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Indoor Environment, Productivity in Offices

By **Olli Seppänen, Lic.techn.,** Fellow ASHRAE; **William J. Fisk,** Fellow ASHRAE; and **Pawel Wargocki, Ph.D.**

Scientific data has shown that a deteriorated IEQ is related to increased sick building syndrome symptoms, respiratory illnesses, sick leave, and to reduced comfort and productivity losses. Some calculations show the cost of deteriorated indoor environments is higher than building heating costs.[1] Macroeconomic estimates indicate that improving IEQ can generate large economic benefits, at least tens of billions of dollars per year in the U.S., and possibly more than $100 billion per year.[2,3]

A few sample calculations have shown that measures to improve IEQ are cost effective when the financial value of health and productivity benefits are considered.[2,4–10] An obvious need exists for models that enable economic outcomes of health and productivity to be integrated with initial, energy and maintenance costs in cost-benefit calculations.

This article presents models for estimating how the indoor environment quantitatively affects sick leave and work performance, two indicators of productivity. The models were developed using the existing data on the issue and acknowledging the high level of uncertainty associated with the models.

More detailed presentations of these models are provided,[11–13] as well as in the papers cited subsequently.

Multiple factors other than IEQ also affect work performance. An individual's performance is influenced by the working environment, personal motivation, and by the person's ability to perform the job. The working environment includes IEQ conditions, such as temperature, ventilation, noise, lighting, etc., but also facility services, such as e-mail service and infrastructure conditions such as workstation layout.[14]

Psychosocial aspects and the occupant's perceptions of the workplace environment may also affect productivity. It is through changes

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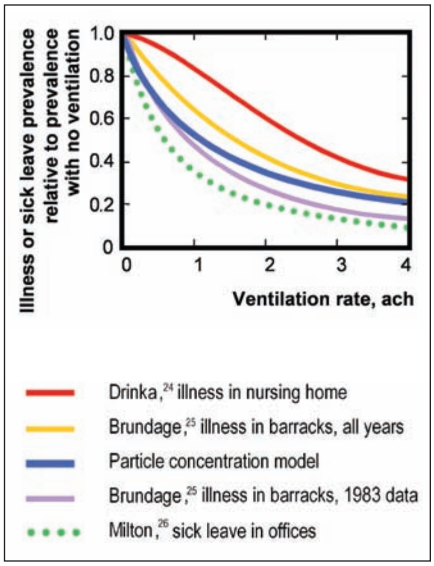

***Figure 1:** Predicted trends in illness or sick leave vs. air-change rate.[5] Different lines represent calibrations of the disease transmission model with empirical data, except the blue line. Particle concentration model is based on an assumption of airborne disease transmission risk, which is inversely proportional to the total removal rate for airborne infectious particles.*

Inside Find out about a new guide that explains how to use ANSI/ASHRAE Standard 62.2. See Page 14.

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in building design and operation that society can improve IEQ and realize associated productivity benefits. Hence, ASHRAE members have an important role to play if we are to attain these benefits.

Quantitative Relationships Between IEQ & Productivity

For engineering cost-benefit calculations, it is necessary to be able to quantitatively estimate how IEQ factors influence productivity. Based on research performed so far, we have estimated the following quantitative relationships:

- Relationship between ventilation rate and short-term sick leave and associated absence;
- Relationship between ventilation rate and work performance;
- Relationship between perceived air quality and work performance; and
- Relationship between temperature and work performance.

Ventilation Rate and Short-Term Sick Leave

Quantitative relationships between ventilation rate and short-term sick leave were estimated by calibrating a theoretical model of airborne transmission of respiratory infections with published field data in which ventilation rate was the independent variable and short-term sick leave or illness incidence were the outcomes.[5] The model accounts for the effects of ventilation, filtration, and indoor particle deposition on airborne concentrations of infectious particles and on the feedback process by which more disease transmission in a building leads to more sick occupants who are the source of infectious particles. The model is calibrated (i.e., it is fitted to several sets of empirical data), resulting in different curves relating ventilation rates with illness prevalence.

The resulting relationships are presented in *Figure 1*. Although the model has many sources of uncertainty,[5] the effect is large and may be economically significant. The curves in *Figure 1* indicate about a 10% reduction in illness for doubling of outdoor air supply rate.

Using these relationships, Fisk, et al.,[5] estimate that the economic benefits from reduced absence when an outdoor air economizer is used exceed the energy cost savings, which is often the sole reason for using an economizer, by a factor of approximately three to eight.

Ventilation Rate and Work Performance

An estimate of the relationship between ventilation rate and work performance was developed based on five studies in offices and two studies that collected data in a controlled laboratory experiment.[15] These studies quantified office work performance by measuring performance of simulated office work (typing, addition, proofreading) and by tracking speed of actual work in call centers. One study used a reaction time test to indicate performance. Each data point was weighted by

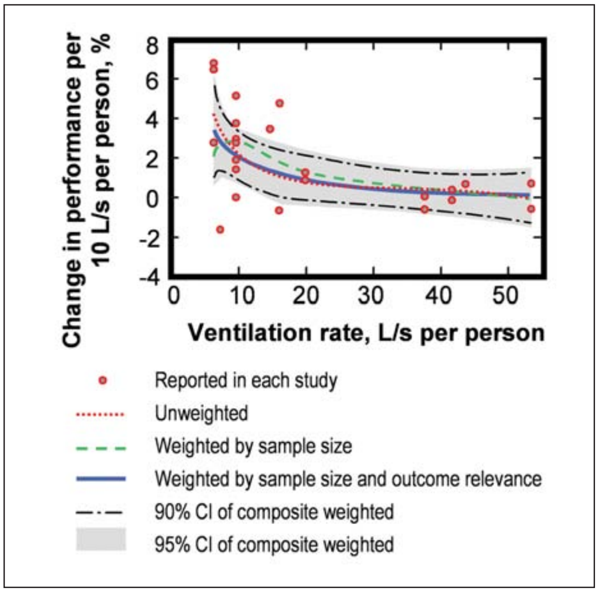

Figure 2: Increase in performance as a function of ventilation rate.[15]

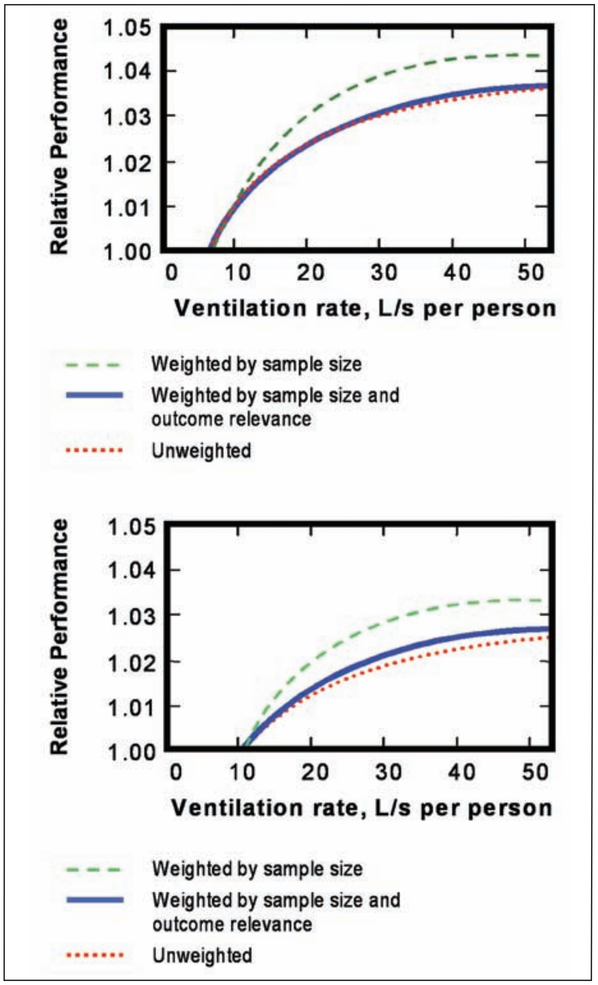

Figure 3: Effect of increasing ventilation rate on performance relative to performance at the reference ventilation rate of 6.5 L/s per person (top figure) and 10 L/s per person (bottom figure).[15]

the number of subjects in the study. The different studies also were assigned weighting factors according to the relevance of the productivity metric for overall office work performance, e.g., the reaction time metric was given a low weight because it is not clear that it is a good predictor of actual office work performance. The resulting normalized adjusted productivity (by percentage) vs. ventilation rate is plotted in *Figure 2* with best fit curves and 90% and 95% confidence intervals (CIs) shown. *Figure 2* shows the best fits to the normalized data: when the initial data were unweighted, weighted by sample size, and composite weighted, i.e., weighted by both sample size and by the relevance of the performance outcome for total work performance. The curves suggest that doubling the outdoor air supply rate will improve the work performance on average by 1.5%. The curves indicate that performance would improve with increased ventilation up to approximately 40 L/s (85 cfm) per person, but performance increases are statistically significant (i.e., 95% CI excludes zero) for ventilation rate increases up to about 15 L/s (32 cfm) per person.

To provide a more practical tool, we used the best fit curves in *Figure 2* to develop curves of relative performance vs. ventilation rate. The results are plotted in *Figure 3* in which the reference ventilation rates were set to 6.5 and 10 L/s (14 and 21 cfm) per person. Due to limitations of data, the ventilation range in the figure cannot be extrapolated.

Perceived IEQ and Work Performance

An estimated relationship between perceived air quality and performance of office work is presented in *Figure 4* based on three experiments with subjects performing simulated office work.[16–19] Air quality was modified by changing the outdoor air supply rate in an office polluted by a sample of a 20-year-old carpet from a problem building, or by removing this carpet from the office. The quantitative relationships indicate a 1.1% increase in performance for every 10% reduction in the proportion of dissatisfied subjects with the air quality, in the range 25%–70% dissatisfied subjects perceived by persons immediately after entering the space from the clean air. When the air quality is evaluated with this procedure, the typical percentage of dissatisfied subjects is 25%–60%.[20] Based on the relationships shown in *Figure 4*, one may predict that improving air quality in the buildings with the highest proportion of dissatisfied subjects to the levels observed in the buildings with the lowest proportion of dissatisfied subjects would improve the performance of office work by about 3%–4%.

The relationship in *Figure 4* was later verified[21] by combining the data from experiments in which carpet was a pollution source[18] with the data obtained in studies when the sources of pollution were personal computers with CRT monitors[22] and linoleum, sealant, and shelves with books and paper.[21] The combined data were used to create the relationship between performance and air quality presented in *Figure 5*. The resulting relationship, about 0.8% change in performance for every 10% change in proportion of subjects dissatisfied with air quality, is similar to that observed in studies with carpet.[18] However, the performance indicator was only text typing,[21] unlike in the studies with carpet,[18] where the performance outcome included performance of text typing, addition and proofreading.

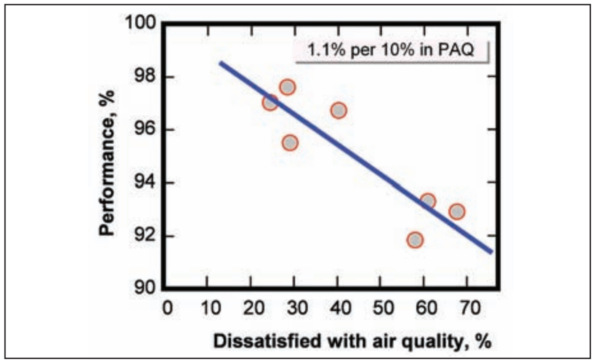

***Figure 4:** Performance of simulated office work as a function of proportion of dissatisfied subjects with air quality (R^2=0.78; P=0.008).[18]*

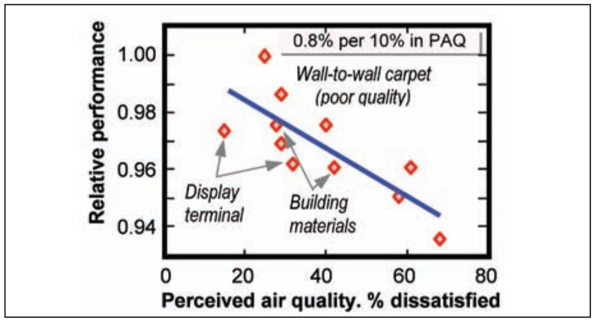

***Figure 5:** Performance of text typing as a function of the proportion of subjects dissatisfied with the air quality (R^2 = 0.60).[21]*

Based on the relationships shown in *Figures 4* and *5*, one can estimate the effect of improving perceived air quality in office buildings on the performance of office work.

Temperature and Performance Of Office Work

Figure 6 shows a relationship between indoor air temperature and work performance based on 148 assessments of performance from 24 studies.[23] These studies tracked objectively measured indicators of work performance (e.g., talk time in call-centers), speed and accuracy of complex tasks or simple visual tasks, performance of vigilance tasks or manual tasks related to office work and measured the rates and accuracy of learning. The results of each study were weighted by the number of study subjects, and the different studies were assigned weighting factors according to the relevance of the productivity metric for overall office work performance. Then, study results were normalized by calculating percentage change in performance for every 1°C (1.8°F) change.

Figure 6 shows the normalized data and shows curve fits to the data with 90% confidence intervals. Positive values indicate that performance improves when temperature is increased and negative values indicate that performance is reduced when the temperature is increased. The curve crosses zero at about 22°C (72°F). Consequently, the data indicate that performance improves with increased temperature when temperature is below 22°C (72°F) and decreases with increased temperature above 22°C (72°F).

The relationship presented in *Figure 6* is replotted in *Figure 7* using 22°C (72°F) as a reference point. *Figure 7* indicates that performance changes by about 1% for every 1°C (1.8°F) change in temperature from the reference of 22°C (72°F).

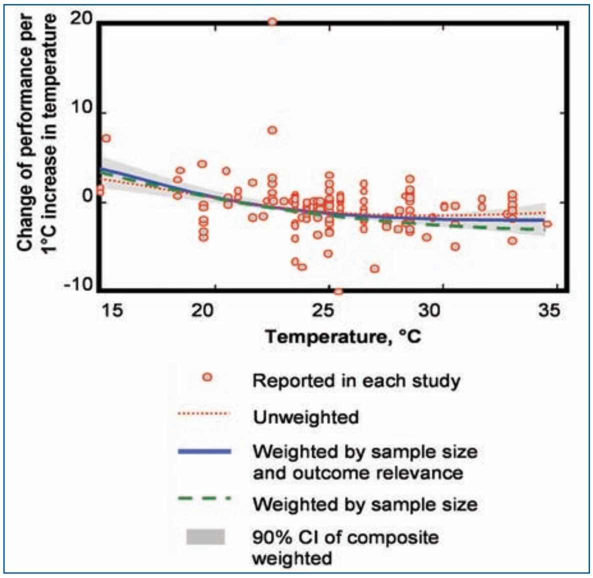

Figure 6: Change of performance (ΔP% per °C increase) as a function of temperature. Positive values indicate that performance is improved when temperature is increased, and the negative values show that performance is reduced when the temperature is increased.[23]

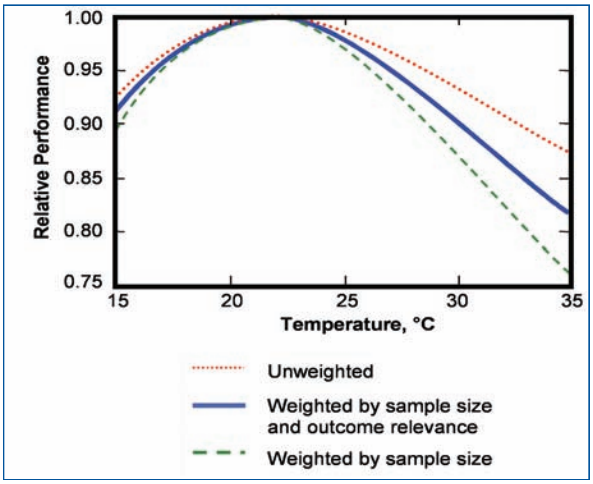

Figure 7: Relative performance as a function of temperature. The reference is performance at 22°C.[23]

Who Receives the Benefits

Based on one's perspective, the cost effectiveness of investments for better building design and operation will vary. Consider the perspectives of the building owner plus employer (i.e., case of owner-occupied building), building owner (lessor), employer (lessee), and society.

In owner-occupied buildings, the owner/employer benefits directly from the improvements in the health and performance of his employees. Real benefits, of course, depend on the specific situation in the company such as: number of employees, type of work, and market situation. In leased buildings, the direct health and productivity benefits of IEQ improvements will be experienced by the lessee, although the lessor should benefit from an ability to increase the rent in a space with more healthy and productive occupants, and from an associated increase in the building's market value.

Hanssen[6] refers to a U.S. study concluding that, when a tenant does not renew the lease agreement (e.g., due to frequent IEQ complaints), the costs of lost rental income, remodelling, etc., to the owner will be equivalent to the rent of one-and-half years. In a building with superior IEQ, the lessor may additionally benefit from reduced maintenance costs resulting from fewer IEQ complaints. In general, neither the lessor nor the lessee benefit from reduced medical care costs, which are usually covered nationally or by insurance. However, the broader society will benefit from reduced medical care costs, and from improved health and productivity.

Conclusion

For cost-benefit analyses, it is not sufficient to have information demonstrating a statistically significant effect of IEQ on health or work performance—the size of that effect must be quantified. Here, we have shown that existing data are adequate to develop some quantitative estimates of relationships between IEQ, or related building design and operational characteristics, and people's health and performance.

Although these relationships may have large financial implications, they also have some limitations. Foremost among the limitations is the high uncertainty in the estimated quantitative relationships between IEQ, health and productivity outcomes. In addition, the relationship between indoor-related productivity outcomes and business is uncertain and case specific. Those concerned with these relationships should recognize the remaining high level of uncertainty, and that benefits of improved IEQ may be distributed among stakeholders.

The benefits of IEQ improvement measures will depend on the initial condition in the building. For example, increased ventilation will be more helpful in a building with strong indoor pollution sources or with an initially low ventilation rate. Hence, uncertainty about magnitude of benefits in specific buildings may inhibit investments in IEQ improvements, even when average benefits can be estimated. IEQ improvement measures should be most cost effective when targeted at buildings with poorer IEQ or more IEQ complaints. However, this does not preclude benefits with substantial net economic paybacks in buildings with average IEQ conditions.

Another consideration is that the susceptibility of occupants to different levels of IEQ may vary between and within buildings. It is possible that only a highly susceptible subpopulation is significantly affected by IEQ. Theoretically, it would be more cost effective to target remedial actions for those who suffer the most from poor IEQ. Such targeting often will be impractical, but there are exceptions (e.g., provision of individual temperature control with local heaters or providing personalized ventilation systems).

The authors acknowledge the high level of uncertainty associated with the incorporation of health and productivity effects in cost-benefit calculations related to building design and operation. At the same time, they believe that estimating productivity benefits using the best available information will generally lead to better decisions about building design and operation compared with the current practice of ignoring the potential benefits.

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Can Displacement Ventilation Control Secondhand ETS?

The article entitled "Can Displacement Ventilation Control Secondhand ETS?" by James Repace and Kenneth C. Johnson, published in the Fall 2006 issue of *ASHRAE IAQ Applications,* appears to be seriously flawed.

The "Toronto Study" neglects to take into account the carryover effect of the desiccant thermal wheel. Five to 10% of the exhaust air can be expected to be returned to the outdoor airstream. Prior to the smoking ban in the Black Dog Pub, the installed HVAC system configuration could be expected to return up to 310 cfm (146 L/s) of smoke-polluted air back into the occupied space via the supply air outlets. Moreover, the desiccant in the thermal wheel may absorb or surface adhere tobacco smoke pollutants from the exhaust air, which could be retransmitted to the outdoor airstream over time and further reduce IAQ performance.

The Black Dog Pub should not be used as a test site for the effectiveness of displacement ventilation in removing secondhand tobacco smoke.

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Umow Lai & Associates Pty. Ltd.,
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ASHRAE IAQ Applications Fall 2006

How to Subscribe

Can Displacement Ventilation Control Secondhand ETS?

By James L. Repace, Associate Member ASHRAE, and Kenneth C. Johnson

Inside A substantial reduction to the required ventilation rate for homes is proposed. See Pages 12–15.

The Authors Respond

We concluded that displacement ventilation fails as a control measure for secondhand smoke. In his letter, Mr. Marklund asserts that our use of the Black Dog Pub in Toronto as a test site for the effectiveness of displacement ventilation in removing ETS is inappropriate because as much as 5% to 10% of the ETS-contaminated exhaust air as well as desorption of ETS from the heat exchanger can be expected to be reentrained in the outdoor air supply.

However, Marklund's criticism is vitiated by the design of the Black Dog's heat recovery system. According to R. Jenkins, who designed, tested, and re-tested the Black Dog system,

> *Following initial sampling of the Black Dog Pub in December 2000, a purge unit was added to the HRV unit, to correct a potential carry over of the exhausted air into the fresh air stream from 4% to a much reduced 0.4%. At the same time an additional bank of filters was added downstream of the HRV to capture any nicotine/particles that might be carried over to the fresh air supply (*see Reference 3 in the original article*).*

The Black Dog Pub was an ideal test vehicle for displacement ventilation and ETS in the hospitality industry, and was as good as it gets, as the disastrous Mesa pub measurements indicated. Nevertheless, it was not good enough to control ETS in the upstream nonsmoking section in the restaurant. The Jenkins study was flawed insofar as its control "nonsmoking" venues had measurable ETS nicotine contamination, which obscured the substantial residual ETS in the Black Dog's nonsmoking area.

Moreover, the Jenkins article cautions that the study addressed only the issue of nonsmoking patron exposure to ETS, and ignored worker exposure. So does Mr. Marklund. Worker exposure in the Black Dog Pub's smoking section in the bar differed little from smoky bars with dilution ventilation that we have studied contemporaneously in Wilmington, Del.; Bismarck, N.D.; and Boston.

For more information, see the fall article's references, as well as Repace J., et al. 2006. "Exposure to secondhand smoke air pollution assessed from bar patrons' urine cotinine." *Nicotine and Tobacco Research* 8:701–711; and Repace, J. et al. 2006. "Air pollution in Boston bars before and after a smoking ban." *BMC Public Health* 6:266. www.biomedcentral.com/1471-2458/6/266.

ETS contains at least 172 known toxic substances, including 33 hazardous air pollutants, 47 hazardous wastes, 67 carcinogens, 3 EPA criteria air pollutants, and 3 OSHA-regulated workplace carcinogens. See Repace, J. 2006. "Exposure to Secondhand Smoke." Chap. 9. In *Exposure Analysis.* CRC Press.

The Surgeon General stated that "there is no safe level of exposure" in 2006. Smoking bans remain the only effective way to control secondhand smoke exposures.

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Ghost in the Machine

The contractor had replaced the AC outdoor unit at considerable cost to himself. He inherited an airflow problem that was brought to light only by a change-out of the AC equipment and an apparent increase in system airflow rate.

By James B. Cummings, Member ASHRAE

Airflow problems in homes and commercial buildings can be surprisingly invisible. They are, in some ways, like ghosts that haunt our buildings and HVAC systems. We may not discover them until an event triggers their visibility.

Recently I was called to look at a house with a humidity control problem. What I found at this house was surprising, and one for the record books! (I would like to apologize in advance for gaps in this research story; this case was a field diagnosis, so I did not have the luxury of a full range of testing.)

Background

The homeowner purchased a new, one-story, slab-on-grade 2,500 ft^2 house in Melbourne, Fla., in 1992. In August 2006, he replaced the 4-ton AC/gas furnace system with newer, higher efficiency 14-SEER 4-ton equipment. It was at that time that humidity control problems surfaced. The pattern, as the owner explained, was that during typical summer weather, indoor RH would typically be in the upper 50% range overnight, but then climb about 10 percentage points during the day.

When I arrived at the house on a late September morning (8:30 a.m.), outdoor conditions were 80°F and 72% RH. Indoor conditions were 77°F and 54% RH. The homeowner reported that he typically set the thermostat to 77°F during the day and 76°F at night. From a diagnostic perspective, elevated indoor RH results either from excess moisture entering the space or an inadequate rate of moisture removal from the space. To examine the latter possibility, I placed a temperature probe in a supply vent, lowered the thermostat setting, and after eight minutes and 25 minutes found supply air temperatures of 58.6°F and 57.9°F, respectively. This indicated an approximate 18°F temperature drop, suggesting that the cooling coil was sufficiently cold to effectively remove water vapor from the room air.

The next step was pressure diagnostics. That is when the nature of the problem revealed itself. Running a tube from the living room through the front door to the yard (winds less than 2 mph), I found house pressure of +8.6 Pa with respect to outdoors! Turning off the air handler, house pressure dropped to neutral. Turning it back on, house pressure returned to +8.6 Pa. This is by far the highest house pressure resulting from duct leakage that I have seen! When one finds a house pressure like this, the diagnostic focus immediately shifts to examination of duct leakage.

Causes of Extreme Pressurization

What was the cause of this extreme house pressure? Positive pressure, of course, occurs when the amount of return duct leakage (from outside) exceeds supply duct leakage. The degree of pressurization is a function of net airflow (incoming airflow minus outgoing airflow) and envelope airtightness. The greater the net airflow and the tighter the envelope, the greater the pressure.

Inspection quickly revealed the source of the large return leakage. While about 90% of the return and supply ducts are located in the attic, the support platform, upon which the gas furnace and a gas water heater were positioned, is located in a corner of the garage. This support platform was acting as a return plenum and had no interior duct or liner. Looking inside the return plenum, I could see wood studs and fiberglass insulation batts of two adjacent walls.

The negative pressure field of the return plenum (about –40 Pa with respect to the garage) could spill into the wall cavities and draw air from the attic above and from the garage. The garage was being depressurized to –2.1 Pa with respect to outdoors and –10.7 Pa with respect to the house when the air handler was turned on. I did not have an opportunity to perform a tracer gas return leak fraction (RLF) test; however, by making a few assumptions, a return leak airflow rate can be estimated.

To make this estimation, let's assume that house airtightness was ACH_{50} = 7 (fairly typical for Florida homes of that vintage). Then assuming an airtightness curve with flow exponent of $n = 0.65$ $\left(Q = C\ [dP]n\right)$,we can conclude that the net return leakage required to produce +8.6 Pa would be on the order of 290 cfm. Supply leakage (to outdoors), while not measured, is typically on the order of 6% of system airflow in recently built Florida homes.[1] If we assume that the air handler of this 4-ton system was moving 1,600 cfm, then the return leak

*ft^2 × 0.929 = m^2; ton × 3.517 = kW; °F – 32 ÷ 1.8 = °C; cfm × 0.4719 = L/s; Btu/h × 0.2931 = W; Pa ÷ 248.8 = in. w.g.

would be 384 cfm or 24% of the system airflow (leakage coming from the garage and from the attic).

The humidity control problem would increase during the day for the following reasons:

- As the attic (and garage) becomes hotter during the late morning and into the afternoon, the amount of cooling energy going toward cooling down the hot entering return leak air would increase. As a result, the coil temperature would rise, causing the exiting air to have a higher dew-point temperature.
- Attic dew-point temperatures also increase as the attic heats up, increasing the amount of moisture that the AC system has to remove. The cause of this dew-point increase is desorption from wood and insulation materials in the attic under the influence of low RH caused by high attic temperatures. It is not unusual for attic dew-point temperatures to increase to 15°F to 20°F above the outdoor dew-point temperature during the hot hours of the day.
- Consider that if the estimated 384 cfm of return leak air was at conditions of, say, 110°F and 85°F dew-point temperature, then the cooling load associated with this return leak air would be 47,700 Btu/h, or essentially 100% of system capacity, therefore leaving little or no cooling capacity to meet the house cooling load. Also, note that at these conditions, 69% of the return leak load would be latent. As a result, this leakage would overwhelm the AC system's latent cooling capacity, causing an increase in relative humidity in the house.

What Is Causing the Problem?

Why did the symptoms of this problem occur at this time, when the support platform plenum leakage had apparently existed from the beginning? Based on discussions with the homeowner, the only factor that seems to have changed was a change-out of the air handler (furnace) and the outdoor unit.

One thought was that the contractor had entered the attic and somehow damaged the return duct. However, the contractor had not entered the attic. Another thought was that the new air-handler cabinet was more leaky. However, inspection found that most of the furnace cabinet seams and penetrations had been sealed by foil tape, and also that the connection of the cabinet to the support platform was tightly sealed by caulk. It seems unlikely that this furnace (and return side connections) would be more leaky than the old unit, given the way it was sealed.

My hypothesis is that the old system had a substantially lower airflow rate. The lower airflow rate would cause less attic/garage air to be drawn into the system. For example, if the old system's airflow rate had been 1,280 cfm (320 cfm per ton), then the return leakage would be 307 cfm (24% of 1,280 cfm = 307). The lower airflow rate also would cause the cooling coil (evaporator) to be colder (all else held constant), so moisture contained in the return leak air would be more effectively stripped away before entering the conditioned space. These two factors—reduced return leakage and a colder coil—would lead to reduced water vapor entry and increased water vapor removal and a substantially different indoor RH outcome.

Whether my hypothesis about the airflow rate is correct or not, occupants had been living in this house with a large return leak for 14 years, and it had remained hidden all of that time. And it was hidden not only from the homeowner, but also from the AC contractor. In his well-intentioned efforts to make the homeowner happy, the contractor had replaced the AC outdoor unit at considerable cost to himself. He inherited an airflow problem that was brought to light only by a change-out of the AC equipment and an apparent increase in system airflow rate.

It is too bad that the AC contractor did not recognize the "ghost" in the machine. If he had been able to recognize the airflow problem, he could have saved himself a great deal of aggravation and money associated with multiple callbacks and eventual replacement of the outdoor unit (the second time at his own expense), which, in all probability, was in perfectly good operating condition.

Interestingly, this return leakage problem likely would not have occurred had this house been built one or two years later, based on field research and a relevant change to the building code. In a study of 160 central Florida homes (built 1919–1989), average RLF (the proportion of return air originating from outside the conditioned space) was found to be 10.7% of system airflow.[2] In another study of 70 central Florida homes (built 1985–1989), average RLF was found to be 9.2% of system airflow.[3] In a recently completed study of 20 central Florida homes built in the period 2002–2004, return leakage was found to be only 3.6% of system airflow (report pending). (In each of these studies, the return leak fraction was obtained by means of a tracer gas test method.[4])

An important change, which seems to account for the large difference between the two earlier studies and the recent field testing, was a 1993 modification to the Florida Mechanical Code requiring that air-handler support platforms no longer act as return plenums. Instead, a duct is required connecting the return grille to the air-handler cabinet inside the platform. As a result of this code change, the chances of a house having a very large return leak has been greatly reduced.

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The IAQ Procedure in Standard 62.1-2004

The IAQ Procedure offers a valid alternative to the Ventilation Rate Procedure, allowing designers to comply with Standard 62 while taking credit for air cleaning and material-emissions enhancements, for instance. However, compliance is neither easy nor risk-free.

By Dennis A. Stanke, Member ASHRAE

Past columns and countless trade journal articles that discuss Standard 62.1-2004 requirements almost seem to ignore the IAQ Procedure (IAQP) and to focus almost exclusively on the Ventilation Rate Procedure (VRP).

Why focus on the VRP?

The VRP provides a prescriptive path to Standard 62 compliance and avoids the somewhat controversial topic of concentrations. The idea is, if you ventilate at or above the minimum rates prescribed, space contaminants will be diluted and removed sufficiently to satisfy most people in most spaces in terms of odor-comfort and contaminant-related adverse health effects.

At the zone level, most designers understand how to use the minimum ventilation rates prescribed by this procedure and they feel comfortable making judgments about occupancy categories, expected population levels, and default zone air distribution effectiveness values.

At the system level, designers can determine the outdoor air intake flow needed for single-zone systems (by far the most common system) and for dedicated outdoor air systems using very simple math and without making any non-engineering judgments. More complicated multiple-zone recirculating systems (e.g., constant volume reheat and VAV systems) require correction for system ventilation efficiency, but the standard clearly spells out this process.

Designers must make some engineering judgments related to minimum expected zone airflow and system population at ventilation-design conditions, and they must choose either to look up a default value for system ventilation efficiency or calculate it using more accurate equations provided in Appendix A. Once established, design system ventilation efficiency can be used quite easily to calculate design outdoor air intake flow for the system. After some experience, and perhaps with the aid of the spreadsheet provided with *62.1-2004 User's Manual*, most designers are comfortable with the engineering judgments and straightforward calculations involved.

What about the IAQ Procedure?

The IAQ Procedure provides an alternative performance-based path to Standard 62 compliance. According to Section 6.1.2, it may be used to determine the outdoor airflow requirements for any project, and it is particularly useful for those projects where specific contaminant concentrations or specific levels of occupant perceived satisfaction are the design goal. (These projects might be expected to require more outdoor airflow than that prescribed by the VRP. The IAQP helps determine how much more.) Also, this procedure must be used to determine outdoor airflow requirements for those projects where the designer uses air cleaning or low-emitting materials, for instance, with the objective of requiring less outdoor airflow than that prescribed by the VRP.

In summary, the idea of the IAQP is to figure out:

- What contaminants pollute the indoor space;
- Where each contaminant originates (from indoor and/or outdoor sources);
- The net amount of each (added by sources, removed by air cleaning); and
- How much outdoor air is needed to dilute those contaminants to target concentration levels, all while satisfying a specific percentage of building occupants with respect to odor and irritant levels.

Sounds simple, right? Many designers would like to use this approach to take intake-airflow credit for increased air-cleaning capability. So, why don't more designers use it? I suspect that many designers are uncomfortable with the "loose" nature of the procedure and the perceived risks associated with the non-engineering judgments and knowledge it requires. Let's take a closer look at it.

Section 6.3.1.1

Section 6.3.1.1 (see *What 62.1 Says About Contaminants*) includes three requirements.

First, the designer must identify the contaminants of concern (CC) "for purposes of the design." In other words, the designer must decide upon a list of contaminants of concern for a given project. Such a list might be based on experience, analysis of similar buildings, documented indoor/outdoor contaminants, or perhaps, the advice or findings of others—the standard doesn't stipulate; it doesn't include a comprehensive list of indoor contaminants. And, it doesn't give any guidance as to what contaminants may be expected in various buildings. Designers must turn to other sources (as explained in more detail in the *62.1-2004 User's Manual*) to develop the required CC list. Designers must make some important non-engineering judgments to identify a reasonable and appropriately complete CC list. While not impossible, this task makes many designers uncomfortable and seems both daunting and risky.

Second, the designer must identify sources for each CC in the list. This requirement might actually precede or parallel the first requirement, since knowing potential contaminant sources can be helpful in establishing the CC list, and vice versa. For instance, if formaldehyde is a CC, how much does a specific chair, carpet or ceiling tile produce? Or, conversely, given that a space will include specific furniture, carpet and ceiling tiles, should the CC list include formaldehyde? Identification of sources requires close interaction between the HVAC system designer and the architect and material-emissions knowledge that most designers probably don't have.

Third, the designer must determine the source-strength for each CC from each identified source, both indoor and outdoor. This can become a significant spreadsheet exercise. The "strength" for outdoor sources is usually reported in terms of volumetric concentration (ppbv) or concentration density (g/m^3). The contaminant generation rate (cfm or g/s) can be determined based on concentration and outdoor air intake flow rate. The "strength" for indoor sources is usually reported in terms of mass-of-contaminant emitted per unit volume per unit time (mg/m^3-h), so contaminant generation rate (mg/h) can be determined based on the volume of each source. Source strengths have been established for many materials (the *62.1-2004 User's Manual* lists various papers and references) but not for all potential sources of each potential CC. So, compliance might require some (or a lot of) literature searching and/or materials-lab testing.

For each CC, the total generation rate from all sources (both indoor and outdoor) within a space must be determined as the sum of the generation rate from each source.

Section 6.3.1.2

Moving on to Section 6.3.1.2 (see *What 62.1 Says About Contaminants*), the designer must specify the target concentration limit (and corresponding exposure time) for each CC listed, and must specify (that is, include) an appropriate reference to a cognizant authority for the target concentration and exposure-time specified. Simple, right? But, what constitutes a cognizant authority? Standard 62 provides a definition (see *Definition*), but designers might still be a little unclear about which

What 62.1 Says About Contaminants

6.3.1.1. Contaminant Sources. Contaminants of concern for purposes of the design shall be identified. For each contaminant of concern, indoor and outdoor sources shall be identified and the strength of each source shall be determined.

6.3.1.2. Contaminant Concentration. For each contaminant of concern, a target concentration limit and its corresponding exposure period and an appropriate reference to a cognizant authority shall be specified.

6.3.1.3. Perceived Indoor Air Quality. The criteria to achieve the design level of acceptability shall be specified in terms of the percentage of building occupants and/or visitors expressing satisfaction with perceived indoor air quality.

6.3.1.4. Design Approaches. Select one or a combination of the following design approaches to determine minimum space and system outdoor airflow rates and all other design parameters deemed relevant (e.g., air cleaning efficiencies and supply airflow rates).

(a) Mass balance analysis. The steady-state equations in Appendix D, which describe the impact of air cleaning on outdoor air and recirculation rates, may be used as part of a mass balance analysis for ventilation systems serving a single space.

(b) Design approaches that have proved successful in similar buildings.

(c) Approaches validated by contaminant monitoring and subjective occupant evaluations in the completed building. An acceptable approach to subjective evaluation is presented in Appendix B, which may be used to validate the acceptability of perceived air quality in the completed building.

(d) Application of one of the preceding design approaches (a, b, or c) to specific contaminants and the use of the Ventilation Rate Procedure to address the general aspects of indoor air quality in the space being designed. In this situation, the Ventilation Rate Procedure would be used to determine the design ventilation rate of the space and the IAQ Procedure would be used to address the control of the specific contaminants through air cleaning or some other means.

authorities are actually expert enough or authoritative enough to be considered cognizant.

Wane Baker, P.E., CIH, Member ASHRAE, discussed cognizant authorities in a seminar at the 2004 ASHRAE Annual Meeting. Among his conclusions: no comprehensive list of such authorities exists; ASHRAE won't make a list; and, the inclusion of any authority in such a list depends on the specific issues and/or contaminants being considered. While the organizations listed in the tables in Appendix B (including EPA, OSHA, MAK, Health Canada, WHO, NIOSH, and ACGIH) may be cognizant for some contaminants, they may not be appropriate for all project-specific CC listed. Appendix B, with its limited list of contaminants, target limits and exposure times, and its limited list of "cognizant authorities" may be a good starting point for this requirement, but information from other sources is likely to be needed. Compliance seems to require non-engineering judgments related to both cognizant authorities and competing target limits.

Section 6.3.1.3

Section 6.3.1.3 (see *Contaminants*) addresses odors and irritants, usually produced by low concentrations of one or more contaminants. The best sensor for the combined effect of low levels of odorous or irritating contaminants seems to be the human nose. With this in mind, the designer must specify "criteria" to be used in judging whether the design level of acceptability has been achieved. It's clear that one element of these criteria entails specifying design acceptability in terms of the percentage of occupants (or visitors) who perceive the indoor air quality as satisfactory. However, it isn't as clear what else must be included in the criteria. For instance, shouldn't the designer also specify either design analysis or field test criteria? Without a design-analysis or field-test method for determining perceived air quality, couldn't a designer merely specify that 60% (or 80% or 99%) of visitors must express satisfaction without making any changes to air cleaning or source-strengths or ventilation? In other words, shouldn't the designer also specify criteria for actually achieving the specified percentage-satisfied design target? It wouldn't be too surprising to find that these perceived air quality requirements confuse designers. Perhaps the committee should be asked to interpret this requirement or an interested user should propose a change to the standard to clarify this section.

Definition

Cognizant authority: An agency or organization that has the expertise and jurisdiction to establish and regulate concentration limits for airborne contaminants; or an agency or organization that is recognized as authoritative and has the scope and expertise to establish guidelines, limit values, or concentration levels for airborne contaminants.

Section 6.3.1.4

Section 6.3.1.4 (see *Contaminants*) addresses design approaches for determining outdoor airflow rates. It offers four acceptable approaches, one or more of which must be used to determine minimum space and system outdoor airflow rates, given target concentrations, net generation rate (i.e., contaminant gain from sources, less contaminant loss via air cleaning), supply airflow rate, and so on. Alternatively, a designer could use one or more of these approaches to find required air cleaning efficiency and supply airflow rate, given target concentrations, contaminant gain from sources, outdoor airflow rate, and so on.

The **first design approach** requires the use of mass balance equations to find required outdoor airflow (or air cleaner efficiency). Perhaps the most designer-friendly, this analytical approach uses mathematical models, such as the steady-state concentration equations for single-zone systems included in Appendix D. For multiple-zone systems, mass balance calculations could be carried out using modeling software, such as CONTAM.

The **second approach** allows designers to use any approach that works, based on its successful application in similar projects. For example, if the designer can show that using MERV 13 filters and reducing VRP-determined intake airflow by 15% has achieved contaminant and perceived air quality targets in ten (for example) similar buildings, using the same design approach would seem to comply with the IAQP requirement. This approach might be more difficult for specifying engineers to apply than, say, design-build contractors, since engineers don't always have good feedback mechanisms to evaluate previous designs in action.

The **third approach** requires contaminant monitoring and subjective evaluation after construction is complete to prove that the design targets for CC and for perceived IAQ have, indeed, been achieved. While straightforward, this approach carries with it the risk of failing the test. If outdoor air intake flow, particle filter efficiency or gaseous air cleaner operation prove to be inadequate, the installed mechanical system may need significant rework after occupancy, such as more coil or chiller capacity, more fan static pressure capability, more air handler space, and so on. These are risks that most designers probably want to avoid.

The **fourth approach** combines the IAQP and the VRP within a single system. That is, a designer could choose to find the minimum zone outdoor airflow for one or more zones using the IAQP, while using the VRP for all other zones in the system. This might be useful if the system includes one or more zones with an unusually high contaminant source-strength. For instance, if an office building includes a conference room used to display carpet or furniture samples, the designer could choose to apply the IAQP to find the outdoor airflow needed in the conference room, but use the VRP to find zone outdoor airflow requirements for the remaining "typical" zones. This approach would be expected to increase system outdoor air intake flow, compared to VRP-only design.

Section 6.3.2

Finally, Section 6.3.2 requires specific information in the design documents. This information includes, for each zone: the CC list, CC sources, CC source strengths, CC target concentration limits (along with exposure times and cognizant authority references), and the design approach used (along with justification for its use) to find the minimum outdoor airflow or minimum air cleaning efficiency. Of course, other relevant design information also should be documented, such as the target satisfaction percentage and the means to show that it will be achieved. In all, this procedure probably entails an increased documentation burden for the designer, compared with the VRP.

Summary

The IAQP offers a valid alternative to the VRP, allowing designers to comply with Standard 62 while taking credit for air cleaning and material-emissions enhancements, for instance. However, compliance is neither easy nor risk-free. As more and more designers use it, its strengths and weaknesses will become more apparent. Within the procedural confines of continuous maintenance of standards, Standing Standards Project Committee 62.1 stands ready and willing to refine it as necessary in response to requests for interpretation and/or change proposals.

Thank you for supporting ASHRAE standards.

Dennis Stanke is chair of Standing Standards Project Committee 62.1.

Standard 62.2 User's Manual

The User's Manual expands and explains the material contained in the standard. Typical design questions are explored and answered. Examples of the calculations required in meeting the standard are presented throughout. Figures are plentiful and are used to illustrate solutions. Responses to hypothetical questions emphasize common-sense, prudent strategies.

By David T. Grimsrud, Ph.D., Fellow ASHRAE; and **Roger L. Hedrick,** Member ASHRAE

Standards are terse—written to be precise, rather than graceful—and often inadvertently confuse their readers. This common perspective of an ASHRAE standard is softened when a user's manual is published. ASHRAE user's manuals serve the roles of assisting understanding and compliance with requirements of the standard, and explaining reasons that certain requirements are included in the standard. Those familiar with the twists and turns of the development process for ANSI/ASHRAE Standard 62.2, *Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings,* will appreciate this as they examine the new *User's Manual for Standard 62.2.*

The manual, released in December, was written by four members of the committee that developed the standard: Roger Hedrick, Member ASHRAE; Terry Brennan, Member ASHRAE; Don Stevens, Member ASHRAE; and H.E. "Barney" Burroughs, Presidential/Fellow/Life Member ASHRAE.

Written in a much more accessible style than the standard, it is designed to explain, with examples and supplementary background material, how the standard is to be applied. Thus, its intended audience is residential building designers and contractors. As the authors note in the preface, it may also be useful for code officials and homeowners—but the primary audience is designers and builders. It does not review the research background that leads to values that are present in the standard. That will be presented in a guideline document that also is being prepared by Standing Standards Project Committee 62.2. This document is intended to help solve practical problems that arise as the standard is applied to the design and construction of new homes.

The standard's terse style often generates questions:

• Does it apply to an eighth-floor condominium unit?

• Will following the standard guarantee good air quality in my house?

• I have invited 12 people to my house for Thanksgiving. How will my ventilation system accommodate this?

• I saw a design for a hybrid ventilation system in Japan. Can I use this in my new house? It does not seem to match the requirements of Standard 62.2.

• Infiltration worked just fine in my grandfather's house. Can I use infiltration in the design of my new house?

• Are the advantages to using supply ventilation rather than exhaust ventilation significant?

• What do you mean, continuous ventilation? Does that mean I cannot turn off the ventilation when my wife and I leave the house?

• This idea of ventilation effectiveness is confusing. Why can't I turn off the ventilation when I'm gone during the day and then use twice as much at night when I'm at home?

• My kitchen is in the corner of my living room in my studio apartment. How do I design kitchen ventilation for that space?

• I have read about a condensing clothes dryer. Can I use that in my design even though the standard requires that clothes dryers be exhausted to the outside?

• I have read that ASHRAE is thinking about banning house designs with attached garages. Is that true? If not, why not?

• What is this thing called MERV that I see on my furnace filter?

The User's Manual will assist in addressing all of these questions. It expands and explains the material contained in the standard. Typical design questions are explored and answered. Examples of the calculations required in meeting the standard are presented throughout. Figures are plentiful and are used to illustrate solutions. Responses to hypothetical questions emphasize common-sense, prudent strategies.

This is a major contribution to the literature supporting ASHRAE standards in general, and Standard 62.2 in particular.

David T. Grimsrud, Ph.D., is chair of SSPC 62.2. Roger L. Hedrick is lead author of the User's Manual and member of SSPC 62.2.

News

IAQ 2007 Focus: Healthy and Sustainable Buildings

ATLANTA—Healthy and sustainable buildings are the talk of the building industry, but what exactly defines what a healthy building is?

ASHRAE will discuss this and other topics at its IAQ 2007: Healthy and Sustainable Buildings conference in Baltimore Oct. 15-17.

IAQ 2007 addresses what tools and metrics can be used to quantify buildings' health and sustainability and how indoor air quality can be certified as sustainable. Plenary session speakers will compare the functionality of rating systems, how they can be improved and what information other than the ratings developers, designers and public entities can use to distinguish high-performing buildings.

Kevin Hydes, P.Eng., P.E., chair of the Board of Directors of the U.S. Green Building Council, will address the Council's Leadership in Energy and Environmental Design building rating system and case studies. Nils Larsson, executive director of the International Initiative for a Sustainable Built Environment, will cover the same questions for other rating systems, labels and green building/IAQ metric tools.

"Buildings' health and efficiency impact everyone," said Larry Schoen, P.E., Fellow ASHRAE, chair of the committee organizing the conference. "It's important to discuss how our designs as building professionals will affect the occupants' lives and the global community for many years to come. This conference helps attendees learn how we can work together to maximize sustainability."

The conference is open to anyone with a stake in the built environment or with an interest in indoor air quality, including researchers, policy makers, owners, designers, builders, building operators and remediation experts.

For more information, visit www.iaq2007.org.

Federal Requirements Aimed at Saving Energy in Residences

WASHINGTON — The U.S. Department of Energy has agreed as part of a settlement to increase energy efficiency requirements for 22 types of household appliances and equipment, including heating and air-conditioning systems, water heaters, boilers and motors, dishwashers, clothes dryers and fluorescent lighting.

The department will phase in the new standards during the next five years. The agreement, filed in the U.S. District Court in New York, settles a lawsuit filed last year by environmental groups, 15 states and the city of New York because of delays in improving federal appliance efficiency requirements.

Once in place, the new requirements could save enough energy to meet the needs of 12 million households and avoid building dozens of new power plants.

For more information, visit www.timesleader.com/mld/timesleader/16007008.htm.

ASHRAE Revises Proposed Cabin Air Quality Standard

ATLANTA—A standard that will address such airplane air quality issues as temperature, humidity and ventilation rates is one step closer to being published. ASHRAE's proposed new Standard 161P, *Air Quality Within Commercial Aircraft*, completed its second public review recently.

After the first public review last year, the committee in charge of the standard's drafting process received approximately 100 comments from more than 20 people. According to committee vice chairman Scott Earnest, important changes were made in many of the topics addressed in the comments.

"The draft standard is expected to significantly improve aircraft air quality for passengers and crews," Earnest said.

Revisions address issues such as general requirements for pressure, temperature and humidity, as well as ventilation rate requirements for various areas within the cabin and supply air for the aircraft while it is on the ground. One change provides more flexibility to meet filtration requirements for recirculated air.

Also addressed were comments related to contaminant concentrations for ozone and carbon monoxide in the cabin. The revised proposed standard also alters the control measures that are specified for bacteria, viruses and pesticides.

The proposed standard would apply to commercial aircraft carrying 20 or more passengers. It is intended to apply to all phases of flight operations and to ground operations whenever the aircraft is occupied by passengers or crew members.

Industry Calendar

NADCA Annual Meeting and Exposition, March 5–8, Nashville, Tenn. Contact the National Air Duct Cleaners Association at 202-737-2926, info@nadca.com, or www.nadca.com.

ACCA Annual Conference and Indoor Air Expo, March 6–8, Orlando, Fla. Contact organizers at 703-575-4477 or www.indoorairexpo.com.

BuildingEnergy07, March 13–15, Boston. www.buildingenergy.nesea.org.

GreenTech Conference & Exposition, March 20–22, Baltimore. Contact organizers at debbie.hanamann@tradepress.com or www.nfmt.com.

Canadian Conference on Building Science and Technology, March 22–23, Banff, AB, Canada. Contact organizers at www.nbec2007conference.com.

MAY

GAMA Annual Meeting, May 5–8, St. Petersburg, Fla. Contact the Gas Appliance Manufacturers Association at 703-525-7060, events@gamanet.org, or www.gamanet.org.

Commercial Construction Show, May 15–17, Chicago. Contact organizers at 877-598-9156 or www.cc-show.net.

OUTSIDE NORTH AMERICA

Refrigeration & Air Conditioning Exhibition 2007, Feb. 27–March 1, Birmingham, England. Contact organizers at 02 8277 5113, lucy.vanrenselar@emap.com, or www.racexhibition.co.uk.

FILTECH 2007, Feb. 27–March 1, Wiesbaden, Germany. Contact organizers at www.filtecheuropa.com.

CLIMATIZACIÓN, Feb. 28–March 3, Madrid, Spain. Contact organizers at climatizacion@ifema.es or www.ifema.es/ferias/climatizacion/default_i.html.

MARCH

ISH 2007/Aircontec/IKK Building Forum, March 6–10, Frankfurt, Germany. Contact organizers at www.ish.messefrankfurt.com.

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