# Using Your HVAC System to Improve IAQ

## Recognizing the Importance of Controlling Key Airflow Rates

*EBTRON,* Inc.[1] updated February, 2016

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## OVERVIEW

In a joint report, Lawrence Berkley National Laboratory and the U.S. Department of Energy (2000) estimated that improving indoor air quality would yield up to $208 billion annually through decreased health care costs and improved productivity. The really good news is that these savings can be achieved with minimal investment and with technology that is readily available.

Since the annual cost for employees per square foot is typically 150-250 times the cost for indoor ventilation, even large percentage increases in annual ventilation costs are quite small compared to the employer benefits.

Although every building will require a uniquely engineered solution depending on its construction, location, and use**, practically every design should include accurate control of the dilution (outdoor) airflow rates and pressurization airflow rates to achieve acceptable IAQ**.

In the early 1990's a methodology of rating indoor air was introduced which equated various contaminant sources (people, carpet, mold, etc.) by using the percentage of people that were dissatisfied with different indoor air samples. Thus, indoor air quality became quantifiable. Today the accepted units of indoor air quality are called *decipols*, with zero decipols being pure air. The task is to determine just how close to zero one can economically design.

Most current codes still reference the 2001 Ventilation Standard published by the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) which, by definition, requires an indoor air quality of 1.4 decipols. This corresponds exactly to 20% of the occupants being dissatisfied. In practice, however, *designs* meeting the Standard will not meet the 1.4 decipol criteria during operation and occupant dissatisfaction will be much greater.

The International Mechanical Code (IMC) chapter 4 on Ventilation in 2009 adopted the essence of the *Ventilation Rate Procedure* from ASHRAE Standard 62.1-2010, which recognized the dilution rate approach on both occupant and building sources of IAQ contaminants. It addresses them separately with rates "per person" to be added to a corresponding rate "per area". That concept has been sustained to the present day in 62.1-2016 version. The latest IMC Chapter 4 (2015) is essentially the same as 2009 for the basic ventilation requirements, and has been crawling through the legislative process in countless jurisdictions. Someday it should become nearly universally accepted in North America.

Although the Standard now lists three alternate design procedures, the *Ventilation Rate Procedure* (VRP) is primarily employed by designers because of its greater performance predictability. A critical problem with the VRP prior to 2004 is that the procedure only acknowledged occupant generated contaminants—even though a significant, if not majority, portion of contaminants are from the building, furnishings and its contents. This particular problem — outdoor air intake rates based on people only — is exacerbated by designs which routinely use carbon dioxide to control outdoor air, one of many possible inputs for demand controlled ventilation. This issue was mostly corrected in 2004 when the ventilation tables were expanded to include a fixed ventilation requirement based on floor area, regardless of population.

Beginning in 2004, the Standard separated the occupant and building components of the contaminants and designates outdoor air rates delivered to the occupied zone for each component in a new Table (6-1). In some cases it allows ventilation rates to fall below the level (15 cfm) shown to be required to dilute bioeffluents (including body odor). However, this revised Standard does a better job addressing outdoor air quality, air distribution and building pressure. Unfortunately, the Standard can be difficult to apply and can result in increased energy consumption and equipment costs; something frowned upon in today's economy.

Many traditional $CO_2$-based control strategies have been shown to severely under ventilate as occupancy decreases and over ventilate as occupancy reaches design levels, unless $CO_2$ and intake airflow rates are used to dynamically calculate requirements and reset zone ventilation based on changes in differential $CO_2$ concentrations. When used in appropriate formulae, $CO_2$ combined with airflow rate inputs allow the estimation of space population through calculation. With a population estimate, we can reset the intake rate set point for the new space condition and satisfy the VRP requirements in 62.1 and IMC.

The ASHRAE Ventilation Standard is only applied to new and retrofit construction. The majority of U.S. buildings were designed under earlier, more lenient, ventilation codes. The earlier codes, which required about one fourth the amount of outdoor air as the 1989 Standard, and resulted in poor indoor air quality.

Still other factors contribute to reducing indoor air quality such as poor maintenance, poor or missing design documentation, roof leaks that are untreated, and improperly operating controls.

The real challenge for owners is to recognize the bottom-line benefits of improved IAQ and insist that engineering firms provide them with appropriate designs which maximize their life-cycle return by delivering superior indoor air quality performance.

Research and documentation of financial returns available for improved indoor air quality is emerging. It is inevitable that indoor air quality will be written into property leases and labor contracts in the not so distant future.

Today's designers and building owners carry the burden of design and operation compliance to maintain acceptable indoor air quality. Accurate airflow measurement inputs are essential for those who wish to use current state-of-the-art technology to improve occupant productivity and health. Byproducts of the increase in occupant well-being are the increase in worker productivity, decrease in healthcare costs, reduction in sick-time lost, reduction of liability, increase in building longevity and improved building performance.

## IAQ BASICS

Contaminants are introduced into a reservoir (room) and dilution air mitigates the impact and/or removes these contaminants. Indoor air quality depends on the suitability of the outdoor air for ventilation, the flow rate of the dilution air and the contaminant generation rate. In buildings the dilution air is not fully mixed into the reservoir, so a ventilation efficiency factor must be used to determine the breathing zone air quality.

The fundamental indoor air quality equation, the *Comfort Ventilation Equation*, was developed by the late Professor P.O. Fanger. Fanger noted that the industry had no method for comparing the effect of various emissions. For example, what concentration of formaldehyde is equivalent to emissions from people? Fanger resolved the problem by exposing groups of people to a variety of indoor environments and recorded the percentage of people who were dissatisfied. In this way he was able to develop a system of measurement which rated the emission strengths (rates) of different contaminants on the same scale. These test groups were *adapted* people, people that had been in the space for some length of time, at least several minutes. People who are not *adapted*—those just entering a space — were more likely to find a space unacceptable because their senses have not tuned out offensive odors. The units of this common scale are *olfs*, with one olf equaling the emission of a sedentary person (with one bath daily). Fanger then defined decipols as the indoor air quality in a space with 1 olf emission rate and 10 liters/second of 0 decipol dilution air.

It is important to remember two facts. The current index of indoor air quality, i.e. decipols, is not based on a standard which correlates indoor air quality with health care costs or any other index of the harmful effects of dirty air. Instead the decipol index is based on the rather arbitrary standard of peoples' perception of indoor air quality.

Secondly, with today's technology, indoor air quality cannot be measured directly. While some contaminants and indicators can be measured relatively easily — such as volatile organic compounds (VOCs) and carbon dioxide — others are more difficult and expensive to measure, including ozone, particulates, and hydrocarbons (traffic exhaust), while still other contaminants, such as human bioeffluents, molds, yeasts, and pollen are currently beyond practical measurement. This leaves dilution air, which can be accurately measured, as a key factor in controlling and monitoring indoor air quality.

Dilution flow can be varied in response to changes in contaminant levels of the breathing zone air. The contaminant level is affected by the emission rates of the contaminants and the level of filtration applied to the contaminants.

Some emissions can be easily reduced by source control, such as using different cleaning chemicals or by selecting low emission materials for construction. Filtration can also be applied but may only reduce contaminant sources after the occupant has already been over exposed. Emissions from people cannot be reduced and must be measured directly or detected using indirect means such as $CO_2$. Mold and fungal growth can be minimized by controlling envelope and space moisture by assuring proper building pressurization and providing sufficient equipment capacity to remove the moisture of the dilution air passing through the air handling systems. Building pressure is most effectively and more stably controlled by maintaining airflow differentials into and out of individual pressure zones.

One important objective of moisture management is to control the moisture content of exterior walls, attics and other perimeter cavities to prevent mold formation, corrosion and structural damage such as efflorescence (salt deposits from water evaporation in cement and other building materials).

Walls, roofs, and overhanging plenums also form one or more pressure compartments, sometimes in combination with each other, allowing moisture to migrate between these spaces. The flow of moisture into and out of these spaces is due to: liquid water, either as rain or other leaks; moisture contained in leakage airflows; and molecular diffusion, the flow of moisture associated with vapor pressure differential.

Liquid flow is the by far the most dangerous source of moisture, about 100 times more potent then airflow, and 1000 times greater than diffusion. Gravity is a strong driving force for liquid water and air pressure differential can augment or retard water flow. Besides the physical augmentation of liquid water flow, the moisture contained in moving air as water vapor is often overlooked.

Outdoor air will carry a significant quantity of water across the building envelope when the building pressure is negative. Assuming an internal wall surface temperature of 74° F, outdoor air with a dew point of 65° F or higher will result in conditions within the building envelope where the relative humidity is high enough for mold growth. These conditions are prevalent throughout much of the United States. Depending on geographic location, as much as 1,000 gallons of water per year can be transported per 1,000 cfm of outdoor air.

The moisture storage capacity of walls varies considerably. The storage capacity for wood frame wall is approximately 10% of the weight of wood. Steel frame walls have drastically less storage capacity, since sheetrock, the only hygroscopic element, has only a 1% storage capacity by weight. The surface limit for mold growth on wood is 80% relative humidity or 16% moisture by weight. The limit for sheetrock is 1% moisture by weight.

It is the architect's responsibility to design a wall assembly that will prevent excessive moisture build up. Architects establish the location of the vapor barrier which divides the wall into two humidity chambers. Since walls need to perform over a long period spanning many decades, it is inevitable that walls will experience excessive humidity. Consequently, architects should design walls to compensate for these incidents by giving walls the means to dry out on both sides of the vapor barrier.

An effective method for drying a wall is to pass dryer air through it. In the summer, that can be accomplished by maintaining a directional pressurization flow (evidenced by the observation of a positive or negative differential pressure) across the building envelope. In the winter, the reverse may be true.

The question of whether it is best to keep a building neutral or slightly negative in the winter is a topic of dispute. Infiltration in the winter may reduce moisture content in the exterior walls but it decreases comfort by drafts and brings particulate into walls, a nutrient for mold. A logical but difficult to execute approach during the winter is to maintain spaces with exterior walls at net neutral. The airflow rate controls required to accomplish this feat must be the most precise and most repeatable available. Over pressurization allows a larger control tolerance to ensure sufficient flow is being maintained, but requires greater expenditure of energy.

Consideration should also be given to pressurization and humidity control during periods when buildings are not occupied. Without sufficient dehumidification and airflow, many schools in the southeastern states become mold incubators. The same is true for offices that use a total system shut-down at 5PM, with no mechanical air movement until 7AM the following day. Mold does not sleep. It takes only minutes or hours to form with sufficient temperature, humidity and food sources.

From the above information, it can be seen that accurate measurement and control of key airflow rates are essential in maintaining acceptable indoor air quality. Proper selection of materials, the addition of filtration and an accurate means of determining occupancy can significantly reduce energy consumption and equipment requirements for a given facility that is otherwise properly designed. A specific design *will not* improve IAQ on its own, without operational assistance.

## BUILDING / SPACE PRESSURE

Buildings should be compartmentalized into unique pressure zones to facilitate *pressurization flow* control to maintain needed zone isolation or prove proper flow direction between interior compartments and the exterior envelope.

A building pressure *compartment* is a volume of space that is enclosed by walls, floors, a roof or some other continuous, but somewhat porous partition. Stairwells, atriums, elevators, as well as electric, duct and piping shafts, are vertical compartments. Operating rooms, isolation rooms, laboratories, clean rooms, kitchens, and in some cases, entire floors (when floor to floor partitions are tight) can be horizontal compartments. Ventilation systems must simultaneously control the overall building envelope leakage airflow and the internal partition leakage airflows (the overall *pressurization flow*). Both the magnitude and the direction of the pressurization flow need to be controlled.

An idealized pressure compartment will have six equal area partitions (four walls, ceiling and floor) of like porosity, suspended in still air, of like temperature. In this idealized case, "conservation of mass" dictates that the leakage flow across each partition will be one sixth the difference between the ventilation in and out flows. Leakage flows through actual compartmental partitions will not be uniform (cfm/ft$^2$- volumetric flow rate) or even the same direction due to porosity differences and variations in surface pressure distribution over inside and exterior partition faces. However, the net pressurization flow will always be equal to the difference between the air supplied and air returned (or exhausted) from the compartment, regardless of externally forced infiltration/exfiltration (i.e. wind and stack effect).

The architect must design, and the contractor must build, partitions with acceptable leakage characteristics. Partitions that are too porous will prevent the compartment from being properly pressurized. Partitions that are too tight will create excessive pressure when doors are cycled (open/close) as a piston effect. When the compartment height is too high, as in a high rise building without effective floor-to-floor separations, ventilation systems do not have the capacity to pressurize the top of the compartment and bidirectional partition leakage occurs.

Under normal wind conditions there is no single point or even group of points that will provide a viable signal for variable control. Consequently, building differential pressure sensors cannot be used to control leakage flow, even though labyrinth wind dampening probe chambers and various averaging of pressures in multiple building faces have been used for years. However, it may be necessary to monitor external differential pressure on every major building external partition to confirm proper direction of leakage flow when wind is not present. Under some circumstances, including after rain, the control system may temporarily increase leakage flow to reduce wall cavity moisture.

Partition leakage flow is ideally controlled by monitoring *partition differential pressure* indirectly with a "bleed" airflow sensor and resetting the total compartment differential flow, generally the differential between supply and return or intake and exhaust airflow rates. In many cases this will also require reset of the outdoor airflow set point which, in turn, will also affect system relief/exhaust. Partition differential pressure positively indicates the direction and magnitude of partition leakage flow. Partition differential pressure is ideal for reset but should not be used for direct control because of its inherent instability. The differential between the total ventilation system flow into and out of a compartment (supply less return airflow) is the control variable that will maintain proper and stable compartment pressure.

Wind complications on exterior partition surfaces dictate that differential flow is always the surrogate control variable for controlling outdoor air leakage through exterior surfaces. Generally speaking, some degree of wind driven infiltration is inevitable. In some cases, resetting the differential flow setpoint by monitoring individual wall differential pressures using "bleed" airflow sensors can compensate for moderate changes in wind speed and direction as long as the maximum pressure of any exterior wall is not exceeded. When buildings have multiple compartments, the desired leakage flow between compartments is controlled by increasing the outdoor airflow differential setpoint in one compartment and reducing the outdoor air differential flow in other compartments by the same amount. This keeps the total building outdoor air ambient exchange constant. Interior partition "bleed" sensors can be used to confirm the direction and magnitude of the interior partition leakage flows.

## DILUTION VENTILATION

Dilution ventilation (outdoor air) flow rates must meet the minimum requirements of ASHRAE Standard 62.1-2016 or the mechanical code, whichever is greater, to assure compliance. In cases where productivity and health are paramount, providing more outdoor air to the breathing zone than specified by ASHRAE Standard 62.1-2016 is desirable.

The scope of this paper is not to specify minimum ventilation rates for acceptable IAQ, ASHRAE 62.1 has already done that. Its scope is simply to provide a method to assure that any specified rates are maintained under "*all load conditions*."

A properly designed dilution ventilation system must consider whether or not the outdoor airflow rates will be variable (due to free cooling, occupancy changes or pressure variations) or fixed. Since outdoor airflow rates are typically low, selection and placement of an outdoor airflow measuring station is critical. Damper sizing and quality are also critical since improperly sized, poor quality control dampers will render your entire air system much less than efficient. Energy can be conserved on VAV and variable occupancy systems by monitoring the occupancy and airflow rate to critical zones for reset of the outdoor airflow setpoint.

*EBTRON* control strategies accommodate changes in the outdoor air setpoint. *EBTRON's* thermal dispersion airflow devices are well suited to the low airflow rates associated with outdoor air intakes and placement guidelines for optimum performance are the least restrictive in the industry. In many cases only a single outdoor air damper is required (even on systems with airside economizers). All *EBTRON*-suggested sequences of operation use a sequential damper strategy that individually actuate the outdoor, return and relief dampers and in some cases a return fan VFD. The sequential approach simplifies damper selection and results in better control with minimal system pressure loss, especially when oversized dampers are selected. *EBTRON* strongly recommends the use of high quality, opposed blade, airfoil dampers with smooth operating linkage and tight sealing blades.

## CONCLUSIONS

Buildings should be compartmentalized into pressure zones. Examples of pressure zones include individual spaces, floors or zones served by a single air handling unit. Airflow rates must be controlled at the building intake(s) and into / out of each pressure zone, to maintain both pressure and dilution air requirements.

A significant financial benefit can be realized by improving indoor air quality. Standards and codes have attempted to address ventilation issues but have fallen short in meaningful methods to verify compliance. Today's designers and building owners carry the burden of design and operation compliance to maintain acceptable indoor air quality.

Dilution air and building pressure control go hand-in-hand. Buildings require outdoor air for both dilution ventilation and pressurization. Many attempts to conserve energy by reducing the outdoor air result in negatively pressurized compartments with high moisture envelopes, especially in humid climates. A sound strategy must assure that the minimum outdoor airflow rate at the air handling unit will (a) meet the ventilation requirements for IAQ and (b) meet the flow requirements for the individual pressure compartments being served. All *EBTRON* control strategies integrate dilution ventilation control with compartmentalized pressure control.

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