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Engineers Newsletter

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Condensation in Air-Handling Systems

In HVAC systems, undesired moisture on surfaces can cause damage to building materials or mechanical equipment.

This *Engineers Newsletter* will focus on how to properly design and operate an air-handling system to minimize undesired condensation within HVAC systems, and how to properly identify causes and return the system to normal operation.

Understanding the different sources of undesirable moisture in HVAC systems can help prevent or solve moisture-related problems.

Moisture carryover from dehumidifying coils, *condensation* on cold surfaces and *fogging* often have different sources and prevention strategies. Because they are often mistaken for each other, it's important to clearly define them.

- **Moisture carryover** is defined as water droplets from a dehumidifying coil that are not captured in the drain pan.
- **Condensation** is caused when the temperature of a surface is below the dew point of the air contacting the surface. Moisture condensing on a cold surface often results in the accumulation of water droplets.
- **Fog** is visible water vapor in air that can form when moist air mixes with air at a colder temperature.

Common sources of moisture in an air-handling system include:

- outdoor air that enters through intake hoods, dampers, or louvers
- leaks from hydronic or steam coils, or their associated piping and valves
- moisture carryover, fogging, or condensation related to dehumidifying coils
- humidifiers, evaporative air coolers or air washers
- condensation that is a byproduct of gas-fired burners
- infiltration of moist air from outside, or leakage of liquid water from outside
- condensate drain pans
- saturated or supersaturated air from building processes

The specific location within the system where leaks, drips, or external water occur can often be a clue to mitigation and can often be traced to their source with some careful investigation.

This EN will focus on condensation and fogging with guidance for prevention and problem resolution.

Condensation: Where, Why and How

Condensation requires a cold surface and air at a dew point above the temperature of that surface. Most often a dehumidifying coil is involved, but there are other contributing factors including:

- infiltration
- bypass
- coil control
- uneven air temperatures
- fogging

Condensation due to infiltration. Air pressure inside an air- handling unit (AHU) cabinet can be both positive and negative with respect to the surrounding environment, depending on the location of the fans (supply, return, or relief/exhaust). When the pressure inside the AHU is negative with respect to the exterior there is an opportunity for air to infiltrate into the AHU.

Infiltration can lead to interior condensation if the dew point of the air leaking in is higher than the temperature of the air inside the AHU. For example, when an AHU is installed outside on the roof, the ambient dew point could easily be above 60°F during the humid summer months, while the cooling coil might be producing air temperature around 55°F. The more humid the ambient air, and the colder the supply air, the greater the potential for condensation to occur due to infiltration.

Where it happens. Any penetration or joint in the air- handling system, whether created in the factory or in the field, is a potential path for air leakage. Common culprits include:

- factory and/or field provided accessories and penetrations
- coil piping penetrations (supply and return connections, drain and vent connections)
- humidifier supply and drain connections
- contractor-assembled joints when the AHU is shipped in separate pieces
- drain pan condensate trapping
- penetrations for electrical and control wiring
- access doors or panels
- exterior joints or associated duct connections

Figure 1. Typical air handler layout.

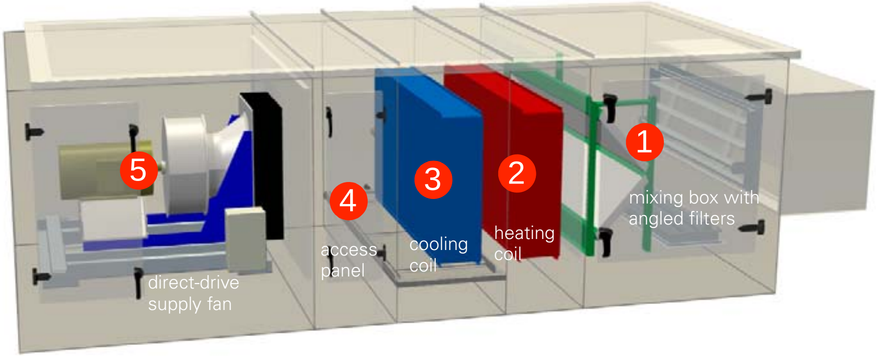


Figure 1 shows a typical layout for an air handler. The air pressure in sections 1 thru 4 would be at a negative pressure relative to the ambient due to the location of the supply fan in section 5. Infiltration that happens prior to the cooling coil (section 3) would not necessarily cause any condensation issues, but infiltration into sections 3 or 4 could result in condensation.

Figure 2 shows an operating AHU system where the supply- and return-water piping connections were sealed, but the coil drain and vent holes were not. The AHU fan configuration results in this section being under negative pressure with respect to the exterior, resulting in a direct path for infiltration directly downstream of the cooling coil.

Guidance. Identifying possible paths of infiltration and preventing it can be challenging. The following recommendations could help minimize infiltration during design, installation, and operation of the equipment.

- Specify air-handling equipment with a low leakage rate.
- Minimize and properly seal all penetrations.
- Use factory-installed controls to eliminate variability during field installation and avoid additional cabinet penetrations due to electrical or control wiring.
- Ensure access doors are closing and sealing correctly.
- Check that drain pan traps are properly sized and primed. This issue is often overlooked as a potential infiltration path.
- Use thermal imaging during unit operation to identify leakage paths.

Figure 2. Unsealed coil drain and vent holes.

Condensation due to bypass air (dehumidifying coils). Untreated, humid air that is allowed to bypass around (or through) a dehumidifying coil and mix with cold air leaving the coil may result in condensation downstream of the coil.

Properly mounting and sealing a dehumidifying coil in an AHU typically requires block-off (blank-off) plates that must be properly fitted to prevent air from bypassing around the coil. Also, air must pass through the coil without any large inactive sections or gaps that may allow varying leaving air conditions.

Where it happens. Common locations for air bypass are:

- seams where the block-offs mount to the coil or walls of the AHU,
- gaps between the coil casing and fins,
- under or above the coil where the mounting and retaining structures are installed,
- inactive portions of the coil (either by design or due to coil capacity control),
- internal wiring chases (control or power) where wiring passes through the coil section.

Guidance. Factory mounting of dehumidifying coils typically results in closer attention to block-off design, installation and sealing. Use gaskets and sealants as needed to minimize or eliminate air gaps.

Coil design also plays a role in air bypass. Minimizing gaps and bypass paths is an important design criteria. Using multiple rows with dehumidifying coils tends to minimize risks of downstream condensation compared to one- or two-row coils, since the leaving-air conditions tend to vary less.

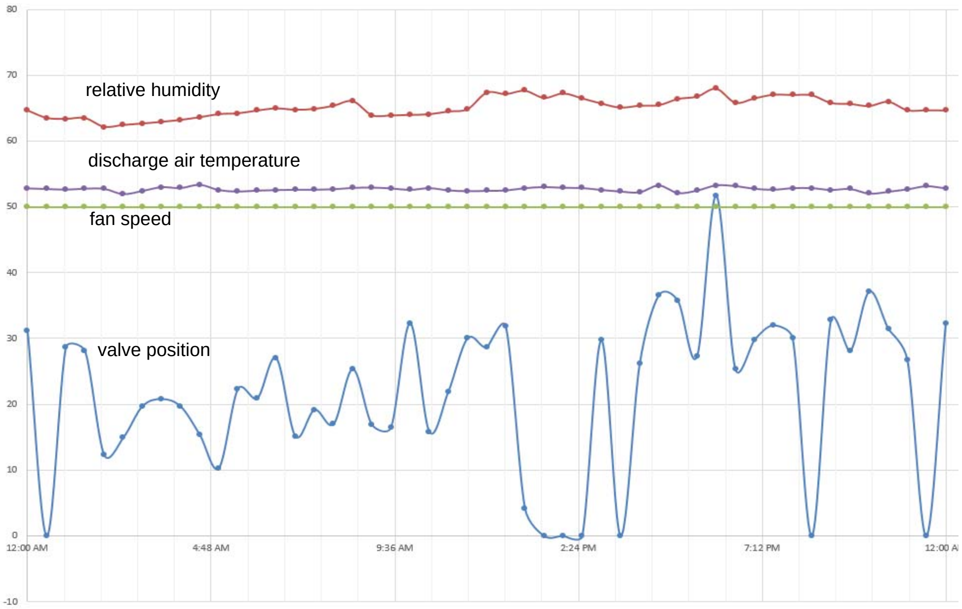
Condensation due to coil control. Control sequences are not often reviewed when looking for causes of condensation. But close analysis of control valve operation shows how this might be an issue. When a system is at steady state with typical leaving-air conditions, the interior surface temperature of the AHU downstream of the cooling coil will be close to the leaving-air temperature. If the control valve is rapidly closed, while airflow remains relatively constant, this could result in condensation.

For several minutes after the control valve is rapidly closed, the air continues to be cooled (and humidified) as the residual condensate on the fins of the dehumidifying coil evaporates into the passing air. This cool, humid air then passes over the cold interior AHU surfaces, possibly resulting in condensation. Condensation is more likely if this valve cycling happens often, and the dew point of the air entering the coil is well above the leaving-air dry-bulb temperature.

Guidance. If cycling control of the valve is necessary, the valve should be closed gradually rather than abruptly. If possible, stopping airflow in conjunction with closing the water flow would also help minimize potential issues.

Acquiring trend data from control devices over an extended period of time can help diagnose this potential cause. Figure 3 shows trend data for discharge air temperature, entering air temperature and humidity, entering and leaving water temperature, and valve position in an AHU. In this particular system the discharge air temperature setpoint is 52°F and the fan speed is held constant, while the control valve modulates. In certain intervals, the control valve is closed while the fan speed is maintained which could result in condensation on the cold interior panels downstream of the coil.The data must be taken rapidly enough, such as every minute. Figure 3 shows a 30-minute interval. Trend data taken slower than this could mask the cause.

Figure 3. Coil trend data.



Condensation due to uneven air temperatures. Stratified air occurs when air streams inside a duct or AHU are at different temperatures, having not been properly mixed. If the dew point of one of these airstreams is higher than the dry-bulb temperature of the adjacent airstream, condensation on downstream surfaces may result.

There are a variety of causes for stratified air including component design, operation, position and control of the equipment.

Where it happens. Stratified air downstream of a dehumidifying coil might be due to stratified air entering the coil, an imbalanced air velocity profile through the coil, or inactive or underperforming portions of the coil. The design and circuiting should be considered as it could contribute to varying leaving air conditions, as can airflow or water flow restrictions.

A non-uniform air-velocity profile can be caused by fan location relative to the coil. Fans located downstream of coils (draw-thru) are less likely to result in condensation or fogging versus fans located upstream of coils (blow-thru). A draw-thru fan tends to create a more uniform air-velocity profile across a coil compared to a blow-thru fan. This is especially noticeable with housed centrifugal fans with a high discharge velocity. And, the motor on a draw-thru fan will add a couple degrees of heat into the airstream, which is often adequate to avoid any condensation.

The proximity of the fan to the dehumidifying coil can also impact the air-velocity profile. As the distance between the fan and coil decreases, the velocity profile becomes less uniform.

In addition, applications with high indoor humidity levels (such as laundry rooms, shower rooms, industrial processes, swimming pools, etc.) can experience fogging and condensation when cold air from outside is mixed with this humid recirculated air.

Guidance. Consideration should be given to the equipment and component orientation to avoid stratification issues, if possible. Flexibility of the equipment design may or may not allow for this. Adding air blenders and/or baffles to properly mix airstreams can be a trial and error process, but can minimize stratification once in the field.

Fogging. Fogging can be the cause of moisture on surfaces. Fog, as it relates to HVAC systems, is visible water vapor (mist) in the airstream. As moist air mixes with colder air, miniscule droplets can condense on particulate material suspended in the cold air, forming visible fog.

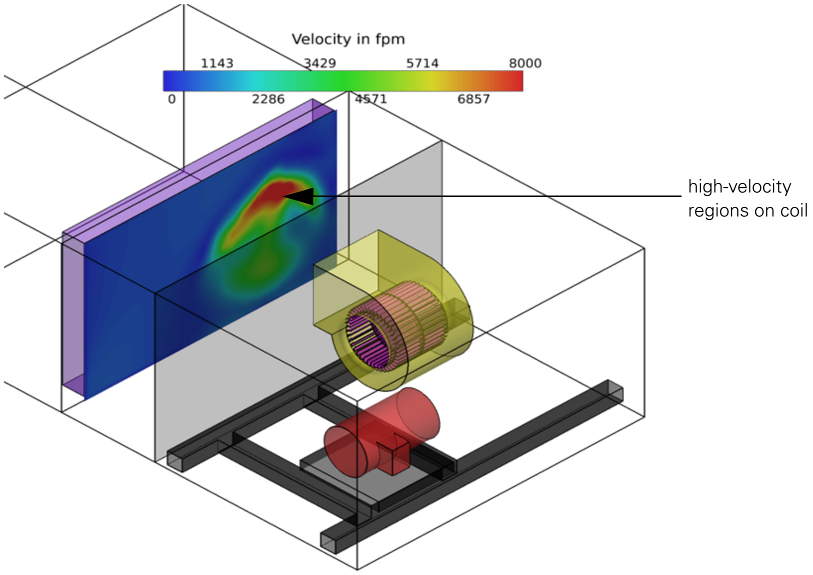
Under certain conditions, this fog can be so substantial that it can reduce visibility and be carried several feet downstream of the dehumidifying coil. This may or may not be a problem depending on the configuration, construction, and intended use of the system.

Because fog is a fine mist entrained in the airstream, it can be challenging to capture and contain. The moisture can wet surfaces and components inside the AHU, or ducts and insulation immediately downstream. Electrical components could also be at risk.

Another potential drawback of fogging is that it may result in higher indoor humidity levels. A dehumidifying coil cools the air to condense water vapor, allowing for capture and removal of the condensate by the drain pan. Instead of being captured, fog may travel into the space, resulting in a higher humidity level than desired.

In most situations, dehumidifying coils are involved in the production of fog. Laboratory and field service experience has shown several common triggers and related conditions that may cause fog to form.

Figure 4. High-velocity regions observed on the coil facing the blower exit.



Poor fin surface wettability. Surface tension between the coil fin surface and the resulting condensate from dehumidification influences whether the moisture will be properly removed from the airstream and captured in the drain pan, or if it will result in moisture carryover or fogging.

Hydrophilic fin surfaces have an affinity for water and result in the film of condensate being properly directed down the fin surface and into the drain pan.

Hydrophobic fin surfaces repel water and are more likely to result in moisture carryover (depending on many other factors). Fogging could occur if the resulting condensate forms small mist droplets instead of large droplets.

The properties of the selected fin surface material or coatings, as well as deposited contaminants, can increase the likelihood of a hydrophobic (repelling) condition. Field experience has shown that many industrial and process facilities release gaseous chemical compounds into the air that can attach to the coil fin surfaces when air is recirculated from the space. These compounds can be related to plastics, polymers, paper, wax, oils, process lubricants, release agents, adhesives, hydrocarbons, and others.

Their presence in the airstream could be continuous or even from a single event that has since passed. High resolution microscopic inspection might be required to identify the presence of these substances.

Once deposited, removal of these contaminants may or may not be possible or practical. Replacing the coil will likely alleviate the problem if the original source of contamination has been removed. Air cleaning and filtration to remove the airborne contaminants, or rearranging ductwork to acquire air from a non-contaminated space, are other potential solutions.

Entering air is too close to saturation. Laboratory test experience has shown that as entering air approaches saturation (100 percent relative humidity), it is easier to produce fog from dehumidifying coils.

Stratified leaving air and non-uniform air-velocity profile. Fog is more easily produced when the air-velocity profile is non-uniform. This can happen when the fan is too close to the dehumidifying coil (see Figure 4).

Inactive coil sections. Coils with partially active fin surfaces are more likely to produce fog than coils with 100 percent active fin surfaces. Potential culprits include part-load operation of intertwined or horizontally (face) split coils, coils with a large number of unused/inactive circuits, or inconsistent fin-to-tube bond that could compromise how uniformly the coil transfers heat.

Guidance. Solutions to prevent condensation also apply to fogging: specifically related to infiltration, bypass, and uneven air temperatures. If coil fin surface contaminiation is expected, remove particles, gases, and vapors from the airstream to avoid the deposition of contaminants.

Fog seems to be more common in a blow-thru fan arrangement than in a draw-thru arrangement. The motor heat from a draw-thru fan is usually enough to raise the dry-bulb temperature a few degrees, and remove the fog by creating separation between the dry-bulb temperature and dew point. And as mentioned earlier draw-thru units typically have a more uniform velocity profile across face of the coil, thus they are less prone to disturb the condensing moisture.

Traditional mist eliminators often cannot successfully capture fog because it is too fine and simply flows through them.

Closing Thoughts

The causes of condensation in air-handling systems can be complex. There are many opportunities during the design, installation, and operation of a system to contribute to uncontrolled moisture. There is no single source or solution and each situation must be evaluated to determine the root cause. Understanding the source can often lead to an effective solution.

By Brian Hafendorfer, systems engineer, Trane. You can find this and previous issues of the Engineers Newsletter at trane.com/engineersnewsletter. To comment, e-mail us at ENL@trane.com.

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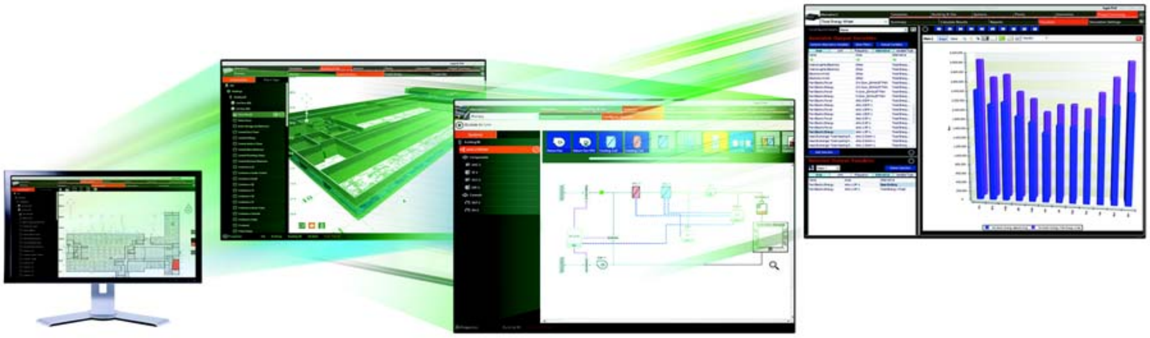

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Chilled-Water System Decisions. Many chilled-water system decisions are made during the course of the design process and, based on the specific application, lead to other system decisions - such as bypass line sizing and length, pump location, use of pressure independent valves, buffer tank size, etc. This ENL covers the reasons for many system decisions and provides practical guidance that can help simplify future chilled-water system design.

Controls Communication Technologies. Recent innovations in the industry have made open, standard communication protocols that deliver flexible, interoperable control systems more prevalent today. This ENL will review various communication protocols (using both wired and wireless technologies), discuss where each best applies, and describe ways to ensure the expectations of the owner are met.

Demand-Controlled Ventilation. The mobility of a building's occupants poses a ventilation challenge: To bring enough outdoor air into the building to help ensure good indoor air quality without wasting energy by bringing in (and conditioning) too much. This ENL will discuss various methods used to vary outdoor airflow based on actual demand. It also review the related requirements.

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