Condensation Issues With Radiant Cooling Panels

The DOAS approach effectively eliminates biological contaminants and inadequate ventilation. It also avoids building-wide distribution of indoor chemical contaminants.

By Stanley A. Mumma, Ph.D., P.E.
Fellow ASHRAE

This column explores condensation concerns.

In the past three issues of *IAQ Applications,* the author has dealt with dedicated OA systems (DOAS).

Those columns presented the DOAS's ability to remove the total outdoor air load, all of the space latent load and a portion of the space sensible load.

It has been asserted that the parallel sensible cooling equipment, preferably either fan coil units or ceiling radiant cooling panels can operate with dry surfaces, thus further minimizing the potential for IAQ problems and related sick-building illnesses.

While specific causes of sick-building illnesses remain elusive, some contributing factors to sick building syndrome are:[1] *chemical contaminants* from outdoor and indoor sources; *biological contaminants,* which can breed in stagnant water that has accumulated in humidifiers, drain pans, and ducts, or where water has collected on ceiling tiles, insulation, or carpet; and *inadequate ventilation*.

The DOAS approach effectively eliminates biological contaminants and inadequate ventilation. It also avoids building-wide distribution of indoor chemical contaminants. The significance of the DOAS is illustrated by estimates from the Lawrence Berkeley National Laboratory[2] that U.S. companies lose as much as $58 billion annually on medical expenses and $200 billion annually in lost productivity as a result of sick-building illnesses. This column investigates the potential of condensation problems and resulting biological contaminants when radiant cooling is used with DOAS's.

Overview

Ceiling radiant cooling panels (CRCP) are an architectural finish product with necessary acoustical qualities, color, and pattern. The panels are available in two designs. The first is a drop-in panel, illustrated in *Figure 1,* compatible with the traditional drop ceiling "Tee grid" system. The second design is a free hanging element. Widths are generally 2 ft (0.61 m), and lengths can vary from 2 ft to 12 ft (0.61 to 4 m) or more.

For cooling applications, the heat flux to the panel surface is in the 30 Btu/h·ft^2 (95 W/m^2) range for drop ceiling applications, and about twice that for the free hanging designs. As a result, the aluminum absorber surface is only about 22 gage (0.76 mm), and the thermally bonded copper cooling water piping is generally ½ in. (12.7 mm) in diameter or less, and on about 6 in. (150 mm) centers.

Panel piping arrangements are generally in a serpentine pattern; however, parallel header arrangements are available on request. As installed, the "drop-in" radiant panels weigh 0.96 lb/ft^2 (4.7 kg/m^2) while the conventional 7/8-in. (2.2 cm) thick mineral fiber acoustical tile that they replace weigh 1.15 lb/ft^2 (5.6 kg/m^2). The lightweight construction results in a transient response "time constant" of only about three to five minutes. That means they respond rapidly to changing space sensible load conditions.

Sixteen radiant system advantages are presented on Page 6.1 of the *2000 ASHRAE Handbook—HVAC Systems and Equipment.* In addition, the proposed radiant/DOAS mechanical system has the potential to generate up to 23 green building rating points, or up to 88% of the minimum points needed for certification.

Condensation Issues

Because of the potential for condensation, radiant cooling cannot even be considered unless another parallel system is in place to decouple the space sensible and latent loads, or the situation illustrated in *Figure 2,* and the associated adverse biological generation may occur. The author recommends[3] that a DOAS be used to remove all of the space latent loads, thus achieving the required load decoupling.

The DOAS is also required[4] to ensure compliance with ANSI/ASHRAE Standard 62-1999, *Ventilation for Acceptable Indoor Air Quality,* which is nearly impossible to verify with an all-air system.

ANSI/ASHRAE/IESNA Standard 90.1-1999, *Energy Efficient Design of New Buildings Except Low-Rise Residential Buildings,* Section 6.3.6.1, Exhaust Air Energy Recovery, addresses the requirements for total energy recovery in the DOAS. The required heat recovery reduces the OA load on the cooling coil by 75 to 80%. This results in reduced energy demand and consumption, as well as reduced chiller size. In general, the supply air conditions from the DOAS[5] required to decouple the space sensible and latent loads, and minimize the sensible load on the parallel radiant cooling system, are about 45°F (7.2°C) and saturated.

Application Issues

Condensation Formation

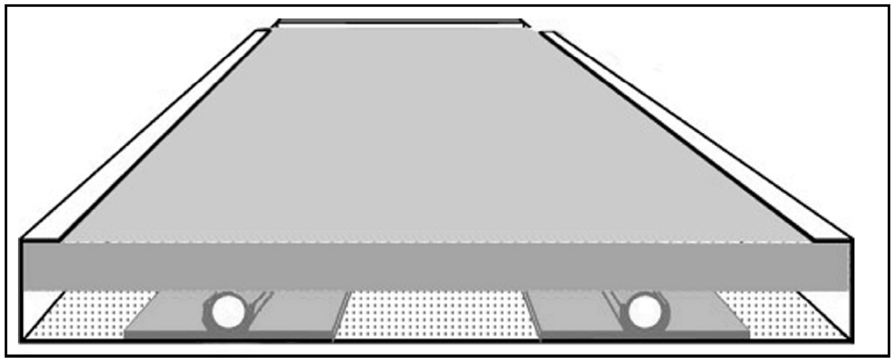

Figure 1: A drop-in ceiling radiant cooling panel design.

Using the DOAS to decouple the space loads at design does not guarantee that some spaces will not occasionally have transient occupancies exceeding design. The extra occupant latent load generation has the potential to create a condensation problem on the approximately 60°F (16°C) chilled ceiling surfaces in time.

To better understand the nature of this potential problem, let us explore two conservative boundary conditions. First, consider the steady state (the period of time following the formation of condensation when there are no changes in occupancy or mechanical system operation as a function of time) rate of moisture condensation in a typical office situation. Let us make the following assumptions:

- Ventilation airflow rate and thermodynamic state point remains constant at the design conditions;
- Occupant latent load, 205 Btu/h per-person (60 W/person);
- Infiltration negligible;
- Occupancy exceeds design by 100%, i.e., two people where one was used in design;
- Enclosure and contents are completely non-hygroscopic, i.e., they do not participate in the moisture transients (an extremely conservative assumption);
- Typical radiant panel area per person at design occupancy, 70 ft^2 (6.5 m^2). This assumes seven people per 1,000 ft^2 (93 m^2) and a 50% chilled ceiling fill factor;
- Chilled ceiling radiant panel temperature is uniform overall.

Under these assumed conditions, the occupant generates less than 0.2 lb/hr (0.025 g/s) of water vapor. When uniformly distributed over 70 ft^2 (6.5 m^2) of panel per person, the water thickness after one hour is 5/10,000 of an inch (13 μm). For reference, a human hair ranges in diameter from 0.0007 to 0.007 in. (17 μm to 181 μm) in diameter. Under these conservative steady state moisture condensation assumptions, it would take one person's latent generation from 90 minutes to 14 hours for the condensation thickness to equal the diameter of a human hair. Now, consider the transient time prior to moisture condensation in a typical office situation.

As in the steady state case, it is assumed that at or below design occupancy, condensation will not occur when the DOAS is working properly. However if the design occupancy is exceeded, the space dew-point temperature (DPT) will increase, leading to potential condensation when the space dew-point temperature exceeds the radiant panel cooling water temperature. Conceptually, this is similar to a bucket of water partially full when filling begins. It does not overflow at first as water is added. In the case of the transient moisture situation, the following additional design condition assumptions were made beyond those used for the steady state case:

- 12 ft (3.65 m) high ceiling;
- Ventilation rate per person, 20 scfm (0.011 kg/s);
- Supply air condition, 44°F (6.7°C) and saturated; or a humidity ratio of 42.6 gr./lbm (0.00608 kg/kg);
- Resulting design steady state space dew-point temperature, 52°F (11°C), or a humidity ratio of 57.73 gr./lbm (0.00825 kg/kg);
- Cooling water temperature to the panels, 55°F (12.8°C) or 3°F (1.7°C) greater than the design space DPT. The humidity ratio for 55°F (12.8°C) and saturated is 64.63 gr./lbm (0.00923 kg/kg);
- The space air is assumed to be well mixed.

The governing differential equation for this problem, based upon water vapor is:

$$dm_{room}/dt = \dot{m}_{in} + \dot{m}_{IG} - \dot{m}_{out} \qquad (3)$$

Where,

$dm_{room}/d\tau$, rate of change of the mass of water vapor in the space at any instant in time.

$\dot{m}_{in}$, mass flow rate of water vapor entering the space with the ventilation air at an instant in time.

$\dot{m}_{IG}$, rate of moisture released by the occupants in the space at an instant in time.

$\dot{m}_{out}$, mass flow rate of water vapor leaving the space at an instant in time.

Under the assumed conditions, if the occupancy suddenly doubled, it would take nearly an hour for the space dew-point temperature to rise to that of the chilled ceiling feed-water temperature (55°F [12.8°C]). If the occupancy suddenly tripled, it would take nearly 30 minutes for condensation to begin forming.

Another transient case to consider is one where the occupancy is suddenly doubled, then after nearly an hour, when the room DPT equals the panel inlet temperature, the occupancy returned to design. The transient response for this case appears as illustrated in *Figure 2*.

As expected, the space humidity ratio begins an exponential rise toward steady state, and then when the space DPT equals the temperature of the cooling fluid—the occupancy suddenly returns to design. The fall in humidity following the rise, responds slower than it did on the way up. Under the assumed conditions this is not a problem. However, if the hygroscopic nature of the enclosure and space contents had been considered, the rise in humidity ratio would have been much slower. Likewise, the return to design conditions is even slower.

Real response characteristics will be important experimentally determined values for each installation. The data will be useful for determining the required DOAS preconditioning dehumidification run time prior to activation of the chilled ceiling and occupancy after a weekend/holiday shutdown.

Only deviations from design resulting from occupancy changes have been addressed to this point. It is possible that condensation could also result from envelope integrity problems. However, if the structure is confirmed to be in compliance with Standard 90.1-1999, Section 5.2.3 — Envelope Air Leakage, that should not be a problem, particularly when care is taken to avoid negative pressures within the building, such as return air plenums.

An extreme case was investigated experimentally under steady boundary conditions. In the 8.5-hour experiment, the radiant panel temperature was intentionally maintained 15°F (8°C) colder than the space dew-point temperature. During that time period, insufficient condensation formed to fall from the panel surface.

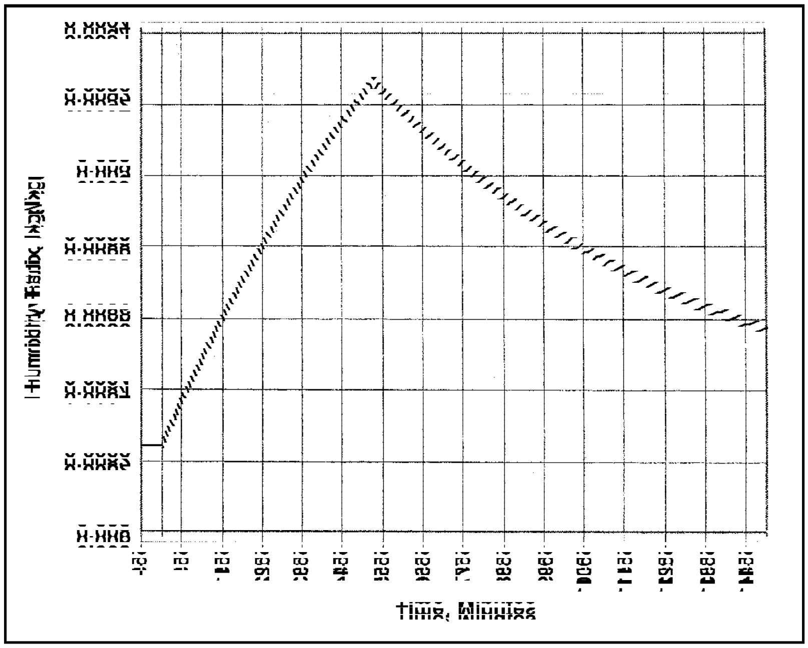

Figure 2: Transient humidity ratio response to a sudden doubling of the design occupancy, followed by a sudden return to design occupancy.

In all cases, condensation is a slowly responding phenomena, and one easy to avoid so long as the DOAS and radiant panel loop temperature controls are operating correctly. In the event those controls fail, several simple control-based *safety* remedies exist for this potential problem. They are:

• Monitor the space dew-point temperature and reset the panel coolant temperature above the space DPT. This has a negative impact on the radiant capacity and will require attention — a good thing.

• Place a moisture sensor at the inlet to the first radiant panel for each group controlled by a control valve. In the event moisture is detected, the control valve must be closed and possibly the panel circulating pump de-energized. Of course, radiant cooling in that space will cease, and the occupants will demand corrective action be taken—a good thing. Most all-air systems continue to operate without occupant awareness even when they are operating poorly, so they rarely receive needed attention.

Conclusions and Recommendations

This column has explored the condensation concern expressed by the building industry in conjunction with radiant cooling. It has been demonstrated that when a DOAS is used to decouple the space sensible and latent loads, the radiant panels are only left with a portion of the space sensible loads. And if the occupancy exceeds design by a factor of 2 or 3, it takes time for the space humidity ratio to increase to the point where condensation can form. Once it does start to form, it could take hours for the condensation thickness to equal the diameter of a human hair.

Control measures necessary to detect condensate were also discussed. It may safely be concluded that condensation can easily be avoided, and it must be for esthetic as well as IAQ reasons. Future columns by the author will address other IAQ concerns related to chilled ceilings/DOAS, including thermal comfort, capacity, and cost.

References

1. Environmental Protection Agency. 2001. www.epa.gov/iaq/pubs/sbs.html.

2. Vaughn, S. 2001. "When the atmosphere at work is just unbearable." *Los Angeles Times*. Work Place Section-Career Challenge. Part W. Page 1, July 22.

3. Mumma, S.A., 2001. "Overview of integrating dedicated outdoor air systems with parallel terminal systems." *ASHRAE Transactions* 107(1).

4. Mumma, S.A., 2001. "Fresh thinking: dedicated outdoor air systems." *Engineered Systems* 18(5):54-60.

5. Shank, K., S. A. Mumma. 2001. "Selecting the supply air conditions for a dedicated outdoor air system working in parallel with distributed sensible cooling terminal equipment." *ASHRAE Transactions* 107(1).

S.A. Mumma, Ph.D., P.E., is a professor of Architectural Engineering at Penn State University, University Park, Pa. He is an ASHRAE Learning Institute trustee and serves on ASHRAE Technical Activities Committees, Integrated Building Design and Solar Energy Utilization. He can be reached at sam11@psu.edu.