles as previously defined. The first class of particles is normally

referred to as inhalable dust. This class of particles are <100 μm in diameter. These particles are normally filtered out of the breathing air by nasal hair, mucous, and sneezing. The second class of particles is normally referred to PM10, which denotes particulate matter that is <10 μm. This class of particulate is also referred to as coarse particulate matter or thoracic dust. When taken in by breathing this respirable class of particles is capable of passing through the nose and throat and reaching the lungs. PM10 contaminants should be a primary consideration for all designers. The affect of PM10 contaminants in outside air used for ventilation is addressed in the NAAQS as mentioned in a previous section. The third class of particles is normally referred to as PM2.5, which denotes particulate matter that is <2.5 μm. This class of particulate is also referred to as fine particulate matter or respirable dust. The PM2.5 class of contaminant is given the most consideration when human health is the main consideration. This class of particulate is capable of being taken into the lungs and it is capable of penetrating the gas-exchange (alveoli) region of the lungs. The human health concern for PM2.5 is that particulates can cause irritation & inflammation within the gas-exchange region of the lungs which can result in more serious secondary health issues (lessened, normal bodily functions).

Particulate contaminants are present in the full range of inhalable and respirable contaminants. As previously mentioned, particulate contaminants include solids, liquids, and complex particles. Included in the solid particles category are dusts, fumes, and bio-aerosols. Dust consists of particles that are projected into the air by natural forces. Dust is comprised mostly of material that does not include fumes and bio-aerosols. A fume is formed by condensation of vapors of solid materials. Fumes are produced in such operations as welding and other similar processes. Bio-aerosols, as their name implies, are air-borne biological organisms such as viruses, bacteria, pollen, and fungal spores. Bio-aerosols receive the greatest amount of attention because they are credited with the largest impact on humans – i.e., allergies, sickness, & other adverse physical reactions. Included in the liquids category are mists and fogs. Mists are air-borne droplets that are ordinarily liquid at normal temperature and pressure. Fogs are fine air-borne particles that are usually formed by condensation of vapors. Included in the complex particles

category are environmental tobacco smoke (ETS) and other smoke. Environmental tobacco smoke receives a great deal of attention and study because of the impact to humans. ETS consists of 0.01 to 1.0 μm liquid particles that form as burning tobacco condenses. Other types of smoke are similar and are produced from burning or smoldering substances. Smoke in general terms consists of solid and/or liquid particles that are produced by incomplete combustion of organic substances. For further reference, 2001 ASHRAE Fundamentals Handbook, Chapter 12 presents an in depth presentation of particulate contaminants.

Gaseous contaminants are also present in the range of inhalable and respirable particles. Gaseous contaminants are separated into one of two categories – organic and inorganic. Organic compounds are those substances that are based upon a skeleton of carbon atoms. A majority of organic compounds are vapors. Inorganic compounds are considered to be all other gaseous contaminants. The most notable organic gaseous contaminants are volatile organic compounds, which are commonly referred to as VOCs. These compounds are called volatile because they readily evaporate into the air at normal temperatures. There are many types of VOCs – some common VOCs are formaldehyde, toluene, and vinyl chloride. A quick internet search for "VOC" will yield a lengthy list if the reader is interested. The main sources of VOCs are solvents, de-greasers, furniture, furnishings, finishes, and cleaning & maintenance products. A secondary type of VOC is microbial volatile organic compound (MVOC). MVOCs are compounds given off by mold and fungi. MVOCs are credited with producing the notable moldy smell in facilities heavily affected with biological growth. The control of VOCs is covered in depth later in this section.

Inorganic compounds encompass a large number of substances. There are several notable substances that will receive the majority of our attention. The most notable inorganic compounds are carbon dioxide (CO_2), carbon monoxide (CO), oxides of nitrogen (NO_X), sulfur dioxide (SO_2), and ozone (O_3). Within built facilities, carbon dioxide is produced by human respiration. CO_2 is also a natural constituent in air (normal levels are considered to be 350-450 ppm). CO_2 is a very important topic and it

is covered more completely in the following paragraph. Carbon monoxide (CO) is an air pollutant that is produced by the incomplete combustion of hydrocarbons. CO requires our attention because it is harmful to humans at low levels (>25 ppm) and it is not readily detectable by humans without special equipment. CO is odorless, colorless, and tasteless. Similar to CO, oxides of nitrogen (NOX) and sulfur dioxide (SO2) are byproducts of combustion. Both NOX (>50 ppm) and SO2 (> 2ppm) are considered to be irritants to humans. SO2 is particular in that the burned fuel must have a sulfur content for SO2 to form. Ozone (O3) is a photochemical oxidant that is formed when hydrocarbons and NOX react with ultraviolet radiation. Ozone (>50 ppb) is considered to be an irritant to humans.

Carbon dioxide has been misunderstood and applied incorrectly by many people over the past decade and a half. A brief history serves well in setting the foundation for this discussion. Prior to the energy crisis of the early and mid 1970s, building tightness (resistance to air leakage) was not a primary concern for many building owners. As energy costs rose so did attention to the infiltration of outside air. Building owner's looked for ways to reduce infiltration and as a result less outside air was introduced into buildings. In the following years the worries of the energy crisis waned and new attention was given to health concerns over operational cost and the introduction of outside air gained a new foothold. This resulted in a revision of ASHRAE Standard 62-1981 Ventilation for Acceptable Indoor Air Quality creating Standard 62-1989 (same title). This revision presented the idea of evaluating CO2 under certain circumstances to help determine the adequacy of the ventilation system. In short, ASHRAE 62-1989 recommended that a maximum ceiling of 1000 ppm for CO2 was adequate to satisfy comfort requirements (emphasize under particular circumstances). The next decade passed with this practice in place. This hard limit of 1000 ppm for CO2 changed with the next revision, ASHRAE Standard 62-1999. The new change recommended a CO2 level of 700 ppm above outside air levels. For some cases this resulted in the previous 1000 ppm maximum because the outside air CO2 level was around 300 ppm, but for cases where the outside air CO2 level is higher, then the maximum would also be higher. The two following revisions of ASHRAE Standard 62.1 have maintained this same practice.

Current outside air CO_2 levels are generally in the range of 350-450 ppm (some sources state 300-500 ppm). These levels could vary depending upon if urban areas are nearby.

The framework for using carbon dioxide in evaluating ventilation systems is presented in current and past editions of ASHRAE 62 - we will reference ASHRAE 62.1-2004. In normal occupancies and under normal conditions CO_2 is not considered to be a harmful contaminant. It is an indicator of oxygen consumption by building occupants. As mentioned above, the maximum CO_2 level in a space will be ~1,000-1,200 ppm – for reference the 8-hour OSHA exposure limit is 5,000 ppm and the IDLH (immediate danger to life & health) is 50,000 ppm. A corrolary to CO_2 not being a harmful contaminant is that CO_2 is considered to be a marker for pollutants, in particular bio-effluents (body odor). CO_2 can be used to mathematically evaluate the effectiveness of ventilation rates, this is presented as an appendix in ASHRAE 62.1. Also, it is important to note that satisfaction with the system is based upon similar assumptions as temperature, relative humidity, and drafts – mainly that 80% satisfaction is the goal.

All of the discussion on contaminants culminates around the topic of control - at least for indoor air quality purposes. Without the ability to control the contaminants, the practice of striving for good indoor air quality would be moot. There are many reasons why we want to control contaminants – primarily to maintain indoor air quality for health and safety. Secondarily we want to control contaminants to help satisfy the comfort and productivity needs of the occupants. Also, we want to control contaminants to help building operations & maintenance be cost-effective and energy-efficient. There are four main methods for controlling contaminants. The four methods are listed in order of preferred approach as well as overall effectiveness.

A. Elimination – remove the contaminant source from the building or area. This should be the first question asked – can the source be eliminated? It obviously eliminates the need to move forward with any other scenario. At first pass this question may seem pointless, we may assume that it has already been asked. Do not assume this – ask if the contaminant source can be removed or if it can be replaced with a different material.

VOCs can be readily addressed in this fashion. VOCs come from cleaning products and interior furnishings – other cleaners can be substituted and other furnishings can be provided. This approach is taken by many green-building methods to help eliminate VOCs.

B. Local Source Control – also called local exhaust or extraction. If elimination is not possible, then local source control should be the next preferred method. This method should be known to designers as it is applied in restrooms, commercial kitchens, etc… Source control has an industrial equivalent as well and more experienced designers are familiar with these types – vehicle garage fume extraction, laboratory chemical hoods, industrial grinding & welding booths, etc… This method requires that the designer be familiar with building & space pressurization and be able to apply make-up/relief air properly.

C. Dilution Ventilation – when elimination is not possible and exhaust is not practical, then dilution ventilation is an alternative. Dilution ventilation is the introduction of sufficient outside air and/or make-up air to reduce indoor air contaminants to below recommended levels. This approach is commonly known to designers in the form of outside air ventilation rates mandated by mechanical codes. Dilution ventilation has an industrial equivalent similar to source control. In industrial settings the amount of outside air is based upon contaminant generation and permissible contaminant levels. The permissible contaminant levels are mandated by OSHA (called PELs – permissible exposure limit). Other resources, such as NIOSH & ACGIH, make recommendations. OSHA PELs are 8 hr TWA and STEL (8 hour time-weighted average & short term exposure limit). NIOSH levels (RELs – recommended exposure limits) are TWA. ACGIH limits are TLVs (threshold limit values). The reader should not be over-whelmed by these terms – the purpose here is to introduce the reader to these terms if they have not already been introduced. This is extremely important – an individual should not attempt to design an industrial dilution ventilation system without the experience & education to do so. This method also requires that the designer be familiar with building & space pressurization and be able to apply make-up/relief air properly.

D. <u>Air Filtration</u> – this method is unique in that most installations will require a minimum level of filtration no matter the circumstance. Therefore it is not reasonable to convey this as a last resort. In reality, air filtration is one of the best tools for helping to ensure good indoor air quality by removing contaminants from outside and inside air. Air filtration is also used to help maintain the condition of mechanical equipment, particularly heat exchangers. Air filtration can even be used to help maintain the quality of manufacturing processes, i.e. clean-rooms & paint booths. Particulate contaminants and gaseous contaminant are different in many ways – the most notable difference is their size. Because of this difference, the two

Excerpt from: Figs 2.1-2.4, NAFA Guide to Air Filtration, 2nd Ed; 1996, Washington, D.C.

IMPINGEMENT   DIFFUSION

INTERCEPTION   STRAINING
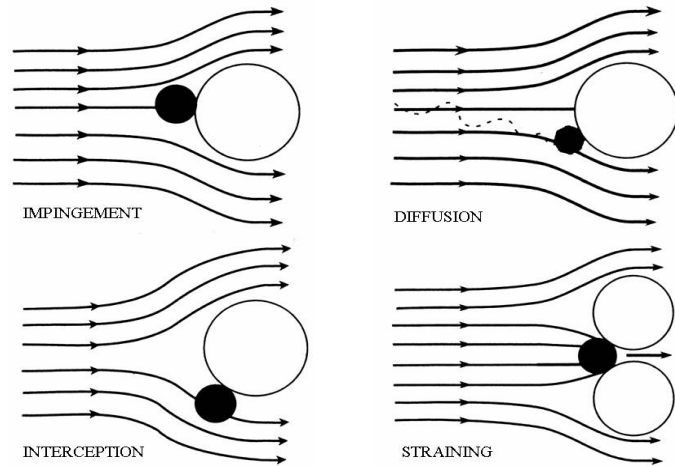
contaminants must be treated in different ways. Particulate contaminants are larger ($>0.01\mu m$) and are captured by means of mechanical filtration. Some other resources also recommend the use of electrostatic air cleaners for particulate contaminants. This method should be approached with a good deal of reserve. Gaseous contaminants

Excerpt from: Table 7.1, NAFA Guide to Air Filtration, 3rd Ed; 2001, Washington, D.C.

ASHRAE 52.2				ASHRAE 52.1		Particle size	
	Particle size range			Test		range, μm	Applications
MERV	3 to 10 μm	1 to 3 μm	.3 to 1 μm	Arrestance	Dust spot		
1	<20%	-	-	<65%	<20%	>10	residential
2	<20%	-	-	65-70%	<20%		light
3	<20%	-	-	70-75%	<20%		pollen,
4	<20%	-	-	>75%	<20%		dust mites
5	20-35%	-	-	80-85%	<20%	3.0-10	industrial,
6	35-50%	-	-	>90%	<20%		dust,
7	50-70%	-	-	>90%	20-25%		molds,
8	>70%	-	-	>95%	25-30%		spores
9	>85%	<50%	-	>95%	40-45%	1.0-3.0	industrial,
10	>85%	50-65%	-	>95%	50-55%		Legionella,
11	>85%	65-80%	-	>98%	60-65%		dust
12	>90%	>80%	-	>98%	70-75%		
13	>90%	>90%	<75%	>98%	80-90%	0.3-1.0	hospitals,
14	>90%	>90%	75-85%	>98%	90-95%		smoke
15	>90%	>90%	85-95%	>98%	~95%		removal,
16	>95%	>95%	>95%	>98%	>95%		bacteria

are very small and are captured by means of gas-phase filtration. Mechanical air filtration generally operates upon four mechanisms. These four mechanisms are described in the adjacent figure. Impingement and interception are the most common methods of capture for mechanical filtration. Refer to NAFA Guide to Air Filtration 2nd

ed. for a complete description of each method. In general terms mechanical filtration is rated based upon its ability to capture and retain particulate contaminants. ASHRAE Standard 52.1-1992 and Standard 52.2-1999 outline the performance requirements for mechanical filtration. The figure below details these performance requirements. ASHRAE 52.1 details performance in terms of arrestance and dust spot efficiency. Both are different measures on how well low and medium efficiency filters capture coarse material. ASHRAE 52.2 details performance in terms of a MERV (minimum efficiency reporting value). MERV quantifies filtration efficiency in different particle size ranges for clean and incrementally loaded filters to provide a composite efficiency value. In summation, the higher the MERV number and the higher the arrestance & dust spot efficiency, then the more effective the filter is at removing particulate contaminant.

8. ENGINEERING DESIGN: BUILDING & SPACE PRESSURIZATION

Controlling building and space pressurization is critical for maintaining acceptable indoor air quality. Controlling building and space pressurization is not only critical for air quality, but it also makes a major impact on fire protection features of a building. Such features would be smoke management systems and pressurized stairwells. Fire protection features are beyond the scope of this presentation. Please see the Society of Fire Protection Engineers or the NFPA for more information. Proper pressurization can be thought of as an invisible barrier that helps control the migration of temperature, humidity, and contaminants from one area to another. This discussion will build upon previous discussions on ventilation, air distribution, and contaminant control.

Building pressurization is controlled in order to prevent outside air from migrating inside or to prevent inside air from migrating outside. Building pressure is not the only factor that determines air migration through the building envelope – building materials and quality of construction also play a major role. It is important to prevent un-planned and un-wanted migration of air through the building envelope for many reasons. Most importantly for our discussion is because it can cause problems that the mechanical systems were not designed to handle – increased moisture, loss of heating, introduction of

drafts and contaminants, etc... Wind pressure on a building can be the driving force behind many of these issues. Wind velocity pressure is often used to approximate the building surface pressure. The equation for wind velocity pressure exerted on a building surface is as follows:

$$Pwi = \alpha \bullet Pa \bullet (Vwi^2)/2$$; Pwi – pressure exerted by wind on wall (Pascal), Pa – density of air (kg/m^3), Vwi – wind speed (m/s), α - dimensionless surface pressure coefficient (.5-.6 when perpendicular & .25-.35 when diagonal).

Example – one side of a building is experiencing a perpendicular 25 MPH wind. Using the above equation for wind velocity pressure, the resultant pressure difference between outside and inside is ~0.16 in. water (assuming the inside space is neutral).

Space pressurization is controlled in order to prevent air from migrating between adjacent interior spaces located on the same level and to prevent air from migrating between adjacent interior spaces located on different levels. Similar to building pressurization, materials and quality of construction also play a role in air migration between spaces. The reasons for maintaining control of space pressure are similar to that of building pressure – temperature, humidity, and contaminants. Building and space pressurization are maintained by controlling the balance of airflow into and out of an area. The proper balancing of these airflows includes an analysis of the supply air, return air, exhaust air, and outside air for the building or space. Other airflows for consideration could be make-up air and relief air. In order to analyze the balance of airflow, each of the above airflow rates must have been previously determined. For many facility types, the previous sections on Temperature & Humidity and Ventilation can assist in determining the required airflow rates.

9. ENGINEERING DESIGN: SOUND & VIBRATION

Part of the goal of maintaining acceptable indoor air quality is to remove and/or prevent objectionable conditions from occurring within a building. This is done for

temperature, humidity, and contaminants. Sound and vibration are also factors to be considered when designing for acceptable indoor air quality. Sound and vibration are not generally associated with the health and well-being of occupants – they are more closely tied to productivity and being a general nuisance. Sound and vibration can quickly become a very complicated subject but this should not prevent design professionals from becoming familiar with the basic concepts and terminology. A design professional can prevent many problems from occurring with the proper application of these basic concepts. For the purpose of this discussion, sound and vibration are similar concepts but they are handled in different ways.

Vibration can be described as a mechanical oscillation transferred through a solid material or structure. Within the built environment, vibration transferred to the building by mechanical rotating and reciprocating machinery is referred to as structure-borne vibration. Structure-borne vibration can also be generated by wind effect, but this is beyond the scope of this discussion. All mechanical equipment that has the potential to produce structure-borne vibration should be controlled by isolation. If isolation is not possible then dampening of the equipment should be considered. There can also be the circumstance where both measures provide an optimal solution. Isolation of mechanical equipment is normally accomplished by separating the equipment from the structure by means of a non-rigid or flexible connection. Isolators can include springs (tension or compression), rubber pads, braided hoses, fabric-type collars, etc… It is important for the design professional to remember that when isolating a piece of equipment all potential paths should be isolated. For example - a chilled-water, air-handling unit suspended from the roof structure would require that the cabinet of the AHU be hung on spring isolators, the chilled-water piping would be connected by braided hose spool-pieces, the ductwork would be connected to the air openings on the cabinet with fabric-type collars, and flexible electrical connection would need to be provided. When isolation can not be implemented or when the vibration is not fully eliminated then dampening could be considered. For the purists in the audience, yes isolation is a form of dampening. In context of this discussion dampening will refer to increasing the mass of the machinery to change the system dynamics. In general, when the mass of the

equipment is increased the vibration is lessened. Application of mass dampening for control of mechanical systems is beyond the scope of this presentation – see the equipment manufacturer for further guidance.

In the simplest terms, sounds are the things that we hear. What we "hear" are changes in pressure within the vicinity of our eardrum. The changes in pressure at our eardrum occur over time or in other words with frequency (measured in cycles per second, hertz, Hz). The frequency of the change in pressure results in what is commonly referred to as the pitch. A high pitch would be associated with high frequencies and low pitch would be associated with low frequencies. For reference, the range of frequency for human hearing is documented to be between 20 and 20,000 Hz. The human body can experience sounds in good, neutral, and objectionable ways. We will refer to the objectionable sounds as noise. For the purpose of designing for acceptable indoor air quality, the elimination of noise is our goal. Understanding the previous concepts are critical to the understanding of sound power, sound pressure, and other related items. These terms are utilized throughout the industry to describe the acoustical performance of mechanical equipment and to estimate the impact of acoustics on the built environment. Sound power and sound pressure are two common terms used within the industry to measure, estimate, and specify acoustical performance. Sound power is a measure of the rate of emission of acoustical energy from a source. Sound power is measured in watts (particularly 10^{-12} w). Sound power is related to the strength of the source only, it is not related to how "loud" the sound is when & where it is heard or measured. Sound pressure is the driving force for what we hear, it is the variation in pressure above and below atmospheric pressure that drives the sound. Sound pressure is the resultant of sound power applied at a

SOUND POWER & SOUND PRESSURE

OBJECT	SOUND POWER, WATTS	SOUND POWER LEVEL, dB re 10^-12 W	SOUND PRESSURE CRITERIA	SOUND PRESSURE, PASCALS	SOUND POWER LEVEL, dB re 20 µPa
Military Jet Take-off	10^4	160	@ 100 feet	200	140
Large Pipe Organ	10	130	Loud Rock Band @~10 feet	6.3	110
Human Conversational Speech	10^-5	70	@ 3 feet	.02	60
Whispered Conversation	10^-9	30	@ 6 feet	.0006	30

Notes:
1. The difference between sound power and sound pressure is not as directly comparable as it appears in this table. This table is formatted to help the user understand that the relationship between power & pressure relates mostly to the distance between the source & the target.
2. Refer to AHSRAE Fundamentals Handbook - Sound & Vibration Chapter for further details.

Retrieved Feb 5, 2008, from "EngineeringToolbox.com" website, http://www.engineeringtoolbox.com/sound-power-level-d_58.html & http://www.engineeringtoolbox.com/sound-pressure-d_711.html

distance from the source. Sound pressure is measured in pascals (particularly μPa). The relative strength level of both sound power and sound pressure are measured in units of decibels, dB (each with respect to its own reference point). A decibel is not a customary linear unit of measure, it is a logarithmic unit used to express the relative difference between two signals. Sound power level is measured in "dB re 10^{-12} w", or decibel with reference to 10^{-12} w (where 10^{-12} w is lowest sound power threshold of human hearing). Sound pressure level is measured in "dB re 20 μPa", or decibel with reference to 20 μPa (where 20 μPa is the lowest sound pressure threshold of human hearing. The table to the right lists several different objects and their associated sound power and sound pressure values.

Properly utilizing sound power and sound pressure information is an important tool in engineering design for acceptable indoor air quality. It was previously stated that the elimination of noise (objectionable sound) is the goal. Similar to any other potential problem – if the source can be removed or omitted then that should be done first. If the source can not be done away with then remedies must be found. Sound power and sound pressure information for a system can be analyzed to help an engineering designer determine which of the two scenarios should be performed (removed or remedied). During engineering design, sound power information usually comes from an equipment manufacturer in the form a table listing fan sound power levels. This can also apply to pumps, motors, and cabinet radiated sound. The information table is normally arranged with 8 data columns. These columns represent the sound power level (dB re 10^{-12} w) of the equipment at each one of the established 8 octave bands. An octave band is a range of frequencies where the highest frequency is twice as large as the lowest frequency. The data label for each column represents the center frequency for each respective octave band. The octave band center frequencies are 63, 125, 250, 500, 1000, 2000, 4000, & 8000 Hz. These represent the octave bands that are in the range of established human hearing. Reviewing the performance of a single piece of equipment has limitations, a more practical use of the data would be to compare the performance of several different pieces of equipment (all of which can serve in the same role). The comparison can help the designer determine whether the selected equipment is a good choice for the application. If not, the designer has already determined the performance of other similar

pieces of equipment and an objective decision can be made from that point. If further advanced sound power analysis is needed, the engineering designer should seek the assistance of a senior engineer qualified in the field or seek the assistance of the equipment manufacturer. Sound pressure influences engineering design in less of

Retrieved Feb. 11, 2008, from "EngineeringToolbox.com" website, http://www.engineeringtoolbox.com/nc-noise-criterion-d_725.html
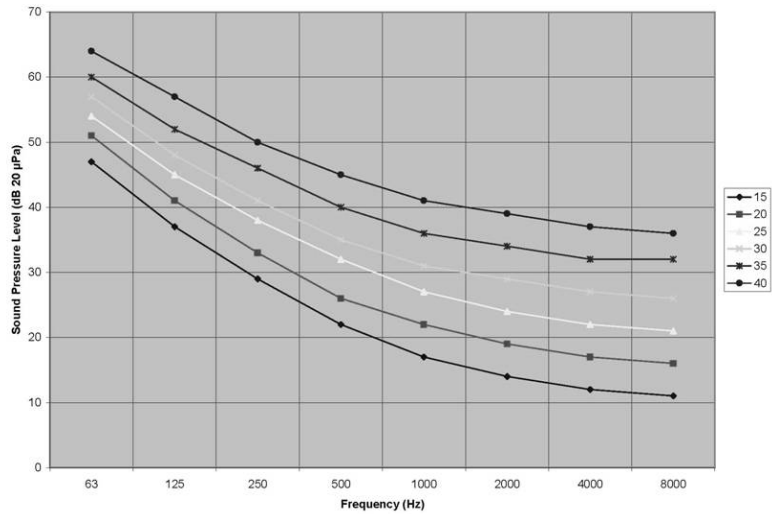
an explicit fashion than sound power. Sound pressure is dependent upon location and comparing one device to another becomes impractical due to the fact that no two locations are the same. Because of this added complexity, it was necessary to develop standardized methods for specifying the

Retrieved Feb. 11, 2008, from "EngineeringToolbox.com" website, http://www.engineeringtoolbox.com/nc-noise-criterion-d_725.html

Recommended Noise Criteria	
Type of Room - Space Type	Recommended NC Range
Assembly Hall	25-30
Church	30-35
Factory	40-65
Hotel Room	25-35
Private Office	30-35
Office Conference Room	25-30
Laboratory	35-40
School Classroom	25-30
Movie Theater	30-35
Library	35-40
Recording Studio	15-20
Sports Arean	45-55
Restaurant	40-45
Private Residence	25-35

acoustic criteria for a building or space. These methods are used in specifying certain types of air devices, particularly air diffusers and grilles. Air devices manufacturer's in the United States utilize Noise Criterion (NC) Curves to specify acoustical performance. The NC Curves are data sets plotted on a sound pressure level versus frequency graph (sound is linear & frequency is logarithmic). The sound pressure is plotted in units of 10

and the frequency is plotted against the 8 octave bands mentioned before. The figure to the right shows a portion of the NC Curves which are applicable to our discussion. Also, various facility types are listed below along with their recommended NC Curve range. Air device manufacturers publish the acoustical performance of air diffusers and grilles utilizing the NC Curve system. The air devices are rated to perform at or below the specified NC Curve. Examples of this are available at www.titus-hvac.com and www.price-hvac.com. If the circumstance warrants a more in depth analysis, the engineering designer should seek the services of an engineer or scientist qualified in the field of acoustics.

10. BUILDING SYSTEM OPERATIONS & ENGINEERING DESIGN

Engineering design includes many things – technical analysis, first-cost impacts, energy efficiency, code-compliance, etc… Engineering design for effective operations should be included in this list and it should be implemented for all designs. Engineering design for effective operations would include helping Building Operations be more accurate, more visible, more efficient, and more cost-effective. Facilities equipped with energy monitoring and control systems can be especially impacted by new designs that take operations effectiveness into account. Building Operations can often be under-funded and under-staffed, the engineering designer should review measures that can help Buildings Operations under these conditions. Special care should be taken by the engineering designer so that their design does not un-reasonably impact Building Operations. The engineering designer should cultivate a relationship with the Building Operations staff and communicate with them on a regular basis throughout the project.

11. BUILDING SYSTEM OPERATION & IAQ

Proper building operation is a fundamental part of every indoor air quality program. Building Operations is responsible for the daily operation and monitoring of all the building systems. The Building Operations staff helps to ensure acceptable indoor air quality by monitoring building systems such as: thermostats & temperature sensors;

humidifiers & de-humidifiers; outside air dampers & exhaust fans; air filters & filtration units; and air diffusers & grilles. Without the proper operation of these building systems it would not be possible to maintain acceptable indoor air quality within an occupied building. Engineering design for effective building operation and acceptable indoor air quality should consider short-term and long-term effects equally and when possible design for both.

12. BUILDING SYSTEM MAINTENANCE & ENGINEERING DESIGN

Similar to building operations, engineering design should include consideration of effective system maintenance along with technical analysis, first-cost, energy, code compliance, etc… Engineering design for effective system maintenance would include planning and implementing systems for Building Maintenance that - allow for ease of access & routine maintenance, increase equipment visibility electronically, are cost-effective, limit system down-time & increase system availability, and utilize proven technologies. It was previously mentioned in Building Operations that a facility with an energy monitoring and control systems can be especially impacted by a new design. When implemented correctly, energy monitoring and control systems can be a very useful tool to Building Maintenance staff. An engineering designer will do well to ensure that new systems and modifications do not negatively impact or impede the existing control system. The same suggestions that were mentioned in the Building Operations section above can also apply for Building Maintenance.

13. BUILDING SYSTEM MAINTENANCE & IAQ

Proper building maintenance is another fundamental part of every indoor air quality program. Building Maintenance is responsible for all planned and un-planned maintenance and repair for the building systems. The Building Maintenance staff assists in maintaining acceptable indoor air quality by ensuring proper system performance, by limiting system downtime, and by performing required & necessary system cleaning and mechanical hygiene. Without proper system maintenance and hygiene it would not be

possible to maintain acceptable indoor air quality within an occupied building. Engineering design for effective building maintenance and acceptable indoor air quality should also consider short-term and long-term effects equally and when possible design for both.

14. ENGINEERING QUALITY INDOOR AIR BY COMBINING DESIGN, OPERATION, AND MAINTENANCE

A good engineering design will incorporate many things: code-compliance, cost, installation, maintenance, reliability, operation, environment, health, safety, energy, indoor air quality… and the list could go on. Our discussion has been focused on combining engineering design fundamentals with building operation and maintenance requirements to produce acceptable indoor air quality within a building. Acceptable indoor air quality could be thought of as a three-legged table where engineering design, building operation, and building maintenance are the three legs. If any one of the three legs were missing then the table would not stand. All three legs are equally important. This presentation is not directly addressed to operation and maintenance personnel, although I believe they could benefit from it. This presentation is directly addressed to engineering designers and design professionals. If the "three-legged" relationship described herein does not already exist in your project team then I believe that the engineering designer should take the initiative to make it so. In the 2nd paragraph of the 1st section of this presentation the true purpose of our work is described in detail – for the public good. I encourage all engineering designers and design professionals to weigh this purpose daily against the results that you produce.