# Improving IEQ To Reduce Transmission Of Airborne Pathogens In Cold Climates

BY STEPHANIE H. TAYLOR, M.D.; C. MICHAEL SCOFIELD, FELLOW/LIFE MEMBER ASHRAE; PATRICIA T. GRAEF, P.E., FELLOW/LIFE MEMBER ASHRAE

Winter indoor environments in cold climates often stabilize at a low relative humidity (RH) due to high outdoor air ventilation rates required for schools and high-occupancy office buildings. Indoor environmental quality (IEQ) is heavily impacted due to the low RH. Recent studies have concluded that low indoor RH and reduced outdoor air ventilation result in reduced student and worker productivity and increased short-term sick leave.[1,2] The variable air volume (VAV) design discussed in this article uses adiabatic hydration (humidification) of all outdoor air during cold-dry ambient conditions.

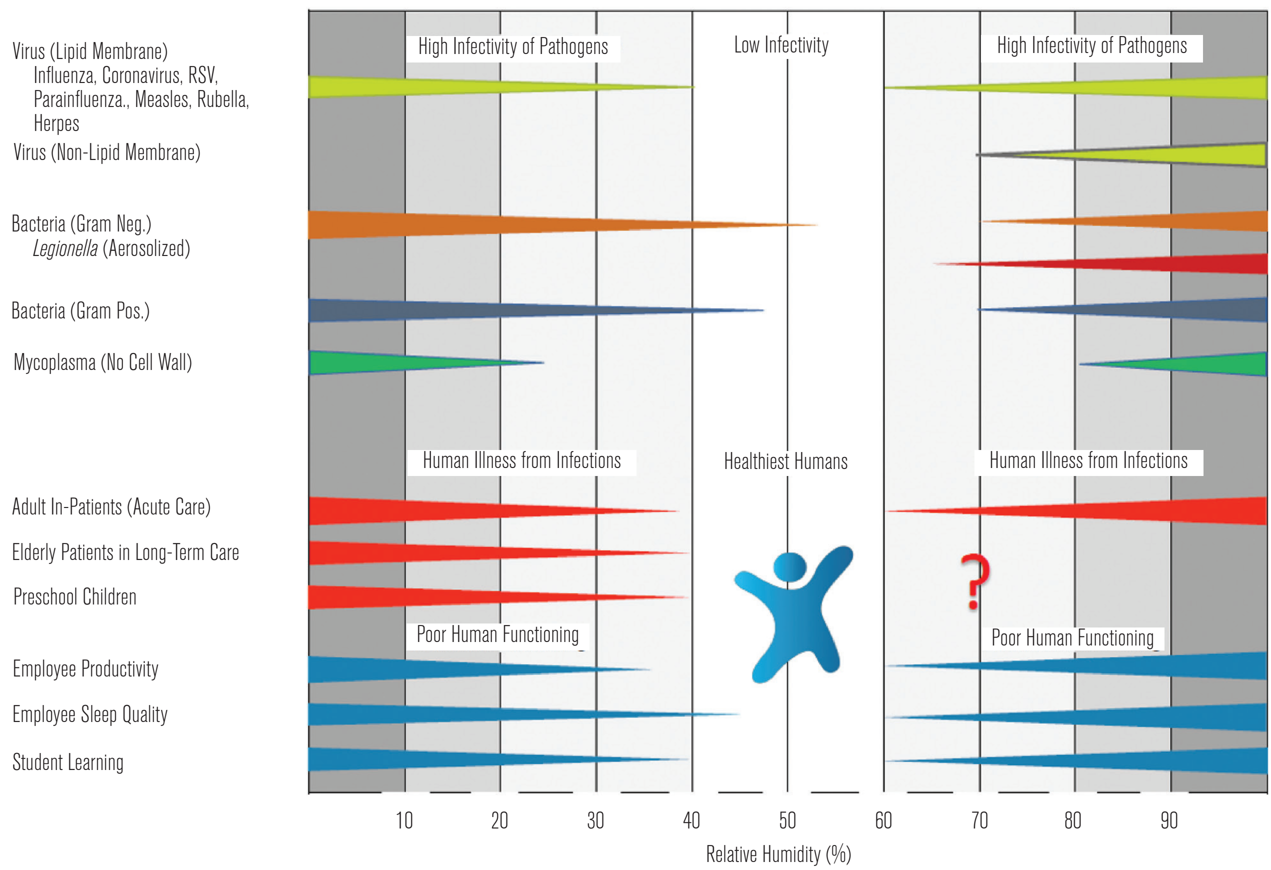
A 45°F (7°C) dew-point (DP) minimum supply to core building VAV terminals will reduce fan energy and room air change rate. Other studies have linked artificially high air change rate with room air turbulence within the human breathing zone, which may lead to the projection of flu virus and other airborne pathogens further from the primary human host and result in infecting other room occupants.[3] Air-to-air heat exchangers are used to recover heat from building exhaust air that was generated by people, lights and plug loads inside the building. Low-cost humidification is provided to the building using an adiabatic cooler/humidifier (AC/H) in a central station air-handling unit (AHU).

## Air Hydration for Human Health and Well-Being

During the winter in cold climates, people spend at least 85% of their time indoors,[4] so it is not surprising that the indoor environment exerts a powerful influence on occupants. Existing ASHRAE guidance refers to managing indoor air to accommodate occupant *comfort*. However, new data clearly show that occupant *health*, a more pressing consideration than comfort for most of us, is impacted by IEQ.[5]

*This peer-reviewed article does not represent official ASHRAE guidance. For more information on ASHRAE resources on COVID-19, visit ashrae.org/COVID19.*

FIGURE 1 Relative humidity of 40% to 60% is optimal for human health. Courtesy of Dr. Stephanie Taylor.




Indoor RH, especially in temperate climate winters, can stabilize at dry levels of 20% or lower when cold outdoor air is brought into a building and heated to temperatures comfortable to lightly clothed people. New research findings are revealing the magnitude of occupant health problems associated with low indoor RH. While many of these health issues have been noted in the past,[2] they are now receiving additional attention because new data are reinforcing the significance of this relationship.

Much of the new information about dry air and health arises from a greater understanding of the coexistence of microbes with humans. New medical diagnostic tests implement tools used to sequence the human genome in 2003. These tests can probe deeply into the causes of acute infections, chronic inflammation and autoimmune disorders. These genetic analysis tests have given rise to revolutionary information about the coexistence of vast numbers of microbes, meaning bacteria, viruses and fungi, on and within our bodies.[6]

This information directly challenges our long-held hygiene theory that microbes are disease-causing germs that need to be eradicated as quickly as possible. We now know that most microbes in our personal ecosystems, called our microbiome, are not only beneficial to our health, but are essential to human survival.

When humans occupy a building, they shed their microbes from direct contact, skin flakes and expired droplets into the built environment. Accumulated occupant microbes combine with those from outdoor sources, giving rise to dynamic microbial communities known as the building microbiome.[7] This building microbiome is further shaped by ongoing occupant shedding, ventilation strategies and surface materials (*Figure 1*). In addition:

- When indoor air is less than 40% RH, the effective, natural immunological defenses of human airways, eyes and skin are impaired. The loss of moisture from these

Stephanie H. Taylor M.D., is a Harvard Medical School Incite Health Fellow in Boston. Mike Scofield, P.E., is president, Conservation Mechanical Systems, Sebastopol, Calif., and is a consultant to California Hydronics Corp., San Francisco. Patricia T. Graef, P.E., is retired and lives in Fort Myers, Fla.

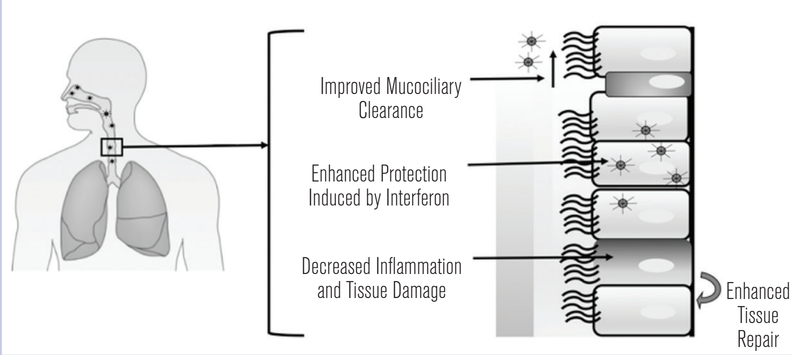
tissues leaves occupants significantly more vulnerable to infectious, inflammatory and allergic diseases[8] (*Figure 2*).

- A dry air-environment with low RH carries more infectious bioaerosols than hydrated air. Airborne pathogens stay buoyant and viable for longer periods of time in dry atmospheres, and they can be spread more readily within the indoor human breathing zone.[9]
- For reasons still not completely understood, when ambient RH is low, the viruses and bacteria in aerosolized droplets are more virulent to a secondary host.[10]
- Humans have a vast surface area that loses significant water to the environment through breathing and skin exposure.[11] In dry air, this insensible water losses result in mild dehydration that stresses brain functioning,[12] impairs natural respiratory tract immunity (discussed above), decreases skin health and wound healing[13] and overstimulates blood clotting, which is associated with poorer outcomes of heart attacks and strokes.[14]

In summary, dry indoor air is harmful to occupant health by causing skin and mucus membrane water losses and by creating building conditions that foster the survival and transmission of pathogenic microbes. Thus, ventilation choices clearly link human health to the built environment. Despite these findings of harm, understanding and remediating dry indoor environments has been largely overlooked by both building and clinical professionals. The reasons for this are several-fold:

- While the temperature of surrounding air is immediately evident to nerve endings in our skin, the degree of dryness is not felt and, therefore, is not experienced as discomfort.[15]
- Acute infections from pathogens that we now know are transmitted via airborne infectious aerosols in dry air have historically been incorrectly attributed to contact transmission routes alone.
- Chronic illnesses associated with dry air often arise slowly and, therefore, are not immediately associated with low humidity indoor environments.
- Providing humidification requires dedicated HVAC equipment (humidifiers) that must be run (using water and energy) and maintained (by human attention) for safety.

FIGURE 2 In ambient RH of 50%, the respiratory system is optimally protected from Influenza A disease.[8]




- Legionnaires' disease outbreaks have focused the public's attention on hazards associated with building water and HVAC systems.

Nevertheless, we now know more clearly than ever that dry interior environments are harmful to our health, productivity and learning.

Adding water vapor to hydrate indoor air to 40% to 60% RH benefits occupants in several ways. First, balanced air-hydration directly supports healthy and functional skin and mucosal barriers[8] necessary to resist invading pathogens and facilitate appropriate immune system responses to microbes. In addition, properly hydrated air reduces skin production of unhealthy stress hormones,[16] improves cognitive abilities, which increase employee productivity and student learning[17] and supports healthy eye physiology. Additionally, RH of 40% to 60% fosters a building microbiome with communities of diverse microorganisms, which are beneficial to human health.

Despite the health benefits from balanced indoor air hydration, there are building-related concerns about providing indoor humidification. Water in buildings, even in the form of vapor, generally has a bad reputation because poorly insulated building envelopes or cold surfaces can allow unintended condensation to occur. Building owners and managers worry about this condensation and associated mold growth.

While liquid water will support mold growth, water in the vapor form will not because fungal organisms are not hygroscopic when the RH is between 40% and 60%.[18] The effective and rational solution to inhibit mold growth, therefore, is to adequately insulate cold building surfaces and use vapor barriers to prevent high water activity in interstitial spaces. The result should not be an overdry indoor environment that compromises occupant health.

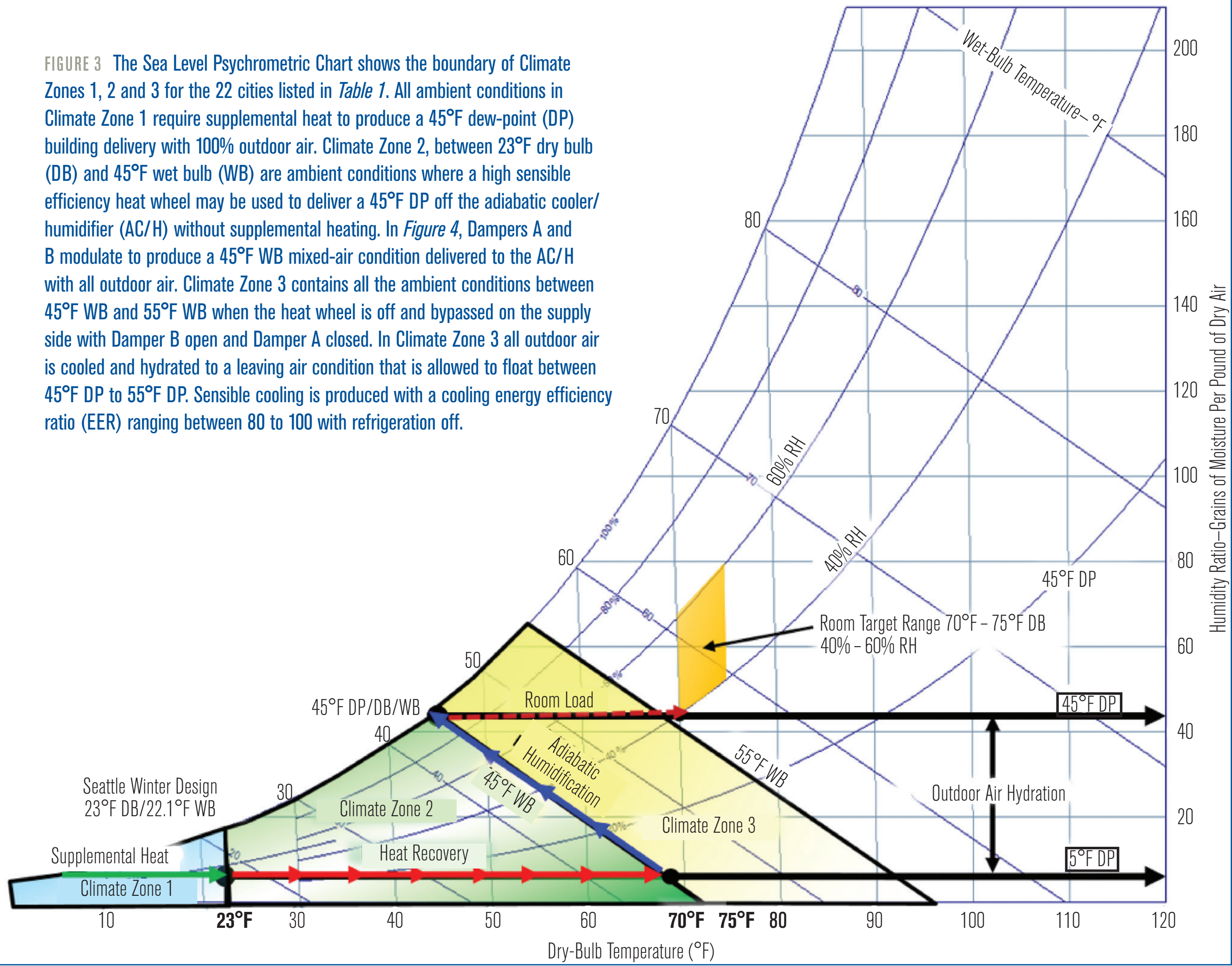



FIGURE 3 The Sea Level Psychrometric Chart shows the boundary of Climate Zones 1, 2 and 3 for the 22 cities listed in *Table 1*. All ambient conditions in Climate Zone 1 require supplemental heat to produce a 45°F dew-point (DP) building delivery with 100% outdoor air. Climate Zone 2, between 23°F dry bulb (DB) and 45°F wet bulb (WB) are ambient conditions where a high sensible efficiency heat wheel may be used to deliver a 45°F DP off the adiabatic cooler/humidifier (AC/H) without supplemental heating. In *Figure 4*, Dampers A and B modulate to produce a 45°F WB mixed-air condition delivered to the AC/H with all outdoor air. Climate Zone 3 contains all the ambient conditions between 45°F WB and 55°F WB when the heat wheel is off and bypassed on the supply side with Damper B open and Damper A closed. In Climate Zone 3 all outdoor air is cooled and hydrated to a leaving air condition that is allowed to float between 45°F DP to 55°F DP. Sensible cooling is produced with a cooling energy efficiency ratio (EER) ranging between 80 to 100 with refrigeration off.

## A Wet-Bulb Heat Recovery Economizer

For more than three decades, air-to-air heat exchangers have been used to recover building generated heat and comply with the minimum winter ventilation requirements of ASHRAE Standard 62.1.[19] These conventional systems use the VAV 55°F (13°C) air delivery setpoint of the building. *Figure 3* demonstrates a novel method to deliver 70°F (21°C) air at 40% relative humidity using heat recovery and adiabatic cooling/humidification (AC/H).

Since VAV systems operate at their lowest flow rates on the coldest days, heat recovery from the building is required to furnish the code-minimum outdoor air to the building. The code minimum airflow rate may be more than that needed at 45°F (7°C) DB to meet the cooling load in core conference rooms and north-facing perimeter zones (in the northern hemisphere). VAV terminal reheat will be required for those mixing boxes.

ASHRAE Research Project RP-1515 demonstrated that, with good aspirating ceiling diffusers, the turndown of a VAV terminal to 10% flow will not lose flow control and will not result in "dumping" of cold air into the space. On the contrary, overcooling complaints in the buildings tested went down, eliminating cold room issues while saving fan energy.[20]

In many northern hemisphere cold climates, high-rise buildings with south-facing glass experience design cooling loads in January and February due to the low angle of the sun and the radiant energy on the south-facing side of the building.[21] A 45°F (7°C) DB delivery to these VAV terminals will provide comfortable indoor environments with reduced fan energy during these peak cooling loads.

When we can hold indoor RH in winter at a minimum of 40%, room thermostat setpoints may be reduced to 70°F (21°C) or lower, saving heating energy. This

TABLE 1 Bin weather data distribution for 22 northern U.S. cities, listing the total annual hours and percent of annual hours where heat recovery and adiabatic cooling and humidification may be used to furnish 100% outdoor air, without supplemental heating energy (Climate Zones 2 and 3 in *Figure 3*), to produce a 45°F to 55°F dew-point (DP) building delivery condition. The building duty cycle is assumed to be 24/7/365, and the VAV fan turndown is 50% of full flow during cold ambient conditions.

| CITY, STATE | ELEVATION (FT) | CLIMATE ZONE 1 PREHEAT REQUIRED FOR 100% OUTDOOR AIR | | CLIMATE ZONE 2 HUMIDIFICATION WITHOUT PREHEAT WITH 100% OUTDOOR AIR AND HEAT RECOVERY | | CLIMATE ZONE 3 HUMIDIFICATION OF 100% OUTDOOR AIR WITHOUT PREHEAT OR REFRIGERATION WET-BULB RANGE 45°F TO 55°F | |
|---|---|---|---|---|---|---|---|
| | | HOURS | % | HOURS | % | HOURS | % |
| Boise, ID* | 2,996 | 225 | 2.6% | 4,214 | 48.1% | 3,050 | 34.8% |
| Chicago, IL | 658 | 692 | 7.9% | 4,272 | 48.8% | 1,304 | 14.9% |
| Des Moines, IA | 938 | 903 | 10.3% | 3,797 | 43.3% | 602 | 6.9% |
| Boston, MA | 133 | 619 | 7.1% | 3,879 | 44.3% | 1,419 | 16.2% |
| Detroit, MI | 583 | 709 | 8.1% | 3,824 | 43.7% | 1,287 | 14.7% |
| Grand Rapids, M | 841 | 721 | 8.2% | 3,851 | 44.0% | 1,276 | 14.6% |
| St. Paul, MN | 834 | 1,404 | 16.0% | 3,236 | 36.9% | 1,166 | 13.3% |
| Billings, MT* | 3,567 | 822 | 9.4% | 4,618 | 52.7% | 1,968 | 22.5% |
| Great Falls, MT* | 3,525 | 1,016 | 11.6% | 4,820 | 55.0% | 2,224 | 25.4% |
| Buffalo, NY | 590 | 520 | 5.9% | 4,050 | 46.2% | 1,331 | 15.2% |
| Bismarck, ND* | 1,647 | 1,772 | 20.2% | 3,297 | 37.6% | 1,822 | 20.8% |
| Grand Forks, ND | 911 | 2,138 | 24.4% | 3,159 | 36.1% | 1,192 | 13.6% |
| Cleveland, OH* | 1,208 | 504 | 5.8% | 3,804 | 43.4% | 1,340 | 15.3% |
| Columbus, OH | 824 | 472 | 5.4% | 3,386 | 38.7% | 1,248 | 14.2% |
| Harrisburg, PA | 308 | 242 | 2.8% | 3,642 | 41.6% | 1,302 | 14.9% |
| Pittsburgh, PA* | 1,137 | 491 | 5.6% | 3,575 | 40.8% | 1,365 | 15.6% |
| Rapid City, SD* | 3,276 | 961 | 11.0% | 4,320 | 49.3% | 1,989 | 22.7% |
| Sioux Falls, SD* | 1,418 | 1,351 | 15.4% | 3,280 | 37.4% | 1,789 | 20.4% |
| Seattle, WA* | 47 | 18 | 0.2% | 3,814 | 43.5% | 2,747 | 31.4% |
| Spokane, WA* | 2,462 | 291 | 3.3% | 4,718 | 53.9% | 3,026 | 34.5% |
| Madison, WI | 858 | 1,018 | 11.6% | 3,612 | 41.2% | 1,187 | 13.6% |
| Casper, WY* | 5,338 | 827 | 9.4% | 4,841 | 55.3% | 2,539 | 29.0% |
| | | 22 Northern Cities Average | 9.2% | | 44.6% | | 19.3% |

*Western cities and cities at high altitude.

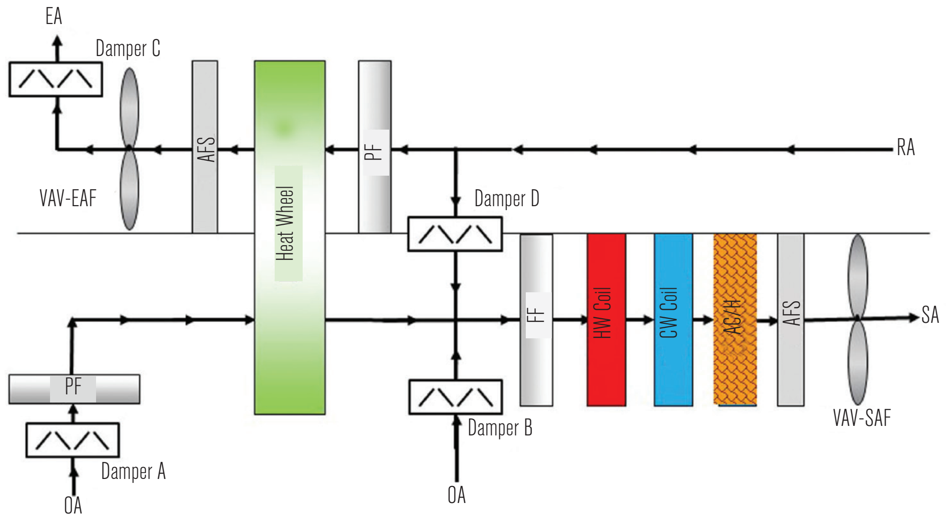
Reference Ecodyne. 1980. *Climate Data Handbook*. McGraw-Hill.

is because the skin evaporation rate for humans is lower at 40% RH compared to 20% RH. The perception of comfort is better for the zone occupant at lower indoor temperatures and lower VAV box flow rates. Cold-climate buildings often include a radiant heating system around the building perimeter to treat cold exterior walls and to raise the room mean radiant temperature (MRT). This separate heating system will also allow exterior space zones to reduce the room set temperature.

The psychrometric chart in *Figure 3* shows the heat recovery process (red line) provided by a high-efficiency sensible heat wheel. The adiabatic process (blue line) of a high saturation efficiency AC/H provides the outdoor air hydration to the 45°F (7°C) DP. The high efficiency of the adiabatic device is critical. With a 95% wet-bulb depression efficiency (WBDE) adiabatic device, the leaving DB can be accurately measured and will always be within 1°F (0.6°C) of the leaving DP condition. Commercial grade DP (enthalpy) sensors are not recommended for this application because when installed in an air duct after a humidifier, they require frequent maintenance and calibration.[22]

With normal room load lines in high-occupancy buildings, such as classrooms, the room target of 40% to 60% room RH can be maintained.

**FIGURE 4** VAV unit schematic and description of components and controls.




**Heat Wheel** Air-to-air heat exchanger selected at 75% sensible effectiveness at full cfm flow. More humid climates with many ambient hours above a 55°F dew point (DP) would select an enthalpy heat wheel.

**AC/H:** An adiabatic cooler/humidifier selected at 90% or higher wet-bulb depression efficiency (WBDE) at full cfm flow. Delivery air dry bulb (DB) should be within 1°F of the delivery DP after adiabatic humidification when the VAV flow is 50% of full flow during cold ambient conditions. Hydration of cold-dry winter outdoor air is shown in *Figure 3*.

**HW Coil:** Hot water coil is the heating source for maintaining a minimum 45°F DP delivery condition to the building during extreme cold ambient conditions (see Climate Zone 1, *Table 1*).

**CW Coil:** Chilled water cooling coil to maintain a minimum 55°F delivered DB temperature to the building, after heat recovery of the outdoor air, at ambient conditions above 55°F DP and above 55°F wet bulb (WB).

**Dampers A and B:** These dampers modulate to deliver a 45°F DP to the building during ambient conditions in Climate Zone 2 (*Figure 3*) by mixing all outdoor air to produce a 45°F WB mixed-air condition delivered to the AC/H.

**Dampers A and C:** Shut-off dampers for night and weekend building shutdown.

**Damper D:** This damper is open during morning warm-up and prehumidification (*Figure 5*) of the building after night or weekend shutdown with Dampers A, B and C closed and the heat wheel off.

**AFS:** Airflow sensors for building pressurization and verification of ASHRAE Standard 62.1-2019.

**PF and FF:** Pre and final filters.

**VAV-SAF and VAV-EAF:** Variable air volume supply air fan and exhaust air fan for the air-handling unit (AHU).

## VAV Central Station Air-Handling Unit

*Figure 4* shows a schematic layout of a VAV central station air-handling unit, which positions the heat wheel between the building return air (RA) and the outdoor air (OA). The heat wheel is sized for full cooling airflow requirements and selected at a 75% sensible effectiveness. As airflow requirements are reduced during cold outdoor conditions, the effectiveness of the sensible heat wheel increases to 87% at 50% of rated airflow. This is due to the reduced mass flow through the fixed surface and increased "dwell time."

During cold outdoor conditions, with Damper C open and Damper D closed, Dampers A and B modulate to deliver 45°F (7°C) DB off the AC/H using 100% outdoor air. The hot water coil (HW) adds supplemental heat during extreme cold conditions below 23°F (–5°C) DB.

When Damper A is closed and Damper B is 100% open, the heat wheel is bypassed, and the supply-side static pressure penalty for heat recovery is eliminated. As the supply air temperatures off the AC/H start to rise above 45°F (7°C), the VAV 100% outdoor air supply fan speeds up to satisfy the interior cooling load at the higher delivery temperature. When the delivery temperature to the building exceeds 55°F (13°C), the refrigeration system is enabled, and the chilled water cooling coil (CW) valve opens to provide enough sensible cooling to hold the delivery setpoint at 55°F (13°C) DB.

For humid climates with a significant number of hours above 55°F (13°C) DP, it is advantageous to use an enthalpy heat wheel (total heat wheel) as well as an airside economizer and minimum outdoor air. ASHRAE Standard 62.1-2019 can be met by modulating Dampers A and D with Damper B closed when the outdoor air temperature is above 75°F (24°C) DB. An outdoor airflow sensor (AFS) is needed at Damper A. The total enthalpy wheel is activated to lower the temperature and humidity of the warm outdoor ventilation air.

The AFS is used to verify ASHRAE Standard 62.1-2019 minimum required outdoor ventilation air to the building, which also maintains building positive pressure.

The AC/H is selected for design airflow and a 90% minimum WBDE. The maximum static pressure penalty should be 0.14 in. w.g. (35 Pa). This selection will

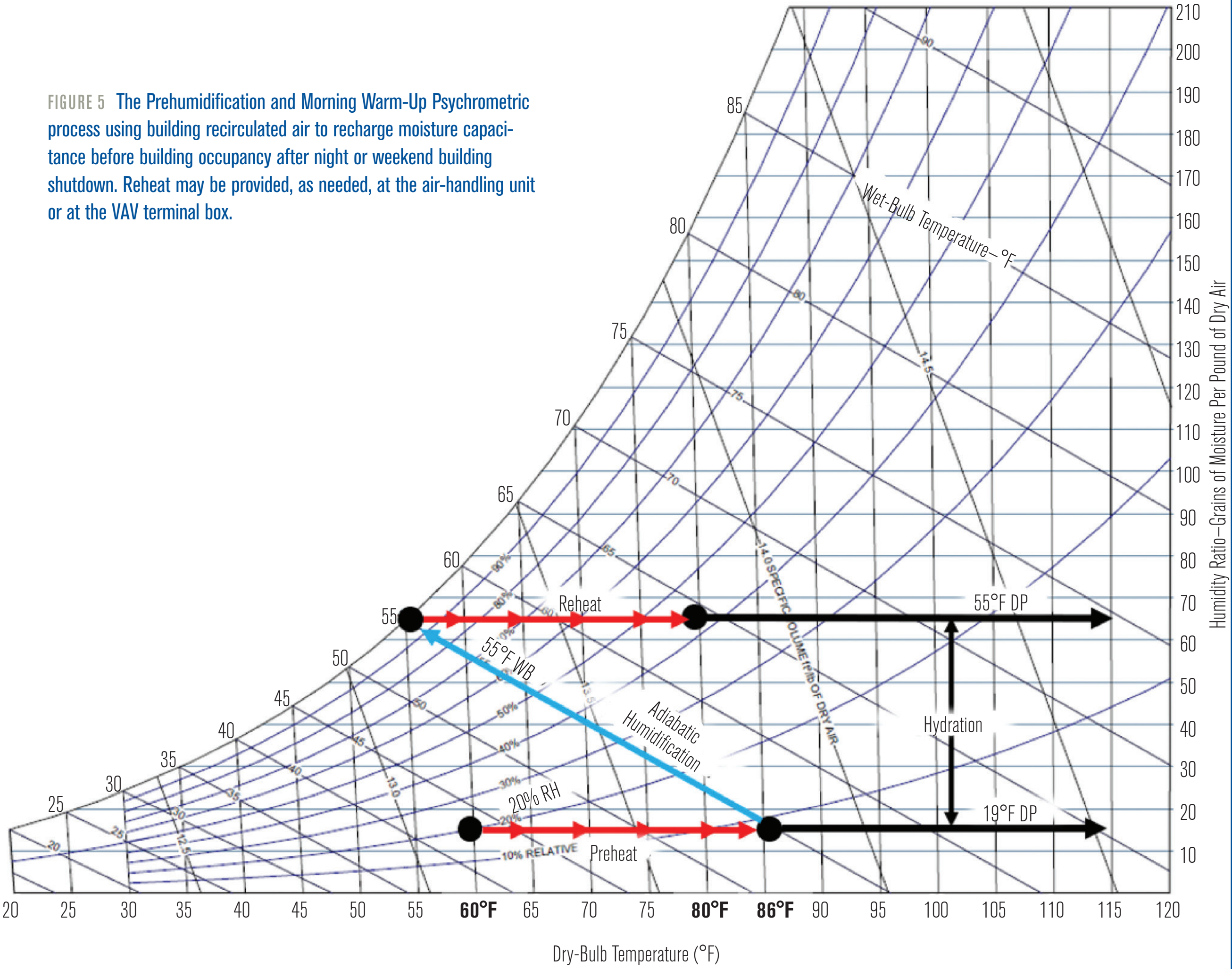



FIGURE 5 The Prehumidification and Morning Warm-Up Psychrometric process using building recirculated air to recharge moisture capacitance before building occupancy after night or weekend building shutdown. Reheat may be provided, as needed, at the air-handling unit or at the VAV terminal box.

increase to a 95% WBDE at 50% of design airflow, while the static pressure will decrease to 0.05 in. w.g. (12 Pa).

The marriage of the heat wheels and AC/H in a VAV design results in significant energy savings because effectiveness increases and the parasitic losses decrease with reduced air mass flow. The building owner benefits from the increased energy exchange efficiency and outdoor air hydration during cold weather.

## Morning Building Prehumidification And Warm-Up Control Strategy

In cold climates, it is customary for buildings with daytime-only duty cycles to schedule a "morning warm-up" cycle after night, holiday or weekend shutdowns, when indoor temperatures are allowed to drop to 60°F (16°C) or lower to save energy. Moisture migration from the building during shutdown often allows indoor relative humidity to drop to 20% or lower, especially after weekend or holiday shutdown periods. Morning warm-ups should include building prehumidification prior to building occupancy.

The AC/H component may be used with recirculated building air to prehumidify the building. *Figure 5* shows the psychrometric process for humidification of the building return air. In *Figure 4*, Dampers A, B and C are closed, and the heat wheel is off with Damper D open and the VAV supply fan on. The reheat after the AC/H may be provided by a coil downstream of the AC/H in the AHU or by the VAV terminal reheat coils in each zone of the building.

A column from the September 2017 issue of *ASHRAE Journal* entitled "It's All Relative"[23] explains the mechanism by which vapor may be stored inside buildings on hygroscopic materials. Water vapor molecules are stacked in the vapor state on these indoor "storage surfaces" and are released to the room when there is a drop in room relative humidity. This "building capacitance for moisture storage" may be replenished after night shutdown during the morning prehumidification control cycle. The daytime release of the water vapor molecules indoors will allow the building to maintain a much more stable indoor relative humidity level during building occupancy.

## Key to Control: Rigid Media Adiabatic Evaporative Cooler/Humidifier

The rigid media evaporative cooler/humidifier AC/H is a very simple device that can consistently cool and humidify the air very close to the saturation line over a wide range of airflows. The media efficiency changes little with variations in water flow, so there is no need to modulate the amount of water supplied to the media to maintain downstream conditions. Earlier discussions explained how conditions are controlled by dew point. *Figure 6* is an illustration of the wet section of a wetted media AC/H that shows all the critical components.

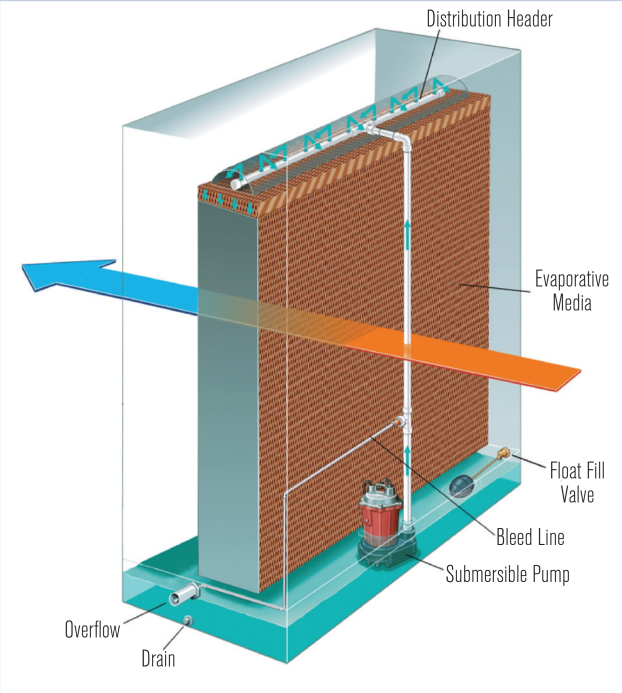
Since all evaporation of water occurs from the surface of the media, there is no excess, unevaporated water carried downstream. Only water vapor is added to the air. Contaminants in the water, such as minerals, stay in the recirculated water and are flushed out by continuous bleed and/or regular flush and dump cycles.

During operation, the AC/H naturally cools the water down to the wet-bulb temperature of the air. For this design, the wet-bulb temperature is between 45°F (7°C) to 55°F (13°C). *Legionella* bacteria is dormant when the water temperature is below 77°F (25°C). When the water temperature is 77°F (25°C) to 108°F (42°C), it is favorable for *Legionella* bacteria growth.[24]

Maintenance of the AC/H is simple:

- If necessary, use nonoxidizing biocides approved by the media manufacturer and the authority having jurisdiction. Oxidizing biocides such as chlorine will destroy the media.
- The media, water distribution and sump should be flushed quarterly.
- Monthly inspection of the media, water distribution and sump will warn the team if more frequent cleaning is necessary. Quarterly cleaning is usually sufficient if the air has been filtered and the water is of good quality.

FIGURE 6 Adiabatic evaporative cooler humidifier section that illustrates the operation of the device. Water is stored in the tank below the media or in a remote reservoir. The pump circulates the water over the evaporative media. Air passes through the channels of the media where evaporation occurs. The media is made from a porous substrate that provides an extended surface for efficient evaporation. Water that is not evaporated returns to the sump where it can be filtered and recirculated over the media. A portion of the water is discharged to drain to keep contaminants from concentrating in the water or depositing on the media. The float valve makes up water that was used for evaporation and bleedoff.




- Monthly, verify that the makeup valve is adjusted and functioning properly.
- Monthly, check the water conductivity or total dissolved solids to ensure there is sufficient bleedoff.
- Annually, calibrate the conductivity controller if one is installed.[25]

## Bin Weather Analysis of 22 Northern U.S. Cities

*Figure 3* shows the heat recovery/humidification psychrometric chart split into three cold weather climate zones for ambient wet-bulb (WB) conditions below 55°F (13°C). The control sequence for the VAV-AHU when ambient WB is 45°F (7°C) to 55°F (13°C) would be to allow the AC/H to generate a range of saturated delivery DP conditions from 45°F (7°C) to 55°F (13°C). The refrigeration is off in Climate Zones 1 to 3. In Climate Zone 3, all outdoor air would be furnished to the AC/H through Damper B with Dampers A and D closed. The heat wheel would be off, and the supply-side parasitic loss would be shunted out of the system. The AC/H cooling in Climate

Zone 3 has energy efficiency ratios (EERs) that approach 100.

Building ventilation rates would be far in excess of the ASHRAE Standard 62.1-2019 minimum outdoor air requirements of 15 cfm/person (7 L/s per person) at the higher VAV delivery temperatures. Room RH in the range of 40% to 60% would be maintained. *Table 1* shows for the northern cities that an average of 44.6% of annual hours land in Climate Zone 2. The heat wheel is able to transfer the heat required to maintain the 45°F (7°C) DP delivery off the AC/H unit with 100% outdoor air through the modulation of Dampers A and B to reach the 45°F (7°C) WB condition.

Only 9.2% of the average annual hours reside in Climate Zone 1, requiring additional heating by the hot water coil to meet the 45°F (7°C) DP condition for a target value of 40% RH in the building.

Clearly, western U.S. climates and arid climates at higher altitudes benefit the most from this VAV design strategy for hydration of outdoor air.

## Seattle Simple Payback Through Humidification Cost Avoidance

The factory-installed cost of a high-performance heat wheel and a 12 in. (305 mm) deep rigid media AC/H is estimated to be $68,000 ($1.70/supply cfm) for a 40,000 cfm (18 878 L/s) custom AHU costing $267,350. For Seattle, hours per year at each average dry bulb (ADB) and mean coincident wet-bulb (MCWB) conditions, were used to estimate humidification energy avoidance provided by the heat wheel in Climate Zones 1, 2 and 3.

Not included in this energy avoidance are the fan energy savings in Climate Zone 2 and 3 when the VAV delivery temperature to the building is below the conventional 55°F (13°C) DB setpoint. If the VAV terminal boxes in the building are set to satisfy the room cooling load at 55°F (13°C) delivery temperature, temperatures lower than 55°F (13°C) will result in reduced fan flow into and out of each core zone where the cooling load is fairly constant. A typical or average ambient condition for Climate Zones 2 and 3 in Seattle is the bin temperature of 47°F (8°C) ADB/45°F (7°C) MCWB. The VAV box delivery to the core zones would be approximately 45°F (7°C) DB at 45°F (7°C) DP. If the room target temperature is 75°F (24°C) DB, then the airflow to that zone would be reduced by 33.3% compared to a 55°F (13°C) supply air temperature delivery. Since there are 6,561 hours/year in Climate Zone 2 and 3, fan energy savings would be significant.

Using the same Seattle bin condition of 47°F (8°C) ADB/45°F (7°C) MCWB and assuming a 50% VAV flow of 20,000 cfm (9439 L/s) over the 2,747 hours/year in Climate Zone 3, given a central plant cooling energy consumption at 0.8 kW/ton (0.2 kW/kW) of cooling, we can estimate sensible cooling energy avoidance in Climate Zone 3 at 40,289.33 kWh/year. At the Seattle electrical energy cost of $0.108 per kWh, avoided cooling energy is estimated to be $4351.24 per year.

Assuming that the average VAV supply fan flow is 50% of full VAV flow for all ambient conditions in Climate Zones 1, 2 and 3, the boiler energy avoided through heat recovery is estimated at 71,263 therms when a boiler and piping loss factor of 0.8 is applied. The approximate value of the annual avoided energy at a Seattle energy cost of $1.127/therm would be $80,313.40. If the factory cost for heat recovery and adiabatic humidification components is increased by 25% to reflect the sales representative and mechanical contractor's markup, the simple payback for a delivered heat wheel and AC/H would be 1.06 years. Other west coast cities such as Vancouver, Portland and San Francisco will reflect similar paybacks for avoided humidification energy.

More difficult to assess in Climate Zone 3 is the value to a building owner of increasing the outdoor air ventilation rate above the minimum code requirement of 15 cfm/person (7 L/s/person) required by ASHRAE Standard 62.1-2019. Studies have attempted to assign a value to increased worker productivity and the reduction in short-term sick leave absence due to better outdoor air ventilation.[1]

As a check against the bin hour method tabulation shown in *Table 1*, Seattle TMY2 hour-by-hour typical year points may be overlaid on the psychrometric chart (*Figure 7*). There are zero hours in Climate Zone 1, 3,836 hours in Climate Zone 2 and 3,231 in Climate Zone 3 or a total of 80.7% of the annual Seattle hours. Hydration and sensible cooling of 100% outdoor air are produced at a very low energy cost for Climate Zones 2 and 3. Central refrigeration plants may be shut down for Climate Zones 2 and 3 climate conditions, the majority of which occur in the spring, winter and fall.

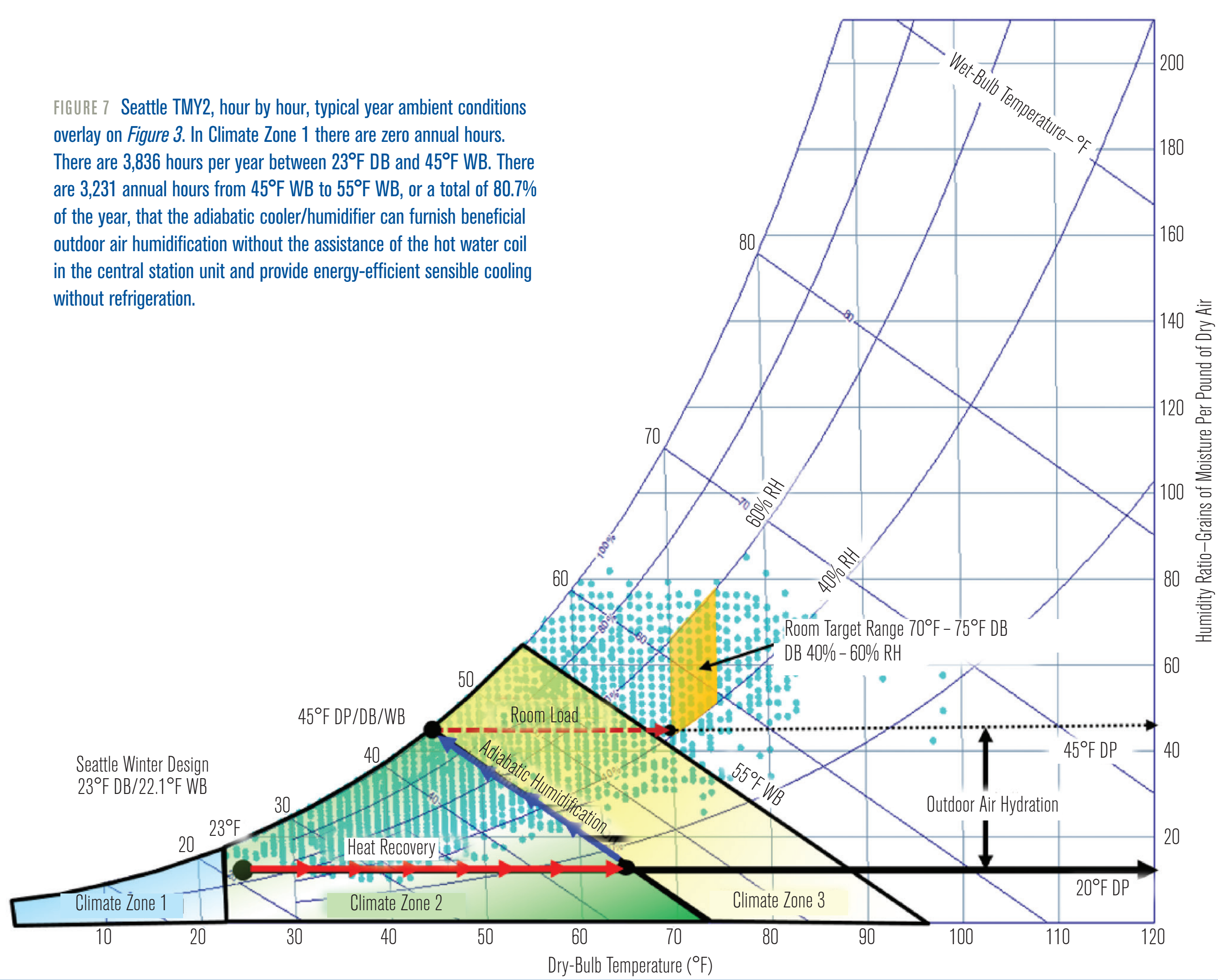



FIGURE 7 Seattle TMY2, hour by hour, typical year ambient conditions overlay on *Figure 3*. In Climate Zone 1 there are zero annual hours. There are 3,836 hours per year between 23°F DB and 45°F WB. There are 3,231 annual hours from 45°F WB to 55°F WB, or a total of 80.7% of the year, that the adiabatic cooler/humidifier can furnish beneficial outdoor air humidification without the assistance of the hot water coil in the central station unit and provide energy-efficient sensible cooling without refrigeration.

During the spring and fall outdoor air often contains large amounts of airborne pollens that can cause allergies in susceptible humans. Pollen ranges in size from 10 microns to 100 microns and should be removed from the outdoor air before it is supplied to the building.

When wet, the 12 in. (305 mm) deep rigid media pads in the AC/H have 90% or better removal efficiency of pollen spores larger than 10 microns in diameter. AC/Hs are often referred to as "wet scrubbers."

The use of air-to-air heat exchangers (sensible heat wheels) and rigid media AC/Hs are key to the success of this system including ease of control, environmental health, energy savings and low maintenance. Refrigerant 718, better known by its chemical formula $H_2O$, has zero global warming potential (GWP), is inexpensive, nonflammable, nontoxic and is a sustainable refrigerant. Water vapor released to the atmosphere returns to the earth as rain, sleet or snow.

## Conclusions

Through the 50 years that VAV systems have been used in the HVAC industry for commercial building air-conditioning systems, the use of airside economizers to save heating and cooling energy have often compromised the fresh air fraction being furnished to meet code or ASHRAE Standard 62.1 and have wasted energy.[26] Dry indoor conditions in winter have led to an increase in respiratory infections and the spread of airborne pathogens such as the influenza virus. IEQ and VAV had become two mutually exclusive acronyms.

This VAV design offers the hydration of all outdoor air in cold climates and offers resiliency in the face of climate change. In the future, more and more annual hours are expected to move from Zone 1 into Zones 2 and 3 shown in *Figure 3*. If the building being analyzed has less than a 24/7/365 duty cycle, daytime ambient conditions in cold climates will have more ambient hours in Zones 2 and 3.

There appears to be a direct correlation between low indoor RH and artificially high air change rates with the spread of airborne pathogens in winter. If we can cost effectively maintain a 40% to 60% indoor RH in winter while simultaneously reducing supply and return/exhaust VAV fan energy costs, why not do it? Quoting another *ASHRAE Journal* author from a recent column, "…but for most building types, we have yet to find any that perform better on a life-cycle cost basis than a 'well designed' VAV system."[27]

## COVID-19 Pandemic and ASHRAE Best Practices for Mitigation

After the substantial completion of this article and prior to its publication, an ASHRAE Epidemic Task Force was formed that is chaired by William P. Bahnfleth, Ph.D., P.E., Presidential Member/Fellow ASHRAE. At that time, the SARS-CoV-2 virus had shown itself to be an airborne pathogen easily spread indoors by an infectious aerosol. The Epidemic Task Force recommends the following steps to mitigate the spread of COVID-19 indoors.

- Air-handling systems that permit building air recirculation should increase outdoor air ventilation above code minimums, and consider installing MERV 13 filters if they are not in place.
- Control indoor relative humidity between 40% to 60% RH.
- Flush the building prior to occupancy with all outdoor air to remove any residual infectious aerosols indoors.

The authors would like to point out that all three of these remedial actions are addressed in this article. The section entitled "Morning Building Prehumidification and Warm-Up Control Strategy" would need to be accomplished with all outdoor air in lieu of recirculated air.

## Acknowledgments

The authors would like to thank United Metal Products of Tempe, Ariz., for their assistance in providing custom air-handling unit costs for the direct evaporative

cooling/humidification and sensible heat wheel air-to-air heat recovery systems under consideration.

## References


1. Seppänen, O., W.J. Fisk, O.H. Lee. 2006. "Ventilation and performance in office work." *Indoor Air* 16(1):28–36.

2. Sterling, E.M., A. Arundel, T.D. Sterling. 1985. "Criteria for human exposure to humidity in occupied buildings." *ASHRAE Transactions* 91(1):611–621.

3. Pantelic, J., K.W. Tham. 2013. "Adequacy of air change rate as the sole indicator of an air distribution system's effectiveness to mitigate infectious disease transmission caused by a cough release in the room with overhead mixing ventilation: a case study." *HVAC&R Research* 19(8):947–961.

4. Klepeis, N.E., C.W. Nelson, W.R. Ott, J.P. Robinson, et al. 2001. "The National Human Activity Pattern Survey (NHAPS): A resource for assessing exposure to environmental pollutants." *Journal of Exposure Analysis and Environmental Epidemiology* 11(3):231–252.

5. Taylor, S., M. Tasi. 2018. "Low indoor-air humidity in an assisted living facility is correlated with increased patient illness and cognitive decline." *Proceedings ISIAQ* 744:1–8.

6. Gilbert, J.A., M.J. Blaser, J.G. Caporaso, J.K. Jansson, et al. 2018. "Current understanding of the human microbiome." *Nature Medicine Review* 24(4):392–400.

7. Gilbert, J.A., B. Stephens. 2018. "Microbiology of the built environment." *Nature Reviews, Microbiology* 16(8):661–670.

8. Kudo, E., E. Song, L.J. Yockey, T. Rakib, et al. 2019. "Low ambient humidity impairs barrier function and innate resistance against influenza infection." *Proceedings of the National Academy of Science* 116(22): 10905–10910.

9. Reiman, J.M., B. Das, G.M.Sindberg, M.D Urban, et al. 2018. "Humidity as a non-pharmaceutical intervention for influenza A." *PLoS ONE* 13(9).

10. Lowen, A.C., J. Steel. 2014. "Roles of humidity and temperature in shaping influenza seasonality." *Journal of Virology* 88(14):7692–7695.

11. Taylor, A.S., C. Machado-Moreira. 2013. "Regional variations in transepidermal water loss, eccrine sweat gland density, sweat secretion rates and electrolyte composition in resting and exercising humans." *Extreme Physiology & Medicine*. 2. 4. https://doi.org/10.1186/2046-7648-2-4.

12. Pross, N. 2017. "Effects of dehydration on brain functioning: a life-span perspective." *Annals of Nutrition and Metabolism* 70(suppl 1):30–36.

13. Junker, J., et al. 2013. "Clinical impact upon wound healing and inflammation in moist, wet, and dry environments." *Advances in Wound Care* 2(7): 348–356.

14. Galson, S.K. 2008. "Prevention of deep vein thrombosis and pulmonary embolism." *Public Health Reports* 123(4):420–421.

15. Sunwoo, Y., C. Chou, J. Takeshita, M. Murakami, et al. 2006. "Physiological and subjective responses to low relative humidity in young and elderly men." *Journal of Physiological Anthropology* 25(3):229–238.

16. Zhu, G., Z. Janjetovic, A. Slominski. 2014. "On the role of environmental

humidity on cortisol production by epidermal keratinocytes." *Experimental Dermatology* 23(1):15 – 17.

17. Zimmerman, E. 2017. "Influence of temperature, relative humidity and carbon dioxide levels on student well-being and performance." *Maturaarbeit Schlussbericht G4f Betreuung* (personal commuication).

18. Block, S. 1953. "Humidity requirements for mold growth." *Appl Microbiol* 1(6):287 – 293. ncbi.nlm.nih.gov*/pmc/articles/PMC* 1056928.

19. Scofield, C.M., J.R. Taylor. 1986, "Building ventilation: a heat pipe economy cycle." *ASHRAE Journal* (10).

20. Paliaga, G., et al. 2019. "Eliminating overcooling discomfort while saving energy." *ASHRAE Journal* 61(4):64.

21. Arens, E., et al. 2018. "Sunlight and indoor thermal comfort." *ASHRAE Journal* (7):12 – 21.

22. Harriman, L. 2009. "*Humidity Control and Design*." Atlanta: ASHRAE.

23. Lstiburek, J. 2017. "Magic and mystery of the water molecule: it's all relative." *ASHRAE Journal* 59(9):68 – 74.

24. ASHRAE Guideline 12-2020, *Minimizing the Risk of Legionellosis Associated with Building Water Systems.*

25. *2016 ASHRAE Handbook-HVAC Systems & Equipment,* Chap. 41, "Evaporative Air-Cooling Equipment."

26. Koenigshofer, D. J. Roberts. 2018. "Do OA economizers make 'cents' in hospitals." *ASHRAE Journal* (11):12 – 21.

27. Taylor, S. 2018, "Making VAV great again." *ASHRAE Journal* 60(8):64 – 71.

## Bibliography

Adams, R.I., A.C. Bateman, H.M. Bik, J.F. Meadow. 2015. "Microbiota of the indoor environment: a meta-analysis." *Microbiome* 3:49.

Cox, C.S. 1998. "The Microbiology of Air." In: L. Collier, A. Balows, M. Sussman (Eds.) *Topley & Wilson's Microbiology and Microbial Infections. 9th Edition*. London; Arnold, Oxford University Press, pp. 339 – 350.

Kembal, S.W., E. Jones, J. Kline, D. Northcutt, et al. 2012. "Architectural design influences the diversity and structure of the built environment microbiome." *International Society for Microbial Ecology Journal* 6:1469 – 1479.

Kramer A., I. Schwebke, G. Kampf. 2006. "How long do nosocomial pathogens persist on inanimate surfaces? A systematic review." *BMC Infectious Diseases* 6(1):130.

Lowen, A.C., S. Mubareka, J. Steel, P. Palese. 2007. "Influenza virus transmission is dependent on relative humidity and temperature." *PLoS Pathogens* 3(10):e151.

Noti, J.D., F.M. Blachere, C.M. McMillen, W.G. Lindsley, et al. 2013. "High humidity leads to loss of infectious influenza virus from simulated coughs." *PLoS One* 8(2):e57485.

Popkin, B.D, K.E. Anci, I.H. Rosenberg. 2010. "Water, hydration and health." *Nutrition Reviews* 68(8):439 – 458.

Robine, E., D. Derangere, D. Robin. 2000. "Survival of a *Pseudomonas fluorescens* and *Enterococcus faecalis* aerosol on inert surfaces." *International Journal of Food Microbiology* 55(1 – 3):229 – 34.

Taylor, S. 2014. "Infectious microorganisms do not care about your existing policies." *Engineered Systems* (11):42.

Tang J.W. 2009. "The effect of environmental parameters on the survival of airborne infectious agents." *Journal of the Royal Society Interface* 6(Suppl 6):S737 – S746. ■

https://bit.ly/3k9ecVE
**Rate this Column**