energydesignresources

design brief

INDOOR AIR QUALITY

Designing buildings for both high indoor air quality and energy efficiency requires an integrated design approach.

Summary

There is a movement in the commercial real estate industry to pay more attention to the issue of indoor air quality (IAQ) throughout the design and construction stages of a building's life. The "Green Design" movement also places emphasis on IAQ. This Design Brief defines indoor air quality, discusses ventilation as a method of maintaining high IAQ, and introduces demand controlled ventilation (DCV). With increasing concerns about electricity demand in California, 2001 Title 24 Standards require that DCV strategies be employed in high-density areas (occupant density of more than one person per 10 square feet). The brief ends with a discussion of seven ways to ensure that a building's indoor air quality strategy is both energy-efficient and health-inducing.

Introduction

The advent of sealed buildings with precise environmental control has been one of the most profound technological changes affecting the 20th-century world. For most of history, occupations kept people outdoors for long periods throughout the day. Today, the majority of the industrialized world's commerce depends on information-based economies, which requires many people to spend the majority of their time indoors. Without a doubt, modern building ventilation systems played a major role in fueling this powerful transformation; the quality of workplace ventilation cannot be underestimated in terms of impact on personal and national productivity.

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There are many sources of indoor pollution. These sources range from building materials and equipment to the human body. Pollutants created by the human body itself and its metabolic processes include carbon dioxide, heat, odors, and perspiration. With the industrial revolution came high-tech electronic equipment and various synthetic materials, both of which are additional pollutant sources; the result is a myriad of pollutants in today's indoor environments.

ASHRAE Definition of Acceptable Air Quality

"Air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority (80 percent or more) of the people exposed do not express dissatisfaction."[1]

Defining Indoor Air Quality

For the past several years, there have been many debates among indoor air quality specialists about the proper definition of indoor air quality and specifically what constitutes "acceptable" indoor air quality. Consequently, it is probably best to reference the currently accepted definition shown in the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) ventilation standard 62-1999 (**Sidebar**).[1]

There are two key elements to this definition. The first is that the levels of contaminants at which health impacts can occur are not set by ASHRAE per se, but by "cognizant authorities." This element recognizes that ASHRAE is a body of engineers, not medical specialists. The second element in this definition is that ASHRAE has accepted that not everyone will find the indoor air quality acceptable, no matter what parameters are varied. The figure of 80 percent acceptability is essentially an arbitrary one, but it has been used for decades. Bear in mind that, in theory at least, in a building housing 1,000 people, 200 people could find conditions in the building unsatisfactory, yet the air may be considered "acceptable" via this definition. Therefore, the latest ASHRAE standard contains an important caveat, which reads as follows:

In a building housing 1,000 people, 200 people could find conditions in the building to be unsatisfactory, yet the air may be considered "acceptable."

> *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 psychological stress; and*

(c) *because of the range of susceptibility in the population.*[1]

Ventilating Buildings

Debate over solutions to indoor air quality problems has included the merits of a broad "building systems" approach versus control of the many individual sources in the building. A building systems approach includes proper application of ASHRAE 62-1999, which is key to providing good IAQ. However, a true building systems approach should go beyond ventilation alone to incorporate a holistic view of careful design, source management, proper building commissioning, and a well-informed building operation and maintenance program.

Most of the pollutants can, to some extent, be controlled by ventilation, conspicuous exceptions being asbestos and sources of contaminants that originate within the ventilation system itself (**Figure 1**). But the value of ventilation is that through a standard such as ASHRAE 62-1999, prescribed volumes of dilution air can have a largely predictable effect on the reduction of many indoor contaminants. While there are necessary caveats in the standard, such as the reminder that it cannot be expected to control all contaminants or potential health effects, the standard plays a very valuable role in limiting designers' liability. The practical effect is that products can be delivered to the market that do an effective if not perfect job of providing acceptable working conditions for the majority of building occupants. This brief deals in part with sensing and diluting certain biological contaminants, namely CO_2 and odor. However, as discussed later in this brief, the process of diluting

Figure 1: Indoor air pollutants of concern

Gases and Vapors
Volatile and semivolatile organic compounds (VOC): 300+ compounds, such as formaldehyde, benzene, and toluene

Inorganic Gases
CO_2, CO, SO_2, NO_x, NH_3, Radon

Fibers
Asbestos, fibrous glass, man-made fibers, cotton, textiles

Dusts
Allergens, house mites, pollens, feathers, danders, smoke (tobacco, wood, coal)

Microbes
Bacteria, protozoa, fungi, viruses

these specific constituents does a credible task of reducing all indoor pollutants, not just these individual components.

Again, though all of these will be discussed, for control of classic "Sick Building Syndrome" (SBS) symptoms, a multidisciplinary approach (ventilation, "source control," or filtration) has considerable long-term benefits over individual techniques, especially as SBS tends to be multifactorial.

How Does Ventilation Rate Affect Indoor Air Quality?

There is a significant body of scientific research that documents the benefits of proper ventilation—the main vehicle for ridding buildings of airborne pollutants. A study conducted during the late 1980s by the Walter Reed Army Institute of Research in Washington, D.C., found as much as a 50 percent higher incidence of upper respiratory problems in military recruits housed in new buildings compared to those living in older, less airtight buildings.[2] What this study and subsequent research does is send a warning that mechanically ventilated buildings have to be designed, operated, and maintained correctly if they are not to cause an increase in symptoms.

In 1993, Mark Mendell published a review of the epidemiological literature examining the true causes of SBS.[3] For each of 32 field studies, Mendell laid out the reported associations of SBS symptoms with 17 environmental factors, 5 building factors, 7 workspace factors, and 8 job/personal factors. This approach allowed Mendell to learn whether candidate factors were consistently giving rise to increased symptoms across more than one study. The factors most consistently associated with increased prevalence of symptoms were identified and are shown (not in order of importance) in the **Sidebar**.

Regarding ventilation, Mendell examined 13 studies in which there was sufficient information to compare ventilation with occupant symptoms. His findings clearly show that the prevalence of occupant symptoms increases significantly when

Factors Associated with Sick Building Syndrome

- Ventilation rates at or below 20 cfm per person
- Buildings equipped with HVAC systems
- Job stress/dissatisfaction
- Allergies/Asthma
- Presence of carpets
- Overcrowding
- Presence of Visual Display Terminals (VDTs)
- Females are more often impacted

ventilation rates are below 20 cfm (cubic feet per minute) per person. A more recent study by Godish and Spengler confirmed these findings.[4]

These two literature reviews, covering a wide range of buildings in many different environments, are the most authoritative and complete reviews that examine the relationship between ventilation rates and sick building symptoms. They both conclude that while ventilation rates above 20 cfm per person make little or no difference in symptom prevalence, ventilation increases of up to 20 cfm per person are effective in reducing symptom prevalence and occupant dissatisfaction with air quality. While the majority of the properties covered were office buildings, there is no significant evidence that supports a different approach in other building types. For instance, Bayer and Downing investigated the relationship between ventilation rates and indoor air quality in classrooms.[5] They concluded that 15 cfm of outside air per student was necessary to maintain carbon dioxide levels below 1,000 parts per million (ppm). They showed that increasing the schoolroom outdoor air ventilation rate from 5 cfm to 15 cfm per person resulted in a drop of 25 to 60 percent in formaldehyde concentrations, with similar reductions in total volatile organic compound (VOC) concentrations. In another study, Nardell et al looked at the effects of ventilation on tuberculosis infection rates, reaching the following conclusions:[6]

- Reducing the ventilation rate from 15 cfm to 5 cfm per person nearly doubled the infection rate.
- Increasing the ventilation rate from 15 cfm to 25 cfm per person would reduce the infection rate by 33 percent.

These kinds of studies help to illustrate that carbon dioxide, a much-used indicator of overall ventilation rates, is simply an indicator of pollutant levels indoors and is not itself a causative factor. It will be shown in this brief that CO_2 is a good indicator of adequate ventilation rate.

Very low ventilation rates have adverse health effects on building occupants.

How Does Ventilation Rate Affect Energy Use?

As shown above, very low ventilation rates have adverse health effects on building occupants, which can be translated into dollars of work lost for a typical office building. A comparison between the cost of energy saved by decreasing ventilation rates and dollars lost to unproductive work reveals that providing healthy indoor environments far outweighs the energy savings for very low-ventilation settings.

While increased ventilation rates do have an impact on energy use, the overall savings of low ventilation (i.e., 5 cfm per person) range from negative 1 cent per square foot each year (an increase in electricity costs) in very mild climates to positive 14 cents per square foot each year in more extreme climates. This is, at best, $1,425 annually for a small office building.[7] A European study by Bergs showed that, due to work-related complaints, 24 percent of office workers called in sick on an average of 2.5 days per year.[8] Bergs estimated that, in the Netherlands alone, this leads to one million lost workdays by office staff per year. Holcomb reviewed the literature and building-specific information to estimate the cost of increasing the ventilation in a poorly ventilated building and the expense of lost employee time that may result from poor ventilation conditions.[9] He concluded that substantial overall savings might result from improved ventilation conditions.

In the interest of saving at most $24 per person by using low-ventilation measures, administrative budget losses of at least $415 per person are inadvertently created.

Assuming that the average office occupant works 240 days per year on an annual salary of $40,000 (the current approximate national median salary), then each day away from the office costs his or her employer $166 plus payroll-associated costs. Thus, aside from the costs of lower productivity that result from SBS symptoms, using Berg's estimate it appears that in the interest of saving at most $24 per person by using low-ventilation measures, administrative budget losses of at least $415 per person are inadvertently created. With respect to the overall costs for the building, and assuming this building holds

60 persons, energy savings of $1,425 (about 8 percent of total energy consumption) would be realized while risking absentee losses of $25,000. If the building is owner-occupied, this is surely a poor business decision. This illustrates the importance of considering the overall effect on a building's profitability rather than a single-minded focus on individual departmental budgets.

Thermal Displacement Ventilation—Improved Ventilation to Make Better Use of Outside Air Delivered

A thermal displacement system is an energy-efficient ventilation strategy that allows a building to operate in a wider (warmer) range of outside air temperatures on free cooling. As a result, the building operates much more during the year on 100 percent outside air than with a conventional system.

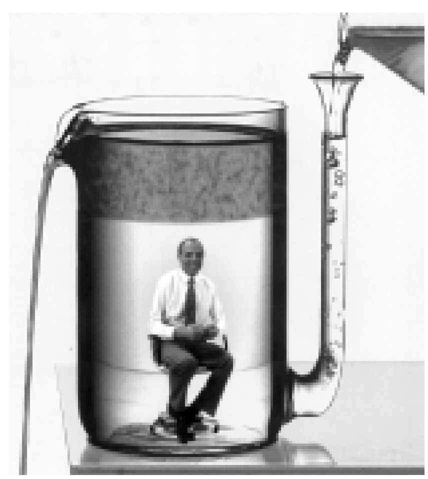
A thermal displacement system calls for cool air to be introduced at a low level into the space (**Figure 2**). Since it is slightly cooler than the room air, the denser cool air is pulled across the floor. Air, though a gas, behaves as a fluid, and cool air spills across the floor as if it were water. All heat sources in the room, such as people, equipment, and lights, heat the air, causing it to rise in convective plumes around and above the heat sources. The natural convective forces become the engines of movement and all the air movement is vertical from floor to ceiling. Since the heat sources are also the primary source of most room pollutants, those pollutants are trapped within the plumes, conveyed away from the room occupants, and then removed at a high level via exhaust grilles. The process is one of separation rather than dilution of the pollutants, and results in approximately 1.3 ventilation efficiency (V_E). See **Figures 3** and **4** for more information.

The secret of a successful thermal displacement design is proper control of the air volume, its supply temperature, and its velocity. By setting the maximum delivery velocity at or below 75 feet per minute (fpm) and by ensuring that the optimum design temperature of air in the supply "pool" on the floor is

Figure 2: Visualizing thermal displacement ventilation

Mixing Ventilation

Displacement Ventilation



Source: Healthy Buildings International

Figure 3: Cross section of an office using TDV

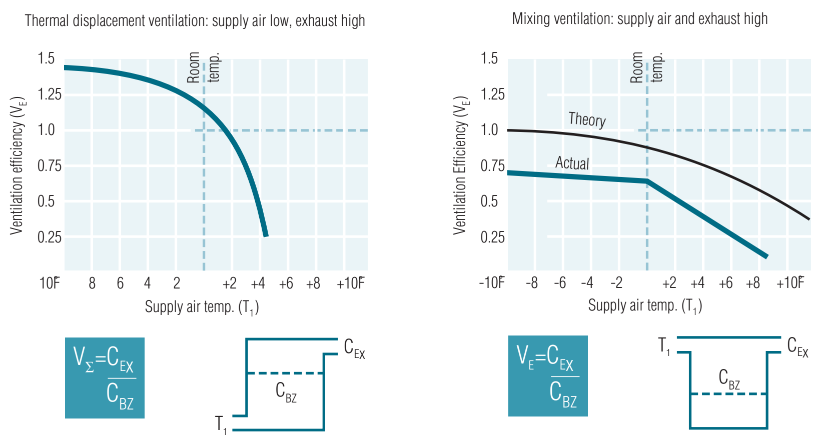
Thermal Displacement Ventilation (TDV) pools cool air across the floor. All heat sources in the room, such as people, equipment, and lights, heat the air, causing it to rise in convective plumes around and above the heat sources. Since the heat sources are also the primary sources of most room pollutants, those pollutants are trapped within the plumes, conveyed away from the room occupants, and then removed at high levels via exhaust grilles.

Source: Healthy Buildings International

about 68–69°F, drafts can be eliminated within the room. Moreover, by limiting the supply air speed to this value, the noise typically encountered with mixing ventilation designs can be eliminated. The wider free cooling temperature range comes from a supply air temperature of 68–69°F, much warmer than typical supply air temperatures of about 55°F. This strategy effectively balances energy efficiency and IAQ requirements. (See Energy Design Resources Design Brief entitled "Displacement Ventilation" for more information.)

Figure 4: Comparative ventilation efficiencies

Ventilation efficiency (VE) is generally defined as the pollutant concentration at the exhaust (CEx) over the pollutant concentration at the breathing zone (CBZ). Depending on the supply air temperature, these efficiencies vary for both mixing and thermal displacement systems. With a supply air/breathing zone ΔT of just 7°F or less, a displacement system can achieve a ventilation efficiency of nearly twice that found with a conventional mixing system, where the ΔT will be in excess of 15°F. Note that the ΔT between the supply air and the exhaust will be about the same as that in a mixing system.



Source: Healthy Buildings International

Natural Ventilation

Depending on the climate, a wide variety of natural ventilation techniques exist that can potentially reduce or even eliminate the need for mechanical ventilation. Natural ventilation has been recognized as a valid ventilation method by ASHRAE, which is in the process of adding an addendum to ASHRAE Standard 62-1999 (62-j). This addendum would change the ways in which natural ventilation is used in new building design. It also discusses how, subject to certain conditions that limit the kinds of spaces where natural ventilation may be used, natural ventilation can supplement or substitute for mechanical ventilation requirements. The ASHRAE addendum also states a requirement that the "openable" area be a minimum of 4 percent of the usable floor area.

Throughout the world, innovative engineering solutions using natural ventilation have been proposed and implemented only in a limited number of buildings. These solutions include the use of windpower, stack effect, and channeling of air through conduits other than windows. The new ASHRAE addendum especially encourages the application of such solutions so long as the "building official" approves of them. In the litigation-prone United States, at least, such approval without more specific guidelines may be difficult to obtain, especially with regard to fire codes. Cities with climates conducive to natural ventilation may be able to encourage this approach by offering liability relief to engineers who adopt it. Additionally, there is a burgeoning school of thought within ASHRAE that calls for a more relaxed approach or, in the context of naturally ventilated buildings, applying an "Adaptive Comfort Standard" to the rigid temperature requirements found in ASHRAE Standard 55.[10,11] This would recognize that human thermal preferences accommodate wider temperature variations when situated in naturally ventilated buildings than in air-conditioned buildings. Note: "presence of air-conditioning" was one of the factors contributing to poor IAQ cited by Mendell.[3]

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Filtration and Source Control

Filtration and source control have long been the cornerstone of an alternative to the classic "Solution to Pollution Is Dilution" approach to indoor air quality. They are the basis of a second procedure in ASHRAE 62-1999, known as the Indoor Air Quality Procedure. Essentially, filtration and source control provide a performance method of achieving acceptable IAQ. This involves limiting the concentration of all known contaminants of concern to specified acceptable levels and incorporating both quantitative and subjective evaluations. This allows, in theory at least, for designers of the future to apply new filtration, source control, and air-cleaning technology to achieve the desired air quality while limiting the volumes of outside air drawn into the mechanical system. Unfortunately, however, with respect to source control, there is relatively little information about the rate of emissions of these contaminants from fixtures, fittings, and building materials. Thus, the designer who chooses the IAQ Procedure makes the assumption that the design is acceptable, and only after the fact—when construction, furnishing, and occupancy are complete—does one know for certain if the design is acceptable. Although attempts have been made to develop specific prescriptions for this approach, the language in the current ASHRAE standard remains purposely vague about how this approach is to be applied.[12,13] Source control is, however, appropriate for Building Related Illness (BRI)—a term for specific and less transient ailments, often caused by infection. An obvious example of BRI is Legionnaires' Disease. In California, source control has also been aggressively applied to cigarette smoking, but with other sources such as printers, copiers, and cooking, the designer may be able to practice good "source management" by grouping and spotting exhaust strategies. However, if its occupants consider a building "sick," inappropriate source control can be a poor substitute for proper ventilation and building operation regimes.

In California, source control has been aggressively applied to cigarette smoking.

ASHRAE Filtration Standards

With respect to filtration, air from commercial ventilation systems may contain particles in a broad range of sizes having varied effects, sometimes dependent on particle size. Coarse particles, for example, cause energy waste when they cover heat transfer surfaces or impede airflow, increasing fan power consumption. Fine particles cause soiling and discoloration of interior surfaces and furnishings. When inhaled by occupants of the space, fine particles may also cause health problems, since smaller particles

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travel more deeply into the lungs. When air cleaners are classified in accordance with their ability to remove particles of certain sizes, there is a basis for comparison and selection for specific tasks. A new filtration standard (ANSI/ASHRAE Standard 52.2-1999: "Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size") was considered necessary because the prior standard (ASHRAE Standard 52.1) did not discriminate adequately across particle size ranges or filter loading cycles. However, Standard 52.1 has been, and will continue to be, a useful guide for evaluation of the relative arrestance values and dust-retaining capacities of all types of filters.

Perceived Air Quality

Perceived air quality refers to the acceptability of indoor air based on odor and irritation. Experimental studies in chambers and occupied spaces have long established the relationship between certain kinds of pollutant sources and the ventilation rates required to satisfy occupants.[1] Most heavily studied criteria are CO_2, body odor, and environmental tobacco smoke (ETS). These studies formed the basis for the ventilation rates in use today under ASHRAE Standard 62-1999.

Temperature and Relative Humidity

These two factors are closely interrelated. The consensus developing in the literature, some of which is discussed below, is that thermal conditions impact not only occupant sensation of heat or cold but also occupant perception of indoor air quality. If the air is warm and humid, the air quality is generally perceived as poor, independent of variations in the levels of pollutant loads.[14]

The consensus is that thermal conditions impact not only occupant sensation of heat or cold but also occupant perception of indoor air quality.

Air containing less than 20 percent relative humidity (RH) is considered below the comfort range recommended by ASHRAE and others. Therefore, in temperate or cold climates, one option is to humidify air in buildings during the winter season. For example, an RH range of 30 to 70 percent is considered ideal for human comfort and the psychological well-being of building occupants. On the other hand, in Sweden, a large study of office buildings indicated that if temperature was reduced by a few degrees toward the lower end of the temperature comfort range, the occupants would experience comfort at lower RH levels.[15] The study found that a 3.6°F reduction in room air temperature, from 73.4°F to 69.8°F, substantially reduced complaints of dry air.

Physiologically, high RH combined with high temperatures reduces the body's ability to lose heat through evaporative cooling. This results in discomfort and dehydration. Low humidity can dry eyes, skin, and mucous membranes, possibly increasing human susceptibility to respiratory infections (viral) and skin irritations as well as exacerbating irritations from other pollutants. Common cold and influenza viruses seem to infect more people in winter in cold or temperate climates—times when homes and workplaces experience lower RH levels due to the heating of indoor air. These viruses, which are believed to be transmitted on airborne droplets, have an increased survival time in the air and an increased ability to infect at low RH levels. However, an increase in occupant density and length of time spent indoors also contributes to spreading these viruses.

An increase in RH will also produce greater chemical emissions (such as formaldehyde) from some building materials and furnishings and possibly set the stage for chemical interactions that may be harmful to the occupants of buildings.[16-18] The mechanism for this reaction is still under study, but is at least partially explained by the chemical breakdown of plasticizers to their corresponding free alcohols at higher relative humidities. Other theories are that water vapor may be carrying polar substances from the substrate itself, and that more hydrophilic VOCs are extracted from substrates to a greater extent at higher relative humidities.[16,19]

Advanced Ventilation Technologies

Increasing ventilation rates can improve perceived IAQ, but can also increase energy use during extremes of hot or cold weather. Previous IAQ guidelines sought to reduce ventilation rates in order to save energy, but this thinking has been largely reversed.

Balancing Energy Use with Indoor Air Quality Demands

ASHRAE-recommended ventilation rates have not changed since 1989, when they were set at 20 cfm per person for office space. The 1981 Standard rates were set at 5 cfm per person, reserving higher rates for occupancies where smoking was allowed. In 1989, ventilation was raised to 20 cfm per person to prevent SBS symptoms whether or not smoking is allowed (**Figure 5**).

When the recommended ventilation rate was increased in 1989, designers were concerned with the overall increased costs of operating new buildings constructed to the new standard. Also, there was concern about the cost implications of imposing ASHRAE 62-1999 ventilation standards on existing buildings constructed in accordance with the previous standard, ASHRAE 62-1981. Since then, the argument has been largely accepted that the benefits of improved ventilation outweigh any increased costs.

The actual energy costs associated with applying ASHRAE 62-1999 are quite small; it may cost even less money under some conditions to operate a building under ASHRAE standard 62-1999 than under ASHRAE Standard 62-1981. By increasing the building's ventilation rate, air conditioning energy can be saved in very mild climates where the outdoor temperature and humidity closely mirror desirable indoor conditions. However, studies that compare energy costs of the two standards show, on average, a 5 percent increase in energy costs with the new standard—a small price to pay for improved indoor air quality and potentially reduced absenteeism.[20-22]

Demand Controlled Ventilation

Demand Controlled Ventilation (DCV) refers to actively regulating the amount of outside air introduced into a building based upon the concentration of carbon dioxide or other indicator pollutants

Figure 5: Timeline of ASHRAE ventilation standards in office spaces

1981: 5 cfm per person (15–20 if smoking was allowed)

1989: 20 cfm per person (whether or not smoking was allowed)

1999: 20 cfm per person (smoking no longer addressed) within the building. While CO_2 sensing systems are more common, installing multigas sensors is a good idea in spaces where nonhuman pollutant loads vary, such as warehouses and smoking areas.

Figure 6: Good applications for DCV using CO2 sensors

- Auditoriums
- Movie theaters
- Conference rooms
- Retail sales floors

Demand controlled ventilation systems that use CO_2 sensors are best applied to spaces that have high occupancy loads and diverse uses (**Figure 6**). If they are not used in a self-contained, dedicated system, the sensor should be installed in the room instead of in a common return.

DCV and Title 24

California's 1998 Title 24 states the following with respect to demand controlled ventilation:

> *The rate of outdoor air provided to an intermittently occupied space may be reduced to 0.15 cfm per square foot of conditioned floor area, if the ventilation system serving the space is controlled by a demand control ventilation device approved by the commission, and*
>
> *A. If the device is a carbon dioxide sensor, it limits the carbon dioxide level to no more than 800 ppm while the space is occupied, and*
>
> *B. The sensor for the device is located in the space, or in a return-air stream from the space with no less than one sensor for every 25,000 square feet of habitable space, or no more space than is recommended by the manufacturer, whichever is less.*[23]

California's 2001 Title 24 Standards require that demand controlled ventilation be installed in all high-density occupancies.

California's 2001 Title 24 Standards require that DCV be installed in all high-density occupancies, which are defined as any space with an occupant density greater than one occupant per 10 square feet. Occupancies affected by this change include ballrooms, convention centers, auditoriums, churches/chapels, main entry lobbies, movie theaters, and performance theater spaces.[24]

Using CO_2 as a Metric for Building Ventilation

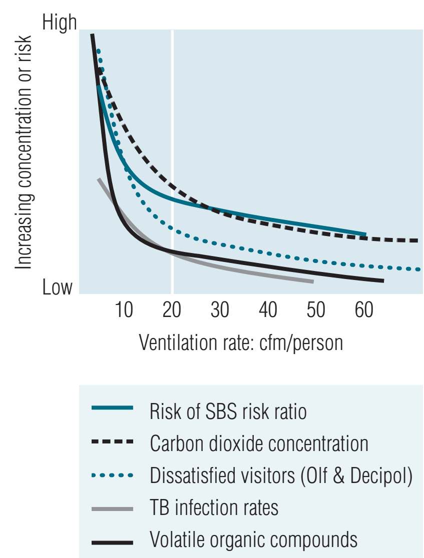
Support for the use of CO_2 as a metric for overall IAQ acceptability is given by the close relationship of other parameters to the same variations in ventilation rates that influence CO_2 levels. For example, **Figure 7** plots results from a number of different types of IAQ studies against ventilation rates, and the similarity in response to ventilation is remarkable. In each case, a rapid improvement in factors related to overall IAQ acceptability is seen as ventilation rates reach the commonly accepted value of 20 cfm per person, followed by leveling-off of benefits as rates exceed this value. The similarity of other parameters to the relationship between ventilation and CO_2 helps to support the case for using CO_2 sensing in DCV applications.

CO_2 Sensors

The technology behind most CO_2 sensors is now well established; most sensors use a nondispersive infrared detector. The principle behind this detector is that a specific gas absorbs infrared energy of a particular frequency. An infrared source (usually an electrically heated wire) emits a wide band of infrared energy, focused through a narrow band filter, to allow through only a range of frequencies that are absorbed by CO_2. This infrared energy is passed through a detector chamber into which the sample gas is introduced intermittently. A detector measures the difference in absorption with and without any CO_2 in the sample gas to determine the concentration. Newer variations in this technique employ a single infrared wavelength and diffusion aspiration of the sample gas, instead of a sampling pump, allowing for silent operation and no moving parts, and thus making it better suited for use as a DCV monitoring station.

Figure 7: Ventilation rate vs. several IAQ parameters

As ventilation rates reach the commonly accepted value of 20 cfm per person, disparate factors related to good indoor air quality improve. As the ventilation rate increases past 20 cfm per person, IAQ factors level off.



Source: Healthy Buildings International

Multigas/VOC Sensors

Multigas sensors have advantages and disadvantages over CO_2 sensors and are a credible alternative in some applications. The most common type of mixed-gas sensor consists of a sintered semiconductor tube with an internal heating coil. The semiconductor material is doped with tin dioxide and acts as a catalytic converter in a reversible redox reaction, changing the conductivity of the semiconductor as it is exposed to oxidizable gases and vapors. This type of sensor reacts to a wide range of gases, such as hydrogen, carbon monoxide, and hydrocarbons, including VOCs such as alcohol and benzene. Heavier compounds will also be measured. However, because the sensor reacts differently to each of these compounds, it is best used to evaluate a gas mixture as a whole. These sensors are typically calibrated with a single reference gas such as methane, usually at a concentration in excess of that found in indoor air (1,000 ppm). Once these sensors are installed, however, they usually require field calibration by the user to achieve a subjective level of acceptability. Unless the indoor sources of pollution change, the sensors have been found to deliver a stable signal over a long period of time. This is because the heating element in the sensor is self-cleaning.

Once multigas sensors are installed, they usually require field calibration by the user to achieve a subjective level of acceptability.

The advantage of the multigas approach is that the building itself generates a much higher sensory pollution load than the occupants (i.e., the multigas sensor is more adept at sensing these building loads, such as VOCs, than the occupant loads, such as CO_2). This has been the basis for both ASHRAE Public Review Draft 62-R and the new European ventilation guidelines; both documents present data to justify this finding/assumption.[13,25] For instance, in mechanically ventilated buildings where smoking is allowed, Fanger broke down sources of sensory pollutants as follows:[26]

Body odor	13%
Smoking	25%
Room furnishings/finishes	20%
HVAC systems	42%

While measuring components such as CO_2 selectively can be an indicator of indoor air quality, measurement of a broader range of components has a theoretical superiority. With respect to specific applications, where nonhuman pollutant loads vary, such as warehouses or smoking areas, mixed-gas sensors may be particularly advantageous. Therefore, they should be recognized for use with DCV systems and when writing standards or specifications, given at least equal weight with single-gas sensors.

Design Issues for Healthy Buildings

The "Green Design" movement has helped the commercial real estate industry place more emphasis on high IAQ during building design and construction. An example of this emphasis is the IAQ provisions in the LEED rating system.[27] The rating system requires that building ventilation systems be designed to ASHRAE 62-1999 and eliminate building occupant exposure to Environmental Tobacco Smoke. The system also has optional measures that include demand controlled ventilation, increased ventilation effectiveness, and a construction IAQ management plan. This approach recognizes the benefits of prevention over cure in treating building system ailments. Often, such a strategy can head off SBS problems before the building is occupied and an operating history is established. This foresight also sets the foundation for a permanently healthy building and lessens the likelihood of SBS problems later during its occupied life. Formally addressing indoor air quality as a significant part of the integrated design process can be an important energy efficiency and communication tool. By increasing the awareness of indoor environment, tenants and employees may enjoy a more comfortable and productive workspace.

Designers must pay attention to factors that will influence the health of future occupants such as thermal comfort, natural light, noise, staffing densities, occupant profiles, and interior materials.

There are many indoor environmental issues to be considered when addressing a building design for good IAQ. Much of the focus is on the building's mechanical system and its interface with both the outdoor environment and the occupied spaces. Additionally, designers must pay attention to other less obvious factors that will influence the health of future occupants, such as thermal comfort, natural light, noise, staffing densities, occupant profiles, and interior materials. There are seven main design issues to be considered:

- Site plan and external factors
- Building configuration
- HVAC system design
- Maintainability
- Materials selection
- Building commissioning
- Ongoing monitoring

Site Plan and External Factors

Study the physical site that the future building will occupy and its outdoor environment with respect to how they will likely impact the future indoor environment. Analyze prevailing weather and wind patterns, ambient air quality, and major outdoor sources of pollution in the vicinity of the building site.

Building Configuration and Its Impact on Migration of Pollutants

In multistory buildings, locate storage areas with potentially hazardous materials near a common exhaust shaft for dedicated room exhaust.

Consider how the building configuration will impact migration of pollutants from the outside to the inside, and within the building. Consider how the pollutants will migrate both vertically from one floor to another and horizontally across floors. Issues to be scrutinized include:

- Location and orientation of building air intakes, exhausts, and stacks
- Vehicle access, parking, and garages
- Pollutant pathways across and between floors within the building
- Apertures and glazing in relation to solar heat load and IAQ

Give careful consideration to vehicle access, parking, and garages with respect to their influence on indoor air quality. In multistory buildings, locate storage areas with potentially hazardous materials near a common exhaust shaft for dedicated room exhaust.

Conduct a critical review of appropriate ventilation rates and air distribution systems under all projected modes of operation and anticipated outdoor conditions. Consider adsorption and other advanced filters capable of improving indoor air quality during filtration system design, selection, and location. Moreover, carefully plan dedicated exhaust from closed spaces such as printing rooms and smoking lounges. Model airflow designs for these spaces before construction begins.

HVAC System Design

In today's tight, sealed, energy-efficient buildings, the majority of indoor air is introduced through the HVAC system. Accordingly, proper design of these mechanical systems is necessary to create a healthy indoor environment. One must review the projected occupant densities, activities, and locations in the building and ensure proper respective ventilation rates and distribution. This task includes critical attention to ventilation flexibility (the ability of the supply and return systems to be redirected to accommodate changes in occupant space layout), core vs. perimeter loads, control systems, humidification/dehumidification, filtration systems, occupied space layout, and energy recovery technology.

Preventing Microbial Growth

Moisture:

- Control free water in HVAC system components
- Prevent entrainment of water droplets from cooling towers
- Prevent relative humidity from rising above 70 percent
- Prevent condensation on cold surfaces

Nutrients:

Keep dirt out of mechanical systems

- Good filtration
- Regular inspection and cleaning when necessary
- Ongoing preventative maintenance program

Maintainability

The ability to conduct frequent and effective maintenance on the HVAC system during the building's operational life will make a considerable contribution toward a healthy indoor environment. Consider the maintainability of the HVAC system at the design stage. Proper access points to critical areas of the HVAC system include access to chambers of the air-handling units, plenums, ductwork components, cooling coils, turning vanes, smoke detectors, etc. These must all be incorporated in the building's design. Specify only those building and mechanical system materials best suited for resistance against corrosion, microbial contamination, and other IAQ factors. Pay close attention to the integrity, material type, and location of insulation materials associated with HVAC equipment, ducting, and ceiling plenums. Pay special attention to prevention of free moisture on internal insulation. This can occur when there is droplet carryover from poorly specified cooling coils, or when there is inadequate or poorly maintained condensate drainage provision.

An often ignored but increasingly important issue is avoiding microbial pollution in the HVAC system and building structure (see **Sidebar**). This includes elimination of insects, bird roosts, and other pests from the HVAC system and air intakes.

Material Selection

Carefully select materials for the interior spaces with regard to their future impact on indoor pollutant loads. Customize the general principles of sound environmental material selection to the specific indoor environment planned. Material selection criteria include off-gassing, fiber release, microbial support, sink effect, durability, proper installation, and maintenance for good IAQ (**Figure 8**). Reference databases of environmentally friendly interior materials that aid product selection are available. Suppliers have an increasing (though by no means complete) information base on VOC emissions from their products.

Also specify the installation and maintenance practices relevant to the specified materials that will help ensure a healthy indoor environment once the building is occupied.

Building Commissioning

While building commissioning should be occurring throughout the building's design and construction phases, the period shortly before a building's completion and subsequent occupation can be the most problematic. New interior materials, HVAC systems, and building management personnel combine with the usual stresses of a building move to create a sensitive situation. Often a sick building reputation can be acquired during this phase, making future efforts to shake this reputation difficult. A formal plan encompassing final HVAC installation and start-up, initial ventilation strategy, design documentation, operation and maintenance training, and remaining pockets of construction goes a long way toward avoiding unnecessary complications. Commissioning considerations for ensuring excellent IAQ include:

- Ensure sound installation practices of those components of the HVAC system vital to indoor air quality, such as sealing ducts during construction.
- Develop an ideal start-up schedule for the HVAC system.
- Plan a building "flush-out" before occupants move in and a prudent ventilation regime during the first months of occupancy.
- Perform acceptance phase inspection and testing procedures.
- Document design criteria procedures and verification of compliance with the latest published ASHRAE Standard 62.
- Develop a coordinated HVAC operating manual and operator training manual.
- Collate mechanical equipment drawings and specifications to ensure compliance with design team recommendations.

Figure 8: Interior products that emit VOCs

Adhesives

Paints, stains, varnishes, and lacquers

Wood preservatives

Waterproofing products, particularly petroleum derivatives

Caulks and sealants

Glazing compounds

Joint fillers

Duct sealants

Carpet seam sealants

Resilient floor coverings

Carpet

Carpet pads

Wall coverings

Ceiling tiles

Thermal and acoustic insulation, including duct insulation

Fireproofing materials on ductwork, ceiling beams, and piping

Workstation partition panels

Textiles

Composite wood products used in construction, furnishings, and cabinetry (such as particleboard, medium-density fiberboard, and hardwood plywood containing urea formaldehyde resin adhesive)

Insecticides and pesticides

Chemicals used in HVAC system

Maintenance products

The key to a good, proactive indoor air quality monitoring program is establishing a baseline database from an initial inspection.

Ongoing Proactive Monitoring

The key to any indoor air quality problem is prevention. Many building owners and employers are adopting a proactive monitoring program to inspect, analyze, and evaluate a building's air-handling system on a regular basis.

The key to a good, proactive indoor air quality monitoring program is establishing a baseline database from an initial inspection. This database is then used as a reference point against which all subsequent inspections can be judged. An initial indoor air quality investigation should involve an extensive analysis of the building's air supply system maintenance, operation, and filtration, in addition to a full range of testing for indoor pollutants. Subsequent inspections should then cover recent trends (positive and negative) and verify the effectiveness of any plant, maintenance, and/or operational changes that have been made in the building since the last inspection.

For More Information

Building Air Quality: A Guide for Building Owners and Facility Managers.
US Environmental Protection Agency and
US Department of Health and Human Services
Superintendent of Documents
P.O. Box 371954
Pittsburgh, PA 15250-7954

Also, EPA Region 9, covering California:
75 Hawthorne Street
A1-1 San Francisco, CA 94105
Phone: (415) 744-1132 (Indoor Air Line)

The Indoor Air Quality Information Clearing House
P.O. Box 37133
Washington, DC 20013-7133
Phone: (800) 438-4318

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