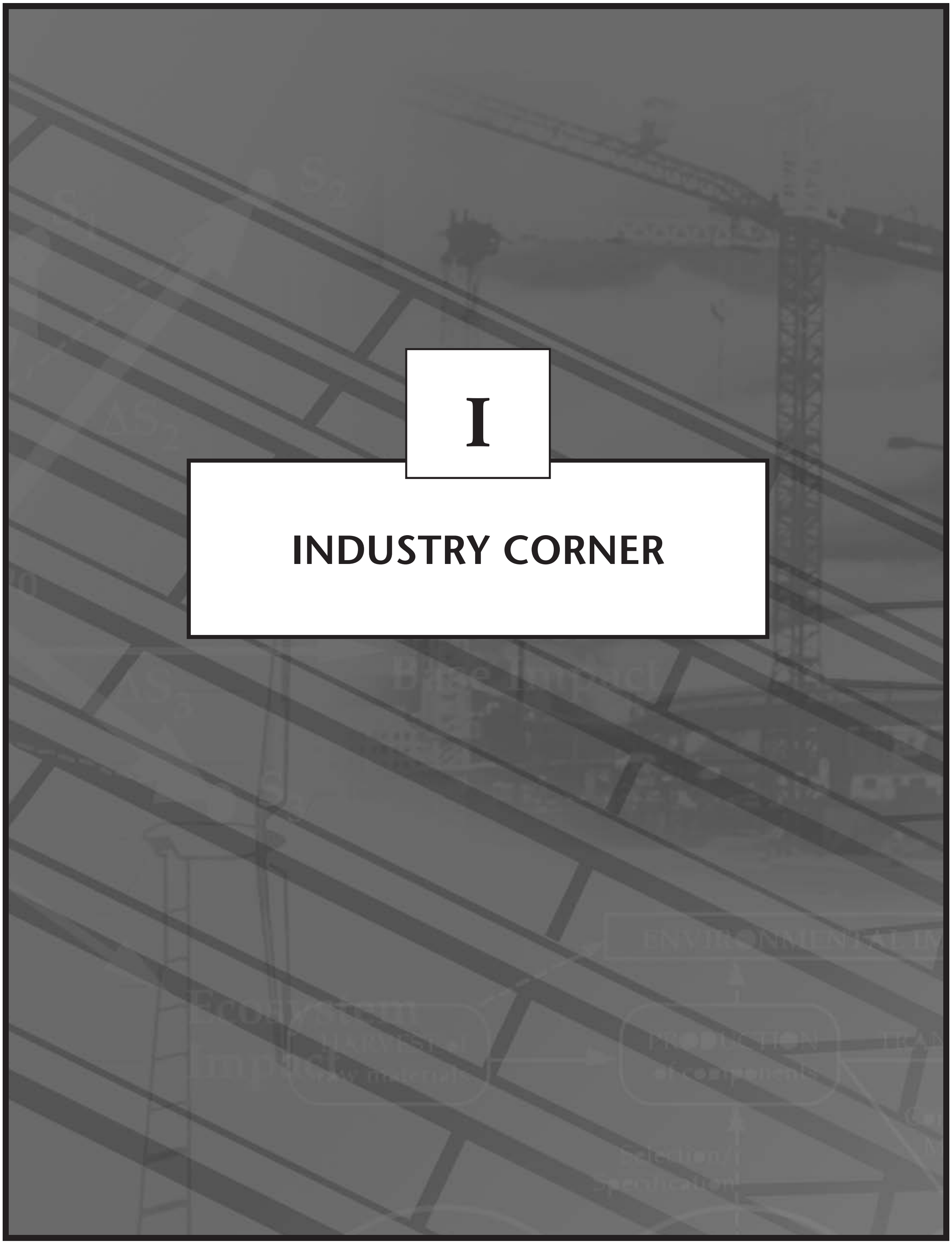

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INDUSTRY CORNER

ACHIEVING AND MAINTAINING HEALTHY GREEN BUILDINGS

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INTRODUCTION

Green buildings are created to provide healthy and productive indoor environments for their occupants. While achieving these goals can consume energy and funds, efforts to conserve energy can end up degrading the quality of the indoor environment. Therefore, a healthy indoor environment will more likely be achieved if certain priorities are established early on in the design process. These goals include understanding the integrated relationship between saving energy and the achievement of good indoor air quality, the importance of effective air sealing of the building envelope, the ability to control air contaminants, and the importance of continually managing moisture and ventilation performance over the life of the building.

While this market transformation toward green buildings has begun largely through the efforts of the U.S. Green Building Council and the LEED products, there are still many more steps along this path that need to be taken if healthy green buildings are to become the norm. Just as operational investment decisions need to focus more on Life Cycle Costs as opposed to merely minimizing initial costs, building performance evaluations need to be more holistic in scope and consider how all of the building components interact to contribute to the achievement of a healthy indoor environment as a whole.

The goal of achieving and maintaining healthy green buildings is dependent on having accurate and timely feedback on such key building parameters as the effectiveness of air barrier sealing, air contaminant control, and ventilation and moisture management performance. The evaluation of these parameters depends on knowing what metrics relating to building performance are most important to have, and what are the best and most accurate ways of obtaining this information on building performance in a timely fashion. Having accurate diagnostic feedback on building performance in these areas will not only help achieve and maintain a healthy environment, it will also reduce risks and uncertainties in building operation and reduce the time between identifying a problem with the building, and when it is understood and corrected. The longer this interval takes, the more the occupants will be adversely affected, and potentially suffer degradations in health, morale, and productivity.

SAVING ENERGY CAN DEGRADE IAQ

While the conflict between saving energy and providing a healthy indoor environment can sometimes be obvious, such as in dealing with the quantity of outdoor air being conditioned for ventilation purposes, the interrelationships among building operational factors can sometimes be less obvious.

For instance, when a lighting retrofit is performed in a building served by a Variable Air Volume (VAV) HVAC system, energy inefficient lighting equipment is replaced by equipment that provides lighting with reduced energy consumption. As a result of this changeover, less waste heat will be released into the building. Since the quantity of supply air provided by the VAV system is directly proportional to the amount of cooling required, this lighting retrofit can directly reduce the quantity of supply air delivered, leading to a reduction in the quantity of outdoor air for ventilation, which in turn results in degradation in IAQ due to this lowered ventilation rate.

The options for correcting this situation include raising the temperature of the delivered supply air so that the original quantity of supply air is again delivered, or increasing the percentage of outdoor air in the supply air. In either case, when building modifications are considered for the purpose of saving energy, an understanding of the interrelationships among the building's operational ecology is

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called for to prevent degrading the healthfulness of the indoor environment. Unfortunately, without a holistic understanding of the interrelationships among building components and operations, efforts to save energy can result in degradation of indoor air quality.

When Integrated Design Teams are being formed for a new building, one seat should therefore be reserved for an expert in the field of Indoor Environmental Quality. Otherwise, opportunities for achieving a healthy indoor environment may be overlooked when setting design and operational priorities for the building.

IMPORTANCE OF AIR SEALING

While some aspects of building design and operation place the achievement of a healthy indoor environment in competition with the goal of energy conservation, the achievement of an effective air barrier around the entire perimeter of a building will provide benefits for both improving IAQ and conserving energy.

In a number of building projects that strive to maintain flexibility of use, the pursuit of the LEED EQ Prerequisite for ETS Control has been included. The prerequisite requires testing and documentation that the amount of air leakage between adjacent units in multifamily housing has been minimized. The pursuit of this prerequisite, and its rigorous assessment of the air barrier effectiveness, is only required in buildings where smoking is going to be allowed. Having effective air sealing, however, results in a better building that not only prevents the migration of air contaminants from smoking, it also provides a better building with less migration of cooking odors and greater acoustical privacy among nearby units in multifamily housing. In all buildings, a presence of a more complete air barrier also provides benefits of more complete fire stopping and less uncontrolled leakage of conditioned air into wall cavities and ultimately to the outdoors. It is this reduction in air leakage to the outdoors that may be the most important benefit achieved by the more effective air barrier the quality of the indoor environment by protecting its occupants against the introduction of unconditioned air, and less fan energy is required to achieve a given amount of pressurization.

Trying to pressurize a leaky building is like trying to blow up a balloon with a hole in it. Air leakage at the top of the building also creates a negative pressure at the base of the building that has the potential to capture air contaminants, such as from basement parking facilities and loading docks, and transport them to the occupants in the upper levels, thus degrading the indoor air quality in the building. Where these air leakage pathways already exist in buildings, tracer testing can be used to more specifically identify these pathways, and ultimately lead to their effective sealing.

In one building where underfloor distribution of air was implemented but rigorous air sealing was not, the delivery of this air required a lot more energy than was anticipated because the building envelope was leaky. Perhaps the steps involved in achieving this ETS Control Prerequisite could be expanded to be required for all buildings. The steps involved include a Design Review to identify potential air leakage pathways that must be sealed, and as part of the construction, Construction Monitoring needs to be performed to make sure that these potential air pathways are effectively sealed during construction, and ultimately Tracer Testing is performed to document the effectiveness of the previous two tasks in achieving this LEED Requirement.

Blower door testing is offered as an alternative evaluation procedure, and can provide useful information on the size and location of leakage areas, but the performance of tracer testing more accurately assesses the potential migration of air contaminants from one location of a building to other locations in the building. This is especially true in buildings with large operable windows, where despite their potential for natural ventilation and daylighting, their leakage area will count against achievement of the LEED Prerequisite for ETS control.

An additional resource in this area is the Journal of Building Enclosure Design,[1] published by the Building Enclosure Technology and Environment Council of the National Institute of Building Sciences. According to information on this web site, this potentially free biannual publication focuses on the latest developments in building energy conservation, security, and improved building envelope design and performance.

The U.S. Green Building Council might add a LEED Credit for achieving and documenting the existence of an effective air barrier. Perhaps an air-tightness goal of 15 cubic feet per minute (cfm) per 100 square feet (ft^2) of enclosure at 50 pascals might be adopted.

While the performance of blower door pressurization and air leakage site determinations can be very useful at the time of initial occupancy, the ability to know how a building is performing in terms of its air leakage over its life is an important tool in the maintenance of a green building. This is because air leakage sites that did not exist at the time of initial occupancy may grow over the life of the building due to settling or failures of caulking or sealants. In this situation a comparison of dew point temperatures between the outdoor and indoor locations will provide a very useful tool for the identification of infiltration over the life of the building. This infiltration of unconditioned air is manifested as a reduction in the difference between the indoor and outdoor absolute humidity values, and is can be assessed throughout most of the cooling season. This is because the operation of the cooling coils reduces the indoor dew point temperature by condensing and removing humidity from the outdoor air. In one building being monitored for its absolute humidity at multiple locations, however, it was determined that supply air from one of the four air handling units (AHUs) was not dehumidifying as much as the others. This lack of dehumidification was determined to be due to a portion of the sheet metal around the coiling coil separating and allowing air to unintentionally bypass the coil.

A review of the dew point values will also indicate the presence of any infiltration occurring, because the dew point at this measured location will be increased over the other indoor locations, as the uncontrolled leakage of humid outdoor air will elevate the local dew point temperature.

When determining the best way to accurately monitor dew point temperatures at multiple locations, consideration should be given to using one of the shared-sensor monitoring systems, as this will allow the use of one accurate dew point sensor to be shared among a number of locations. Not only does this sharing among multiple locations offer an economic benefit as the cost of this expensive piece of monitoring equipment is amortized over multiple locations, it offers greater confidence in results as compared with the use of individual sensors. This is because, with all the measurements of absolute humidity at each of these locations with the same sensor, any differences detected, no matter how small will be real, and not merely due to varying sensors' responses. The shared-sensor monitoring equipment offers an additional benefit in this application because this approach uses tubing to transport an air sample from the location being assessed to the central housing where the sensor and intelligence is actually located. Therefore, the sampling end of the tubing can be located in a wall cavity close to the exterior wall, or even in it.

The data from a shared sensor monitoring system, as shown in Figure 1, can also identify a moisture intrusion due to a deficiency in the ability of the building envelope and its flashing details to exclude rainwater from penetrating into the building's interior.

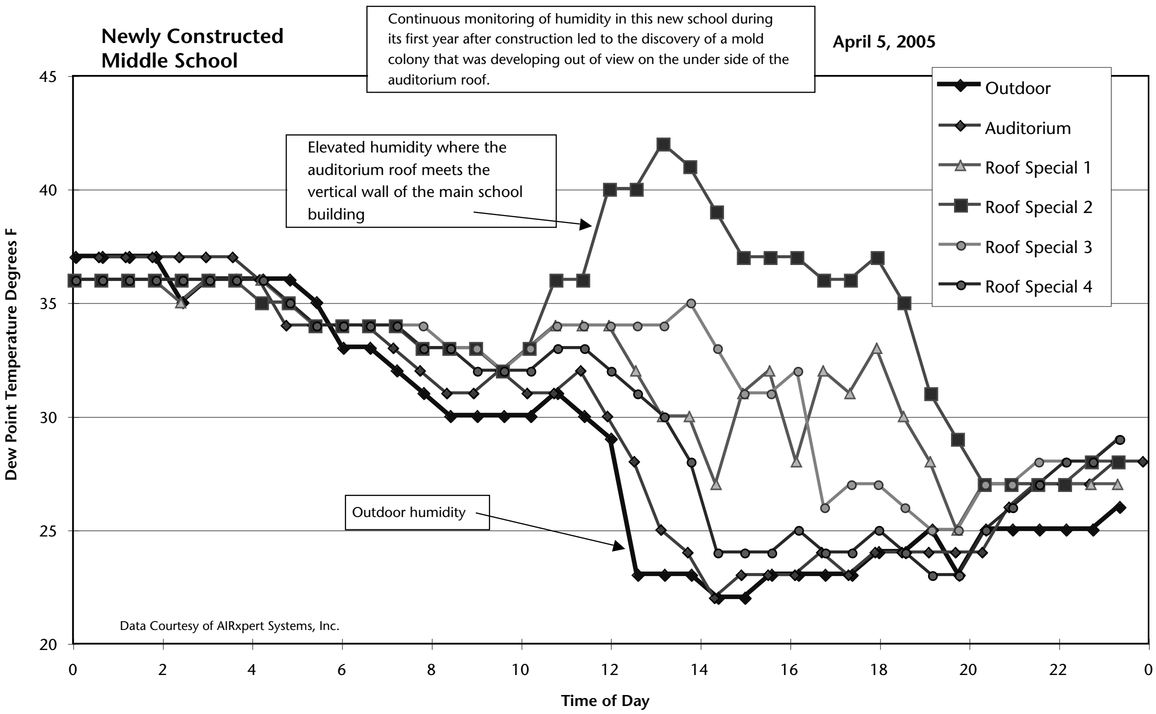
This ongoing evaluation ability can be very important in older buildings that were designed and constructed without redundant drainage planes and rely on face sealing of penetrations to exclude the introduction of wind driven rain. In this situation, concerns about the ability to rapidly detect any failures of these face sealing efforts can be put aside, as the presence of a multi-point monitoring system serves as an early warning mechanism to detect the occurrence of moisture penetration into the building envelope.

Having accurate diagnostic feedback on the effectiveness of moisture management efforts is a key tool for achieving and maintaining a healthy green building so that the operators will be able to know, both initially and over the life of the building, whether or not the systems are functioning as intended.

CONTROLLING AIR CONTAMINANTS

The achievement of a healthy indoor environment requires that the presence of, and exposure to, air contaminants be minimized in this space. Indoor air quality is basically a function of the dynamic interaction between the presence of air contaminants and the air movement to dilute and remove these

FIGURE 1. Identification of moisture intrusion from dew point monitoring.



air contaminants, including both the volumetric quantity of air being moved, and how this air moves through the space being ventilated.

While many of the credits offered under the LEED program are for the elimination or minimization of volatile organic compounds (VOCs) used in the construction of buildings, more attention could be focused on the VOCs arising from the people and the activities occurring within the building. People account for air contaminants in various forms that include particulate matter, chemicals (VOCs), bioeffluents, moisture, and heat.

Particulate Matter Air Contaminants

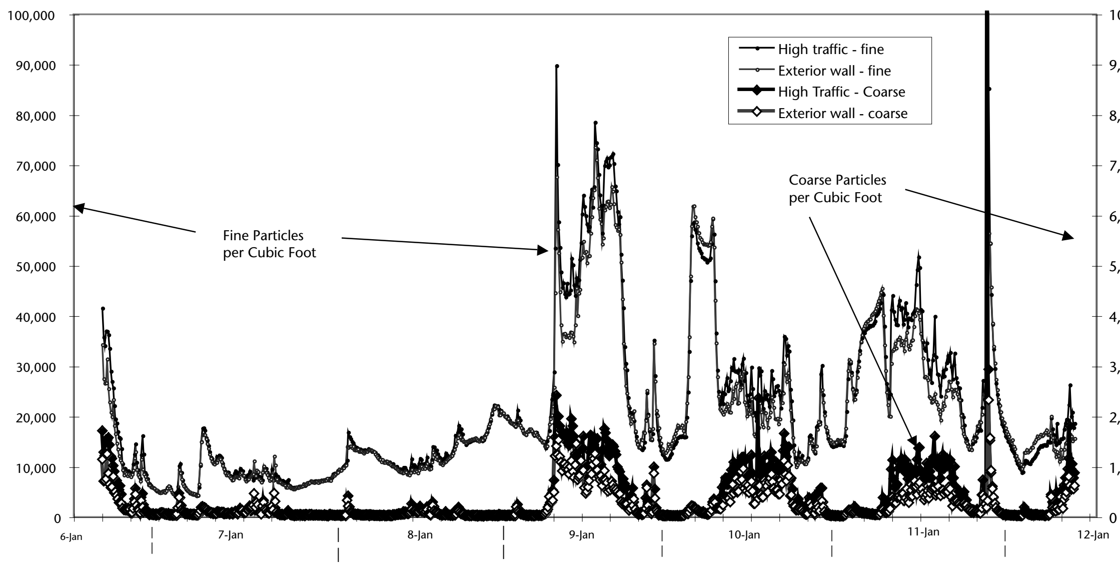
The Peanuts comic strip character Pigpen, with his accompanying cloud of dust and dirt, is the epitome of a person's contribution to air contaminants. A Clean Room protocol PowerPoint presentation from Montana State University[2] states that people are the number one source of particulates in clean rooms from their shedding of skin, hair, lint, etc. According to this reference, an individual just standing or sitting motionless corresponds to a generation of 100,000 particles in the 0.3 micron or larger size. Walking at two miles per hour increases this generation rate to 5,000,000 particles.

The impact of the presence of people on airborne levels of particulate matter can be observed in Figure 2, showing a comparison of airborne fine and coarse particulate matter in both a high traffic and low traffic office space. This particulate monitoring effort is from 2006 and so January 7 is a Saturday. The fine particulate refers to the monitored size range of 0.5 micron and larger, while the coarse particulate is for the size range of 5.0 micron and larger. As the particle size decreases, the number of particles in the air increases significantly. This can be observed in this figure, where over this weekend the fine particle counts are in the 10,000 to 20,000 particles per cubic foot range, while the coarse particle counts are typically below a few hundred particles per cubic foot. The larger "coarse" particles are typically removed by most well designed and maintained HVAC systems, but only the higher MERV filters will capture and remove the smaller particles. Due to the differing capture mechanisms for particulate matter in the air, it is the 0.3 micron size range that is the most difficult to be captured and removed, both for HVAC mechanical systems and the human respiratory tract. It is therefore this fine particulate matter that can penetrate most deeply into the lungs.

On Monday morning, when the people come in from the outdoors and remove their coats, the airborne particulate counts increase dramatically, typically above 60,000 particles per cubic foot for the fines, and over 1,000 particles per cubic foot for the larger particles. This data suggests the limited knowledge gained about the level of particulates in a given building by just measuring the particle removal ability of the filter bank, while ignoring the particulate contribution of the supply air ductwork and the activities of the people in the space. Now if a particular person in the indoor environment is also a smoker, then his contribution of particulate matter can include what is now called "third-hand smoke." This term refers to the cocktail of toxins that linger in carpets, sofas, clothes, and other materials hours or even days after a cigarette is put out, and is a health hazard for infants and children.

Another significant finding in this post-occupancy IAQ assessment testing effort is the similarity between the low traffic and high traffic areas. But this result is a direct outcome of the fact that this space is served by supply air registers in the ceiling whose intent is to achieve a well-mixed, thermally uniform space temperature. In contrast, if the goal were to achieve a healthy indoor environment, there would need to be a redefinition of the design and operational goals, focusing on ventilation effectiveness, and how rapidly any air contaminants present would be diluted and removed from this space, and not on the achievement of the uniformity of temperature within the indoor spaces. In addition, achieving a uniform temperature distribution in an indoor space does not reflect the inherent variability of temperature preferences by the people in that space. To achieve comfortable thermal conditions for more people is to give them control over local air speeds, air temperatures, and even the temperature of nearby radiant surfaces, such as chilled beams. Achieving a more rapid dilution and removal of air contaminants is done by having displacement or piston flow through the space, as opposed to the more traditional well-mixed case. Moving away with this well-mixed design for ventilating indoor spaces will

FIGURE 2. Comparison of fine and coarse particles per cubic foot between high and low traffic areas, January 6 through 12, 2006.



achieve a healthier indoor environment by reducing the residence time not only of particulates generated in the space, but also from viruses shed by the people there.

Biologically Active Air Contaminants

While the presence of viruses in the indoor environment has not yet been extensively studied, there is enough information published to indicate that the achievement of a healthy indoor environment requires the rapid dilution and removal of air contaminants from the people in the space, with a minimum of mixing between the air spaces of nearby people. One mention of the monitoring of viruses in the air is for mumps and measles viruses in a hospital:[3] Monitoring procedures were performed in hospital infection wards with patients suffering from mumps and measles diseases to detect the corresponding disease causing viruses in the ambient air. The results for the existence of the airborne viruses were obtained for both strains.

The amount of ventilation provided and its impact on the rate of transmission of short-term illness was looked into by Donald Milton, et al.[4] In this paper it was reported that a consistent association of increased sick leave was found with lower levels of outdoor air supply, in the evaluation of sick leave among employees of a large Massachusetts manufacturer. Airborne transmission of airborne infection may be an important factor in determining the relationship of building ventilation with health and productivity. It is also stated that experimental human exposures suggest that airborne transmission of rhinovirus, adenovirus, and coxsackievirus is a potential, and for some agents a common, route of infection.

The airborne spread of viruses can also depend on the absolute humidity level, as reported in the Proceedings of the National Academy of Sciences,[5] that when absolute humidity is low, influenza virus survival is prolonged, and transmission rates go up.

There is also limited information available on the transmission of the severe acute respiratory syndrome (SARS) virus. One source indicates that the probable environmental causes for airborne transmission were associated with the air movements between flats in Block E.[6]

Volatile Organic Compound (VOC) Air Contaminants

People can be sources of air contaminants from gasses, as well. These chemicals, or VOCs, arise from things that people do, or don't do. For example, besides smoking, they may apply fragrances to their bodies in the form of perfumes and colognes. Unfortunately, these chemicals can cause adverse health effects in other people more sensitive than they are. Already certain indoor environments are requiring that they be "fragrance free" zones. In terms of what the people present may not be doing, they may not practice good oral or personal hygiene, leading to the generation of body odors. The relationship between ventilation rates and body odors has been studied for a long time, and has resulted in the basis for the ventilation rates called for in ASHRAE Standard 62. Unfortunately, from a standpoint of achieving a healthy indoor environment, the goal of these ventilation rates has been to merely achieve acceptable indoor air quality where a substantial majority (80% or more) of the people exposed do not express dissatisfaction. If the goal is to achieve a healthy building for all, then merely achieving the minimum ventilation rates listed by ASHRAE Standard 62 will not be sufficient. As pointed out by the previously mentioned article by Milton,[4] health benefits accrue when delivered ventilation rates are increased above 10 liters per second per person (20 cfm/person).

ASHRAE Standard 62 also requires that there be no known contaminants at harmful concentrations as determined by cognizant authorities. What happens when sampling for viruses becomes more widespread and concentrations sufficient to cause illness are detected in more and more environments? Viruses are present in the air as very small particles, typically less than 0.1 micron and are therefore difficult for even HEPA filtration to remove from the airstream. The Montana State University reference on Clean Room2 also reports that the particle size distribution from sneezes is >40% in the less than 1 micron size range, while the particle size distribution for coughs is >70% in the less than 1 micron size range. Minimizing exposures to shed viruses will require reductions in mixing within the space, and so there will need to be a phasing out of the traditionally relied on overhead mixing supply air design approach.

Air Contaminants from Office Equipment

Office equipment can be expected to contribute to air contaminants as well. Published research in the emissions from office equipment dates back to an EPA paper in 1995,[7] in which emissions of hydrocarbons, respirable particulates (toner powder), and ozone were identified as coming from dry-process photocopying machines and laser printers. A more recent assessment of emissions from sources within the office environment[8] has reported that the operation of the printer, copier, and computer had the most significant impact on the overall VOC concentrations in a typical office environment. More details on the impact of indoor pollutant emissions from office equipment continue to be forthcoming,[9] but the question remains as to how well this information is being incorporated into the achievement of healthy indoor environments. This presentation reported that, during operation, emissions from office equipment can result in room concentrations comparable to those from other indoor sources. While a Credit is given under LEED® for having high volume copiers in isolating rooms under negative pressure with respect to their surroundings, the question remains as to whether this is enough for achieving a healthy indoor environment, and whether there should no longer be a laser printer on most desks, as this would also save money on capital costs and people would have to get up and walk around to retrieve what they've had printed.

There is also the particulate matter coming from the HVAC mechanical equipment delivering air to an indoor environment, but this tends to be less than the particulate matter generated in the space by the people and their activities. Some of particulate matter can even be brought in on the people's shoes; hence the benefit of having walk-off carpets to capture this particulate matter before it enters the building.

Mold-Related Air Contaminants

Another major category of air contaminants that can degrade the healthfulness of the indoor environment is mold growth. If mold growth were to occur, this would mean that there are elevated levels of moisture in the building. Prevention of mold growth is therefore achieved by effective moisture management that rapidly identifies the existence of any areas of elevated moisture levels that would allow indoor mold growth to occur.

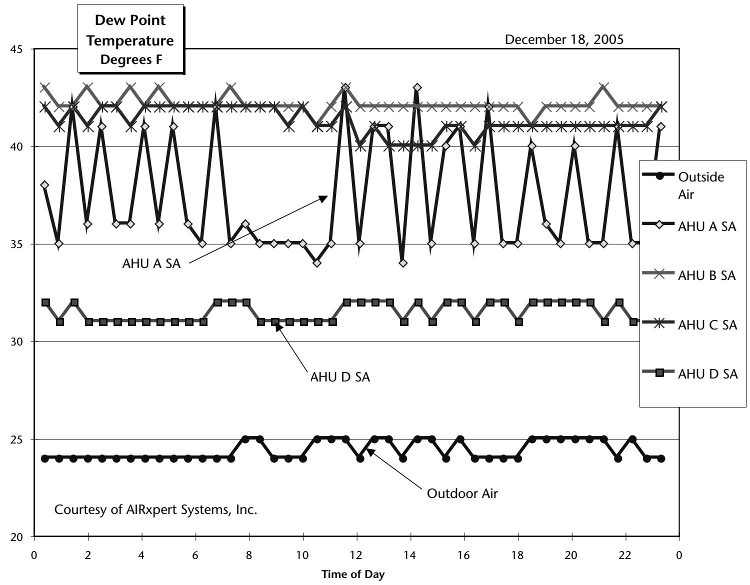
Having feedback on building conditions that can identify the presence of elevated moisture not only provides an early warning system to alert the building operators to the possibility of mold growth, it will offer several other benefits that will help them better manage the building in terms of achieving and maintaining a healthy indoor environment while saving energy at the same time.

This moisture monitoring effort can identify the presence of water leaks. This is of concern especially due to the presence of water valves distributed throughout, and if more valves can be expected as more buildings include chilled beams to provide cooling. As mentioned earlier, this moisture monitoring effort can also identify a moisture intrusion due to a deficiency in the ability of the building envelope and its flashing details to keep rainwater from penetrating into the building's interior. Local dew point temperatures can be measured in areas where this is occurring. This building management tool can also be used to balance the use of outdoor air for cooling so as to not overdry the building occupant and cause discomfort for contact lens wearers.

Knowing the absolute humidity in the building also provides operational feedback on any mechanical processes providing either humidification or dehumidification. Humidification systems tend to be high maintenance processes where many things can go wrong to either waste energy, degrade IAQ, or just fail to achieve the desired level of humidity control. The data from one such absolute humidity monitoring effort at a medical facility, as displayed in Figure 3, shows how much variation can occur. In this figure, it can be observed that AHUs B and C are working as intended, raising the dew point temperature to the low 40 degrees as compared with the outdoor air in the low 20 degrees. The supply air from AHU D is only in the low 30 degrees, while the supply air from AHU A is cycling between 35 and the low 40 degrees.

Another reported finding of the Milton[4] study was the association between humidification and increased worker absence that was attributed to increased bioaerosol exposures.

FIGURE 3. Humidification variations at medical center.



Humidity control is an important goal involved in achieving a healthy indoor environment. Back before the energy disruptions of the early 1970s, the moisture levels in the supply air was controlled by cooling to a given dew point temperature and then reheating to the desired supply air temperature. As important as it is to control moisture to maintain a healthy building, the energy consequences of subcooling with reheating has been deemed unacceptable with many placing their priority on energy conservation over achieving superior indoor air quality. The conflict between energy savings and achieving a healthy indoor environment continues.

Motor Vehicle Air Contaminants

Effective air sealing will also be very important in the achievement and maintenance of healthy buildings that have ground level Loading Docks or below grade parking facilities. This is because air leakage occurring at the top of the building will create a negative pressure at the base of the building that can capture and transport motor vehicle air contaminants up into the occupied areas of the building. There also needs to be a broader recognition of the fact that with the widespread implementation of catalytic converters in cars, there has been a huge reduction in the generation of carbon monoxide in these motor vehicles. Cars, however, continue to be a complex source of other air contaminants that include oxides of nitrogen, unburned hydrocarbons, aldehydes, and particulates. Therefore, if one component of achieving and maintaining a healthy building is to be able to provide ventilation for each vehicle entering or leaving a below grade parking facility, basing a ventilation control system on just carbon monoxide will not be able to achieve this goal. One published effort[10] to deal with this issue has reported that CO_2 is an effective estimator of oxides of nitrogen and particulates in a garage.

MONITORING VENTILATION PERFORMANCE

Even after as many air contaminants as possible have either been eliminated or minimized, it is still a requirement for the achievement of a healthy indoor environment that sufficient ventilation be provided to rapidly and effectively dilute and remove any air contaminants that are still present. Even if there are no air contaminants coming from the building equipment or furnishing, there will also be the odors, bacteria, and viruses shed by the occupants themselves. The conditioning and introduction of outdoor air may also be required to pressurize the building against the infiltration of unconditioned outdoor air into the building.

Recognizing this essential requirement for the achievement of a healthy indoor environment, the following operational decisions must be made:

1. Decide what the ventilation goal is for the occupants.
2. Install the monitoring equipment necessary to determine if this ventilation goal is actually being achieved.
3. Commit the resources to have this ventilation performance monitoring data trended and reviewed in a timely fashion.

The goal of the ventilation rates listed in ASHRAE Standard 62 is to achieve a level of perceived comfort conditions among the building's occupants. So, it needs to be more widely appreciated that merely achieving the requirements of this Standard are not sufficient to achieve a healthy indoor environment for the reasons stated earlier that this is just trying to achieve a certain level of perceived comfort. Therefore, there should be a discussion early on in the design of a building as to whether there will be the delivery of sufficient outdoor air for ventilation to rapidly dilute and remove the air contaminants present in that space.

There are also significant energy consequences associated with the conditioning of this air for ventilation. The energy consequences can also be expected to become more important as buildings become greener as the amount of energy consumed for conditioning the building air will become a larger percentage of all of the building energy consumed. This will occur as there are improvements to the thermal performance of building envelopes, and as lighting requirements are achieved more efficiently.

Combining these two goals of providing a healthy indoor environment for the smallest energy expenditure requires that the amount of ventilation actually being delivered to the occupied spaces be accurately determined. In order to effectively manage an aspect of building performance, accurate diagnostic feedback on its performance is required. This is a basic truth, whether the building characteristic is its energy use, water consumption, or ventilation delivery amount.

The tool for determining the ventilation delivery amount is accurate carbon dioxide (CO_2) monitoring. While this seems to be reflected in the fact that more buildings are being built with CO_2 sensors in them, there is still more to be done in achieving this goal of actually being able to manage this important part of building performance. The additional steps that need to occur are the logging of this CO_2 monitoring data and the timely review of this trended data. Only when these additional steps are performed as well can the goal of having CO_2 sensors to help balance the achievement of a healthy indoor environment with energy conservation be accomplished.

Also, the specific design of the CO_2 monitoring makes a difference in the accuracy of the resulting monitoring data, stemming from the fact that the ventilation is a function of the increase in concentration indoors over outdoors. In a small building with just a few sensors, the accuracy of these sensors therefore should be frequently checked with an independent high quality sensor. In larger buildings, this higher degree of accuracy can be achieved by using one of the shared-sensor, or centralized monitoring systems. For example, if two different sensors are used to measure the indoor location and the outdoor location, errors in these readings, while still within the manufacturer's limits of calibration, can introduce significant error in the ventilation determination. If, for instance, the indoor sensor were reading 60 ppm low and the outdoor sensor were reading 60 ppm high, still within the manufacturer's claim of ±ppm being "in calibration," and a difference between these locations was reported at 520 ppm, the ventilation calculation would yield a result of 20.4 cfm per person. A reported result of this value would be interpreted as the ASHRAE recommended minimum of 20 cfm person being achieved. In reality, however, the difference between indoors and outdoors was really 640 ppm, equivalent to a ventilation rate of only 16.5 cfm per person.

This example stresses the importance of either using the same sensor for both the indoor and outdoor locations, or having a program of periodic calibration checks if multiple sensors are being used.

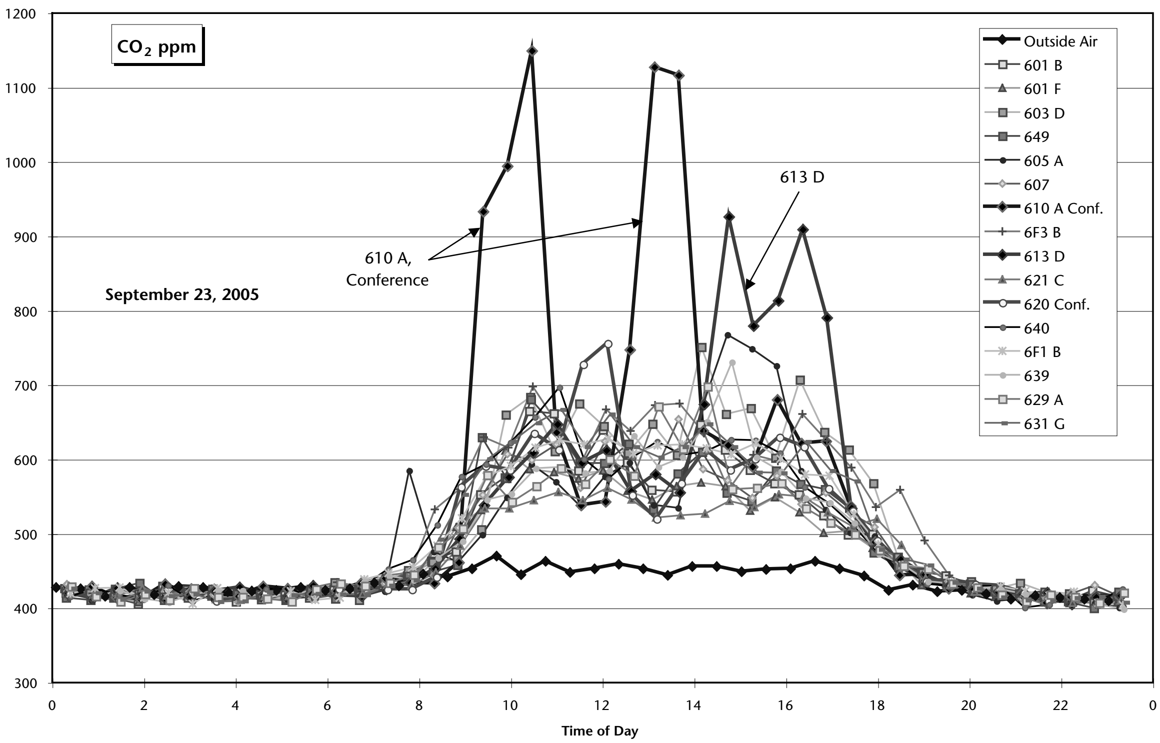
An indication of the calibration accuracy can be determined from a review of monitoring data obtained at an off hour, such as in an unoccupied building on a Sunday morning at 2:00 a.m. The building's sensors should all be reading the same, at between around 370 and 390 parts per million. If this is not the case, then the data is suspect. Despite published information from the Lawrence Berkeley Laboratories[11] expressing strongly that the accuracy of CO_2 sensors used may not be sufficient to rely on for automated control, and what should be a basic acknowledgement of the dictates of Murphy's Law that, "What can go wrong will go wrong," engineers are not requiring that CO_2 sensors have their calibration performance checked on a routine basis.

Inherent in the fact that to manage ventilation performance you need to have accurate feedback on the amount of outdoor air actually being delivered to the building's occupants, there is much information that can be obtained. One example of this information includes how much variation in ventilation is occurring among the locations being monitored. This variation in ventilation, as displayed in Figure 4, can be significant. In this figure, the CO_2 monitoring results for the Conference room 610A indicates that during occupancy only about 16 cfm per person is being provided. This is in huge contrast with the other locations that, with the exception of 613D receiving around 23 cfm per person, are receiving in excess of 30 cfm per person.

This variation among locations is a common phenomenon, and requires that if automatic Demand-Controlled Ventilation (DCV) is going to be pursued, then there needs to be an initial diagnostic phase where ventilation deficiencies are corrected. The potential for DCV to provide energy saving while still maintaining the delivery of the intended amount of ventilation necessary for achieving a healthy indoor environment will best occur in buildings with a varying occupancy pattern through the day. For occupancies that are fairly similar from day to day, the need for the expense of implementing automatic control may not be justified, but frequent review of the trended data will provide assessments of how well the operational schedule of the HVAC equipment matches the occupancy pattern of the building.

Another problem with respect to CO_2 monitoring has to do with the placement of the sensor itself, in the return air stream, near the AHU. Measuring the CO_2 concentration at this location means that,

FIGURE 4. Variations in ventilation at a medical center.



at best, the reviewer of this data will see an average of the ventilation rates of all of the locations served by this AHU. Since this includes unoccupied locations as well as any leakage of supply air directly back into the return air stream, measurements of CO_2 concentrations at this location typically indicate that a generous amount of ventilation is being provided. Unfortunately, measuring CO_2 concentrations at this location will fail to identify localized ventilation deficiencies should they occur. Additional recommendations pertaining to measurement issues and other aspects of CO_2 monitoring are presented and discussed in ASTM D6245,[12] Standard Guide for Using Indoor CO_2 Concentrations to Evaluate Indoor Air Quality and Ventilation. One component is the derivation of the equation where, at equilibrium, the ventilation rate per person is equal to the per person CO_2 generation rate divided by the increase of the indoor CO_2 concentration over the outdoor CO_2 concentration. A typically used CO_2 generation rate for office workers at 1.2 Met units is 0.0106 cfm. Multiplying this generation rate by 1,000,000 to make the units consistent with the part per million (ppm) CO_2 concentrations yields an equation for the determination of the per person ventilation rate to be 10,600 divided by the increase in the indoor CO_2 ppm value over the outdoor CO_2 ppm value. Since the time to achieve equilibrium is a function of the ventilation rate, at low ventilation rates the use of this equation will yield a value in excess of the true ventilation rate. However, at these low ventilation rates, even this overestimation will still indicate a ventilation deficiency as compared with the ASHRAE recommended minimums.

In addition to being able to determine the ventilation rates being provided during peak occupancies, monitoring will also provide an assessment of the effectiveness of the overnight purge and the appropriateness of the on/off schedule for the HVAC equipment.

The achievement of healthy building environments is happening as part of the market transformation being led by the Green Building movement. This is evidenced by the fact that more and more buildings are getting carbon dioxide sensors installed. The market still has further to go in utilizing tools for balancing the delivery of sufficient ventilation to provide a healthy indoor environment with the goal of minimizing energy use by the HVAC system.

In order to achieve and maintain a healthy indoor environment, there needs to be a greater priority set on understanding how a healthy indoor environment is achieved, and that buildings need to have a greater amount of diagnostic feedback to reduce uncertainty and risk by giving the operators accurate feedback on both ventilation and moisture management performance.

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