Improving Humidity Control for Commercial Buildings

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For more than 100 years, temperature control has been the principal concern of our industry. That focus and our collective efforts have achieved immense improvements in the human condition — improvements so fundamental that they are usually overlooked and unappreciated, even by ourselves. We seldom reflect on what the world was like before the refrigeration of food and medicine, or before the availability of low-cost, reliable heat in the winter and cooling in the summer. However, in spite of — or because of — those achievements, the expectations of the public have moved higher. Now, we face the challenge of providing cost-effective control of humidity.

The Public Perceives a Problem

In recent years, problems associated with too much or too little moisture in buildings have become notorious. The American Hotel & Motel Association estimated its members spend more than $68 million each year dealing with mold and mildew problems (AH&MA 1991). Similarly, *Engineering News Record* reported that more than 50% of construction claims against architects, engineers and contractors were related to moisture and humidity problems (ENR 1991). Television and print news energetically report indoor air quality and health hazards caused by excess moisture that promotes the growth of fungus in buildings and in HVAC systems (WSJ 1999).

These problems are less widespread than the public perceives. They have complex causes that are not always under the control of the HVAC designer. On the other hand, some aspects of the problems are indeed related to the temperature and humidity of air inside the building, and related to where the air moves in response to the pressure changes caused by the HVAC system. Our profession can help limit those problems, while providing a more comfortable and productive environment than ever before — by improving humidity control. The process begins with better moisture load calculations.

Moisture Load Data

ASHRAE has taken a lead role in providing the HVAC designer and equipment manufacturers with moisture load data, a fundamental tool for better equipment and humidity control systems. Through Research Project 890, ASHRAE invested more than $250,000 to document and publish the peak outdoor moisture conditions worldwide. Chapter 26 of the *ASHRAE Handbook—Fundamentals* now contains that data. A brief example will show how moisture loads are much larger than assumed in the past, when the sensible load was the main driver of the system design.

Figure 2 shows the moisture difference between outdoor air at the peak sensible design condition compared to peak dew point conditions. The high dry-bulb temperature is 99°F (35°C), with an average humidity ratio of 105 gr/lb. In sharp contrast to past industry perception, the peak dehumidification load actually occurs at the dew point extreme, when the humidity ratio is 153 gr/lb and the average tempera-

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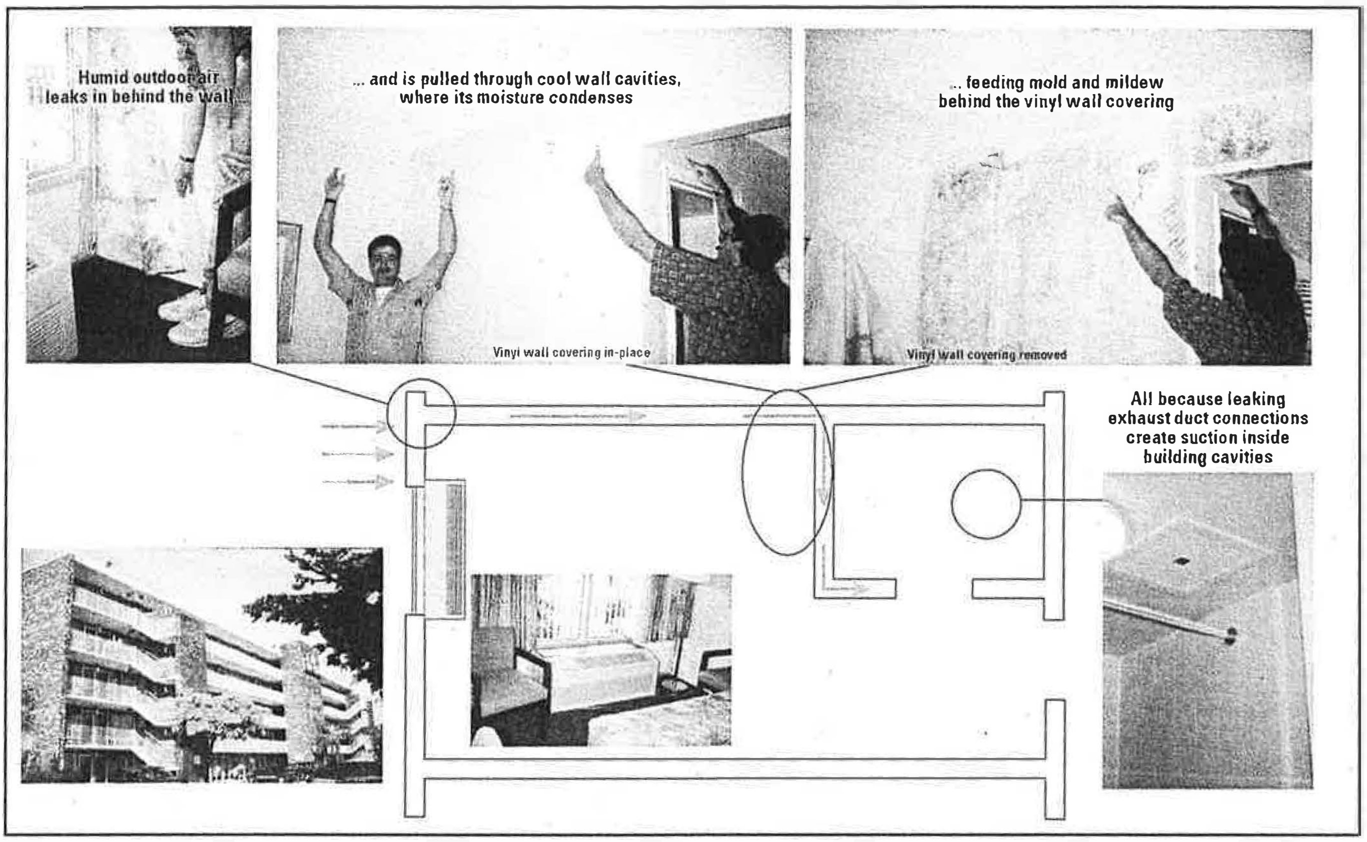

Figure 1: Suction created by unsealed exhaust ducts leads to mold problems in humid climates.

ture is only 83°F (28°C). (At the extreme temperature of 37.2°C (99°F), the humidity ratio is only 15 g/kg. The largest moisture load occurs at the more moderate temperature of 83°F (28°C), when the humidity ratio outdoors is much higher at 21.9 g/kg).

If a designer were making equipment decisions based on the moisture at the sensible peak, the system would encounter moisture loads far in excess of the designer's expectations. Also, those loads occur when the temperature is moderate—not when the sensible load is high. With the new peak dew-point information, system designers and manufacturers can make better judgements about equipment selection and controls.

In addition to ASHRAE-funded tools like the information in Chapter 26 of *ASHRAE Handbook — Fundamentals,* the U.S. and Canadian governments also have contributed new humidity-related design data. The psychrometric display of weather history shown in *Figure 2* is one example of new, taxpayer-funded information resources. These data, along with their availability and use, were described in an earlier *ASHRAE Journal* article (Harriman et al. 1999).

Beyond a better quantification of the loads, HVAC designers need a clear understanding of the mechanisms of humidity-related problems. Much progress has been made in this respect, although the issues are so complex that complete understanding remains elusive.

Humidity-Related Problems in Buildings

Several problems are well understood and have relatively simple solutions. Others are more complex. All are caused by too much moisture in the building, combined with an inability of the building and/or the HVAC system to remove the excess moisture. The problems fall into three broad categories:

1. Water intrusion.
2. Cold-climate condensation.
3. Hot & humid climate condensation.

Water Intrusion

The most common and serious moisture-related problems are caused by rain or groundwater intrusion combined with the building's inability to dry out. These problems often happen during or shortly after construction. Examples include the highly visible problems in the Pacific Northwest, and the failure of hotels in the southeast United States (Tsongas 1992, Handigord 1994 and Lstiburek 1993). In these cases, water leaked through cracks or holes in the building exterior, usually where one component is joined to another. Historically, such leakage happens all the time without problems. The difficulty arises when walls *trap* that water, creating a fungus incubator. This happens when an interior vapor barrier prevents the water from drying out to the inside, or when vapor-tight exterior surfaces do not let breezes carry away evaporating water from the outside.

Water trapped in exterior walls and in floor slabs generates odors quickly, as fungus thrives and consumes cellulosic or other carbon-based food sources from the building materials. Sun heats the exterior wall, accelerating the problem by creating the ideal environment for fungal growth in building cavities and on wallboard facing.

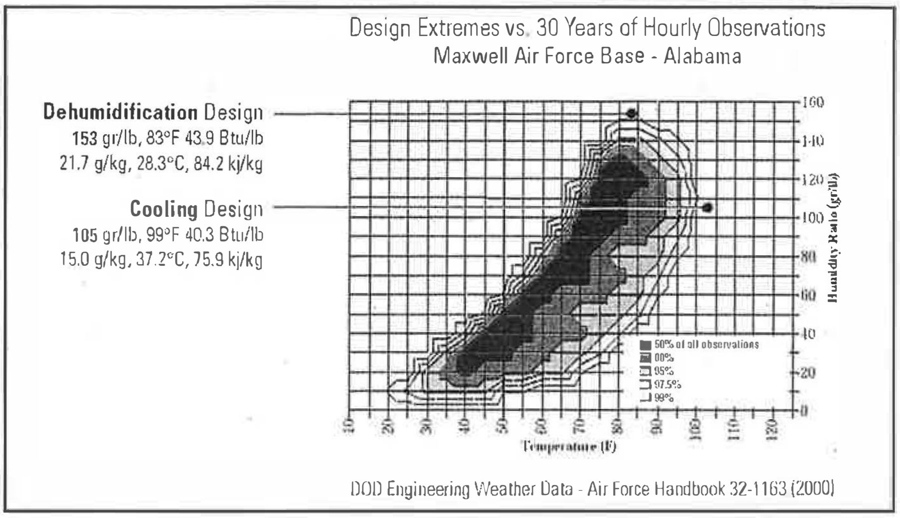

Figure 2: Ventilation moisture loads peak at moderate temperatures, not at the peak dry bulb condition.

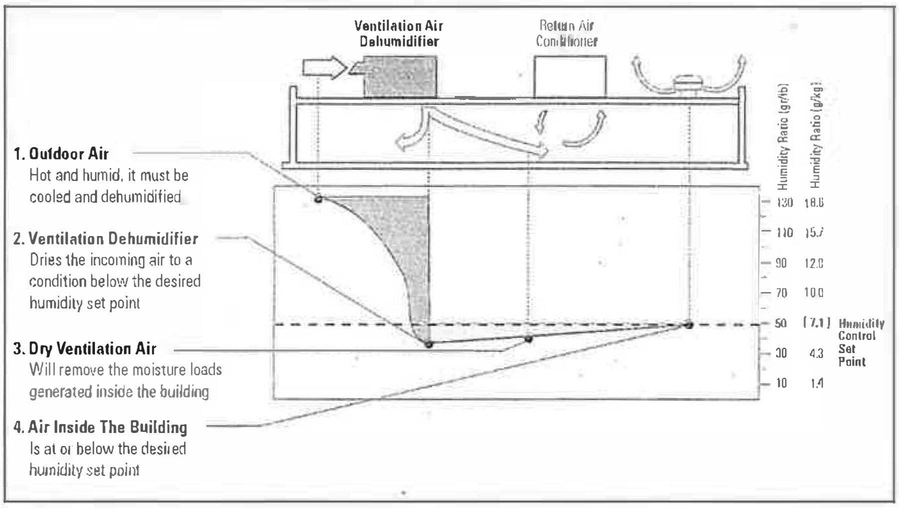

Figure 3: In humid climates, one solution uses pre-dried ventilation air to control humidity and downsize cooling.

In many of these cases, the HVAC designer becomes involved because the problem first becomes apparent to occupants as "bad indoor air quality." The building smells musty and people develop allergic reactions to the mold (Bayer et al. 1995). In most cases, the HVAC designer eventually stands aside quietly, watching while our colleagues in the legal, architectural and contracting professions sort out the problems and come up with a solution. These are primarily design and construction problems with the exterior envelope or construction-wetted materials, on which the HVAC system has little influence.

Our profession, however, is directly involved with condensation problems. These often are difficult to separate from water intrusion, since a building may suffer from both intrusion and condensation at the same time (Kudder et al. 1986).

Cold-Climate Condensation

Musty odors in cold climates often are caused by fungal growth in building cavities, and structural problems can occur with buildings containing swimming pools in cold climates. The HVAC designer can help the architect and owner avoid these problems by:

1. Keeping the indoor air dew point as low as possible, consistent with health and comfort requirements.

2. Keeping internal air pressure neutral near the exterior wall to avoid positive internal air pressure that would force humid indoor air into cold cavities.

Most HVAC designers are aware of the potential for condensation in cold climates. We all know that water vapor will diffuse outward through building materials in response to differences in vapor pressure. At some locations in the wall, the water encounters a surface cold enough to produce condensation. Much attention is given to this potential problem in the literature, and we have good calculation tools for estimating rates of diffusion and heat loss from building components (Chapter 24, *ASHRAE Handbook—Fundamentals*). Unfortunately, we lack good tools for predicting and avoiding the more common, but more complex problem: localized air pressure differences that force humid air outwards and into cold building cavities.

Diffusion through solid material is a very slow transport mechanism and only allows small amounts of condensation. In contrast, humid air exfiltration is fast and can create large volumes of condensed water inside the walls in a short period of time. The mechanics of the problem are not obvious.

In theory, the designer can balance the airflows entering and leaving the building so that apart from wind gusts, no pressure difference exists across the exterior wall. However, wall systems and HVAC systems are complex assemblies of small, connected chambers. Contrary to intuition, a building is not a simple large vessel in which interior pressure can be equal at all points. Just because most of the building has an *average* neutral air pressure with respect to the outdoors does not prevent some parts of the interior from being positive with respect to the building cavities. Humid air can be forced to leak *outwards* in some places while at the same time, cold air is leaking *inwards*.

Consider the common design detail of a supply air duct passing through the unfinished space above a dropped ceiling. In moderate or cold climates, such

Figure 4: Suction created by unsealed return air and exhaust air ducts pulls humid air into the building to feed mold and mildew.

ductwork is not always sealed and insulated, since the duct is indoors. When air leaks outward through seams and joints, humidity blows into the cold wall cavities that *connect* to the area above the dropped ceiling. The "locally positive" air pressure caused by leaking supply ducts contributes to condensation problems in cold climates.

One solution is to specify that all supply and return ductwork be sealed and insulated, and that the return air registers be sealed to the ductwork and gasketed to the interior finish. Sealing prevents accidental suction or excess pressure in building cavities. And, insulation prevents condensation inside ductwork as it passes through cool cavities. These precautions are especially useful in buildings that need humidification to ensure comfort and health during cold, dry seasons.

Hot-Climate Condensation

About the time the AH&MA highlighted the mold and mildew problems in hotels and motels, building codes changed to reflect the higher outdoor air ventilation rates recommended by ASHRAE Standard 62-1989, *Ventilation for Acceptable Indoor Air Quality*. More outdoor air gave designers a much bigger moisture load to remove in hot and humid climates—just as most conventional air-conditioning units had been redesigned for maximum cooling efficiency instead of dehumidification capacity.

For several years, disputes concerning mold and mildew in humid climates centered on these issues (Shakun 1990). Those design challenges continue, and they play a role in the difficulty of controlling humidity cost effectively in commercial buildings (Shirey 1996). The most popular solutions seem to rely on pre-drying the ventilation air before it enters the build-

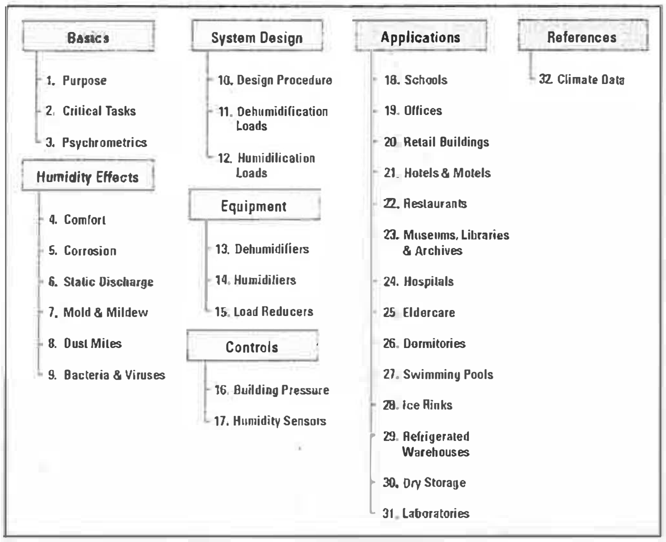

Figure 5: The structure and content of the new ASHRAE Humidity Control Design Guide for Commercial Buildings.

ing, so that the cooling units are largely relieved of the dehumidification load carried by the ventilation air, as shown in *Figure 3* (Turpin 2000).

Although providing a dedicated dehumidification unit certainly improves humidity control and comfort, the really severe problems are caused by condensation and high relative humidity inside the walls of buildings—not in the occupied spaces. Problems in hot climates often occur when humid outdoor air is pulled through the exterior walls by suction created accidentally, by unsealed return air or exhaust ducts, or by packaged air-conditioning units installed in the walls (Lstiburek 1999). When incoming humid air contacts a cold surface like an inside wall near a cooling unit, moisture condenses and fungus thrives. The problem is magnified and accelerated when the incoming moisture is prevented from passing into the conditioned space by a vapor retarder, such as the popular vinyl wall covering used in many commercial buildings. More trapped moisture means more fungus behind the wall covering.

Figure 1 shows the classic example of a small hotel in the southeastern United Sates. The rooms are equipped with a wall-mounted cooling unit on the exterior wall and have vinyl wall covering. Air is exhausted from the bathroom continuously, and pulled out of the hotel by roof-mounted fans. The rooms feel damp, they smell musty, and vinyl keeps peeling off the wallboard.

The investigation showed how the mold and mildew growth follows the path of humid air pulled into the building by the suction created by unsealed exhaust ductwork. Fans pull air from the walls between rooms, creating suction at the exterior wall. It does not matter that the room pressure is positive—the *wall cavity* pressure is negative, so humid outdoor air flows into the building, condensing moisture behind the vinyl wall covering and feeding the fungus shown in *Figures 1* and *4*.

One could argue that the problem is caused by the vinyl wall covering, and by the leaky exterior wall and by the overcooling of the room by the occupants. Not our problem. As Mark Twain once observed, "Nothing needs reforming more than other people's habits." The HVAC designer can contribute to the solution as well.

Continuous suction can be avoided by specifying that the return and exhaust duct work must be sealed, and that the exhaust and return grilles be gasketed to the interior finish.

Wall-mounted air-conditioning units can also create suction inside the walls if their internal casings have slots or holes that allow the fan to pull a negative pressure on the wall cavity. Any manufacturer's product can be mounted incorrectly, and some have internal casing designs with negative-pressure plenums that are not airtight. The designer should consider the equipment selection or the mounting specifications accordingly. Finally, as a minimum the building should be supplied with more pre-dried makeup air than the volume of air exhausted from the building.

These minimal precautions will help avoid the worst of the problems seen in commercial buildings. As noted earlier, many more complex issues are associated with humidity control. In an effort to assist all members of a design and construction team, ASHRAE has partnered with the U.S. Department of Energy and industry to provide design guidance in more depth.

New ASHRAE Humidity Control Design Guide

Work is currently in progress to produce a design guide for humidity control that takes a multidisciplinary approach to the topic, and incorporates the results of research performed in recent years. The project was generated by ASHRAE Technical Committee 9.12, Tall Buildings, and is supervised by a joint committee with representatives from TC 3.5, Desiccant and Sorption Technology, TC 7.5, Mechanical Dehumidification Equipment and Heat Pipes and TC 8.7, Humidifying Equipment as well as with representatives of the co-funding organizations: the Gas Research Institute and Oak Ridge National Laboratory acting on behalf of the U.S. Department of Energy.

The authors and the monitoring committee have been humbled by the magnitude of the task of compressing what is known about humidity control in commercial buildings into a single volume. The guide will be, at best, a good start on the subject rather than the definitive reference containing answers to all questions.

The project began with an informal survey of the needs of the design community, equipment manufacturers and of building owners that have directly experienced the difficulty of improving humidity control in budget-limited commercial buildings. Based on that input, the book will be focused on the needs of the board-level HVAC designer more than the needs of the senior HVAC engineer or the building scientist.

The book assumes the client has attached a value to better humidity control, identified a budget for that purpose and asked the HVAC designer to proceed accordingly. The information is structured and written for the designer who then "...has to get it done by Friday." Consequently, the book will contain more photos, diagrams and checklists than complex equations. *Figure 5* shows the structure and content. The project is scheduled for completion in early 2001.

Summary

Creating the design guide has convinced its authors that better and more cost-effective humidity control is not simply a matter of adding equipment—although that is usually a necessary part of the solution and adds cost beyond the typical commercial building budget. Avoiding problems and minimizing costs will demand a holistic, multidisciplinary approach.

In the past, our industry has shown more talent for reducing problems to individual components than for bridging the gaps between members of the construction team. We have good tools for calculating heat and mass transfer across exterior wall sections at steady state—but no tools to quantify and to avoid problems created in a building with cracks between the air-conditioning unit and the wallboard—which are delivered to the job site and installed through separate subcontracts completed at different times. The current business structure of the construction industry reflects specialization and separation of responsibilities. This atomization leads to coordination foul-ups, which probably create more frequent and serious problems than any caused by sub-optimal components. The new humidity control design guide will be one attempt to bridge some of those gaps with the goal of better and more cost-effective service to the building owner.

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