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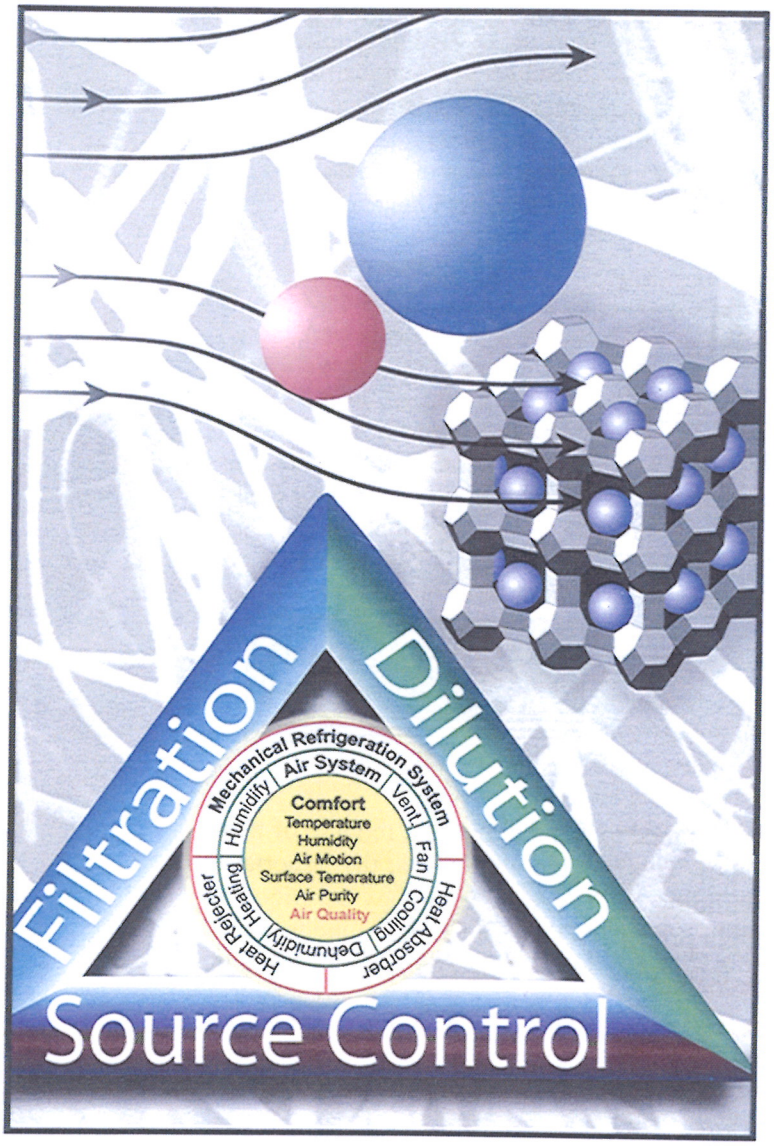


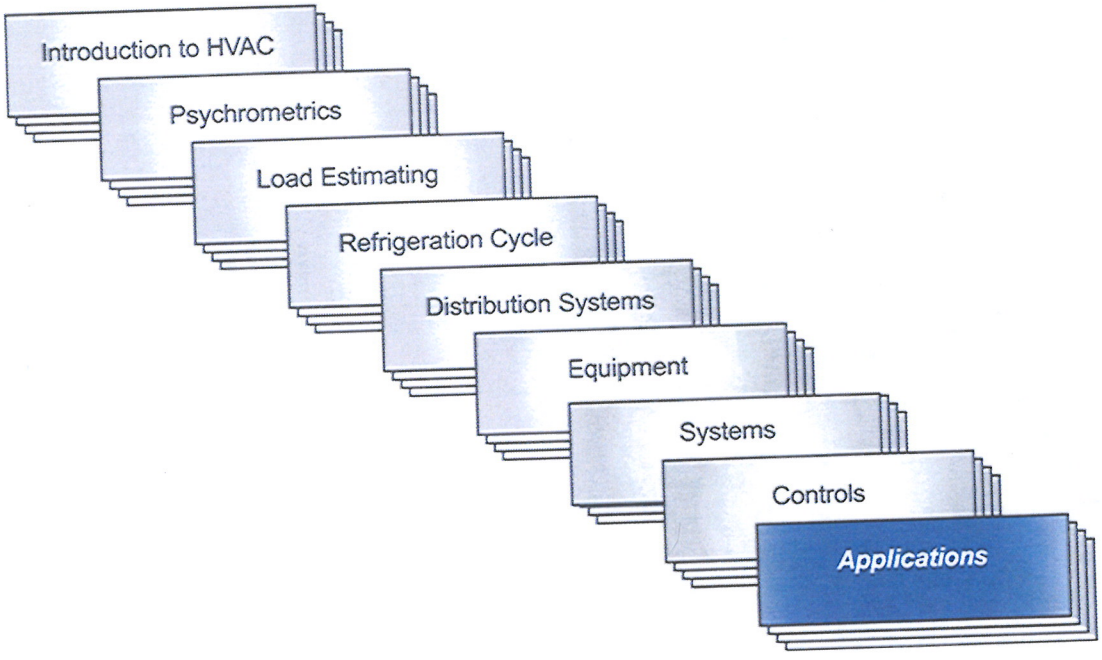
APPLICATIONS

Indoor Air Quality

Technical Development Program

Technical Development Programs (TDP) are modules of technical training on HVAC theory, system design, equipment selection and application topics. They are targeted at engineers and designers who wish to develop their knowledge in this field to effectively design, specify, sell or apply HVAC equipment in commercial applications.

Although TDP topics have been developed as stand-alone modules, there are logical groupings of topics. The modules within each group begin at an introductory level and progress to advanced levels. The breadth of this offering allows for customization into a complete HVAC curriculum – from a complete HVAC design course at an introductory-level or to an advanced-level design course. Advanced-level modules assume prerequisite knowledge and do not review basic concepts.



This Technical Development Program (TDP) is designed to stand alone as a module of training. It is one of the Application series of TDP modules. This module will look at the importance of Indoor Air Quality (IAQ) to the occupants of a building. An HVAC system may contribute to the problem of poor IAQ or provide means to maintain proper IAQ. Recent changes incorporated in *ASHRAE Standard 62.1-2004 – Ventilation for Acceptable Indoor Air Quality* will be highlighted.

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Introduction

Indoor air quality (IAQ) is commonly thought of as the condition of the air within buildings, cars, planes, etc. Since we spend so much time indoors, the quality of the air is very important to our health and productivity. The causes of poor indoor air quality are numerous and varied. It is critical that proper air quality be designed into building components and systems, including site considerations and effects of the natural elements on the performance of the building.

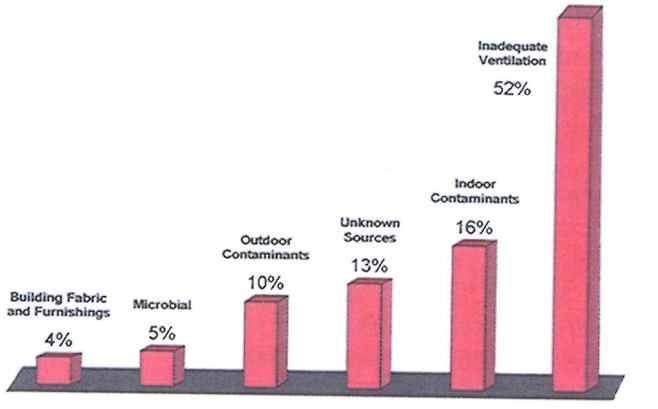


Figure 1

Poor IAQ Contaminant Sources

Throughout history, humans have both intentionally and unknowingly performed actions that have impacted the air quality of our indoor environments. From the simple acts of starting a fire inside a cave or vacuuming the home, to the introduction of tobacco smoke into the air, we have been releasing contaminants into the air. See Figure 1. Indoor air quality has emerged as a major area of concern within all types of buildings because it is now understood that the quality of indoor air has significant health, comfort, productivity, and financial impacts on the occupants.

Building occupants have become perceptive about environmental impacts upon their health and performance, so we will spend time in this TDP on the comfort and health aspects of the indoor air, along with the various types of contaminants and their sources. A simple three-step IAQ control strategy will help the designer minimize contaminant impacts through proper IAQ-design of HVAC systems.

Since its introduction, Standard 62 from the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) has been the primary design reference affecting the ventilation aspects of HVAC systems. The newly published *Standard 62.1-2004 Ventilation for Acceptable Indoor Air Quality* once again has revised outdoor air requirements for various types of occupancies. The standard has also completely overhauled the methods for determining minimum airflow rates of ***outdoor air (OA).***

This TDP will conclude with a multi-step IAQ design sequence that will provide guidance for integrating IAQ performance into the design of HVAC systems.

Indoor air quality is too often defined in negative terms. The strict definition refers only to the presence of ***contaminants***, which may result in either an immediate or delayed unpleasant or unhealthful response by the occupants. The ASHRAE Standard defines acceptable IAQ as air quality "with which a substantial majority (80 percent or more) of the people exposed do not express dissatisfaction." The European definition of appropriate IAQ, shown to the right, while more positively stated, remains somewhat vague and subjective, underscoring the difficulty in defining this topic in clear and concise terms.

Appropriate Indoor Air Quality Definition

IAQ is defined as the physical, mechanical, and chemical properties enabling people to live and work in healthy and comfortable conditions.

Indoor Air Quality is a Complex Issue

Indoor air quality is part of a complex system of building characteristics. Many factors are used to characterize a comfortable and healthy indoor environment. As shown in Figure 2, IAQ is part of the larger indoor environmental quality (IEQ) picture. Indoor environmental quality is the sum of all elements that impact the personal well being of an individual within the indoor environment. Some of the elements that impact occupants are as diverse as sound, lighting, humidity, temperature, vibrations, ergonomics, and IAQ. Often, investigations into ***environmental illnesses*** too quickly focus on indoor air contaminants before studying all IEQ factors.

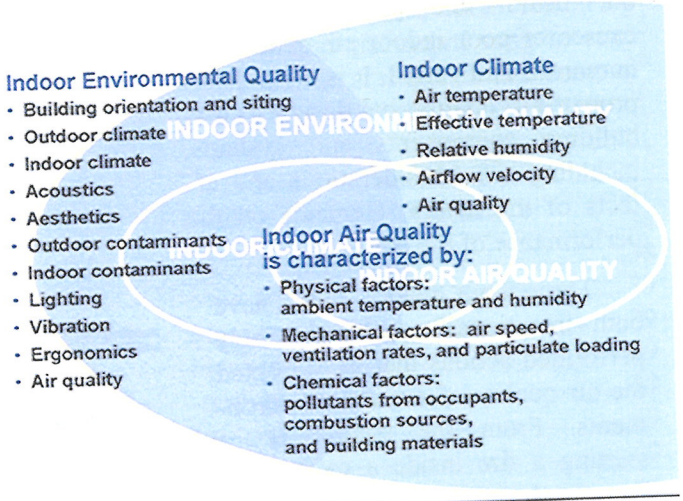


Figure 2

Indoor air quality factors are part of overall IEQ.

> ***Indoor Environmental Quality Definition***
>
> ***IEQ is the sum of all elements that impact the personal well being of an individual within an indoor environment.***

Like a Rubik's cube (Figure 3), indoor air quality issues are a complex puzzle comprised of many different, yet related aspects of contaminant sources (blue), economic issues (yellow), and key control strategies (red). We will explore many of these aspects of IAQ later in the TDP.

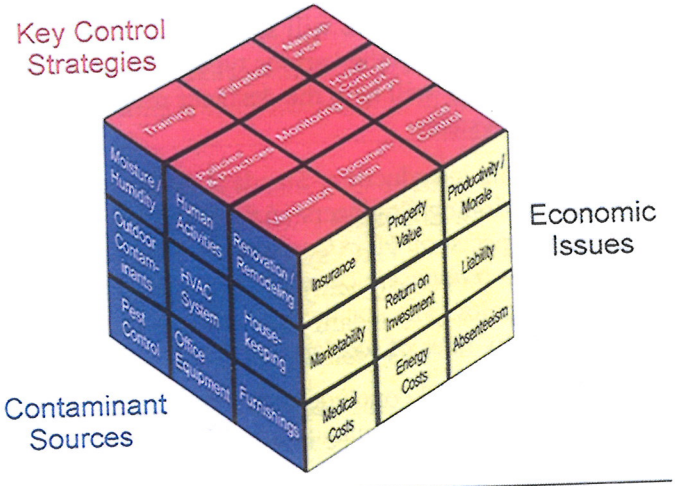


Figure 3

Complex Issues of IAQ

The quality of the air we breathe is adversely affected by four elements:

- Excessive indoor and outdoor contaminant sources
- Design deficiencies in all building systems, including HVAC
- Construction deficiencies in implementing project plans and specifications
- Operational and maintenance deficiencies across all aspects of building components and systems

Poor IAQ can cause absenteeism, decreased employee productivity, poor employee morale, increased workers' compensation claims and medical expenses, union grievances, and legal expenses. Occupant complaints and litigations have greatly elevated the visibility of IAQ concerns. A number of high profile cases have involved large-scale remediation activities. Liability has affected the owner, architect, developer, engineer, general contractor, mechanical contractor, facility manager, equipment manufacturer, and the service contractor. Because of such legal considerations, clauses referring to IAQ requirements are becoming part of the standard lease document.

Indoor air quality has become an integral part of the design, construction, commissioning, operation, and maintenance phases of a building project. Whether it is a new construction project or renovation, the impact of IAQ must be given due consideration during each of the building project phases. If such consideration is delayed to a later stage in a building's construction or operation, the magnitude of the problem, and potential costs for remediation, can be greatly increased as shown in Figure 4. Individuals involved in any of the aspects of a building project must realize that their activities may impact the IAQ in the occupied space.

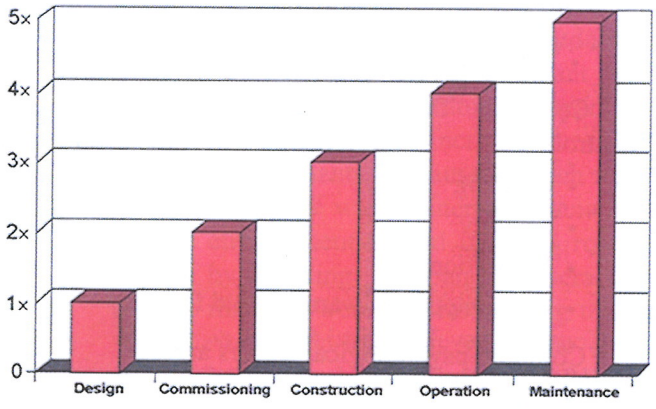


Figure 4

Costs of Delaying IAQ Considerations

IAQ Expectations and Effects

Occupants of a building are unique in their response to the building environment. Individuals are different in their expectations, their tolerance, and their physical and psychological responses to the many and varied environmental conditions. Due to differences in age, sex, health, and social and emotional factors, one person may complain bitterly about the same conditions that are tolerated with little concern by another. One person may become genuinely ill because of conditions that do not affect most other people.

Comfort

Many complaints about indoor air quality result from poor temperature control, even though this is only a minor element of the many comfort factors that can be controlled (Figure 5). Humidity is a significant factor in both the perception and reality of IAQ. Proper levels, 30 to 60 percent ***relative humidity (rh)***, generally result in fewer complaints and improved performance and productivity among workers. Sensory comfort is believed to relate directly to the ventilation rate (the amount of outdoor air provided in buildings).

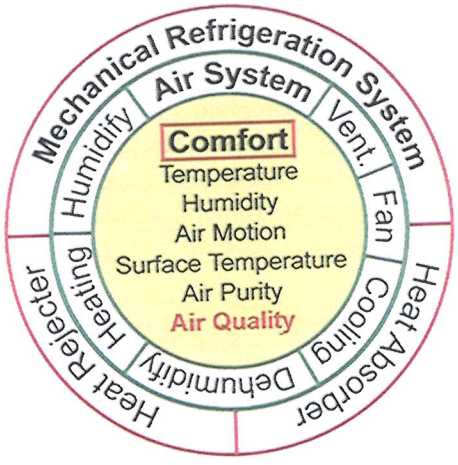


Figure 5

Comfort Factors

Common measurable environmental factors are:

- Temperature
- Humidity
- Air motion
- Surface temperature
- Air purity
- Air quality

Common factors under personal control are:

- Clothing
- Activity
- Relocation
- Consumption of warm or cold foods

Common psychological factors are:

- Light
- Sound
- Color
- Texture
- Movement
- Scent

Health Effects

Indoor air quality-related adverse health effects derive from exposure to contaminants within the indoor environment that include particulates and chemical, biological, and radiological (CBR) agents. The magnitude and complexity of the health effects is a function of concentration of the contaminant, duration of exposure, respiration rate, and susceptibility of the individual who is exposed.

From the U.N. World Health Organization

"Health is a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity."

A major source of modern day IAQ problems can be related to the building practices generated in the early 1970s. During that time, there was an oil embargo against the United States which led to a growing focus on energy conservation. In order to conserve energy, there was a concerted effort to reduce infiltration of outdoor air and reduce the amount of ventilation air. The building industry also introduced a record number of new synthetic materials that are now known to emit volatile organic compounds. In order to maximize space utilization, the population density of occupants in the buildings was also increased. This combination of reduced outdoor air and increased indoor pollutant levels resulted in the building occupants being exposed to an increased amount of contaminants. Because of such activities, there was an increased amount of environment-related illnesses reported by building occupants. Several new illnesses were reported during this period. Sick building syndrome (SBS), building-related illnesses (BRI), and multiple chemical sensitivity (MCS) are some of the new health conditions that were discovered in the newer, tighter buildings. See Figure 6.



Figure 6

Tight Buildings

Sick Building Syndrome (SBS)

Sick building syndrome is a group of medical symptoms that are worse in a particular building and abate when away from the building, having no other identifiable cause. These symptoms include eye, nose, and throat irritation; headache and fatigue; and dry skin or rashes. People have sick building syndrome, not buildings. See Figure 7. There is no set of clinical standards to determine the existence of sick building syndrome. Though the cause is unknown, it is thought to be a physical, chemical, or microbiological agent that is aggravated by poor ventilation, among other things. The key concept is that no specific cause of the syndrome can be identified, despite investigation and testing.

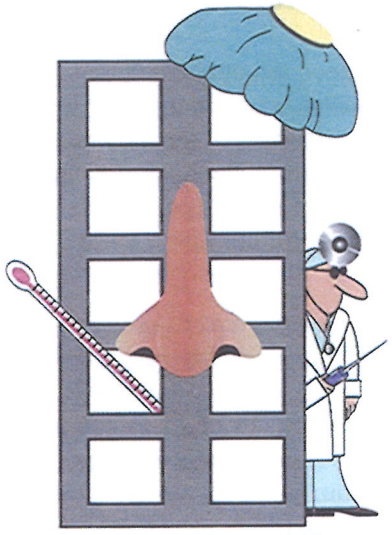


Figure 7

Sick Building Syndrome is Not About the Building.

Building-Related Illnesses (BRI)

Building-related illnesses are diagnosable illnesses that can be traced to a specific cause, such as a chemical or biological contaminant in a building. Sometimes the illnesses are serious and occasionally even life-threatening. Examples include asthma, hypersensitivity pneumonitis, Legionnaires' disease, and carbon monoxide poisoning. Clinical diagnosis is the critical determining factor of a building-related illness. The cause may be traceable to a specific exposure by an individual to that causal agent. Hypersensitivity pneumonitis is a complex and problematic building-related illness. It appears to be caused by chronic exposure to bioaerosols to which the affected individual is sensitive. It often is seen as a respiratory illness that just will not go away, such as seemingly incurable pneumonia.

Legionnaires' disease or legionellosis is a lung infection (pneumonia) caused by a bacterium named *legionella pneumophila*. The name Legionnaires' disease is derived from the original outbreak at the 1976 American Legion Convention in Philadelphia. The waterborne bacteria reproduces best at 80 to 120° F, and lives in cracks, scale, and backwaters. The major source is the water distribution system of large buildings including hotels and hospitals. Cooling towers have long been thought to be a major source for legionella, but new data suggest that this is an overemphasized mode of transmission. Other sources include mist machines, humidifiers, whirlpool spas, and hot springs. Air conditioners are not a source for Legionnaires' disease. They were suspected to be the source in the original American Legion outbreak in a Philadelphia hotel, but new data now suggests that the water in the hotel was the actual source.

Legionnaires' Disease

ASHRAE has published* Guideline 12-2000 Minimizing the Risk of Legionellosis Associated with Building Water Systems *to assist the design community in dealing with this building-related illness that is often associated with building mechanical systems.

The only way to get sick with Legionnaires' disease is to inhale the bacteria in an aerosolized form. The CDC (Centers for Disease Control) estimates that as many as 25,000 cases of legionella occur in the US each year, with a 15 percent fatality rate. Many cases of legionella go undiagnosed, according to the CDC, because it is treated as general pneumonia and never properly characterized.

Multiple Chemical Sensitivity (MCS)

Multiple chemical sensitivity, or environmental illness, is a chronic condition marked by increased sensitivity when exposed to chemical substances. This sensitivity is thought to be caused by short-term or chronic exposure to one or more chemicals. Multiple chemical sensitivity is often referred to as "chemical allergy," but the illness is not the same as a traditional allergy to dust, animals, or pollen. The medical community is inconclusive about the diagnosis on MCS. The National Academy of Sciences estimates that 15 percent of the population has MCS, however, physicians who practice environmental medicine estimate that chemical sensitivity affects up to 50 percent of the US population.

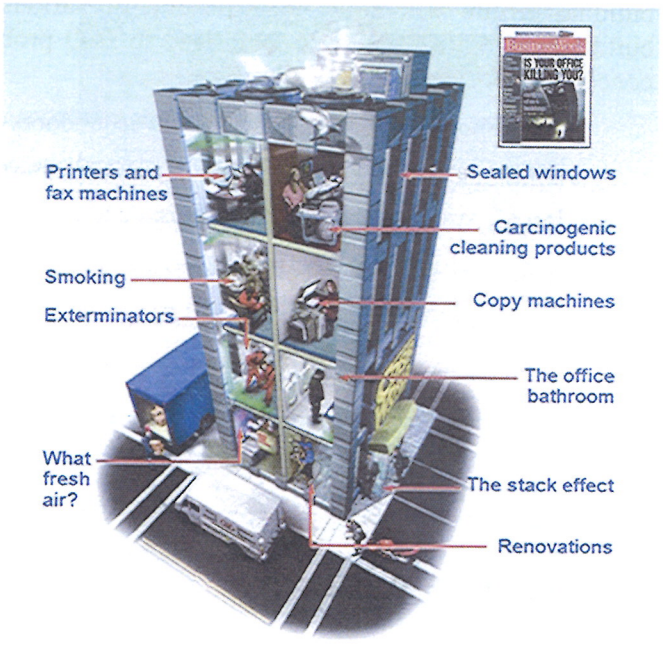


Figure 8

Multiple Chemical Sensitivity
(Photos Courtesy of BusinessWeek Magazine.)

Symptoms vary from case to case, with common symptoms being respiratory constriction, swelling of certain glands (which vary from case to case), or rashes and skin eruptions. Additional symptoms can be headaches, fevers, chills, nausea, fatigue, dizziness, "brain fog," depression, anxiety, and even vision and hearing problems. In addition, other factors seem to predispose individuals to increased sensitivity to chemicals such as low thyroid levels, nutritional deficiencies, and other stressors. There are now over 70,000 chemicals commercially produced and the number is increasing every day. As an average, we are exposed to more than 500 chemicals and toxic substances every day. People with MCS are like an early warning system when chemicals are present in the building. See Figure 8.

Multiple Chemical Sensitivity

Control of MCS begins at the source by choosing materials that do not pollute. The HVAC system can contribute positively by utilizing VOC filters that reduce the loading in the areas served.

Control of MCS begins at the source by choosing materials that do not pollute. The HVAC system can contribute positively by utilizing VOC (volatile organic compounds) filters that reduce the loading in the occupied spaces of the areas served. The cost of VOC filters is currently high, but buildings with susceptible occupants, like healthcare and pre-schools, and urban settings with polluted outdoor air, should seriously consider adding VOC filters to the HVAC system.

Building and HVAC System Operations

Controlling the quality of the air we breathe depends not only on the building and its materials, but also on how its various systems are maintained and operated. Developing a building profile will allow identification of various areas where inappropriate operation of building and HVAC systems could lead to IAQ problems. Listed below are common areas of concern in developing the profile:

- Building envelope – the barrier between indoors and outdoors
- Outdoor pollutants – both general and local sources
- HVAC system – transport mechanism and sources
- Human activities – bioeffluents create odors
- Housekeeping – cleaning supplies and procedures are key
- Pest control – chemicals used can become sources
- Existing complaints, practices and related activities – historical trends can point to the problem
- Gathering of appropriate standards – indicate proper O&M
- Baseline data collection – accurate records of current conditions allow assessing the situation

Strategic IAQ Planning

For any building manager, the issues surrounding IAQ may appear at first to be difficult to solve. The old adage that you cannot please all the people all the time rings true. Yet IAQ should not become a quest to please a wide range of individual desires. Practicing environmental stewardship is necessary, and IAQ is just one prong in an overall strategy.

A proactive approach to managing air quality begins with the development of a strategic IAQ management plan. Like any strategic planning, IAQ planning can be divided into three basic steps: analyze, organize and plan, and execute. A detailed flow chart of Carrier's Strategic IAQ Management Plan is included in Appendix A.

Contaminants and Their Sources

A contaminant is anything in the air, regardless of the source, that is harmful or objectionable to the building occupants. A contaminant can also disrupt an industrial process within the building or damage the building or its contents. In IAQ terms, a contaminant is anything that pollutes the air within the occupied zone (up to 6 or 7 ft above the floor) of a building. Contaminants can be either physical particles that are suspended in the air or gaseous substances. Figure 9 shows the approximate size and other physical properties of the contaminants that may have to be removed from the air.

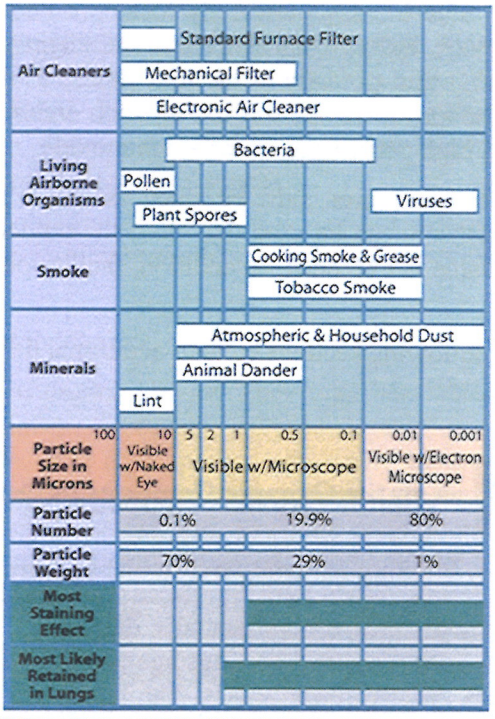


Figure 9

Contaminants, Sources, and Characteristics

Types of Contaminants

Indoor contaminants can come from both inside and outside the building. The national primary outdoor contaminants as measured and reported by the Environmental Protection agency as part of the National Primary Ambient-Air Quality Standard (NAAQS) are shown in Figure 10. Whenever these outdoor contaminant levels exceed the minimum values, bringing in untreated outdoor air can negatively affect the indoor air quality. Based on outdoor air quality, monitoring outdoor air may be necessary for some buildings.

TABLE 4-1
National Primary Ambient Air Quality Standards for Outdoor Air as Set by the U.S. Environmental Protection Agency

	Long Term			Short Term		
	Concentration Averaging			Concentration Averaging		
Contaminant	µg/m³	ppm		µg/m³	ppm	
Sulfur dioxide	80	0.03	1 year	365	0.14	24 hours
Particles (PM 10)	50	—	1 year	150	—	24 hours
Carbon Monoxide				40,000	35	1 hour
Carbon Monoxide				10,000	9	8 hours
Oxidants (ozone)				235	0.12	1 hour
Nitrogen dioxide	100	0.055	1 year			
Lead	1.5	—	3 months			

Source: ASHRAE Standard 62.1-2004



Figure 10

National Ambient Air Quality Standards
(Reproduced with permission from ASHRAE)

Busy roads near a building represent a typical outdoor air quality problem. The particulate load from roadways can be a significant source of irritation. Common local sources of outdoor air pollution also include incorrectly located outdoor air intakes, such as an intake located near a loading dock. Exhaust fumes from diesel engines include emissions of particulates and a number of irritating and potentially harmful gases. Controls using carbon monoxide sensors that shut down outdoor air dampers based on such emissions are not effective, since diesel fumes do not contain a high percentage of carbon monoxide.

Control measures must be taken to ensure that the indoor air quality is not compromised. Special sensors can be used that close the outdoor air dampers when the upper limit outdoor air quality value is exceeded. In addition, facility personnel need to be alerted with a control system alarm.

The following sections contain additional detail on some of the most common contaminants.



Volatile Organic Compounds (VOC)

Many building materials and furnishings are made with synthetic materials. When they are placed in the building, there can be substantial release of potentially detrimental chemicals. As materials, adhesives, and coatings age through the initial service cycle, they release fewer VOCs. The length of VOC release is dependant on many factors, including temperature and humidity. The rate of release affects the pollutant level within the building.

VOC Issues

Older buildings may have few remaining VOC issues, but need to be evaluated for such contaminants as lead or asbestos.



Suspended Particulates (TSP and RSP)

Total suspended particulates (TSP) refer to all solid and liquid particles suspended in the air. Depending on their size and other properties, they may remain suspended in the air for a few seconds or indefinitely. Primarily, TSP is important from a nuisance perspective. Suspended particles come from a variety of natural and human sources. Sources include vehicle exhaust emissions, industrial emission sources, soil, road dust, dust resulting from other human activities (i.e., agriculture), forest fires, smoke from tobacco, and smoke from recreational sources (i.e., campfires and fireplaces).

Respirable suspended particulates (RSP) refer to that portion of the total suspended particulate matter that can be inhaled and reach the deep recesses of the lung. Particulate matter of less than 10 micrometers or 10 μm in diameter (PM10) has been the common measure of respirable particulates in both outdoor and indoor air quality evaluations.

Respirable Particulates

With increased knowledge of the damage caused by inhaled and ingested particulates in the human body, the new standard of concern is now 2.5 microns, or PM 2.5.

Gases

Gases may be organic or inorganic. They have many sources, including combustion and respiration, as well as evaporation of cleaning agents and toner from office equipment. Many gases, such as formaldehyde, are irritants. Others, such as carbon monoxide, which is a product of incomplete combustion, are asphyxiants. Still others, such as radon, are carcinogens. Water treatment should not be used in steam generators that are connected to injection humidifiers or else the chemicals may vaporize and carry over into the occupied spaces.

Bioaerosols

Bioaerosols are small airborne particulates of organic nature. They may be viable or non-viable. Viable means they are living microorganisms or can be cultured. Examples of viable bioaerosols are bacteria, viruses, molds, mildews, and their spores. Non-viable bioaerosols include dead organisms like pollen and parts of insects and vermin. Also included are their dander, excrements, and respiratory gases, which are often allergenic, and may even be toxic or carcinogenic.

Mycotoxins are expelled as a defensive mechanism by certain species of molds, and are extremely dangerous in large doses. Seldom are the quantities a concern from normal limited contact of small colonies of mold.

Moisture incursion and material water damage makes it likely that the building envelope has become a home to both invisible (mold and mildew behind walls) and visible (cockroaches and mice) contaminants.

Poor design and maintenance contribute to bioaerosol problems in the HVAC system. For example, poorly fitting air filters (gaps around the media frames) can result in particulates bypassing the filter media. This creates dirty cooling coils and dirty wet drain pans, which are significant potential sources of bioaerosols. Dirty coils and poorly draining pans offer a source of food and moisture for the growth of bacteria and fungus. Their location in the airstream makes them effective distributors of viable organisms and spores. See Figure 11.

Fiberglass

Insulation and duct lining in the ventilation can contribute to IAQ problems. Damaged lining may introduce particulates, and dirty lining exposed to damp air can become a source of microorganism growth, making cleaning and repair difficult.



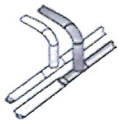
Figure 11

Dirty Coils Cause Bioaerosols



Radon

Radon is radioactive gas associated with specific geological formations. Radon gas leaks into buildings from soil gases and can also be found in water. As an airborne contaminant, it is a potential carcinogen. The United States EPA (Environmental Protection Agency) regulates radon at 4 picocuries (one trillionth of a curie) per liter. The best control method is depressurization of subfoundation soils to capture the gas and exhaust it into the air above the building where the gas is sufficiently diluted.



Asbestos

Asbestos is a natural mineral that separates into threadlike fibers. Some varieties of asbestos can cause respiratory ailments and cancer. It is highly regulated by EPA and OSHA (Occupational Safety and Health Act). The EPA recommends encapsulation of non-***friable*** asbestos and removal of damaged asbestos materials. Asbestos has been removed from buildings for the last few decades, but asbestos may still be present in much older buildings that have not had major renovations or a change in occupancy or ownership. The most common locations are as pipe coverings, particularly the fitting joint compound, and central equipment insulation for air handling, heating and cooling equipment.



Lead

Lead in older buildings is especially problematic where the paint is peeling, or the paint has been sanded or abraded during remodeling. Presence of lead in respirable areas can cause serious health problems resulting in neurological damage. The EPA and OSHA both regulate lead exposure levels.



Ozone

Ozone (O_3) is found outdoors in nature (such as after lightning strikes), and is created in stagnant urban meteorological settings with excessive vehicle exhausts and adequate sunshine. Ozone is also a byproduct of copiers and laser printers and can be dangerous when inhaled in higher concentrations. The EPA is monitoring ozone at the ground level and issues warnings when the concentration reaches an unacceptable level.

Ozone Levels

Copy centers should have dedicated exhaust to avoid build-up of ozone and other contaminants.



Environmental Tobacco Smoke (ETS)

Environmental tobacco smoke is one of the most controversial indoor air contaminants. It is a class A carcinogen and a recognized contributor to childhood respiratory illnesses. For this reason, ASHRAE no longer publishes recommendations on how to design buildings where ETS is present, simply stating that smoking areas must have more ventilation and/or cleaning than comparable no-smoking areas. Specific ventilation rate requirements cannot be determined until authorities determine the concentration of smoke that achieves an acceptable level of risk.

Acceptable Concentration Levels

There is no document that specifies acceptable levels of contaminants within the indoor environment. Permissible exposure limits (PELS) are established by OSHA to protect workers in industrial and similar work environments from exposure to workplace hazards. The PELS are typically specified for an 8-hour time-weighted average. Industrial hygienists generally work with threshold limit values (TLVs). Threshold limit values are guidelines (not standards) prepared by the American Conference of Governmental Industrial Hygienists, Inc. (ACGIH) to assist industrial hygienists in making decisions regarding safe levels of exposure to various hazards found in the workplace. A TLV reflects the level of exposure that the typical worker can experience without an unreasonable risk of disease or injury.

There are many sources for acceptable concentrations of various indoor air constituents. The American Industrial Hygiene Association (AIHA), the ACGIH, the International Agency for Research on Cancer (IARC), and the World Health Organization (WHO) all offer recommended concentration limits.

Acceptable Concentration Levels

Extreme care should be taken to understand the background behind each of the recommended values before they are used to evaluate the indoor air quality of a building.

IAQ Control Strategy

As we have just read, there are problems with indoor air quality in many of our buildings and homes. There are also solutions, as shown in the industrial hygienist's triangle of best practices.

1. Source Control is the foundation of the triangle, keeping contaminants from entering the room air.
2. Filtration reduces source levels of particulates, bioaerosols, and gases.
3. Dilution lessens the remaining levels with the introduction of uncontaminated air.

Efforts should be made in the order shown, always stressing source control to minimize the amounts of contaminants polluting the indoor air. See Figure 12.



Figure 12

IAQ Control Strategy

Source Control

Control the Generation of Pollutants

The first and most important step in any IAQ strategy is to minimize the generation of contaminants within the space by controlling the materials and processes within the building. Many synthetic building materials and furnishings emit VOCs and particulates into the air, which can be inhaled and result in damage to the respiratory system and or otherwise affect our health.

Some of these materials also absorb chemicals emitted by other sources, and then later emit them under different conditions. An example would be the paints and varnishes that are used during construction. Paints and varnishes release chemicals during curing and drying that are picked up by ceiling tiles and porous furnishing fabrics, which then emit them long after the construction period is complete. Therefore, it is becoming common practice to use low-polluting building products such as finishes, furnishings, wall coverings, carpets, and ceiling tiles. Many manufacturers and industry associations have started labeling such low-emitting products. See Figure 13.



Figure 13

Control the Generation of Pollutants

Local Exhausts

Sometimes it is not possible to control the generation of pollutants in a building. An office copy center with reproduction and fax machines will generate pollutants. In such cases, direct or indirect local exhaust can be utilized to take the pollutants out of the building before they contaminate the rest of the indoor air. This works best when a pollutant is generated by a process that is contained in a small area. Minimizing the spread of local contaminants into the general building area greatly reduces the potential of needing to treat the entire building.

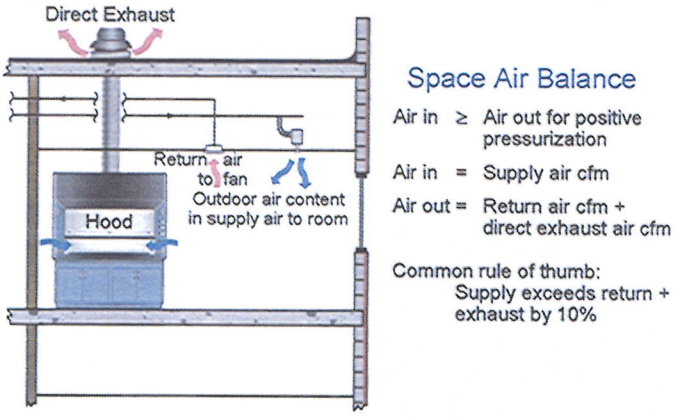


Figure 14

Local Exhaust

Buildings housing various processes such as labs, kitchens, and workshops, where large amount of chemical and particulate pollutants are released, can usually be provided with separate HVAC systems. These systems use hoods and exhaust systems dedicated to removing the pollutants, as shown Figure 14. This greatly improves capture of the contaminants and reduces any recirculation to office and assembly spaces remote from the process itself. Special care needs to be taken to make sure that the exhaust airflow is discharged out the building at a high velocity, usually at least 1500 fpm, and at a location/direction where the exhaust will not be brought back into the building (re-entrainment) through openings or the building ventilation system's outdoor air intakes.

Water and Moisture Control

Water and moisture are major pollutant drivers in our buildings. Moisture in the presence of dirt and darkness is an ideal condition for the growth of mold and mildew. Therefore, moisture control is a major strategy to maintain good IAQ in a building. It is the keystone of the three Ds - damp, dark, and dirt as shown in Figure 15. Without moisture, organism cannot grow. Generally, standing water or excess moisture in the air should not be allowed in buildings.

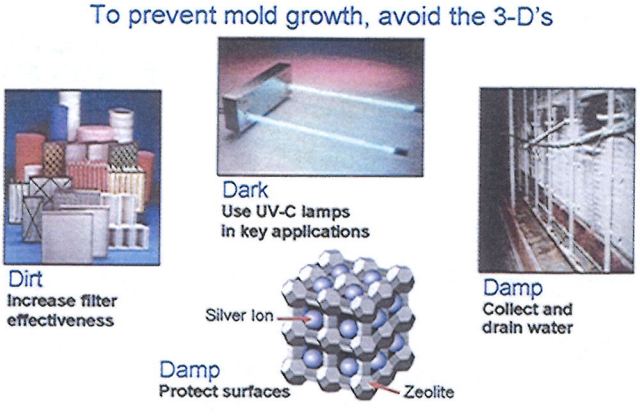


Figure 15

Water and Moisture Control

Example 1

An air-handling unit is equipped with a poorly fitting filter rack and is improperly trapped. Even though the drain pan pitches toward the drain connection there is always water remaining in the pan when the fan is running. There is now moisture and a food source, so growth of biological organisms (biofilm) is likely on both the drain pan and the wetted surfaces of the cooling coil. Not only do we have an IAQ problem, but the increased static pressure on the fan raises energy costs. The degraded heat transfer on the fouled fin and tube surfaces raises the condensing temperature in the refrigeration circuit, costing even more money.

Moisture Control

Humidity levels should be controlled to below 60 percent relative humidity whenever possible.

Mold and Mildew

A building with high internal relative humidity for long periods of time is likely to have microbial contamination.

Many HVAC systems vary greatly in their moisture removal capacity. This capacity is limited when the room sensible cooling load is less than "design load" conditions and the system is operated by a dry bulb thermostat without any space relative humidity control. This problem is multiplied several fold when "safety factors" are used to oversize the equipment. Recognizing that HVAC systems seldom operate at these peak design loads, it is prudent to evaluate the humidity control performance of the proposed system at partial loads.

Example 2

An office area HVAC system is designed with enough capacity to handle large loads, which occur during the normal daytime periods. The system must also operate during nights and weekends to serve greatly reduced occupancy and structural heat gains. Figure 16 shows that an indoor relative humidity of over 70 percent will probably occur if the system uses a constant volume air-handling unit with a modulating chilled water valve controlled by a dry bulb thermostat.

TYPICAL CONSTANT VOLUME SYSTEM
DRAW-THRU AIR HANDLING UNIT WITH MODULATING CHILLED WATER COIL VALVE

Load Condition	Design Load, Sunny Day	Part-Load, Night
Occupancy	100%	20%
Outdoor Air Condition	95 db, 76 wb	80 db, 71 wb
Room Sensible Heat Room Latent Heat Safety Factor Outdoor Air Sensible Heat Fan Heat Gain Outdoor Air Latent Heat	270,000 25,000 27,000 43,200 90,000 57,100	100,000 5,000 0 10,800 90,000 9,200
Supply Air cfm Cooling Coil Dewpoint	15,000 53.5° F	15,000 65.5° F
Room Conditions	*75 db 48% rh*	*75 db 71% rh*

Figure 16

Humidity Buildup at Part Load

The two columns show that as the chilled water valve modulates toward its closed position, the coil latent capacity is reduced much more rapidly than its sensible capacity. Even though the latent cooling load from both the space and outdoor air are greatly reduced, the space relative humidity is quite high. This happens because reduced water flow raises the cooling coil dew point temperature, reducing the latent capacity. Better humidity control can be achieved by changing the system and control

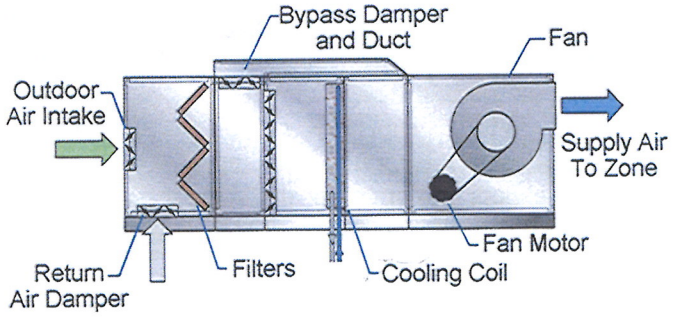


Figure 17

Face and Bypass Control

method so that the room thermostat modulates airflow through or around the chilled water coil, using a face and bypass damper instead of modulating the chilled water flow through the coil (Figure 17).

Other alternatives with better part-load humidity performance include variable air volume control and reheat control. Consult TDP-702, Comfort Control Principles for additional discussion on these alternatives. Reheat controls are banned by some building energy codes because of increased energy usage from the simultaneous heating and cooling. However, condenser reheat coils and various heat reclaim applications often permit reheat without serious energy compromise. ***Sorbent*** (adsorbent or absorbent) dehumidification by the use of ***desiccant*** (a chemical agent that removes moisture) wheels or other devices is a chemical alternative for humidity removal.

Stopping Microbial Growth

When surfaces will remain wet for long periods of time, consider using permanent antimicrobial-coated materials and illuminating surfaces with ultraviolet radiation for its germicidal effect.

Filtration

In further developing an IAQ strategy, the HVAC designer must make appropriate use of filtration systems. Filtration systems can be used to remove both particulates as well as gaseous or chemical compounds. Although technologies and engineering standards are readily available for the selection of particulate filters, the science for gaseous filtration is still evolving and as such, extreme caution should be used when applying such products. Gas-phase filters include carbon-based or catalytic types.

Keep the System Clean

Air filtration is always required to keep the HVAC system equipment, components, and ductwork clean, and may be needed to reduce the indoor levels of particulate and gaseous pollutants.

Methods of Filtration

There are five physical mechanisms by which particulates are mechanically filtered through a filter media or collector mechanism.

- Straining occurs when a particle is larger than the opening between fibers and cannot pass through.
- Impingement means that as air flows through a filter, it repeatedly changes direction as it passes around each fiber. Larger particles cannot follow the abrupt changes in directions because of their inertia, so they collide with the fibers. This type of filter often coats the fiber with an adhesive to help retain the particles.

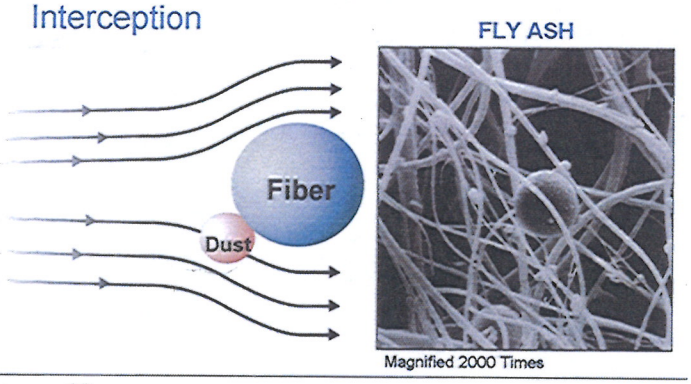


Figure 18

Mechanical Filtration - Interception

- Interception is a special case of impingement that works with smaller particles that follow the airstream and collide with the fibers. Adhesive coating is not required with the smaller particles because the molecular ***van der Waals forces*** are sufficient to hold them in place. See Figure 18.
- Diffusion takes place on particles so small that their direction and velocity are influenced by molecular collisions (called Brownian movement). They do not follow the airstream, behaving more like a gas than particulate. When a particle actually strikes a fiber, it is held there by the van der Waals forces.
- Precipitation means that particles carrying opposite electrical charges are attracted to one another. An ionizer imparts a positive charge to particles passing by it, and then as they pass through a collector of alternately charged plates, they are attracted and held to the negative plates where they agglomerate (build up into larger particle clumps).

Air filtration is always required to keep the HVAC equipment, components, and ductwork clean, and may be needed to reduce the indoor levels of particulate and gaseous pollutants. In addition, filters should be located upstream of moisture sources such as cooling coils or humidifiers to reduce potential for growth of microorganisms.

As mentioned previously, the growth of microorganisms is promoted by dirt, moisture, and a warm, dark environment where the particulates act as nutrients. Therefore, by taking away the particulates with better filtration, we limit the growth of microorganisms by both the lack of food and water. In addition, good filtration reduces building cleaning and redecorating costs. High efficiency particulate air (HEPA) filters can reduce the spread of communicable diseases caused by bacteria and viruses.

Rating of Particulate Filters

Two filter rating methods are commonly used in the HVAC industry.

- *ASHRAE Standard 52.1-1992 Gravimetric and Dust Spot Procedures for Testing Air Cleaning Devices Used in General Ventilation for Removing Particulate Matter*
- *ASHRAE 52.2-1999 Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size*

Standard 52.1 was primarily developed to protect HVAC equipment and reduce soiling of the furnishings. Standard ASHRAE 52.2 was developed to address the health concerns caused by inhaling fine particulates (RSP), and secondarily for the protection of HVAC equipment and reduce soiling of furnishings. Standard 52.2 classifies particulate filters by filtration efficiencies called Minimum Efficiency Reporting Value (MERV). There are 20 categories for rating these filters (Figure 19 or the full ASHRAE Table E-1 in Appendix B).

MERV	Particle Size	Typical Pollutants	Applications	Filter Types
1	>10 µm	Pollen, Dust mites, Sanding dust	Residential, Light commercial	Construction, Throwaway
2				
3				
4				
5	3-10 µm	Dust, Molds, Spores	Commercial, Manufacturing	Pleated, Panel Filters
6				
7				
8				
9	1-3 µm	Legionella, Auto Fumes, Welding Dust	Commercial, Industrial	Bag, Cartridge, Mini-pleat
10				
11				
12				
13	0.1-0.3 µm	Tobacco smoke, Copier toner, Bacteria	Commercial, Medical, Industrial	Bag, Cartridge
14				
15				
16				
17	<0.3 µm	Sea salt, carbon dust, chem-bio, viruses	Clean rooms, Surgery, Isolation	HEPA
18				
19				
20				ULPA

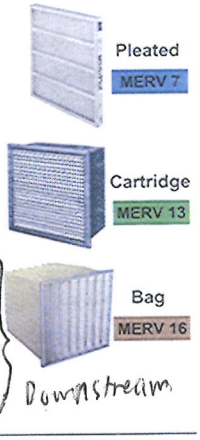


Figure 19

MERV Efficiency Ratings

Particulate filters rated MERV 8 or higher are recommended for improved removal of respirable particulate (less than 10 µm or micrometers). Figure 20 shows the distribution of the many particles (nearly 2.5 billion) in one cubic foot of standard office air. Further information on filters can be found in TDP-644, Filtration.

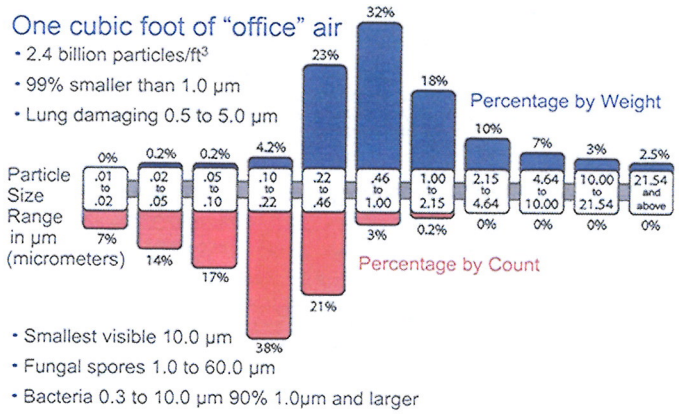


Figure 20

Particle Size Distribution

Selection of Filter Efficiency

There are various types of filters such as roll, high velocity, low velocity, rigid cartridge (pleated), and bag. Higher efficiency media types have greater pressure drops, and the pressure drop increases substantially as the media becomes dirtier. The pressure drop is also related to the area of the media exposed to the airflow. Increasing the airway depth of the filter by pleating the media or arranging the media as a bag extension downstream provides a larger media surface in a much smaller cross-sectional area filter. The useful life of the filter is limited by the maximum pressure drop that can be tolerated by both the filter and the air system fan. The dirt holding capacity identifies how much dirt can be captured before the pressure drop reaches the maximum value. A filter with a larger media area usually has greater dirt holding capacity and therefore a longer life. See Figure 21.

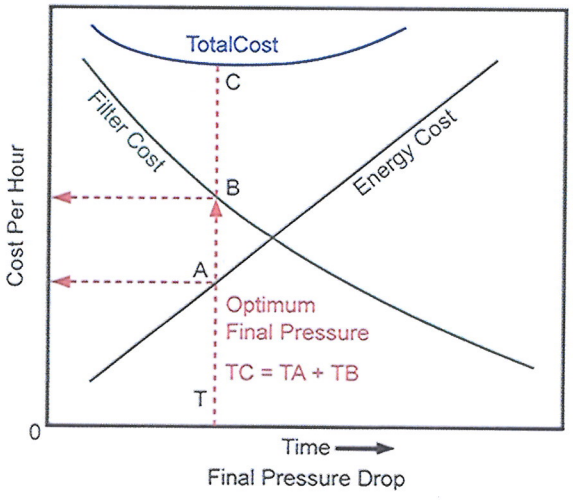


Figure 21

Selection of Filter Efficiency

The selection of a media-type filter consists of first choosing the type of media that will capture the desired particle size effectively at an acceptable air static pressure loss. Then the area should be optimized to fit within the available space and provide a reasonable balance of initial cost, useful life and fan energy consumption.

Changing Filters

Filters need to be changed regularly in order to get the maximum benefit without sacrificing energy. Use periodic maintenance based on pre-determined timing, pressure drop measurements, or visual observation.

Dilution

Dilution of general indoor air contaminants (making them less concentrated) is achieved by supplying the indoor space with uncontaminated outdoor air. Adequate outdoor air ventilation must be provided as mandated by local building and energy codes and their referenced standards. Most mechanical codes reference *ASHRAE Standard 62.1-2004 Ventilation for Acceptable Indoor Air Quality*, which specifies among other things, the minimum ventilation requirements for various types of occupancies (a portion of the key table is shown in Figure 22).

TABLE 6-1 MINIMUM VENTILATION RATES IN BREATHING ZONE
(This table is not valid in isolation; it must be used in conjunction with the accompanying notes.)

Occupancy Category	People Outdoor Air Rate R_p		Area Outdoor Air Rate R_a		Notes	Default Values			Air Class
						Occupant Density (see Note 4)	Combined Outdoor Air Rate (see Note 5)		
	cfm/person	L/s • person	cfm/ft²	L/s • m²		#1000 ft² Or #100 m²	cfm/person	L/s • person	
Correctional Facilities									
Cell	5	2.5	0.12	0.6		25	10	4.9	2
Day room	5	2.5	0.06	0.3		30	7	3.5	1
Guard stations	5	[illegible]	0.06	0.3		15	9	[illegible]	[illegible]

Figure 22

Dilution Using Outdoor Air Ventilation
(Reproduced with permission from ASHRAE)

Other necessary ventilation system criteria are:

- The ventilation air must not be contaminated.
- The ventilation air must be delivered throughout the occupied space.
- The ventilation system should not promote contaminant accumulation.
- The HVAC system performing the ventilation should be designed for ease of periodic inspection and maintenance.
- Ventilation systems should be designed for all operating conditions and loads. VAV systems specifically should be designed to maintain minimum ventilation rates to all occupied zones under all conditions.
- The ability of control systems to deliver minimum ventilation rates to each zone should be verified with testing during the commissioning of building systems.

Outdoor Air Contaminants

Outdoor air may be contaminated by pollen, dust, fungal spores, industrial pollutants, vehicle exhaust (from nearby roads, parking lots, garages, and loading docks), dumpster odors, re-entrained building exhausts, or unsanitary debris near outdoor air intakes as shown in Figure 23. The location of outdoor air intakes is important. The designer must consider such potential contaminant sources and the airflow patterns on the exterior of the building. Outdoor air must also meet minimum air quality standards such as the National Ambient Air Quality Standards established by the U.S. Environmental Protection Agency.

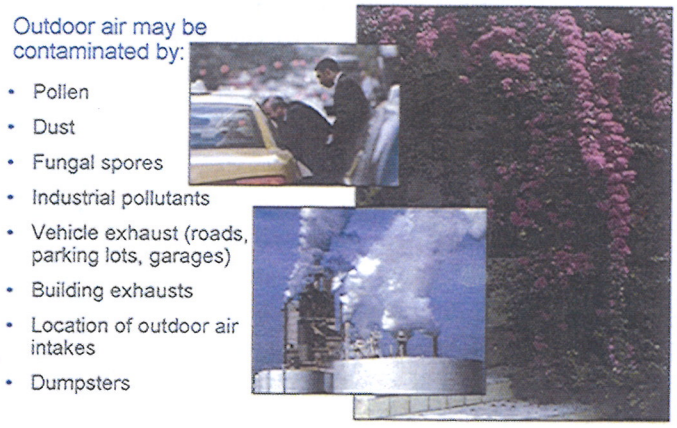


Figure 23

Contamination of Outdoor Air

Outdoor Air Quality

Additional filtration or air cleaning is necessary if the outdoor air quality is not acceptable for ventilation.

Air Distribution Effectiveness

Distribution of the ventilation air to the occupied space is affected by many design factors, including supply air temperature, duct pressure, and diffuser type and location. See Figure 24 and Appendix N. It is important that the ventilation air reach all occupied areas of the space. Most room air distribution systems, which thoroughly mix the supply air with the room air, provide an adequate quantity of outdoor ventilation air to each space. Displacement systems like underfloor air distribution, which minimize the mixing of supply air to within the occupied space, offer the highest rate of air contaminant dilution and removal from the space.

More detailed discussions on air distribution effectiveness and ventilation efficiency as aspects of HVAC system design are presented in TDP-507, Room Air Distribution.

TABLE 6-2
Zone Air Distribution Effectiveness

Air Distribution Configuration	E_z
Ceiling supply of cool air	1.0
Ceiling supply of warm air and floor return	1.0
Ceiling supply of warm air 15°F (8°C) or more above space temperature and ceiling return	0.8
Ceiling supply of warm air less than 15°F (8°C) above space temperature [illegible] ceiling return provide[illegible] that the	1.0

Source: ASHRAE Standard 62.1-2004

Figure 24

Zone Air Distribution Effectiveness
(Reproduced with permission from ASHRAE)

Minimizing the Energy Penalty

Interior locations with higher emission rates of particulates, chemicals, or moisture should use separate ventilation or exhaust systems. Demand for increased amounts of outdoor air means that energy saving equipment and control systems are becoming more popular. The use of heat or energy recovery ventilators (HRV or ERV) provides a means for achieving good IAQ while minimizing the energy penalty. Figure 25 shows areas where ERV and HRV use is recommended. These ventilators recapture some of the exhaust heat, and reheat or pre-cool the ventilation air as required. System controls for zoning or inter-zone pressure control may be needed in special situations to control migration of pollutants from one area to another (i.e., smoking areas).

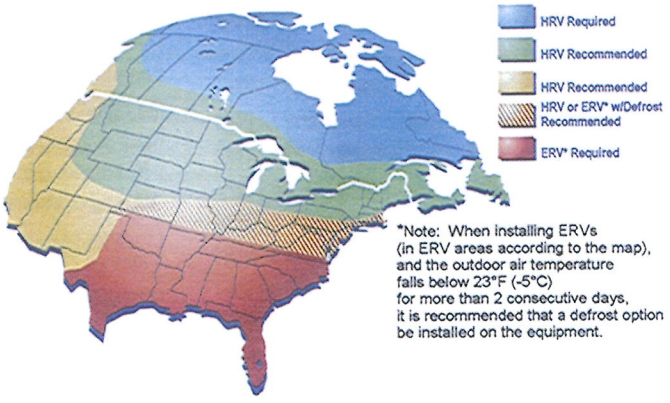


Figure 25

Suggested HRV and ERV Usage for Canada and the U.S.
(Reproduced with permission of Fantech, Inc.)

CO_2 and Ventilation

Demand controlled ventilation (DCV), which controls the ventilation rates based on a signal from an "occupancy" sensor (most commonly CO_2) is seeing increased usage. As shown in Figure 26, DCV links the ventilation rate to the occupancy rate, also minimizing the energy penalty while meeting the IAQ needs of each zone. According to ASHRAE Standard 62.1-2004, "Comfort (odor) criteria with respect to human bioeffluents are likely to be satisfied if the ventilation results in indoor CO_2 concentrations less than 700 ppm above the outdoor air concentration."

Demand Controlled Ventilation

Controlling the ventilation rate based on occupancy can be done by determining the CO_2 concentration within the zone. People exhale predictable quantities of CO_2 in proportion to their degree of physical activity.

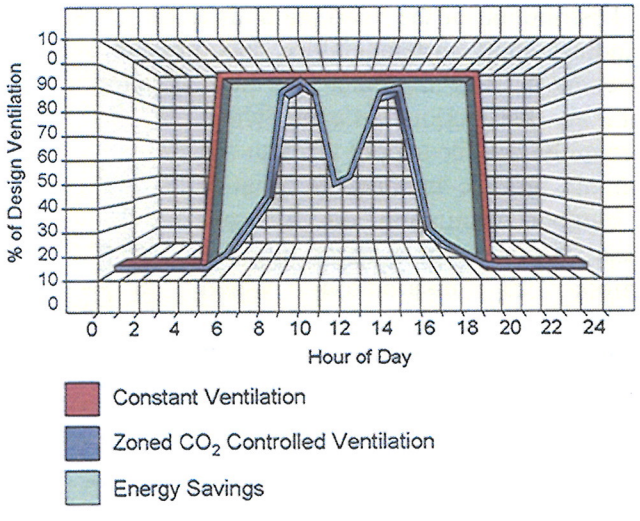


Figure 26

Demand Controlled Ventilation Solution

As part of the normal physiological process called respiration, human beings inhale oxygen from the air and exhale carbon dioxide (CO_2). The rate at which this takes place depends upon the degree of physical activity. The greater the activity level, the greater the production of CO_2. See Figure 27. There are also other limited sources of CO_2 in a building such as unvented combustion devices in kitchenettes and some lab equipment. Unvented combustion devices are generally not found outside of storage buildings. In fact, highly elevated levels of CO_2 (i.e., 3000 to 5000 ppm) can indicate the presence of potentially dangerous combustion fumes. Because CO_2 production is consistent and predictable, it can be used as a good indicator of general occupancy. For example, if the number of people in the space is doubled, the amount of CO_2 produced by the occupants' respiration will double. If one or two people leave a space, the CO_2 production will decrease correspondingly. Indoor CO_2 measurement is a dynamic measure of the relative number of people in a space and the amount of outdoor air that is being introduced. The result is that it is possible to determine the cfm per person ventilation rates in a space by measuring the CO_2 differential.

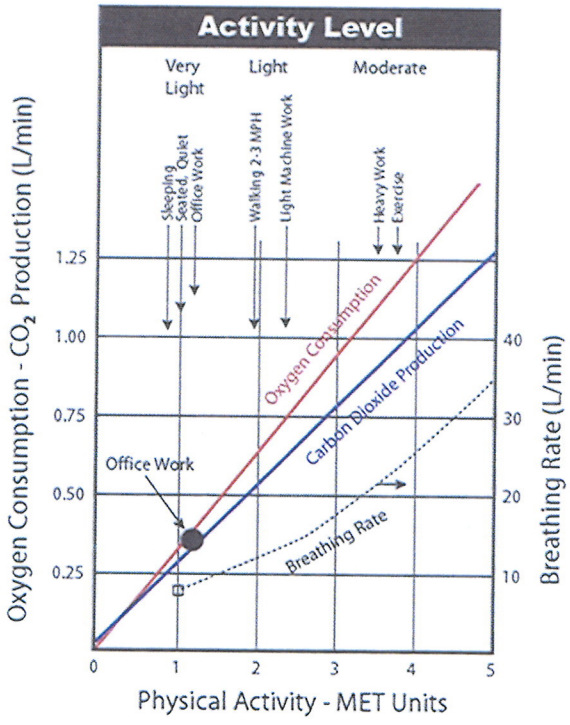


Figure 27

CO_2 Production and Activity Level
(Awaiting permission from ASHRAE)

Figure 28 shows the typical pattern of build-up of CO_2 in a space with activity levels typically found in an office (1.2 ***MET***). The chart assumes a steady state condition where a constant occupancy is present and the ventilation rate is constant. Once people enter a room, CO_2 concentrations will begin to increase. These levels will continue to increase until the amount of CO_2 produced by the occupants and the dilution air delivered to the space are in balance. This is called the equilibrium point.

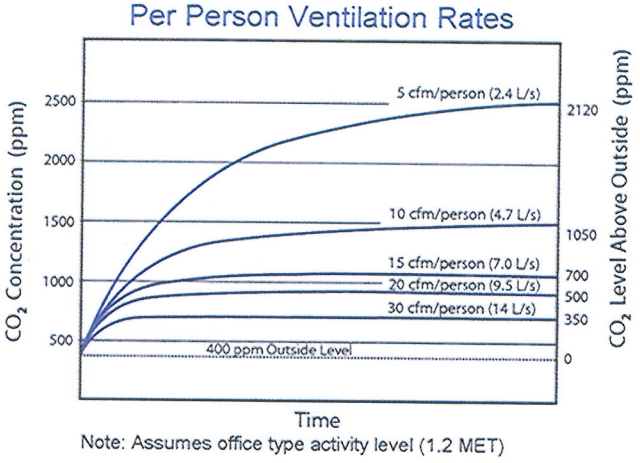


Figure 28

CO_2 Equilibrium Levels

Figure 29 shows how sensors may be located to provide zone level IAQ.

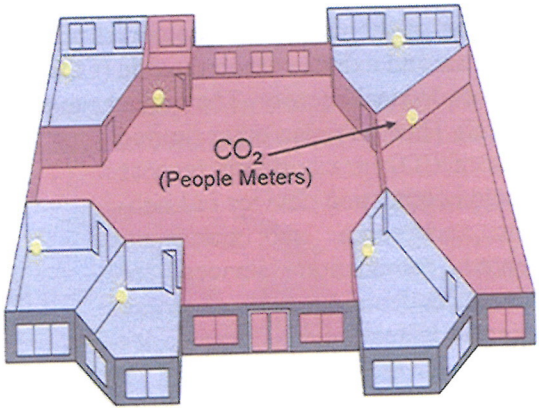


Figure 29

DCV Zone Level IAQ

Guidelines for Determining Acceptable IAQ in Existing Buildings

Often, HVAC system equipment and controls go out of calibration, or are not maintained at their peak performance. Sometimes floor plan remodeling occurs without requisite changes to the HVAC system layout and/or capacity. The result is that comfort parameters, including IAQ, suffer, causing discomfort and potentially contributing to health issues.

Located in Appendixes C-G are five tables that provide guidelines and an evaluation process for the primary comfort parameters of temperature, humidity, filtration, ventilation, and microbial growth. An example is shown in Figure 30. The tables are set up to guide the reviewer in a walk-through and evaluation of the existing HVAC systems and the spaces in the building they serve. Once key problems are identified, changes can be made to bring basic comfort and IAQ back in line with the original design, as well as point out areas of improvement.

Ventilation Guidelines and Evaluation Process

Step	Criteria / Norm	Results / Action
1. Determine design for supply/exhaust air cfm, outlet placements.	Use design, as-built, and remodeling drawings.	Field verify data and update drawings; keep current.
2. Review space use, process requirements for ventilation.	Interview users, consult standards of good practice.	Modify as-built drawings with new requirements; implement changes to ventilation system.
3. Field evaluate exhaust system: outlet placement, source capture devices.	Current system drawings, ACGIH Industrial Ventilation.	Record shortfalls, review standards of practice for design

Figure 30

IAQ Guidelines for Existing Buildings

ASHRAE Standard 62.1-2004, Ventilation for Acceptable Indoor Air Quality

Standard 62.1 has become the HVAC standard of design for IAQ. This standard has been given a "continuous maintenance" status by ASHRAE, meaning it can be updated yearly with addenda incorporating the latest practical and scientific knowledge that is available. The standard is also re-published periodically, most recently in late 2004. When an addendum to the standard has been approved, it can be downloaded free of charge from www.ashrae.org.

The standard is divided into following 9 sections:

1. Purpose
2. Scope
3. Definitions
4. Outdoor Air Quality
5. Systems and Equipment
6. Procedures
7. Construction and System Start-Up
8. Operations and Maintenance
9. References

There are also 8 appendices:

A. Multiple-Zone Systems
B. Summary of Selected Air Quality Guidelines
C. Rationale for Minimum Physiological Requirements for Respiration Air based on CO_2 Concentration
D. Acceptable Mass Balance Equations for Use with Indoor Air Quality Procedure
E. Ventilation Rates for Health Care Facilities, Residential Buildings, and Vehicles
F. Separation of Exhaust Outlets and Outdoor Air Intakes
G. Application and Compliance
H. Addenda Description Information

On pages 25 and 26 is a brief presentation of selected paragraphs from the purpose and scope sections of Standard 62.1. Additional application-oriented material on Standard 62.1 will be presented in certain IAQ Design Sequence Steps that follow.

Section 1. Purpose

The purpose of this standard is to specify minimum ventilation rates and indoor air quality that will be acceptable to human occupants. It is intended to minimize the potential for adverse health effects.

Remember that these are minimum rates and many situations will require additional amounts of source control, filtration, and dilution using outdoor air to control the indoor contaminant levels. As shown in Figure 31, there has been a long history of just what is the correct amount of outdoor air to ventilate buildings for acceptable indoor air quality. It remains the designer's responsibility to assess the needs and apply good science and engineering principles to the project HVAC design.

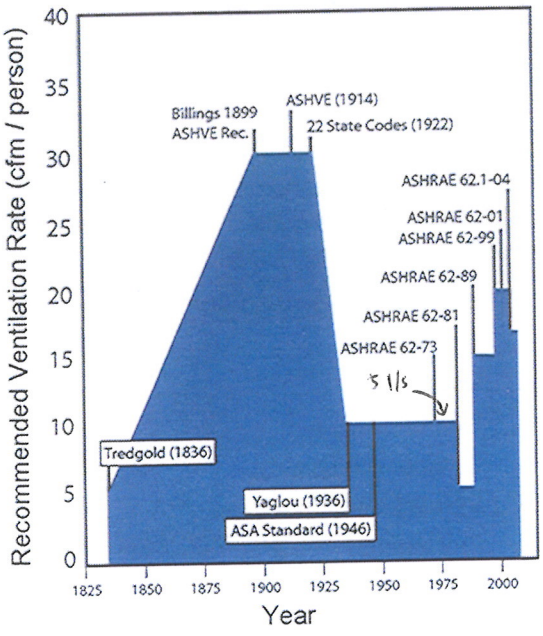


Figure 31

Evolution of Minimum Ventilation Rates

Section 2. Scope

2.1 This standard applies to all indoor or enclosed spaces that people may occupy, except where other applicable standards and requirements dictate larger amounts of ventilation than this standard. Release of moisture in residential kitchens and bathrooms, locker rooms, and swimming pools is included in the scope of this standard.

2.4 This standard considers chemical, physical, and biological contaminants that can affect air quality. Thermal comfort requirements are not included in this standard.

2.5 Acceptable indoor air quality may not be achieved in all buildings meeting the requirements of this standard for one or more of the following reasons:

(a) because of the diversity of sources and contaminants in indoor air;

(b) because of the many other factors that may affect occupant perception and acceptance of indoor air quality such as air temperature, humidity, noise, lighting, and physiological stress;

(c) because of the range of susceptibility in the population; and

(d) because outdoor air brought into the building may be unacceptable or may not be adequately cleaned.

IAQ Design Sequence

The IAQ design sequence builds upon the normal HVAC system design tasks used by designers throughout the industry.

- Design Step 1: Establish IAQ Criteria
- Design Step 2: Review HVAC Systems, Zoning, and Room Air Distribution
- Design Step 3: Identify Ventilation Requirements
- Design Step 4: Integrate IAQ into HVAC Design
- Design Step 5: Closeout and Follow-Up

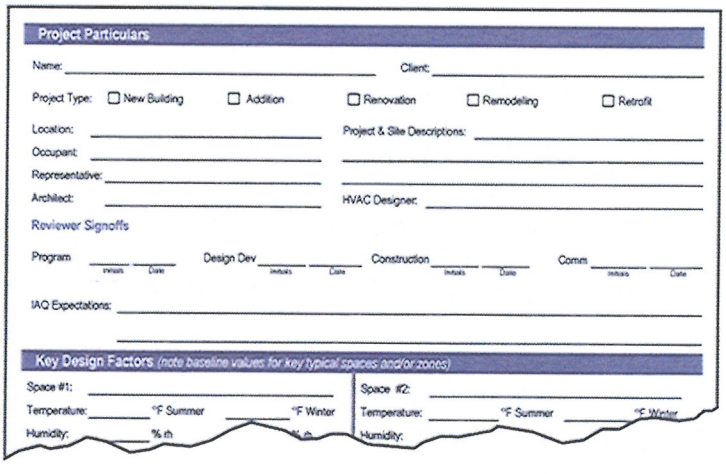
Some general IAQ recommendations for design of the overall building and its many systems (not just the HVAC system) are:

- Design to exceed today's codes and guidelines. Indoor air quality issues are complex and prevalent in our buildings today; so much needs to be done to resolve them.
- Design systems with flexibility in usage and configuration. Much of what owner's and occupants deal with in IAQ issues come about over time as a building goes through normal changes in occupancy, layout, and usage.
- Document all assumptions, choices and specifications. Put the IAQ Design Checklist and the Design Record from TDP-701, System Selection to good use. Blank forms are shown in Appendix H.

What follows are an IAQ Design Checklist, the Design Record, a sample documentation letter, and an example using the multi-step IAQ Design Sequence. These were created to help with the HVAC system design to avoid IAQ issues later.

IAQ Design Checklist and Documentation

A comprehensive set of checklists, design documentation forms, and master specifications is invaluable for designers and engineers, especially where the design tasks may be done at different times by different individuals. An IAQ Design Checklist is presented in Appendix H for designers who have not established their own IAQ design procedures. Figure 32 shows a portion of the checklist. A filled-in example can be found in Appendix I.


Project Particulars

Name: _____ Client: _____

Project Type: ☐ New Building ☐ Addition ☐ Renovation ☐ Remodeling ☐ Retrofit

Location: _____ Project & Site Descriptions: _____

Occupant: _____

Representative: _____

Architect: _____ HVAC Designer: _____

Reviewer Signoffs

Program _____ Initials _____ Date Design Dev _____ Initials _____ Date Construction _____ Initials _____ Date Comm _____ Initials _____ Date

IAQ Expectations: _____

Key Design Factors (note baseline values for key typical spaces and/or zones)

Space #1: _____ Space #2: _____

Temperature: _____ °F Summer _____ °F Winter Temperature: _____ °F Summer _____ °F Winter

Humidity: _____ % rh Humidity:

Figure 32

IAQ Design Checklist

Proper Documentation

The IAQ Checklist and Design Record provide a way to record your IAQ criteria, system selection, and design decisions for most any HVAC project.

As a normal part of any HVAC system design, proper documentation is a fundamental requirement. In Step 1 of the IAQ Design Sequence we will begin using the IAQ Design Checklist with the Chicago Office Building. This is a companion form to the Design Record presented in TDP-701, System Selection. The Design Record form is provided in Appendix J.

Ventilation System Terms and Layout

Using the ASHRAE ventilation standard, Figure 33 shows a generic ventilation system layout and terms used to describe the basic components and airflows. We will use this as a guide as we work through the IAQ design sequence.

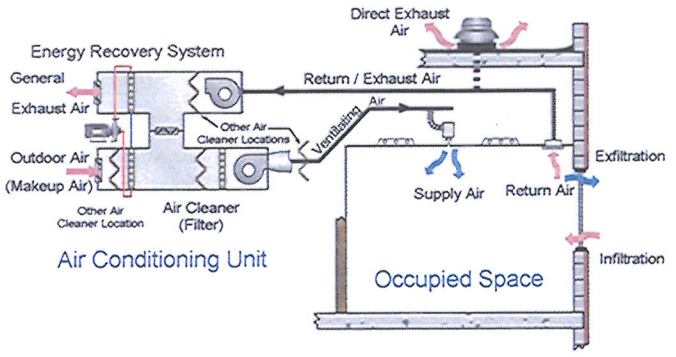


Figure 33

Ventilation System Terms and Layout

ASHRAE Ventilation Standard 62.1-2004 Procedures

The ASHRAE ventilation standard specifies two alternative procedures for the design of mechanical ventilation systems in Section 6 of the standard.

Section 6.1.1 Ventilation Rate Procedure

Acceptable perceived air quality is achieved by providing ventilation air of specified quality and quantity to the space.

This is a prescriptive procedure in which outdoor air ventilation rates are determined based on occupancy level (cfm per person), and space type/application and floor area (cfm per sq ft). These are minimum rates based on contaminant sources and strengths typical for the listed space types.

Section 6.1.2 Indoor Air Quality Procedure

Acceptable perceived air quality is achieved within the space by controlling known and specifiable contaminants.

This is a design procedure in which outdoor air ventilation rates and other system design parameters are based on an analysis of contaminant sources, contaminant concentration targets, and acceptability targets.

For the Chicago Office Building example that follows, we will be employing the Ventilation Rate Procedure to direct our HVAC system selection and design features relative to IAQ.

Design Step 1: Establish IAQ Criteria

When a project begins, the early preliminary planning and schematic design stages establish the IAQ criteria that are followed throughout the design process. Indoor air quality criteria need to be established early, right along with the more traditional comfort parameters, when the effort is most effective. The HVAC system design phases are shown in Figure 34.

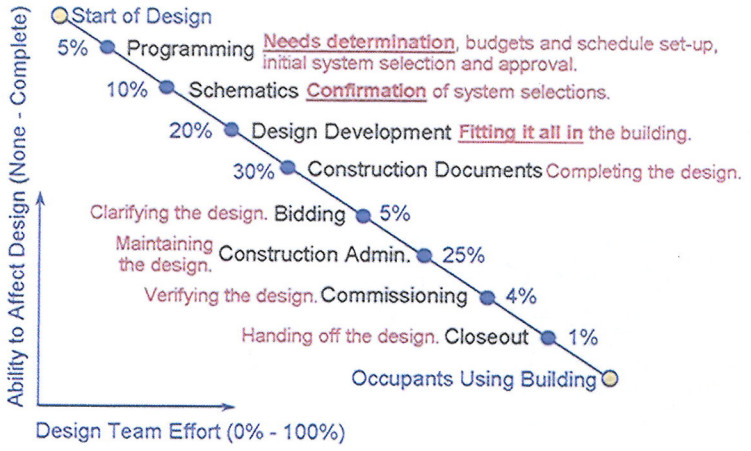


Figure 34

HVAC System Design Phases

Gather Project Particulars

First, we need to assemble all the information we can about our example building, the Chicago Office Building. It is a multi-story office building in a north side suburb near the O'Hare airport as shown in Figure 35. The developer is building it as Class A rental property with only a few leases signed before design and construction begin. Indoor air quality is a high priority design criteria that will be used in the marketing campaign to attract higher-paying clients.

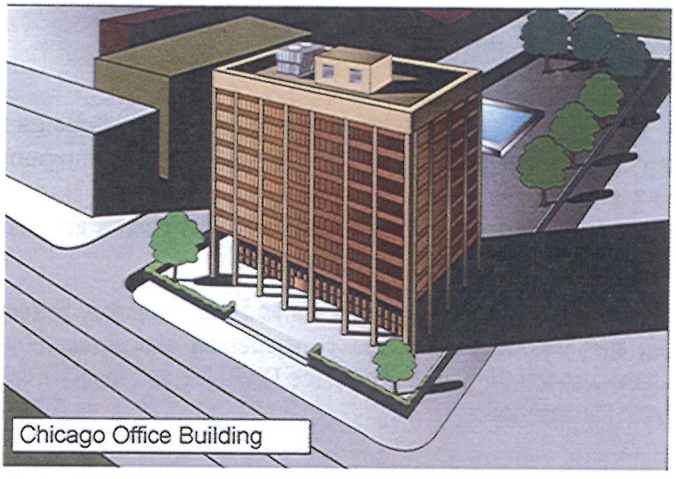
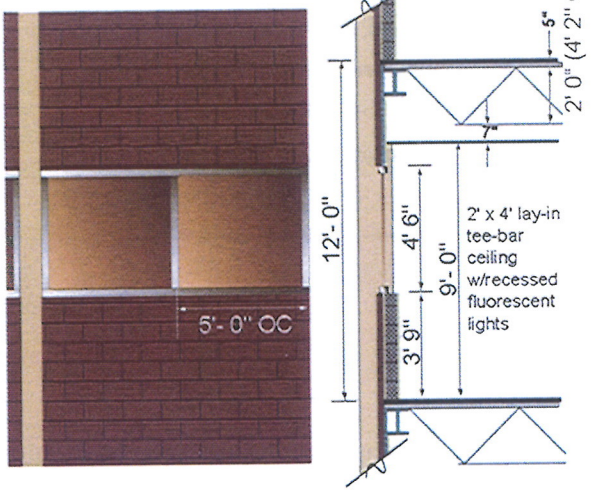


Figure 35

Example Building for IAQ Design Sequence

As can be seen from the building elevations and floor plan in Appendices K and L, the building is a simple design with basic IAQ-driven zoning of the open office floor. The developer has a basic standard design that most projects start from so we have been able to assemble quite a bit of building data (Figure 36) early on in the design process. This allows good definition of IAQ criteria to be used as the drawings and specifications are produced. From an IAQ aspect, we are interested in both client and occupant inputs because their expectations may be different and require resolution or compromise.



Occupancy: Business (B)
Construction Type: IA,
Overall Dimensions:
175' x 100' x 100' high (top of stl)
17,500 ft^2 / flr * 8 flrs = 140,000 ft^2
126,000 ft^2 / 1,008,600 ft^3 (occ.)
Ceiling Height: 9'- 0"
Weight:
Walls – 100 lbs / ft^3
Building – 70 lbs / ft^3
Roof – 54 lbs / ft^3
Color:
Medium walls (brown) and roof (stone)
Usage:
16 hours of operation
Design Temperatures:
75° F (summer)
70° F (winter)
85° F unocc. (summer)
60° F unocc. (winter)
Electrical Service:
460 Volts / 3 phase / 60 Hertz
Heat: Natural gas available

Lights:
1.5 Watts / ft^2
recessed fluorescent,
0.50 Watts / ft^2 task
Other Electrical:
0.81 Watts / ft^2
Glass: Double-glazed, brz, medium drapes
SHC - 0.547
U-Factors:
Walls - 0.181
Roof - 0.090
Windows - 0.544
Partition - 0.294
Occupancy: 200 ft^2/person
Outdoor Air Ventilation:
5 cfm / person (people)
0.06 cfm / ft^2 (area)
0.05 cfm / ft^2 (pressurization)
Infiltration: 0.02 cfm / ft^2
Exhaust: 12,600 cfm

Figure 36

Chicago Office Building Data

Record names and phone numbers for all the design team members, such as the architect (and even the interior designer). Many of the IAQ contaminants come from finishes and furnishings that go into the rooms after tenants sign leases. Use the project/site description lines to record adequate detail on how the facility will be used and what is around the immediate vicinity that could impact the indoor air quality.

Do not forget to get reviews and signoffs at key milestones to make sure IAQ criteria are being met as the design and construction progresses. In Appendix I, there is a completed IAQ Checklist for the Chicago Office Building that can be followed throughout the presentation of the IAQ Design Steps.

Determine Key Design Factors

Indoor air quality is a relatively new key design factor when determining the space comfort design conditions, but one that is greatly affected if any of the others are not being met. Comfort design conditions are shown in Figure 37. When space temperature or humidity are not within comfort design conditions, the occupants will usually say that they have poor IAQ. This makes it important that traditional comfort parameter set points be identified early in the design process. Steps should be taken to make sure the building design and the chosen HVAC system work together to provide the level of comfort set for the project.

Referring to the Appendix in TDP-102, ABCs of Comfort, we are able to establish comfort set points for the Chicago Office Building.

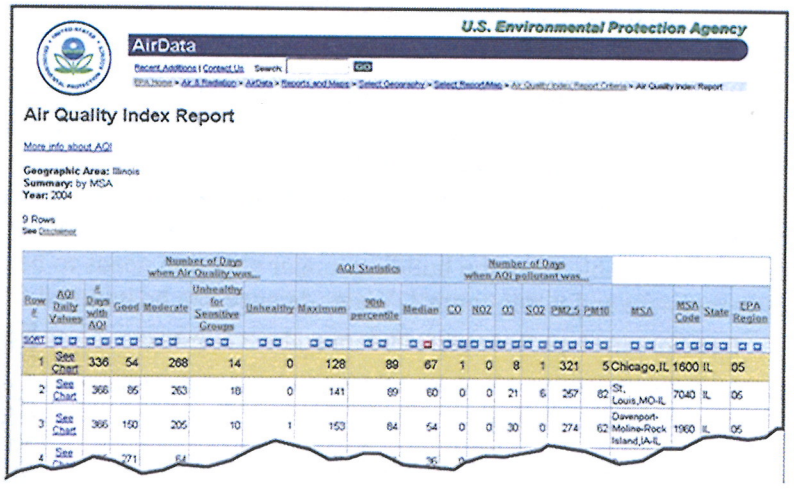
Space / Activity	Office					
Temperature	Occupied		Unoccupied		Throttling Range	Swing
	Design	Min	Design	Min		
Summer	75	70	85	0	1-1/2	0
Winter	70	68	0	60		
Humidity	Design	Max	Min			
Summer	50	60				
Winter	None		None			
Air Motion	Max	Min	Notes			
fpm	30	15				
Ventilation	Occupied		Unoccupied		Notes:	
	Design	Min	Min			
cfm	20 / P	0.25 / ft²	0			
Direct Exhaust	0.10 / ft²					
Filtration	Condition		MERV	Type	Other	
	Standard		6	Pleat		
Radiant Surfaces	Glass	Wall	Floor	Roof	Other	
Summer	84F @ 95F					
Winter	38F @-10F				33% glass	
Acoustics	Room RC		Other Notes:			
	RC 35 - N					
Notes:						

Figure 37

Chicago Office Building Comfort Design Conditions

Verify the Outdoor and Indoor Air Quality

Reviewing the Contaminants and Their Sources section starting on page 9, we see that for the many possible contaminants there is no definitive way of determining either outdoor or indoor air quality. If the outdoor air quality, as measured by the NAAQS primary pollutants and reported on EPA's Air Quality Index Report (Figure 38), is unacceptable for your project location, ASHRAE 62.1-2004 requires the designer to identify the treatment that will be used to reduce the contamination to acceptable levels.


U.S. Environmental Protection Agency

AirData

Air Quality Index Report

More info about AQI

Geographic Area: Illinois
Summary: by MSA
Year: 2004

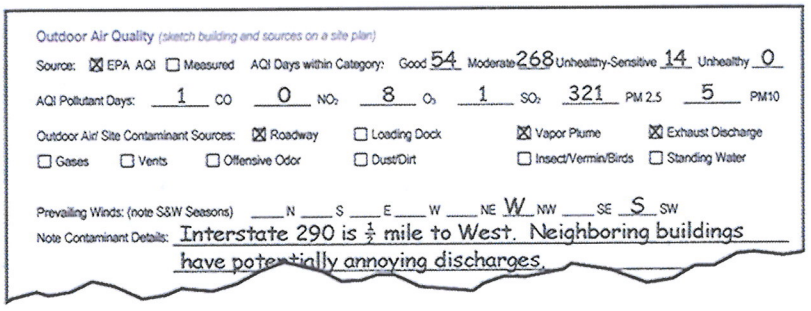
9 Rows

Row #	AQI Daily Values	# Days with AQI	Number of Days when Air Quality was... Good	Moderate	Unhealthy for Sensitive Groups	Unhealthy	AQI Statistics Maximum	90th percentile	Median	Number of Days when AQI pollutant was... CO	NO2	O3	SO2	PM2.5	PM10	MSA	MSA Code	State	EPA Region
1	See Chart	336	54	268	14	0	128	89	67	1	0	8	1	321	5	Chicago,IL	1600	IL	05
2	See Chart	366	86	263	18	0	141	89	60	0	0	21	6	257	82	St. Louis,MO-IL	7040	IL	06
3	See Chart	366	150	205	10	1	153	84	54	0	0	30	0	274	62	Davenport-Moline-Rock Island,IA-IL	1960	IL	05
4	See Chart	271	64																

Figure 38

Outdoor Air Quality

Reviewing the EPA website for Chicago, IL (URL link is noted in the References) we find that the outdoor air has some potential issues with fine particles (PM2.5) and ozone (O_3), both common in major metropolitan areas. While there are no "unhealthy" Air Quality Index (AQI) days, there are nine days that are rated "unhealthy for sensitive groups," which should exclude our office usage project. If you click on "See Chart" on the AQI Report, you will see a few ozone (smog) days in the summer and scattered PM2.5 excursions throughout the year. The IAQ checklist data is shown in Figure 39.


Outdoor Air Quality (sketch building and sources on a site plan)

Source: ☒ EPA AQI ☐ Measured AQI Days within Category: Good 54 Moderate 268 Unhealthy-Sensitive 14 Unhealthy 0

AQI Pollutant Days: 1 CO 0 NO_2 8 O_3 1 SO_2 321 PM 2.5 5 PM10

Outdoor Air/ Site Contaminant Sources: ☒ Roadway ☐ Loading Dock ☒ Vapor Plume ☒ Exhaust Discharge
☐ Gases ☐ Vents ☐ Offensive Odor ☐ Dust/Dirt ☐ Insect/Vermin/Birds ☐ Standing Water

Prevailing Winds: (note S&W Seasons) ___N ___S ___E ___W ___NE W NW ___SE S SW

Note Contaminant Details: Interstate 290 is ½ mile to West. Neighboring buildings have potentially annoying discharges.

Figure 39

IAQ Checklist Data

Continuing the assessment of the outdoor air, we can see from the site drawing (Figure 35) that to the north there are mature trees, a reflecting pool, and possibly a fountain. The developer usually puts central station air-handling units in a rooftop penthouse, but with MERV 13 filters and even with a remote location, there should be no increased risks from springtime plant pollen. The plaza is covered with stone pavers, so any fountain moisture plume should not cause increased microbial counts in the ventilation air. Complete the outdoor air evaluation by looking over the Outdoor Air/Site Contaminant Sources section of the IAQ Design Checklist for other potential sources at our Chicago Office Building site. Carefully note any contaminant details on the form.

Treating the Outdoor Air

Based on the EPA AQI Report for Chicago, it is recommended that the outdoor ventilation air be filtered at ≥MERV 13. Installation areas should be left in the air-handling units for future gas-phase filters as well.

Potential indoor air quality contaminant issues can be assessed during design by carefully reviewing the noted Indoor Air Contaminant Sources with the architect and interior designer. When working on a new building or major R-market project (remodeling, renovation or retrofit) this is the time to eliminate any contaminant sources with the design, remembering source control as the foundational base of the IAQ triangle (Figure 12). After eliminating as many potentially polluting materials as possible from the building, major attention needs to be paid by all design team members to moisture and water control. Water damage can be initiated from many sources:

- Exterior envelope leakage, both rain and wind-driven
- Incomplete/incorrect envelope vapor and moisture barriers
- Piping system leakage
- Improper trapping of and drainage from coil condensate pans
- Condensation on cold pipes and ducts
- Compromised humidifier controls
- Poor outdoor air intake design (louvers and ductwork)

Avoid Mold Growth

If any food source (dirt and cellulose are common) becomes wet, and temperature and light conditions are ideal, mold growth will almost certainly occur within 24 to 72 hours after the event.

Remember, architects can design ways for moisture incursions to drain back outside, but engineers must make sure equipment, pipes, and fittings do not leak and that vapor barriers next to cold surfaces are not compromised.

Design Step 2: Review HVAC Systems, Zoning, and Room Air Distribution

Once we have established the IAQ criteria for the project, we need to begin the process of setting (new system design) or determining (existing system evaluation) the ability of the HVAC system to meet those criteria. Many different HVAC systems meet the basic comfort requirements for most projects. Paying close attention to the IAQ-related features of each, and matching them up to the project IAQ criteria, will help refine that choice.

System Ventilation Features

When reviewing HVAC systems there are issues of both quality and quantity to be addressed. These issues are covered in the ASHRAE ventilation standard 62.1. The following list covers the major quality concerns to be evaluated:

- Location of outdoor air intake – meet minimum separation distances (Appendix M)
- Rain and snow entrainment – design and airflow fpm must prevent the intake of moisture into the HVAC system
- Rain intrusion – equipment mounted outdoors must be sealed weather tight
- HVAC system source control – design features and expected maintenance must not result in bioaerosols and particulates being generated within the equipment and distribution systems
- Air recirculation – tougher standard guidelines address return air contamination classifications and set strict limits on recirculation

Looking at the Chicago Office Building we can expect an applied system using a central station air-handling unit in a rooftop penthouse, so most of the outdoor air quality issues associated with the ventilation system should not be concerns on this project. Location of the outdoor air intake must be chosen away from the cooling tower to meet ASHRAE Standard 62.1-2004 Table 5-1 requirements (see copy in Appendix M).

When using packaged equipment-zoned systems, like fan coils, water source heat pumps, PTACs (packaged terminal air conditioners), and unit ventilators, HVAC equipment source control becomes a major concern on projects with high IAQ criteria. Unit filtration is normally no better than the MERV 6 required minimum, and maintenance frequency and scope often lead to unit/ductwork moisture issues and potential bioaerosols contamination.

Zoning Criteria

Zoning is often driven by differing exterior exposures, occupant activities, or temperature criteria. Zoning needs to be thought of as an IAQ decision as well. Job economic pressures continue to push the number of zones towards smaller totals, but uniquely different areas need to be zoned individually. Each zone should have their own controls (thermostat, humidistat, or CO_2). As can be seen on the floor plan in Figure 40, the Chicago Office Building has separate zones for the corner offices and conference room. Rooms like copy centers and break rooms will not only be zoned separately, they will get dedicated exhaust to capture contaminants at the source.

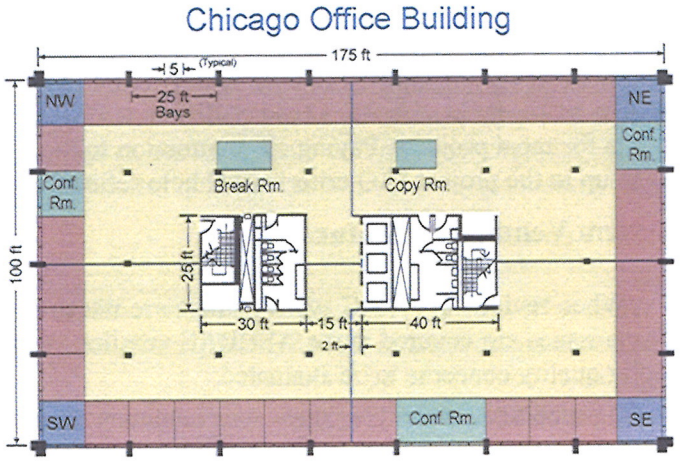


Figure 40

Zoning Criteria

Zone Air Distribution Effectiveness

The type and locations of the air supply and return outlets (air distribution configuration) is used to determine the effectiveness (E_Z) of delivering the ventilation air to the occupants within the spaces.

Table 6-2, Zone Air Distribution Effectiveness (found in Appendix N) and Equation 6-2, from ASHRAE 62.1-2004 are used to determine the adjustment factor to the breathing zone outdoor air requirement. A moderate reduction in the ventilation effectiveness factor can be offset by further increasing the proportion of ventilation air in the supply airstream.

Room Airflow

The airflow pattern should not permit the supply air to bypass the breathing zone as it flows from the supply outlets to the return/exhaust grilles.

The Chicago Office Building will be allowing flexibility in tenant usage of the various spaces once leases are signed. Typical diffusers used on past projects were all ceiling supply of cool air, so the E_z will be 1.0. Therefore, from formula 6-2,

$$V_{oz} = V_{bz} \div E_z = V_{bz}, \text{or}$$

the zone outdoor airflow (V_{oz}) will be equal to the breathing zone outdoor airflow (V_{bz}) determined from Table 6-1 (See Figure 22). Whenever E_z is greater or less than 1.0, V_{oz} will be different than V_{bz}.

System Ventilation Efficiency

Whenever a single-zone system is used, there is no further need to modify the outdoor air quantity determined through review of the air distribution configuration. See Appendix O. Therefore, the outdoor air intake flow (V_{ot}) of the HVAC system is equal to the zone outdoor airflow (V_{oz}).

Multi-zone recirculating systems require a detailed evaluation of the system ventilation efficiency (E_v) before V_{ot} can be determined. There is a spreadsheet created by ASHRAE to cut down the effort required to input values for each zone and compute equation 6-8, $V_{ot} = V_{ou} \div E_v$, where V_{ou}, the uncorrected outdoor air intake, is computed using an occupant diversity factor.

Design Step 3: Identify Ventilation Requirements

At this point in the design process, it is time to actually determine how much outdoor ventilation air is needed by each space. We will continue using the ventilation rate procedure presented in section 6.2 of ASHRAE Standard 62.1-2004.

General Ventilation Requirements

Minimum ventilation rates are determined from Table 6-1 of ASHRAE Standard 62.1-2004 (Figure 22). The breathing zone outdoor airflow (V_{bz}) is the sum of two look-up value calculations from the table.

$$V_{bz} = R_p P_z + R_a A_z$$

Where:

R_p = outdoor airflow required per person, cfm

P_z = largest number of people expected to occupy zone

R_a = outdoor airflow required per unit area, cfm

A_z = net occupiable floor area of the zone, ft^2

The typical values for the Chicago Office Building are shown in the Key Design Factors portion of the IAQ Design Checklist on page 54. Any unusual space values would be entered later on in the checklist as shown on the bottom of page 54, along with any special ventilation requirements and local exhaust/contaminant control needs.

Special Ventilation Requirements

Beyond the typical areas that make up the majority of a building, look for auditoriums, conference rooms, and training rooms that will have higher density occupancy for periods of more than a few hours. Certain occupancies, like food, beverage, and pharmacy preparation areas have high cfm per area values, while sports and entertainment occupancies have high activity cfm per person values.

The ventilation system may be designed to reset the outdoor airflow (V_{ot}) as operating conditions change, using such methods as time-of-day scheduling, direct count of occupants, or an estimate of ventilation rate per person using indoor CO_2 concentrations.

Variable Occupancy

For spaces like conference rooms, use the average value over time, $T = 3v/V_{bz}$

Section 6.2.6 of ASHRAE Standard 62.1-2004 provides guidance for variable load and short-term occupancy conditions. Ventilation systems need to be designed to provide proper outdoor airflow to the zone from peak design conditions to the minimum occupancy part load condition. When it is known that a zone will be occupied only intermittently, the design can be based on the average value over a time period (T) computed by dividing the volume (v) of the zone by the breathing zone outdoor airflow (V_{bz}).

Local Exhaust and Contaminant Control Needs

Look for food preparation areas, food service areas, and smoking lounges. The release of fumes (such as from electric welding equipment), chemicals (such as from photographic development equipment), or infectious biological agents (such as in hospital isolation rooms) must also be prevented from contaminating other areas. This is done most effectively by capturing the contaminants at the point of generation with hoods and exhaust systems or by enclosing the contaminant area and maintaining it at a negative pressure with respect to the surrounding uncontaminated areas.

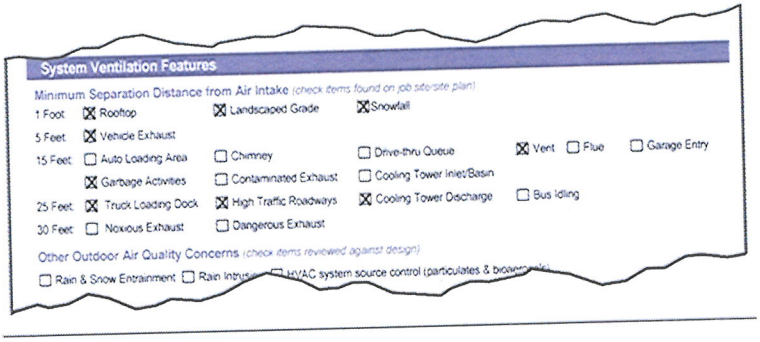


Figure 41

System Ventilation Features

Recirculation

Return air from contaminated areas should not be returned to a central system serving uncontaminated areas.

For normal HVAC return systems, the air is classified based on contaminant concentration, and its recirculation is limited. In general, return air can only be recirculated to similar or higher classification spaces.

Document IAQ Design Features to Client

Now would be a good time to review the IAQ Design Checklist (Figure 41 and Appendix I) in detail and make sure that all the blanks that can be filled in have been. At this stage of the design process the programming is done, most of the schematics phase materials are completed, and even some of the preliminary equipment selections could be done. The HVAC designer should have the checklist reviewed and initialed by a senior project engineer/manager and copies sent off to the other members of the design team. This includes the architect, owner/developer, and if known at this stage, the occupant representative. Before any final lines are put to paper, make sure there is buy-in and approval from all the design team members.

Design Step 4: Integrate IAQ into HVAC Design

Quite a bit of the IAQ design has been accomplished up this point, and now the process begins of documenting the design on paper. Final equipment selections are made, layouts completed and specifications written to document to the contractors what is needed to implement the design. The following sections highlight key aspects of the design that addresses IAQ features of the HVAC system.

Develop Commissioning Plan

The word commission has many varied meanings. In this context, we will use the following definitions:

- the act of granting authority to undertake certain functions [syn: commissioning]
- the state of being in good working order and ready for operation; put the ships (or buildings) into commission.

Commissioning involves all aspects of the building and its many systems. Its use has increased greatly over the last decade because of the serious IAQ problems experienced in our tighter new building designs. The recent surge in sustainable design and building LEED certification has helped bring commissioning into the mainstream for most projects.

Commissioning Plan

The plan for the Chicago Office Building is determined by the developer's past building project IAQ successes and failures.

Commissioning activities begin at the earliest programming phase of the project. Verification is needed at each design milestone that approved IAQ criteria are being implemented in the design, as well as in the traditional construction and start-up activities. An independent third-party commissioning agent follows procedures that have been called out in the specifications to ensure that the IAQ will be acceptable before the building is occupied. The designer incorporates many of the items in the IAQ Design Checklist to commission the HVAC system. There is a commissioning resource library listed in the References that will guide designers in creating an appropriate commissioning plan for the project that includes IAQ items.

Air Intake and Exhaust Openings

Coordinate the location of the air intake and exhaust openings so the ventilation air will not be contaminated by nearby exhausts, bacteria from water in cooling towers or evaporative condensers, traffic fumes, or other combustion engine exhausts. Do not locate the openings near sources of contamination that can be avoided.

This aspect of the design needs to involve the full design team to be truly successful. Site issues can be significant and require the involvement of the HVAC designer in the earliest stages of the design, often long before the architect or developer brings in their consultants. Once again, proper source control is far more cost effective than added filtration or outdoor dilution air.

The Chicago Office Building has utilized rooftop and penthouse-located central HVAC equipment, avoiding many of the pitfalls that occur with street-level outdoor air intakes and zone-level system equipment features.

Filtration

Select the type and efficiency of particulate filters, or the gaseous treatment device that will be used to remove the contaminants. Note which contaminants are likely to exist in the outdoor and return air. Identify whether separate or common systems will be used to remove contaminants from the outdoor air and the return air.

Humidity Control Needs

Identify the most difficult operating conditions that are likely to occur for a prolonged period. Identify the relative humidity that will occur in the building with the type of equipment and controls that have been selected. Modify the design, if necessary, to prevent unacceptable relative humidity. Relative humidity is usually limited to 65 percent rh maximum and may be limited to as low as 30 percent rh minimum. See Figure 42 for example building outdoor design conditions.

Table 1B Cooling and Dehumidification Design Conditions—United States

	Cooling DB/MWB						Evaporation WB/MDB						Dehumidification DP/MDB and HR									Range of DB
	0.4%		1%		2%		0.4%		1%		2%		0.4%			1%			2%			
Station	DB	MWB	DB	MWB	DB	MWB	WB	MWB	WB	MDB	WB	MDB	DP	HR	MDB	DP	HR	MDB	DP	HR	MDB	
1	2a	2b	2c	2d	2e	2f	3a	3b	3c	3d	3e	3f	4a	4b	4c	4d	4e	4f	4g	4h	4i	5
Mountain Home, AFB	99	63	96	62	93	61	66	91	64	91	63	89	58	79	71	54	70	69	52	64	71	32.8
Mullan	87	62	84	61	80	60	65	81	63	79	62	77	60	86	69	58	80	68	56	75	66	28.1
Pocatello	93	61	90	60	87	59	64	84	62	83	61	82	57	83	70	55	76	70	53	70	69	32.1
ILLINOIS																						
Belleville, Scott AFB	95	78	93	77	90	76	80	92	78	90	77	88	77	141	87	76	136	85	74	131	84	19.8
Chicago, Meigs Field	92	74	89	73	86	71	77	88	76	85	74	83	74	132	84	72	121	80	71	115	80	16.0
Chicago, O'Hare Intl A	91	74	88	73	86	71	77	88	75	85	74	83	74	130	84	72	123	82	71	115	80	19.6
Decatur	94	76	91	75	88	74	79	90	78	89	76	86	76	140	86	75	133	84	73	127	83	20.0
Glenview, NAS	93	75	89	73	87	71	78	90	76	87	74	84	74	130	85	72	120	82	70	113	81	17.6
Marseilles	93	74	89	73	86	71	78	89	76	86	74	84	75	135	85	73	126	82	71	117	81	19.4
Moline/Davenport IA	93	76	90	74	87	73	78	90	77	87	75	85	75	134	85	73	127	83	72	120	82	20.0
Peoria	92	76	89	74	86	73	78	89	77	86	75	84	75	137	85	74	130	83	72	123	81	19.5
Quincy	94	76	91	75	88	74	78	89	77	88	76	85	76	138	84	74	132	82	73	126	82	18.9

Partial view from ASHRAE 2001 Fundamentals Handbook, Chapter 27.

Figure 42

Humidity Control – Outdoor Design Conditions

System performance should be checked at both of the following conditions:

- Peak outdoor dew point design conditions and at the peak indoor design latent load
- Lowest space sensible heat ratio expected to occur and the concurrent outside conditions

Checking maximum latent loading of the HVAC equipment, often not at the traditional outdoor design conditions, pinpoints high latent part load conditions that could cause excessive relative humidity conditions conducive to microbial growth.

It is not possible to run final loads for the Chicago Office Building until we have a better idea about the major tenants and the resulting load components. A base run should be done with a normal tenant profile to verify that there are no high latent loading conditions that the selected equipment could not handle.

Balancing

Using the preliminary outdoor air and exhaust airflows, increase the outdoor airflow as necessary to maintain positive pressurization of the general building spaces with respect to the outdoors. Make sure that all ASHRAE Standard 62.1 Class 3 and 4 spaces (contaminated areas) are maintained at a negative pressure with respect to the cleaner adjacent spaces.

Control and Monitoring

Determine the automatic controls and devices that will be used to control and measure the ventilation airflow. Determine whether continuous measurement of building contaminants is required.

Operations and Maintenance

Coordinate the space requirements, access, and other provisions that are necessary for adequate inspection and maintenance of the cooling towers, outdoor air intakes, filters, air handling equipment, humidifiers, terminals, sensors, and controls.

Design Step 5: Closeout and Follow-Up

Review the IAQ Design Checklist for completeness and maintain the file for a period for at least five years after occupancy of the building in order to provide necessary proof of correct design intent within the statute of limitations. As is the case with all HVAC designs, occasional contact with the owner and occupant after the warranty period is beneficial to assess HVAC system IAQ performance and their overall satisfaction with the building.

Maintaining IAQ

As pointed out by the five guidelines and evaluation process tables in the Appendix, minor adjustments and fixes are often all that is needed to get the HVAC system back on track.

Summary

You have learned that indoor air quality has become a major consideration in the construction and HVAC industry. Indoor air quality is a small portion of a larger issue referred to as Indoor Environmental Quality (IEQ). The impact of poor indoor air quality is not only health-related, but can have a major financial impact on the building occupant, as well as the employer and building owner. Legal considerations are growing because of updates to building codes and engineering standards, as well as an increase in IAQ-related lawsuits. There are several new illnesses attributed to poor IAQ, and the health industry is gaining a better understanding of the cause and effect relationships.

There are various types of pollutants and different strategies that need to be employed in order to control them. The best strategies make use of three factors: source control, filtration, and dilution. The HVAC standard of design for IAQ is ASHRAE Standard 62.1, which is incorporated into the building codes of most states. Lastly, it is not sufficient to just design the HVAC system appropriately, it must be commissioned, operated and maintained as originally intended by the system designer and the equipment manufacturer. Any changes to the original design intent should be reevaluated for its impact on the indoor air quality.

Work Session

1. Indoor Air Quality (IAQ) is a broadly based subject that is difficult to define. Write a definition of IAQ using material presented in the TDP, and quote the source(s).

_____

_____

_____

2. Air quality, in particular indoor air quality, is part of the complex indoor environmental quality (IEQ) picture. Name five of the ten aspects of IEQ other than air quality.

a) _____
b) _____
c) _____
d) _____
e) _____

3. Since IAQ is a complex issue, as many elements as possible within its three key facets need to be understood. List three elements in each of the following three facets, trying to capture priority issues that relate to your personal or work situation.

Contaminant Sources: _____ _____ _____

Economic Issues: _____ _____ _____

Key Control Strategies: _____ _____ _____

4. Solutions for sick building syndrome and multiple chemical sensitivity remain elusive for medical researchers. However, building-related illnesses (BRI) are better understood and good IAQ design and practices can lesson the chances of contracting them. List two common BRI and any aspect of the illness you have learned from the TDP.

_____

_____

5. What is a contaminant? _____

_____

6. Name five of the nine common indoor air contaminants and their prevalent source(s).

   a) _____ d) _____

   b) _____ e) _____

   c) _____

7. Name the three elements of the industrial hygiene triangle of best practices that form the basis of the IAQ control strategy.

   _____

   _____

   _____

8. The most important element of the IAQ control strategy is_____, and its purpose/function is to _____.

9. Name three of the five ways of controlling the level of pollutants.

   _____

   _____

   _____

10. For improved removal of respirable suspended particulates, use filters with a MERV rating of _____ or better.

11. True or False? Since dilution is the solution to pollution, then it must be the most important leg of the IAQ Control Strategy triangle. _____

12. True or False? ASHRAE Standard 62.1 *Ventilation for Acceptable Indoor Air Quality* has provided sound, consistent, advice on minimum ventilation rates over the decades. _____

13. Which of the following describes a means of lessoning the energy penalty associated with ventilating with outdoor air? _____

    a) Demand controlled ventilation using CO_2 "occupancy" sensors

    b) Energy recovery ventilator

    c) Displacement ventilation system

14. Name the five steps of the IAQ Design Sequence.

    a) _____
    b) _____
    c) _____
    d) _____
    e) _____

15. What are the three key elements of the "Establish IAQ Criteria" step of the IAQ Design Sequence?

    a) _____
    b) _____
    c) _____

16. After reviewing the AQI for our example building, should we be concerned about the outdoor air quality? _____

17. When designing HVAC systems there are many quality and quantity issues to be addressed. What are three of the five major IAQ issues that the designer needs to pay attention to that are covered in ASHRAE 62.1-2004?

    a) _____
    b) _____
    c) _____

Notes:

Work Session Answers

1. IAQ is defined as the physical, mechanical, and chemical properties enabling people to live and work in healthy and comfortable conditions (European communities).

   IAQ refers only to the presence of *contaminants*, which either may result in an immediate or delayed unpleasant or unhealthful response by the occupants (strict "dictionary" definition).

   Good IAQ is achieved whenever a substantial majority (80 percent or more) of the people exposed (to the indoor air) do not express dissatisfaction (ASHRAE).

2. Building orientation and siting
   External climate
   Indoor climate
   Acoustics
   Aesthetics
   External contaminants
   Internal contaminants
   Lighting
   Vibration
   Ergonomics

3. Contaminant Sources: Moisture/humidity, human activities, renovation/ remodeling, outdoor contaminants, HVAC system, housekeeping, pest control, office equipment, furnishings.

   Economic Issues: Insurance, property value, productivity/morale, marketability, return on investment, liability, medical costs, energy costs, absenteeism.

   Key Control Strategies: Training, filtration, maintenance, policies & practices, monitoring, HVAC controls/equipment, ventilation, documentation, source control.

4. Asthma: diagnosable illnesses that can be traced to a specific cause.

   Hypersensitivity pneumonitis: diagnosable illnesses that can be traced to a specific cause; appears to be caused by chronic exposure to bioaerosols to which the affected individual is sensitive;

   Legionnaires' disease: diagnosable illnesses that can be traced to a specific cause; lung infection (pneumonia) caused by a bacterium named *legionella pneumophila; t*he waterborne bacteria reproduces best at 80 to 120° F, and lives in cracks, scale, and backwaters; air conditioners are not a source for Legionnaires' disease.

   Carbon monoxide poisoning: diagnosable illnesses that can be traced to a specific cause.

5. A contaminant is anything in the air, regardless of the source, that is harmful or objectionable to the building occupants.

6. Volatile organic compounds: building materials, finishes, and furnishings made from or with synthetics.

   Suspended particulates: particles suspended in the air that come from a variety of natural and human sources.

   Gases: combustion and respiration, as well as evaporation of cleaning agents and toner from office equipment.

   Bioaerosols: bacteria, viruses, molds, mildews, and their spores, plus dead organisms like pollen and parts of insects and vermin.

   Radon: radioactive gas that leaks into buildings from soil gases, and can also be found in water.

   Asbestos: pipe coverings, particularly the fitting joint compound, and central equipment insulation for air handling, heating and cooling operations.

   Lead: older buildings with peeling paint, or paint that has been sanded or abraded during remodeling.

   Ozone: stagnant urban meteorological settings with excessive vehicle exhausts and adequate sunshine.

   Environmental tobacco smoke: interior smoking areas without proper ventilation and exhaust, and exterior smoking areas improperly located with respect to building openings of any kind.

7. source control, filtration, and dilution

8. source control; keep contaminants from entering the room air

9. Control the materials and processes within the building.

   Direct or indirect local exhaust to take the pollutants out of the building before they contaminate the rest of the indoor air.

   Collect and drain water where it occurs.

   Protect wetted surfaces within HVAC equipment and distribution systems.

   Provide better latent cooling of the supply air by using face and bypass control on the air-handling unit.

10. 8

11. False. Dilution, ventilating the building spaces with "uncontaminated" outdoor air, is the most recognizable control strategy, but it should be considered only as a last resort after applying source control and filtration solutions to the situation.

12. False. Judging by Figure 31 there has been significant variation in the recommendation. Designers are reminded that these are minimum ventilation rates and it is their responsibility to assess the job requirements and provide adequate outdoor air.

13. a), b), and c)

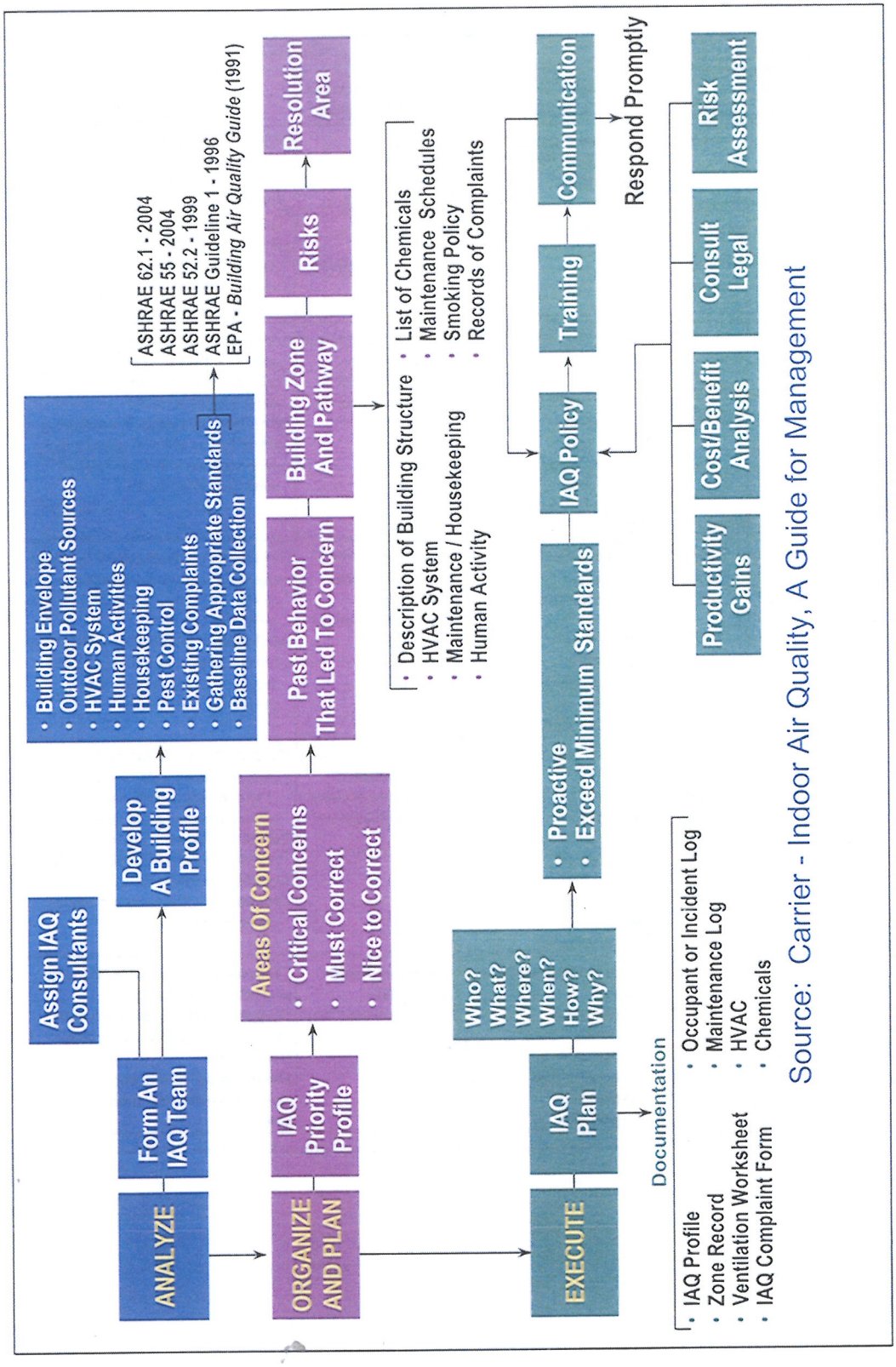
14. The five steps of the IAQ Design Sequence are:
    a) Establish IAQ Criteria
    b) Review HVAC Systems, Zoning, and Room Air Distribution
    c) Identify Ventilation Requirements
    d) Integrate IAQ into HVAC Design
    e) Closeout and Follow-Up

15. a) Gather Project Particulars
    b) Determine Key Design Factors
    c) Verify the Outdoor and Indoor Air Quality

16. Yes. Both fine particles and ozone levels are potentially high. Since the 8 ozone level days would likely relate to the 14 occurrences in the "unhealthy for sensitive groups" box, and this is an office building, we probably have no potential HVAC system design issues. For the high PM2.5 levels, an upgrade in the filter rating to MERV 13 or greater is recommended.

17. a) Location of outdoor air intake – meet minimum separation distances.
    b) Rain and snow entrainment – design and airflow fpm must prevent the intake of moisture into the HVAC system.
    c) Rain intrusion – equipment mounted outdoors must be sealed weather tight.
    d) HVAC system source control – design features and expected maintenance must not result in bioaerosols and particulates being generated within the equipment and distribution systems.
    e) Air recirculation – tougher standard guidelines address return air contamination classifications and set strict limits on recirculation.

Appendix A – Strategic IAQ Management Plan



Appendix B – Application Guidelines for Particulate Filters

Table E-1 Application Guidelines (ASHRAE 52.2-1999)

Std. 52.2 Minimum Efficiency Reporting Value (MERV)	Approx. Std. 52.1 Results		Application Guidelines		
	Dust Spot Efficiency	Arrestance	Typical Controlled Contaminant	Typical Applications and Limitations	Typical Air Filter/Cleaner Type
20	n/a	n/a	**≤0.30 µm Particle Size** Virus (unattached)	Cleanrooms Radioactive materials	**HEPA/ULPA Filters** ≥99.999% efficiency on 0.10–0.20 µm particles, IEST Type F ≥99.999% efficiency on 0.30 µm particles, IEST Type D ≥99.99% efficiency on 0.30 µm particles, IEST Type C ≥99.97% efficiency on 0.30 µm particles, IEST Type A
19	n/a	n/a	Carbon dust Sea salt	Pharmaceutical manufacturing	
18	n/a	n/a	All combustion smoke Radon progeny	Carcinogenic materials	
17	n/a	n/a		Orthopedic surgery	
16	n/a	n/a	**0.30–1.0 µm Particle Size** All bacteria	Hospital inpatient care General surgery	**Bag Filters** Nonsupported (flexible) microfine fiberglass or synthetic media. 300 to 900 mm (12 to 36 in.) deep, 6 to 12 pockets. **Box Filters** Rigid style cartridge filters 150 to 300 mm (6 to 12 in.) deep may use lofted (air laid) or paper (wet laid) media.
15	>95%	n/a	Most tobacco smoke Droplet nuclei (sneeze)	Smoking lounges Superior commercial buildings	
14	90–95%	>98%	Cooking oil Most smoke		
13	80–90%	>98%	Insecticide dust Copier toner Most face powder Most paint pigments		
12	70–75%	>95%	**1.0–3.0 µm Particle Size** Legionella	Superior residential Better commercial buildings Hospital laboratories	**Bag Filters** Nonsupported (flexible) microfine fiberglass or synthetic media. 300 to 900 mm (12 to 36 in.) deep, 6 to 12 pockets. **Box Filters** Rigid style cartridge filters 150 to 300 mm (6 to 12 in.) deep may use lofted (air laid) or paper (wet laid) media.
11	60–65%	>95%	Humidifier dust Lead dust		
10	50–55%	>95%	Milled flour Coal dust		
9	40–45%	>90%	Auto emissions Nebulizer drops Welding fumes		
8	30-35%	>90%	**3.0–10.0 µm Particle Size** Mold	Commercial buildings Better residential Industrial workplaces Paint booth inlet air	**Pleated Filters** Disposable, extended surface, 25 to 125 mm (1 to 5 in.) thick with cotton-polyester blend media, cardboard frame. **Cartridge Filters** Graded density viscous coated cube or pocket filters, synthetic media **Throwaway** Disposable synthetic media panel filters
7	25-30%	>90%	Spores Hair spray		
6	<20%	85–90%	Fabric protector Dusting aids		
5	<20%	80–85%	Cement dust Pudding mix Snuff Powdered milk		
4	<20%	75–80%	**>10.0 µm Particle Size** Pollen	Minimum filtration Residential Window air conditioners	**Throwaway** Disposable fiberglass or synthetic panel filters **Washable** Aluminum mesh, latex coated animal hair, or foam rubber panel filters **Electrostatic** Self charging (passive) woven polycarbonate panel filter
3	<20%	70–75%	Spanish moss Dust mites		
2	<20%	65–70%	Sanding dust Spray paint dust		
1	<20%	<65%	Textile fibers Carpet fibers		

Note: A MERV for other than HEPA/ULPA filters also includes a test airflow rate, but it is not shown here because it has no significance for the purposes of this table.

Appendix C – Temperature Guidelines and Evaluation Process

Step	Criteria / Norm	Results / Action
1. Determine the heating and cooling set points for the area; measure actual.	Heating - 68° F to 72° F Cooling - 72° F to 75° F Provide 5° F deadband.	Note offset and evaluate HVAC system operating condition.
2. Field evaluate location of zone thermostat. Is it responding to system demand correctly?	Central to zone, away from windows, heat sources and outside walls.	Calibrate thermostat and relocate if required; consider additional zoning in problem areas.
3. For areas not able to maintain set point, check heating and cooling load against system delivered capacity.	Quick check can be made with sq ft/ton and cfm/sq ft rules of thumb.	Add heating or cooling capacity to overcome shortfalls; either with cfm or HVAC equipment.
4. Review air delivery patterns for effective coverage of area and adequate mixing within the occupied zone; review ADPI in problem areas.	ASHRAE Handbook and air diffuser manufacturer technical reference manuals.	Clean, adjust, and balance diffusers to design cfms; adjust location to improve diffusion performance.
5. Inspect area for high infiltration, poor glazing, and envelope insulation.	Energy Conservation Code requires minimum values.	Note shortfalls and implement corrective upgrades.
6. Field review furniture placement – "do not sit near the window," winter drafts, and summer heat and glare.	Occupant placement at outside wall is not recommended.	Special glazing and perimeter heating can minimize problems.

Appendix D – Humidity Guidelines and Evaluation Process

Step	Criteria / Norm	Results / Action
1. Determine need for humidity control, what are set points and actual.	Office-occupant comfort Factory-comfort, plus process requirements	Note offset and evaluate HVAC system operating condition.
2. Determine cooling system capability to dehumidify at maximum and part load conditions.	50-60% rh is norm for comfort cooling.	Consider cascade refrigeration or desiccant for drier air.
3. Determine heating system capability to humidify at maximum loading conditions.	30-40% rh is norm for comfort heating.	Consider clean steam or ultrasonic for higher rh needs.
4. Field evaluate existing humidifier; visually inspect it for microbial contamination.	Clean steam or ultrasonic are best; no wheel or pad types with reservoir.	Clean away dirt and organics, disinfect wetted surfaces; consider antimicrobial coatings and/or tablets.
5. Check humidifier controls for calibration; is a high limit provided?	Use a sling psychrometer and distilled water.	Note offsets, recalibrate within tolerance; replace if required.
6. Field check for water leaks and damage to building components.	Overflow drains must be kept clean; controls calibrated.	Note wetted and/or damaged materials, remove and replace; fix cause of damage.
7. Field check for wetting due to condensation.	Less insulation that required; thermal bridging coldspots; HVAC system capacity shortfall.	Record shortfalls, review standards of practice for potential design modifications; correct items.

Appendix E – Filtration Guidelines and Evaluation Process

Step	Criteria / Norm	Results / Action
1. Field inspect outdoor air intakes; dirt or exhaust re-entrainment sources should not be evident.	Outdoor air intakes should not be at grade or flush with rooftop levels.	No easy fixes short of moving intake to better location.
2. Open HVAC system air handler filter section(s); note seal/gaps that would allow contaminated air to bypass media.	Proper filtration requires that all system air passes through the media.	Record shortfalls, review standards of practice for potential design modifications; correct items.
3. Field evaluate air delivery system for dirt streaking.	Air leaks are normal; HVAC system filtration should prevent dust build-up on surfaces.	Clean surfaces, inspect filters; replace or upgrade to MERV 8 minimum, reinspect monthly until corrected.
4. Does space have particle loading; e.g., copy center, material handling?	Ventilation exhaust and/or local filtration.	If no special systems exist, install local filtration with recirculation, or exhaust from a source capture device.
5. Inspect room surfaces, computer screens, ceiling areas around diffusers for dust and dirt build-up.	Dirt streaking should be minimal. Housekeeping should control dirt levels.	Upgrade to HEPA vacuuming; upgrade HVAC system filtration efficiency; MERV 13 extended surface.
6. Are occupants complaining about eye irritation and allergies?	Additional filtration may be warranted.	Consider upgrading to electrostatic precipitator, MERV 16, or HEPA.
7. Review MSDS for cleaning or process chemicals that could be in the area.	Concentrations should be maintained at a safe level.	Take air samples and note lab results that exceed OSHA limits; change process, replace chemical or install ventilation and/or exhaust.

Appendix F – Microbial Guidelines and Evaluation Process

Step	Criteria / Norm	Results / Action
1. Perform building walkthrough, noting water damage on building surfaces.	Most building materials cannot withstand water.	Locate source of water and repair leak; remove and replace damaged building material.
2. Inspect hidden areas such as above ceilings for sources of damage or to isolate leaks.	These areas must remain dry, even from condensation.	Continue to locate and repair as noted above.
3. Review building construction documents if water damage has been endemic.	Vapor barrier must be continuous and means of directing water back outside the envelope (moisture barrier).	Record shortfalls; review standards of practice for potential design modifications; correct items.
4. Are there signs of mold and mildew growth on surfaces; is there a musty smell anywhere?	Building surfaces should not be contaminated with active microbial growth.	Take air samples and perform lab tests to determine strain; remove and replace contaminated building materials.

Appendix G – Ventilation Guidelines and Evaluation Process

Step	Criteria / Norm	Results / Action
1. Determine design for supply/return air cfm, outlet placements.	Use design, as-built, and remodeling drawings.	Field verify data and update drawings; keep current.
2. Review space use, process requirements for ventilation.	Interview users, consult standards of good practice.	Modify as-built drawings with new requirements; implement changes to ventilation system.
3. Field evaluate exhaust system: intake placement, source capture devices, cfms.	Current system drawings, ACGIH Industrial Ventilation.	Record shortfalls, review standards of practice for potential design modifications; correct items.
4. Field evaluate makeup air system: outlet placement, cfms, ventilation effectiveness.	Current system drawings, ASHRAE Handbooks.	Record shortfalls, review standards of practice for potential design modifications; correct items.
5. Calculate area/room air balance; is it process or comfort determined?	Consult users and standards of good practice.	Record shortfalls; implement design changes when critical.
6. Field evaluate exhaust system discharge: outlet design, stack velocity, reentrainment potential; sketch rooftop.	ACGIH Industrial Ventilation, ASHRAE Handbooks.	Record shortfalls; implement design changes for any system shortcoming.
7. Evaluate outdoor air dilution: intake location and cfm, control sequences, system ability to deliver to space.	Current system shop drawings, ASHRAE Std. 62.1-2004[1]	Field verify data and controls operation; measure outdoor air cfm at intake. Record shortfalls; implement design changes for any system shortcoming.

[1] *ASHRAE Standard 62.1-2004 – "Ventilation for Acceptable Indoor Air Quality" offers design guidance on adequate outdoor air introduction for HVAC systems. It is commonly inclusive to local building codes.*

Appendix H – IAQ Design Checklist

Project Particulars

Name: _____ Client: _____

Project Type: ☐ New Building ☐ Addition ☐ Renovation ☐ Remodeling ☐ Retrofit

Location: _____ Project & Site Descriptions: _____

Occupant: _____

Representative: _____

Architect: _____ HVAC Designer: _____

Reviewer Signoffs

Program _____ *Initials* _____ *Date* Design Dev _____ *Initials* _____ *Date* Construction _____ *Initials* _____ *Date* Comm _____ *Initials* _____ *Date*

IAQ Expectations: _____

Key Design Factors *(note baseline values for key typical spaces)*

Space #1: _____

Temperature: _____ °F Summer _____ °F Winter

Humidity: _____ % rh _____ % rh

Air Motion: _____ fpm max _____ fpm min

Ventilation: _____cfm/person _____cfm/ft² _____air changes/hr

Occupancy: _____ Max _____ Min or _____/1000 ft²

Room Air Distribution: _____

E_z: _____ E_v: _____ w/ $Z_p \leq$ _____

Contaminant: _____ Class____

Filtration: Type _____ MERV ____(remote)

Type _____ MERV ____(local)

Direct Exh: _____cfm _____cfm/ft² ☐ dedicated ☐ central

Space #2: _____

Temperature: _____ °F Summer _____ °F Winter

Humidity: _____ % rh _____ % rh

Air Motion: _____ fpm max _____ fpm min

Ventilation: _____cfm/person _____cfm/ft² _____air changes/hr

Occupancy: _____ Max _____ Min or _____/1000 ft²

Room Air Distribution: _____

E_z: _____ E_v: _____ w/ $Z_p \leq$ _____

Contaminant: _____ Class____

Filtration: Type _____ MERV ____(remote)

Type _____ MERV ____(local)

Direct Exh: _____cfm _____cfm/ft² ☐ dedicated ☐ central

Space #3: _____

Temperature: _____ °F Summer _____ °F Winter

Humidity: _____ % rh _____ % rh

Air Motion: _____ fpm max _____ fpm min

Ventilation: _____cfm/person _____cfm/ft² _____air changes/hr

Occupancy: _____ Max _____ Min or _____/1000 ft²

Room Air Distribution: _____

E_z: _____ E_v: _____ w/ $Z_p \leq$ _____

Contaminant: _____ Class____

Filtration: Type _____ MERV ____(remote)

Type _____ MERV ____(local)

Direct Exh: _____cfm _____cfm/ft² ☐ dedicated ☐ central

Space #4: _____

Temperature: _____ °F Summer _____ °F Winter

Humidity: _____ % rh _____ % rh

Air Motion: _____ fpm max _____ fpm min

Ventilation: _____cfm/person _____cfm/ft² _____air changes/hr

Occupancy: _____ Max _____ Min or _____/1000 ft²

Room Air Distribution: _____

E_z: _____ E_v: _____ w/ $Z_p \leq$ _____

Contaminant: _____ Class____

Filtration: Type _____ MERV ____(remote)

Type _____ MERV ____(local)

Direct Exh: _____cfm _____cfm/ft² ☐ dedicated ☐ central

Outdoor Air Quality *(sketch building and sources on a site plan)*

Source: ☐ EPA AQI ☐ Measured AQI Days within Category: Good _____ Moderate _____ Unhealthy-Sensitive _____ Unhealthy _____

AQI Pollutant Days: _____ CO _____ NO_2 _____ O_3 _____ SO_2 _____ PM 2.5 _____ PM10

Outdoor Air/ Site Contaminant Sources: ☐ Roadway ☐ Loading Dock ☐ Vapor Plume ☐ Exhaust Discharge
☐ Gases ☐ Vents ☐ Offensive Odor ☐ Dust/Dirt ☐ Insect/Vermin/Birds ☐ Standing Water

Prevailing Winds: (note S&W Seasons) _____ N _____ S _____ E _____ W _____ NE _____ NW _____ SE _____ SW

Note Contaminant Details: _____

_____

Indoor Air Quality *(normally applies to existing facilities; sketch sources on floor plan)*

Indoor Air & Building Contaminant Sources:

☐ Finishes ☐ Furnishings ☐ Drapes/Floor Coverings
☐ Vapor Barrier ☐ Moisture Barrier ☐ Wetted Materials
☐ Mold/Mildew ☐ Condensate ☐ Condensation ☐ ACM ☐ Lead
☐ Deposits ☐ Odors ☐ Radon ☐ Gases ☐ Particulate/Vapor
☐ Smoking/ETS ☐ Duplicating Machines ☐ Labs ☐ Industrial Processes

Note Contaminant Details: _____

_____

System Ventilation Features

Minimum Separation Distance from Air Intake *(check items found on job site/site plan)*

1 Foot: ☐ Rooftop ☐ Landscaped Grade ☐ Snowfall

5 Feet: ☐ Vehicle Exhaust

15 Feet: ☐ Auto Loading Area ☐ Chimney ☐ Drive-thru Queue ☐ Vent ☐ Flue ☐ Garage Entry
☐ Garbage Activities ☐ Contaminated Exhaust ☐ Cooling Tower Inlet/Basin

25 Feet: ☐ Truck Loading Dock ☐ High Traffic Roadways ☐ Cooling Tower Discharge ☐ Bus Idling

30 Feet: ☐ Noxious Exhaust ☐ Dangerous Exhaust

Other Outdoor Air Quality Concerns *(check items reviewed against design)*

☐ Rain & Snow Entrainment ☐ Rain Intrusion ☐ HVAC system source control (particulates & bioaerosols)

Ventilation Requirements

Procedure: ☐ Ventilation Rate Procedure ☐ Indoor Air Quality Procedure

General Ventilation *(see Key Design Factors for typical space)*

Special Ventilation

Space A (_____) : _____ cfm/person _____ cfm/ft^2 Space B (_____) : _____ cfm/person _____ cfm/ft^2
Space C (_____) : _____ cfm/person _____ cfm/ft^2 Space D (_____) : _____ cfm/person _____ cfm/ft^2
Space E (_____) : _____ cfm/person _____ cfm/ft^2 Space F (_____) : _____ cfm/person _____ cfm/ft^2
Space G (_____) : _____ cfm/person _____ cfm/ft^2 Space H (_____) : _____ cfm/person _____ cfm/ft^2
Space I (_____) : _____ cfm/person _____ cfm/ft^2 Space J (_____) : _____ cfm/person _____ cfm/ft^2

Appendix H – IAQ Design Checklist (cont)

Minimum Exhaust Rate *(check areas found on project)*

0.25 cfm/ft²: ☐ Dressing Room

0.30 cfm/ft²: ☐ Kitchenette

0.50 cfm/ft²: ☐ Barber Shop ☐ Woodwork Shop/Classroom ☐ Locker Room ☐ Copy/Printing Room ☐ Arena

0.60 cfm/ft²: ☐ Beauty and Nail Salon

0.70 cfm/ft²: ☐ Art Classroom ☐ Commercial Kitchen

0.75 cfm/ft²: ☐ Parking Garage

0.90 cfm/ft²: ☐ Pet Store (animal area)

1.00 cfm/ft²: ☐ Cell with Toilet ☐ Science Lab Classroom ☐ Janitor Closet ☐ Trash Room ☐ Darkroom

1.50 cfm/ft²: ☐ Auto Repair Spaces

50 cfm/unit: ☐ Public Toilet ☐ Public Urinal

Air Recirculation Class *(check for these "other spaces" on the job)*

Class 1: (low) ☐ Break Room ☐ Coffee Station ☐ Equipment Room ☐ Electric/Telephone Closet ☐ Elevator Machine Room

Class 2: (moderate) ☐ Kitchenette ☐ Private Restroom ☐ Locker Room ☐ Laundry Room ☐ University Laboratories

Class 3: (significant contaminant) ☐ Daycare Sickroom ☐ Soiled Laundry Room ☐ Janitor's Closet ☐ Trash Room ☐ Chemical/Biological Laboratories ☐ Refrigerating Machinery Room ☐ Kitchen Hood (non-grease)

Class 4: (harmful) ☐ Chemical Storage Room ☐ Paint Spray Booth ☐ Kitchen Grease Hood ☐ Laboratory Hood ☐ Diazo Printing

HVAC System IAQ Design Features

System: _____ Type: ☐ All-Air ☐ All-Water ☐ Direct Refrigerant ☐ Air-Water ☐ Multiple Zones ☐ Reheat

Primary Airflow: ☐ CAV ☐ VAV Zone Airflow: ☐ CAV ☐ VAV ☐ Minimums Specified

Locations-Equipment: _____ Outdoor Air Intake: _____

Primary Outdoor Contaminants: _____

Primary Indoor Contaminants: _____

Filtration *(list remote at central equipment and/or local at zone area)*

Filter 1: Type _____ MERV ____ fpm____ Ps: Initial _____ / Final _____ Location: _____ Airstream _____

Filter 2: Type _____ MERV ____ fpm____ Ps: Initial _____ / Final _____ Location: _____ Airstream _____

Filter 3: Type _____ MERV ____ fpm____ Ps: Initial _____ / Final _____ Location: _____ Airstream _____

Humidity Control *(additional cooling load estimates may need to be run)*

HVAC Design Load (peak loads at Design Cond): _____Tons _____MBtuh sensible _____ MBtuh latent _____ RSHF

Part Load at Design Cond (diversified internal loads): _____Tons _____MBtuh sensible _____ MBtuh latent _____ RSHF

Part Load at Dehumid (light loads with max OA latent): _____Tons _____MBtuh sensible _____ MBtuh latent _____ RSHF

Cooling Design Conditions: _____° F db _____° F wb, resulting room conditions: _____° F db _____ %rh

Dehumidification Design Conditions: _____° F db _____° F dp _____ gr/lb, resulting room conditions: _____° F db _____% rh

Balancing *(pressurize for containment & avoiding infiltration)*

Class 3 and 4 spaces: _____

Infiltration Potentials: ☐ Older Building ☐ Tall Building ☐ Windy Site ☐ Operable Windows ☐ Floor Penetrations ☐ Wall Openings

Pressurization: _____ cfm of outdoor air - _____ cfm exhaust = _____ cfm 4 _____ cfm supply air = _____ %

Operations and Maintenance *(check final specification coverage)*

- ☐ Commissioning Plan
- ☐ Testing & Balancing
- ☐ Construction IAQ Plan
- ☐ Start-up/Training
- ☐ O&M Manuals
- ☐ Spare Filters

Control Sequences, Check Conformance with ASHRAE 62.1-_____:

- ☐ Minimum Outdoor Airflow
- ☐ Unoccupied Humidity Limit
- ☐ Occupied Humidity Limit
- ☐ Moisture Intrusion
- ☐ Contaminant Exceedence
- ☐ Dynamic Reset

Contaminant Monitoring: ☐ CO ☐ CO_2 ☐ NO_x ☐ O_3 ☐ SO_2 ☐ TVOC ☐ PM2.5 ☐ O_2 Refrigerant, R-_____

Ventilation Flow Measurement:

- ☐ Return Air
- ☐ Outdoor Air
- ☐ Supply Air
- ☐ Differential (Pressurization)
- ☐ Exhaust Air

Access and Service Required:

- ☐ Cooling Towers
- ☐ OA Intakes
- ☐ Plenum Drains
- ☐ Wet Ducts
- ☐ Dampers
- ☐ Filters
- ☐ Coils
- ☐ Drain Pans
- ☐ Humidifiers
- ☐ Terminals
- ☐ Sensors
- ☐ Controls

Appendix I – Chicago Office Building IAQ Checklist

Project Particulars

Name: Chicago Office Building Client: Wagner Development

Project Type: ☒ New Building ☐ Addition ☐ Renovation ☐ Remodeling ☐ Retrofit

Location: Elk Grove Village, IL

Occupant: Multi-tenant leases

Representative: Ed J. - Wagner Dev.

Architect: Dave T.

Project & Site Descriptions: Large floor plate multi-story office building on a flat suburban site. Airport to E. Interstate ½ mi. to W.

HVAC Designer: Bill C.

Reviewer Signoffs

	Initials	Date
Program	WCC	5/3/05
Design Dev		
Construction		
Comm		

IAQ Expectations: Developer specializes in class "A" real estate. IAQ must be above minimum standards.

Key Design Factors *(note baseline values for key typical spaces)*

Space #1: Open office areas

Temperature:	75 °F Summer	70 °F Winter
Humidity:	50 %rh	20 %rh
Air Motion:	45 fpm max	35 fpm min
Ventilation:	20 cfm/person -- cfm/ft² -- air changes/hr	
Occupancy:	____ Max ____ Min or 5 /1000 ft²	

Room Air Distribution: Clg. 4-way blow; Perf. ret.

E_z: ____ E_v: ____ w/ $Z_p \leq$ ____

Contaminant: Bioeffluents, OA Class 1

Filtration: Type Bag MERV 16 (remote)

Type ____ MERV ____ (local)

Direct Exh: ____ cfm ____ cfm/ft² ☐ dedicated ☐ central

Space #2: Private offices

Temperature:	72 °F Summer	70 °F Winter
Humidity:	50 %rh	30 %rh
Air Motion:	30 fpm max	30 fpm min
Ventilation:	25 cfm/person -- cfm/ft² -- air changes/hr	
Occupancy:	3 Max 1 Min or ____ /1000 ft²	

Room Air Distribution: 2-way/1-way slots; Light fixt. ret.

E_z: ____ E_v: ____ w/ $Z_p \leq$ ____

Contaminant: Bioeffluents, OA Class 1

Filtration: Type Bag MERV 16 (remote)

Type ____ MERV ____ (local)

Direct Exh: ____ cfm ____ cfm/ft² ☐ dedicated ☐ central

Space #3: Conference Rooms

Temperature:	74 °F Summer	70 °F Winter
Humidity:	50 %rh	20 %rh
Air Motion:	35 fpm max	-- fpm min
Ventilation:	30 cfm/person 2 cfm/ft² ____ air changes/hr	
Occupancy:	____ Max ____ Min or ____ /1000 ft²	

Room Air Distribution: 2-way slots; Light fixt. ret.

E_z: ____ E_v: ____ w/ $Z_p \leq$ ____

Contaminant: Food odors Class ____

Filtration: Type Bag MERV 16 (remote)

Type Carbon, ESP MERV ____ (local)

Direct Exh: ____ cfm 1.0 cfm/ft² ☐ dedicated ☒ central

Space #4: Copy centers

Temperature:	76 °F Summer	72 °F Winter
Humidity:	45 %rh	35 %rh
Air Motion:	50 fpm max	-- fpm min
Ventilation:	30 cfm/person 1 cfm/ft² ____ air changes/hr	
Occupancy:	____ Max ____ Min or ____ /1000 ft²	

Room Air Distribution: Clg. 4-way blow; Perf. Ret. ret.

E_z: ____ E_v: ____ w/ $Z_p \leq$ ____

Contaminant: Particulates/O_3 Class 1

Filtration: Type Bag MERV 16 (remote)

Type ____ MERV ____ (local)

Direct Exh: ____ cfm 1.5 cfm/ft² ☐ dedicated ☒ central

Outdoor Air Quality *(sketch building and sources on a site plan)*

Source: ☒ EPA AQI ☐ Measured AQI Days within Category: Good 54 Moderate 268 Unhealthy-Sensitive 14 Unhealthy 0

AQI Pollutant Days: 1 CO 0 NO_2 8 O_3 1 SO_2 321 PM 2.5 5 PM10

Outdoor Air/ Site Contaminant Sources: ☒ Roadway ☐ Loading Dock ☒ Vapor Plume ☒ Exhaust Discharge
☐ Gases ☐ Vents ☐ Offensive Odor ☐ Dust/Dirt ☐ Insect/Vermin/Birds ☐ Standing Water

Prevailing Winds: (note S&W Seasons) ___ N ___ S ___ E ___ W ___ NE W NW ___ SE S SW

Note Contaminant Details: Interstate 290 is ½ mile to West. Neighboring buildings have potentially annoying discharges.

Indoor Air Quality *(normally applies to existing facilities; sketch sources on floor plan)*

Indoor Air & Building Contaminant Sources:
☒ Finishes ☒ Furnishings ☒ Drapes/Floor Coverings
☐ Vapor Barrier ☐ Moisture Barrier ☐ Wetted Materials
☐ Mold/Mildew ☐ Condensate ☐ Condensation ☐ ACM ☐ Lead
☐ Deposits ☐ Odors ☐ Radon ☐ Gases ☐ Particulate/Vapor
☐ Smoking/ETS ☐ Duplicating Machines ☐ Labs ☐ Industrial Processes

Note Contaminant Details: Building commissioning includes a 60 hour, 100% OA flush-out procedure before occupancy.

System Ventilation Features

Minimum Separation Distance from Air Intake *(check items found on job site/site plan)*

1 Foot: ☒ Rooftop ☒ Landscaped Grade ☒ Snowfall
5 Feet: ☒ Vehicle Exhaust
15 Feet: ☐ Auto Loading Area ☐ Chimney ☐ Drive-thru Queue ☒ Vent ☐ Flue ☐ Garage Entry
☒ Garbage Activities ☐ Contaminated Exhaust ☐ Cooling Tower Inlet/Basin
25 Feet: ☒ Truck Loading Dock ☒ High Traffic Roadways ☒ Cooling Tower Discharge ☐ Bus Idling
30 Feet: ☐ Noxious Exhaust ☐ Dangerous Exhaust

Other Outdoor Air Quality Concerns *(check items reviewed against design)*

☐ Rain & Snow Entrainment ☐ Rain Intrusion ☐ HVAC system source control (particulates & bioaerosols)

Ventilation Requirements

Procedure: ☒ Ventilation Rate Procedure ☐ Indoor Air Quality Procedure

General Ventilation *(see Key Design Factors for typical space)* (4 people/100 ft²)

Special Ventilation

Space A (Break room):	9 cfm/person	___ cfm/ft²	Space B (Computer rm.):	20 cfm/person	___ cfm/ft²
Space C (Restrooms):	___ cfm/person	0.12 cfm/ft²	Space D (Lobby):	11 cfm/person	___ cfm/ft²
Space E (Janitor clst.):	___ cfm/person	1(exh) cfm/ft²	Space F (___):	___ cfm/person	___ cfm/ft²
Space G (___):	___ cfm/person	___ cfm/ft²	Space H (___):	___ cfm/person	___ cfm/ft²
Space I (___):	___ cfm/person	___ cfm/ft²	Space J (___):	___ cfm/person	___ cfm/ft²

Appendix I – Chicago Office Building IAQ Checklist (cont)

Minimum Exhaust Rate *(check areas found on project)*

0.25 cfm/ft²: ☒ Dressing Room

0.30 cfm/ft²: ☐ Kitchenette

0.50 cfm/ft²: ☐ Barber Shop ☐ Woodwork Shop/Classroom ☐ Locker Room ☒ Copy/Printing Room ☐ Arena

0.60 cfm/ft²: ☐ Beauty and Nail Salon

0.70 cfm/ft²: ☐ Art Classroom ☐ Commercial Kitchen

0.75 cfm/ft²: ☐ Parking Garage

0.90 cfm/ft²: ☐ Pet Store (animal area)

1.00 cfm/ft²: ☐ Cell with Toilet ☐ Science Lab Classroom ☒ Janitor Closet ☐ Trash Room ☐ Darkroom

1.50 cfm/ft²: ☐ Auto Repair Spaces

50 cfm/unit: ☒ Public Toilet ☒ Public Urinal

Air Recirculation Class *(check for these "other spaces" on the job)*

Class 1: (low) ☒ Break Room ☒ Coffee Station ☒ Equipment Room ☒ Electric/Telephone Closet ☒ Elevator Machine Room

Class 2: (moderate) ☐ Kitchenette ☐ Private Restroom ☐ Locker Room ☐ Laundry Room ☐ University Laboratories

Class 3: (significant contaminant) ☐ Daycare Sickroom ☐ Soiled Laundry Room ☒ Janitor's Closet ☐ Trash Room ☐ Chemical/Biological Laboratories ☒ Refrigerating Machinery Room ☐ Kitchen Hood (non-grease)

Class 4: (harmful) ☐ Chemical Storage Room ☐ Paint Spray Booth ☐ Kitchen Grease Hood ☐ Laboratory Hood ☐ Diazo Printing

HVAC System IAQ Design Features

System: Cntl. AHU/PFPMB Type: ☒ All-Air ☐ All-Water ☐ Direct Refrigerant ☐ Air-Water ☐ Multiple Zones ☐ Reheat

Primary Airflow: ☐ CAV ☒ VAV Zone Airflow: ☐ CAV ☐ VAV ☐ Minimums Specified

Locations-Equipment: Penthouse-Clg. Pln. Outdoor Air Intake: Roofop Penthouse - 4' AFR

Primary Outdoor Contaminants: Particulates (PM2.5)

Primary Indoor Contaminants: TVOC, Bioaerosols

Filtration *(list remote at central equipment and/or local at zone area)*

Filter 1: Type Pleated MERV 6 fpm 400 Ps: Initial 0.50 / Final 1.0 Location: Cntl. AHU Airstream OA

Filter 2: Type Bag MERV 16 fpm 250 Ps: Initial 0.30 / Final 1.0 Location: Cntl. AHU Airstream MA

Filter 3: Type Carbon MERV ____ fpm 400 Ps: Initial 0.40 / Final 0.50 Location: Cntl. AHU Airstream MA

Humidity Control *(additional cooling load estimates may need to be run)*

HVAC Design Load (peak loads at Design Cond): _____ Tons _____ MBtuh sensible _____ MBtuh latent _____ RSHF

Part Load at Design Cond (diversified internal loads): _____ Tons _____ MBtuh sensible _____ MBtuh latent _____ RSHF

Part Load at Dehumid (light loads with max OA latent): _____ Tons _____ MBtuh sensible _____ MBtuh latent _____ RSHF

Cooling Design Conditions: _____ ° F db _____ ° F wb, resulting room conditions: _____ ° F db _____ %rh

Dehumidification Design Conditions: _____ ° F db _____ ° F dp _____ gr/lb, resulting room conditions: _____ ° F db _____ %rh

Balancing *(pressurize for containment & avoiding infiltration)*

Class 3 and 4 spaces: 3-Refrigerating machinery room, janitor closets

Infiltration Potentials: ☐ Older Building ☐ Tall Building ☐ Windy Site ☐ Operable Windows ☐ Floor Penetrations ☐ Wall Openings

Pressurization: _____ cfm of outdoor air - _____ cfm exhaust = _____ cfm 4 _____ cfm supply air = _____ %

Operations and Maintenance *(check final specification coverage)*

- [x] Commissioning Plan
- [x] Testing & Balancing
- [x] Construction IAQ Plan
- [x] Start-up/Training
- [x] O&M Manuals
- [x] Spare Filters

Control Sequences, Check Conformance with ASHRAE 62.1- 2004

- [x] Minimum Outdoor Airflow
- [x] Unoccupied Humidity Limit
- [x] Occupied Humidity Limit
- [x] Moisture Intrusion
- [ ] Contaminant Exceedence
- [x] Dynamic Reset

Contaminant Monitoring: [ ] CO [x] CO_2 [ ] NO_x [ ] O_3 [ ] SO_2 [ ] TVOC [x] PM2.5 [ ] O_2 Refrigerant, R- 134a

Ventilation Flow Measurement:

- [ ] Return Air
- [x] Outdoor Air
- [ ] Supply Air
- [ ] Differential (Pressurization)
- [ ] Exhaust Air

Access and Service Required:

- [x] Cooling Towers
- [x] OA Intakes
- [x] Plenum Drains
- [x] Wet Ducts
- [x] Dampers
- [x] Filters
- [x] Coils
- [x] Drain Pans
- [x] Humidifiers
- [x] Terminals
- [x] Sensors
- [x] Controls

Appendix J – HVAC System Selection and Design Documentation Form

(Enter values where appropriate throughout design)

Design Team

HVAC Designer: _____ HVAC Project Engineer: _____

Project Manager: _____ Contractor: _____

Architect: _____ Owner's Representative: _____

Reviewer Signoffs

Program _____ (Initials) _____ (Date) Schematics _____ (Initials) _____ (Date) Design Dev _____ (Initials) _____ (Date) Constr Doc _____ (Initials) _____ (Date)

Bidding _____ (Initials) _____ (Date) Construction _____ (Initials) _____ (Date) Comm _____ (Initials) _____ (Date) Warranty _____ (Initials) _____ (Date)

Project Particulars

Name: _____ Location: _____ Latitude: _____

Client: _____ Occupant: _____ Job No.: _____

Project Description: _____

Project Type: ☐ New Building ☐ Addition ☐ Renovation ☐ Remodeling ☐ Retrofit

Construction Type: _____ Occupancy Group: _____

Construction Area (ft)

Length: _____ Width: _____ Height: _____

Gross Area: _____ Conditioned Area: _____ Volume: _____

Construction Budgets

	Overall	HVAC	Plumbing	Electric
$1000				
$ per sq ft				

Design and Construction Schedule: Kickoff Date: _____ Bid Date: _____ Move-in Date: _____

Delivery Method

☐ Plan and Spec ☐ Construction Management

☐ Design-Build ☐ Performance/Contract

Sustainable Design Level (LEED)

☐ Basic ☐ Silver ☐ Gold ☐ Platinum

Certified: ☐ Yes ☐ No

Key Design Factors *(list priority criteria for design, equipment selection, and layout)*

Temperature-related: _____

_____

Humidity-related: _____

_____

Airflow-related: _____

_____

Air quality-related: _____

_____

Available space-related: _____

_____

Zoning-related: _____

_____

Codes-related: _____

_____

Acoustics-related: _____

Comfort Design Criteria *(Baseline – note unusual conditions above)*

	Space #1:						Space #2:					
Temperature	Occupied		Unoccupied		Throttling Range	Swing	Occupied		Unoccupied		Throttling Range	Swing
	Design	Min	Design	Min			Design	Min	Design	Min		
Summer												
Winter												
Humidity	Design	Max	Min				Design	Max	Min			
Summer												
Winter												
Air Motion	Max	Min	Notes				Max	Min	Notes			
fpm												
Ventilation	Occupied		Unoccupied		Notes		Occupied		Unoccupied		Notes	
	People	Area	Min	Purge			People	Area	Min	Purge		
cfm												
Direct Exhaust												
Filtration	Contaminant		MERV	Type	Other		Contaminant		MERV	Type	Other	
Radiant Surface	Glass	Wall	Floor	Roof	Other		Glass	Wall	Floor	Roof	Other	
Summer												
Winter												
Acoustics												
Notes												

Appendix J – HVAC System Selection and Design Documentation Form (cont)

Rough Heating, Cooling, and Airflow Loads *(note space/area covered in calculations)*

Heating	sq ft * Btuh / sq ft	
Cooling	sq ft ÷ sq ft / ton	
Sensible Heat Ratio	sensible Btuh ÷ total Btuh	
Airflow	sq ft * cfm / sq ft	
Air Changes / hour	(airflow * 60) ÷ (sq ft * ht)	

Initial System Choices

Name	Elements	Advantages	Disadvantages	Relative Cost

Basic Design Criteria *(Distill out of above items and design team conversations)*

Comfort *(note any details beyond Comfort Design Criteria)*

Temperature: _____

Humidity: _____

Air Motion: _____

Ventilation: _____

Filtration: _____

IAQ: _____

Energy: _____

Sound: _____

Capacity *(list main system/building total, and ft² served)*

Cooling _____ $\frac{\text{Btuh}}{\text{ft}^2}$ = _____ Btuh/ft² *OR* _____ $\frac{\text{ft}^2}{\text{tons}}$ = _____ ft²/ton

Heating _____ $\frac{\text{Btuh}}{\text{ft}^2}$ = _____ Btuh/ft² *OR* _____ $\frac{\text{Boiler hp}}{\text{ft}^2}$ = _____ ft²/bhp

Airflow _____ $\frac{\text{cfm}}{\text{ft}^2}$ = _____ cfm/ft²

RAD Configuration: _____

_____ E_z: _____

System Ventilation Efficiency, E_v _____ w/ max (Z_p) ≤ _____, > 0.55

Installation *(note building space restraints affecting design)*

MER: _____ ft² Ceiling Plenum Depth: _____ in. Structure Depth: _____ in. Underfloor Plenum Depth: _____ in.

Rooftop Equipment Restrictions: _____

Site Equipment Restrictions: _____

HVAC Cost Design Guidelines *(Note "amounts" used for "dollars per" calculations)*

Project Budgets	Overall HVAC	Cooling _____ ton	Heating _____ MBtuh	AHU _____ cfm	Airside	Waterside	Ductwork _____ lb	Piping _____ gpm	Controls _____ points	Commissioning
Dollars (1000s)										
Dollars/ft²										
Dollars/ton										
Dollars/MBtuh										
Dollars/lb										
Dollars/cfm										
Dollars/gpm										
Dollars/point										

Schedule *(note any details beyond Project Particulars)*

Design Period: _____

_____

Construction Period: _____

_____

Phasing: _____

_____

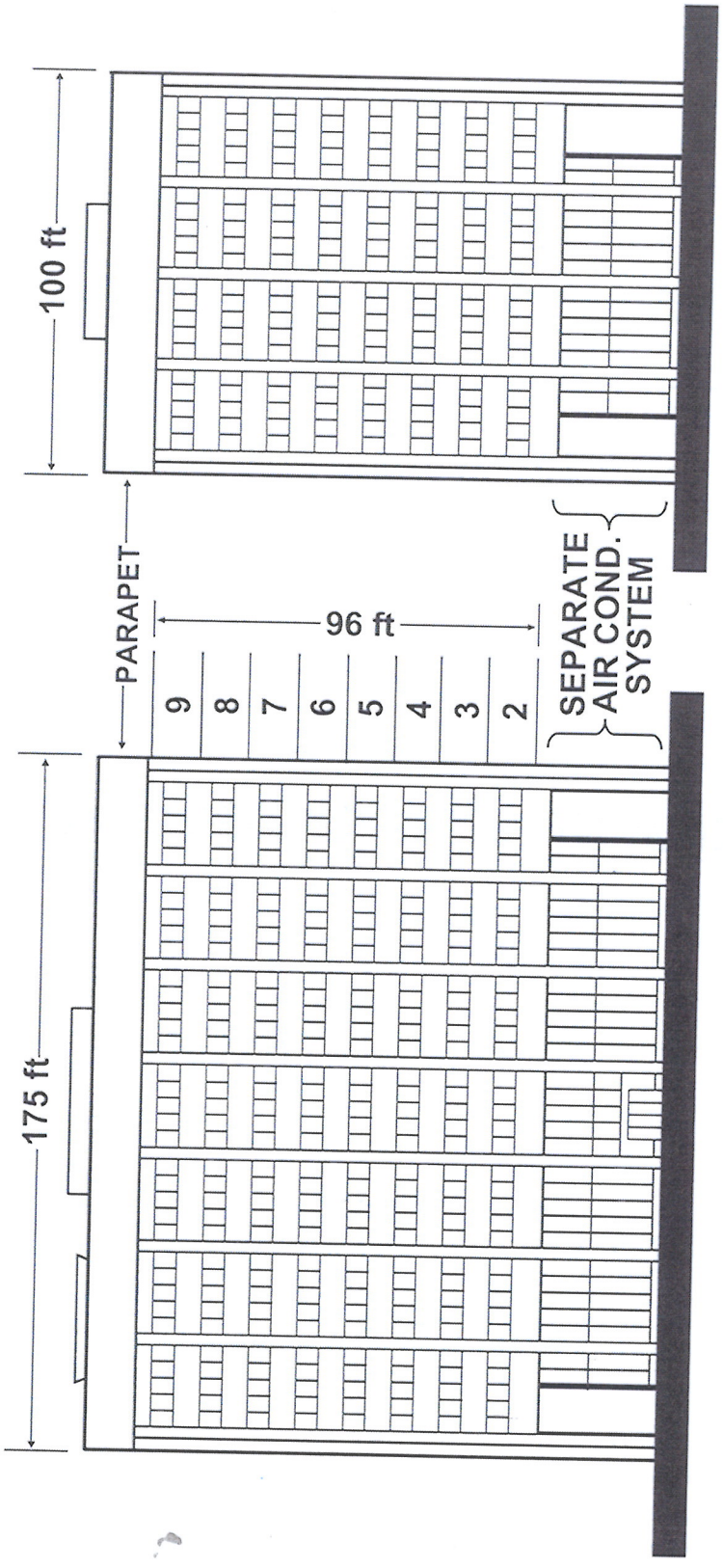
Commissioning: _____

_____

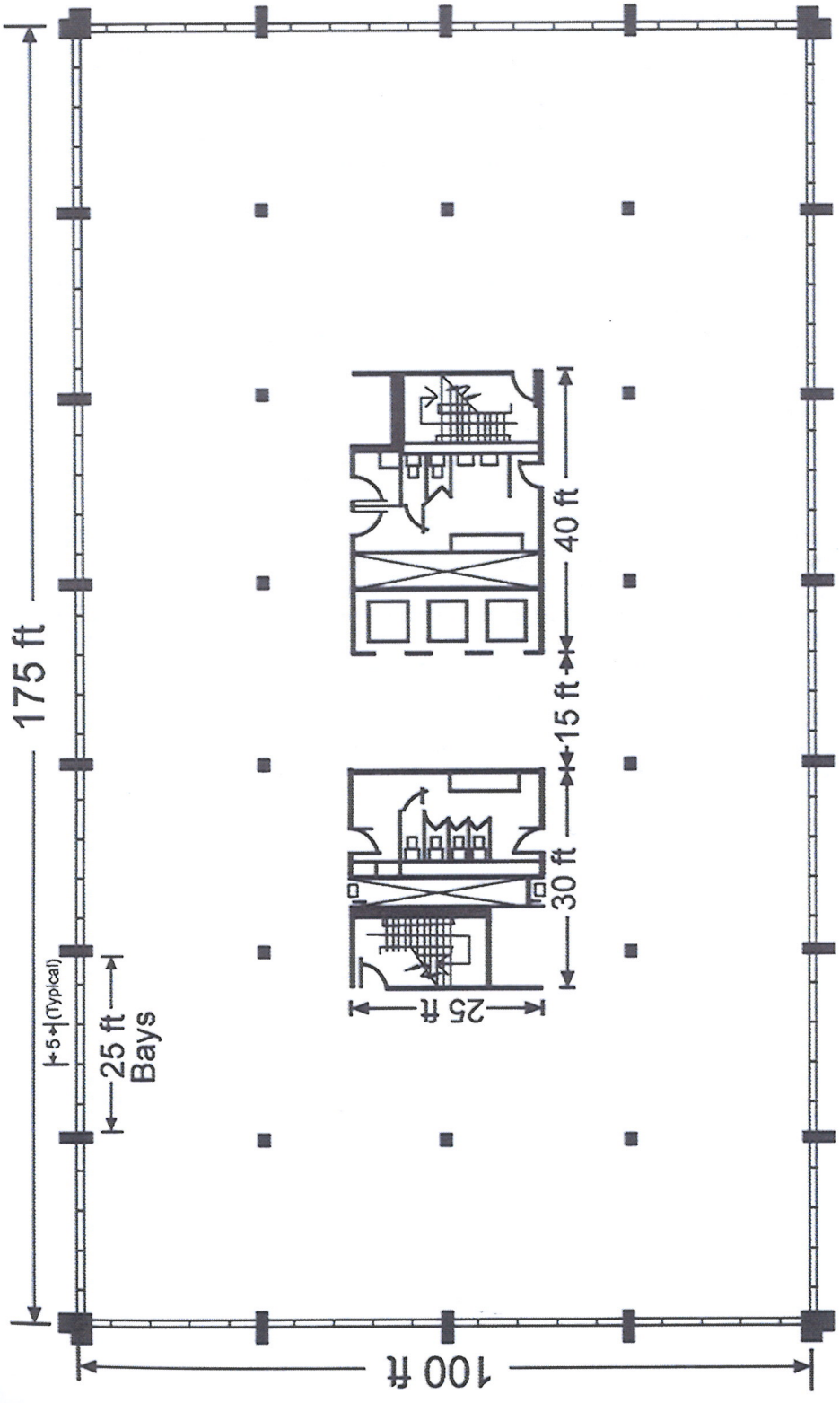
Additional Notes and Later Phase Changes

Functional Criteria	Special Criteria
Evaluated Systems	Priority Evaluation Criteria
Selected System (draw schematics, air and water)	Schematic Design Parameters
Design Development Adjustments	Bidding Changes
Construction Changes	Other

Appendix K – Chicago Office Building Elevations



Appendix L – Chicago Office Building Typical Floor Plan



Appendix M – Air Intake Minimum Separation Distance

Table 5-1 Air Intake Minimum Separation Distance (ASHRAE 62.1-2004)

Object	Minimum Distance, ft (m)
Significantly contaminated exhaust (Note 1)	15 (5)
Noxious or dangerous exhaust (Notes 2 and 3)	30 (10)
Vents, chimneys, and flues from combustion appliances and equipment (Note 4)	15 (5)
Garage entry, automobile loading area, or drive-in queue (Note 5)	15 (5)
Truck loading area or dock, bys parking/idling area (Note 5)	25 (7.5)
Driveway, street, or parking place (Note 5)	5 (1.5)
Thoroughfare with high traffic volume	25 (7.5)
Roof, landscaped grade, or other surface directly below intake (Notes 6 and 7)	1 (0.30)
Garbage storage/pick-up area, dumpsters	15 (5)
Cooling tower intake or basin	15 (5)
Cooling tower exhaust	25 (7.5)

Note 1: Significantly contaminated exhaust is exhaust air with significant contaminant concentration, significant sensory-irritation intensity, or offensive odor.

Note 2: Laboratory fume hood exhaust air outlets shall be in compliance with NFPA 45-1991 and ANSI/AIHA Z9.5-1992.

Note 3: Noxious or dangerous exhaust is exhaust air with highly objectionable fume or gases and/or exhaust air with potentially dangerous particles, bioaerosols, or gases at concentrations high enough to be considered harmful. Information on separation criteria for industrial environments can be found in the ACGIH Industrial Ventilation Manual and in the *ASHRAE Handbook — HVAC Applications*.

Note 4: Shorter separation distances are permitted when determined in accordance with (a) Chapter 7 of ANSI Z223.1/NFPA 54-2002 for fuel gas burning appliances and equipment; (b) Chapter 6 of NFPA 31-2001 for oil burning appliances and equipment, or (c) Chapter 7 of NFPA 211-2003 for other combustion appliances and equipment.

Note 5: Distance measured to closest place that vehicle exhaust is likely to be located.

Note 6: No minimum separation distance applies to surfaces that are sloped more than 45 degrees from horizontal or that are less than 1 in. (3 cm) wide.

Note 7: Where snow accumulation is expected, distance listed shall be increased by the expected average snow depth.

Appendix N – Zone Air Distribution Effectiveness

Table 6-2 Zone Air Distribution Effectiveness (ASHRAE 62.1-2004)

Air Distribution Configuration	E_z
Ceiling supply of cool air	1.0
Ceiling supply of warm air and floor return	1.0
Ceiling supply of warm air 15° F (8° C) or more above space temperature and ceiling return.	0.8
Ceiling supply of warm air less than 15° F (8° C) above space temperature and ceiling return provided that the 150 fpm (0.8 m/s) supply air jet reaches to within 4.5 ft (1.4 m) of floor level. Note: For lower velocity supply air, E_z = 0.8.	1.0
Floor supply of cool air and ceiling return provided that the 150 fpm (0.8 m/s) supply jet reaches 4.5 (1.4 m) or more above the floor. Note: Most underfloor air distribution systems comply with this proviso.	1.0
Floor supply of cool and ceiling return, provided low-velocity displacement ventilation achieves unidirectional flow and thermal stratification.	1.2
Floor supply of warm air and floor return	1.0
Floor supply of warm air and ceiling return	0.7
Makeup supply drawn in on the opposite side of the room from the exhaust and/or return	0.8
Makeup supply drawn in near to the exhaust and/or return location.	0.5

1. "Cool air" is air cooler than space temperature.
2. "Warm air" is air warmer than space temperature.
3. "Ceiling" includes any point above the *breathing zone*.
4. "Floor" includes any point below the *breathing zone*.
5. As an alternative to using the above values, E_z may be regarded as equal to air change effectiveness determined in accordance with ASHRAE Standard 129 for all air distribution configurations except unidirectional flow.

Appendix O – System Ventilation Efficiency

Table 6-3 System Ventilation Efficiency (ASHRAE 62.1-2004)

Max (Z_p)	E_v
≤ 0.15	1.0
≤ 0.25	0.9
≤ 0.35	0.8
≤ 0.45	0.7
≤ 0.55	0.7
> 0.55	Use Appendix A of ASHRAE Standard 62.1-2004

1. "Max Z_p" refers to the largest value of Z_p, calculated using Equation 6-5, among all the zones served by the system.
2. For values of Z_p between 0.15 and 0.55, one may determine the corresponding value of E_v by interpolating the values in the table.
3. The values of E_v in this table are based on a 0.15 average outdoor air fraction for the system (i.e., the ratio of the *uncorrected outdoor air intake* V_{ou} to the total *zone primary airflow* for all the zones served by the air handler). For systems with higher values of the average outdoor air fraction, this table may result in unrealistically low values of E_v and the use of Appendix A may yield more practical results.

References

ASHRAE. (1992) "Standard 52.1 – Gravimetric and Dust Spot Procedures for Testing Air-Cleaning Devices Used in General Ventilation for Removing Particulate Matter."

ASHRAE. (1999) "Standard 52.2 – Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size."

ASHRAE. (2004) "Standard 62.1 – Ventilation for Acceptable Indoor Air Quality."

Carrier Corporation, "Comfort Design Made Simple." Form No. ENG-01, Cat. No. 795-200.

Carrier Corporation, "Room Air Distribution." Form No. TDP-507, Cat. No. 06-796-048.

Carrier Corporation, "System Selection." Form No. TDP-701, Cat. No. 06-796-066.

Commissioning Resource Library. http://www.peci.org/library.htm

EPA's Tools for Schools. http://www.epa.gov/iaq/schools/tools4s2.html

EPA Air Quality Index Reports. http://www.epa.gov/air/data/geosel.html

Glossary

absorbent	material which, due to an affinity, extracts one or more substances from a liquid or gaseous medium with which it is in contact and which changes physically or chemically, or both, during the process. Calcium chloride is an example of a solid absorbent, while solutions of lithium chloride, lithium bromide, and the ethylene glycols are examples of liquid absorbents.
adsorbent	material that has the ability to cause molecules of gases, liquids, or solids to adhere to its surfaces without changing the adsorbent physically or chemically. Certain commercially available solid materials, such as silica gel, activated carbon, and activated alumina, have this property.
Air Quality Index (AQI)	reported evaluation by the United States Environmental Protection Agency of the number of days within a calendar year that the National Ambient Air Quality Standards for the primary pollutants have been exceeded.
allergenic	a substance inducing a hypersensitivity reaction in an individual which in similar amounts is harmless to most people.
asphyxiant	a chemical or substance that causes or tends to cause loss of consciousness as a result of too little oxygen and too much carbon dioxide in the blood.
bioeffluents	odors produced by human activities
biofilm	a thin, usually resistant, layer of microorganisms that form on and coat various surfaces (such as cooling coils or water pipes)
carbon monoxide (CO)	a colorless, odorless, highly poisonous gas produced by the incomplete combustion of carbonaceous material.
carcinogens	substances that produce cancer.
contaminant	any substance that is foreign to a system that infects it or makes it impure.
desiccant	a substance that is absorbent or adsorbent, liquid or solid, that removes water or water vapor from a material.
dilution	process of weakening a contaminated substance by mixing it with a less contaminated substance.
environmental tobacco smoke (ETS)	smoke from tobacco combustion that diffuses within the indoor environment and is inhaled by the occupants.
filtration	the process of extracting impurities
formaldehyde (HCHO)	a colorless, pungent gas, used in solution as a strong disinfectant and preservative, and in the manufacture of synthetic resins, dyes, etc.
germicidal effect	ability to destroy microorganisms, especially bacteria that cause disease.
HEPA filter (absolute filter)	high efficiency particulate air filter
indoor air quality (IAQ)	controlling the types and levels of indoor contaminants. This process involves: material selection and moisture control within buildings; adequate ventilation with outdoor air; proper filtration; and the design, operation, and maintenance of comfort air conditioning systems for occupant benefit.
inorganic	composed of matter that is not animal or vegetable; not having the organized structure of living things.
ionizer	a device which creates electrically charged atoms or groups of atoms.
irritant	a substance which causes an organ or part of the body to be inflamed or sore.

MET	unit of metabolic rate for people. One MET is defined as 18.4 Btuh/ft^2, which is equal to the energy produced per unit surface area of a seated person at rest. The surface area of an average person is about 19 ft^2.
microbial growth	an increase in the number of microscopic organisms (microorganisms).
moisture incursion	a brief entry of water or moisture into the building materials of a space.
mycotoxin	a poisonous substance produced by a fungus, especially a mold.
organic	having the characteristics of, or derived from, living organisms.
outdoor air	air outside a building or air taken from outdoors and not previously circulated through an air conditioning system.
Ozone (O_3)	a form of oxygen usually produced by a discharge of electricity in the air, or by a photochemical reaction of sunlight and combustion fumes.
permissible exposure limit (PEL)	maximum allowed amount or concentration of a substance in the air issued by the U.S. Occupational Safety and Health Administration to protect workers against the health effects of exposure to hazardous substances.
pollutant	a substance that makes another substance unclean, impure or corrupt.
relative humidity	a measure of the moisture content in the air as a percentage of the maximum amount of moisture the air could hold at that dry bulb temperature.
respirable suspended particles	particles within the air, small enough to be inhaled into a nonciliated portion of the lung. Peak deposition of respirable particles occurs within the size range of 0.2 to 5.0 micrometers. Particles that have a diameter greater than 10 micrometers (aerodynamic) are not respirable.
sorbent	material which extracts one or more substances present in an atmosphere or mixture of gases or liquids with which it is in contact, due to an affinity for such substances.
threshold limit value (TLV)	exposure guidelines to hazardous substances published by the U.S. American Council of Governmental Industrial Hygienists.
total suspended particulates (TSP)	mass of particulates suspended in a unit volume of air as collected by a high-volume air sampler.
van der Waals force	the weak forces that contribute to intermolecular bonding.
vapor barrier	material or construction that adequately impedes the transmission of water vapor under specified conditions.
ventilation	process of supplying or removing air by natural or mechanical means to or from any space; such air may or may not have been conditioned.
volatile organic compounds (VOC)	organic compounds that readily produce vapor at room temperature and normal atmospheric pressure.

Notes:

Prerequisites:

To obtain the highest benefit from this module, it is suggested that participants have prerequisite knowledge from the TDPs listed below, or equivalent.

TDP No.	Book Cat. No.	Instructor CD Cat. No.	Title
TDP-102	796-026	797-026	ABCs of Comfort
TDP-103	796-027	797-027	Concepts of Air Conditioning

Learning Objectives:

After reading this module, participants will be able to:

- Understand the importance of IAQ and its effects on building occupants and operations.
- Understand the relationship between HVAC system design and operation to IAQ issues.
- Define common health effects resulting from poor IAQ.
- Identify air contaminants and their sources.
- Define a multi-step IAQ control strategy.
- Incorporate an IAQ design sequence into the design of an air-conditioning system.

Supplemental Material:

Those who wish to build their knowledge of IAQ should consider the following related publications for their library:

TDP No.	Book Cat. No.	Instructor CD Cat. No.	Title
TDP-909	06-796-063	06-797-063	Filtration
TDP-702	06-796-067	06-797-067	Comfort Control Principles
TDP-904	06-796-079	06-797-079	Sustainable HVAC Design

ASHRAE Guideline 10P, Criteria for Achieving Acceptable Indoor Environments

Instructor Information

Each TDP topic is supported with a number of different items to meet the specific needs of the user. Instructor materials consist of a CD-ROM disk that includes a PowerPoint™ presentation with convenient links to all required support materials required for the topic. This always includes: slides, presenter notes, text file including work sessions and work session solutions, quiz and quiz answers. Depending upon the topic, the instructor CD may also include sound, video, spreadsheets, forms, or other material required to present a complete class. Self-study or student material consists of a text including work sessions and work session answers, and may also include forms, worksheets, calculators, etc.



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