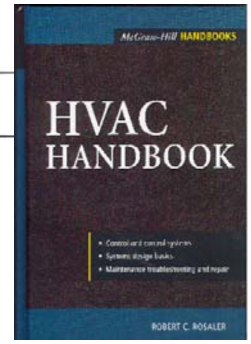


18.8 CONDENSATE CONTROL

Warren C. Trent, M.S., P.E.
CEO, Trent Technologies, Inc., Tyler, Texas

C. Curtis Trent, Ph.D.
President Emeritus, Trent Technologies, Inc., Tyler, Texas

Hudy C. Hewitt, Jr., Ph.D.
Chairman, Department of Mechanical Engineering, University of New Orleans, New Orleans, Louisiana

18.8.1 INTRODUCTION

One of the primary functions of an air-conditioning system is to remove water from the air it circulates. Proper collection and disposal of this water is essential to maintaining a dry, clean, and uncontaminated HVAC system.

Water is both the most useful and most destructive of compounds. In the right places it is invaluable. In the wrong places it can cause disaster.

In a HVAC system the *right* places—that is, the only acceptable places—for water (condensate) are:

1. Surfaces of the cooling coil,
2. A "small and well drained" condensate drain pan, and
3. A free-flowing (nonstagnant) condensate drain line.

The *wrong* places for condensate in a HVAC system are on

1. Internal insulation;
2. Surfaces of walls, top, and floor of air handlers;
3. Large condensate drain pans that cover the floor of air handlers;
4. Surfaces of the fan motor, fan, fan casing, and blades;
5. Internal duct walls;
6. Air supply grilles; and
7. Surrounding structures that support the air handler.

In these places, water is not only destructive to the HVAC system, surrounding property, and building contents, it creates a growth haven for algae, fungi (mold, mildew, etc.), and various forms of bacteria, including *Legionella pneumophilia*.

The consequences of these conditions are excessive and unnecessary costs for building owners-users in terms of service calls, maintenance effort, equipment damage, surrounding property damage, and the threat to human health.

All these costly consequences are avoided by systems designed to confine the spread of condensate and eliminate internal system wetness attributable to the following:

1. Condensate carryover and drips
2. Condensate drain pan
3. Humidity and temperature in the air supply system

4. Position of fan (blower) in the air handler
5. Seal on condensate drain line
6. Condensate drain line sizes and slope

Far too many existing systems in this country exhibit deficiencies in one or more of the above categories. The deficiencies inevitably increase building operating costs and contribute to "sick building syndrome" and "building related illnesses."

How to prevent these deficiencies in new system designs, remedy them in existing systems, and minimize system maintenance is the subject of this chapter.

18.8.2 SYSTEM DESIGN

A successful condensate drain system design must address each of the areas of potential deficiency enumerated above, including consideration of critical design factors, economic factors, and clarity of specifications.

18.8.3 CONDENSATE CARRYOVER AND DRIPS

Condensate carryover and condensate drips are common causes of wet, dirty, and contaminated HVAC systems.

Excessive air velocity through the cooling coil will blow condensate from the coil onto the plenum floor and/or onto other components of the system. Sloped cooling coils and noninsulated coolant (refrigerant or circulated fluid) lines often allow condensate to drip onto internal surfaces, damage equipment, and cause contamination inside the air handler.

18.8.3.1 Critical Design Factors

Condensate Carryover. The capacity of a particular cooling coil design to resist condensate blow-off (carryover) depends upon a number of factors, including the following:

1. Velocity of the air approaching the cooling coil
2. Diameter of tubes
3. Distance between tubes
4. Number of fins per inch
5. Thickness of fins
6. Amount of condensate present on surfaces of the cooling coil

The velocity of air approaching the cooling coil (coil-face air velocity) is too low to entrain condensate and cause carryover. However, as air passes through the coil, it is accelerated to higher velocities. Whether this velocity reaches a level sufficient to entrain condensate from the coil surfaces depends upon the reduction of flow area effected by tubes, fins, and the condensate held on the coil surfaces.

How these variables interact to affect condensate carryover is illustrated in Fig. 18.8.1, for a typical cooling coil design. For this particular coil type, coil-face velocities above those shown will result in condensate carryover. Other coil designs may exhibit somewhat

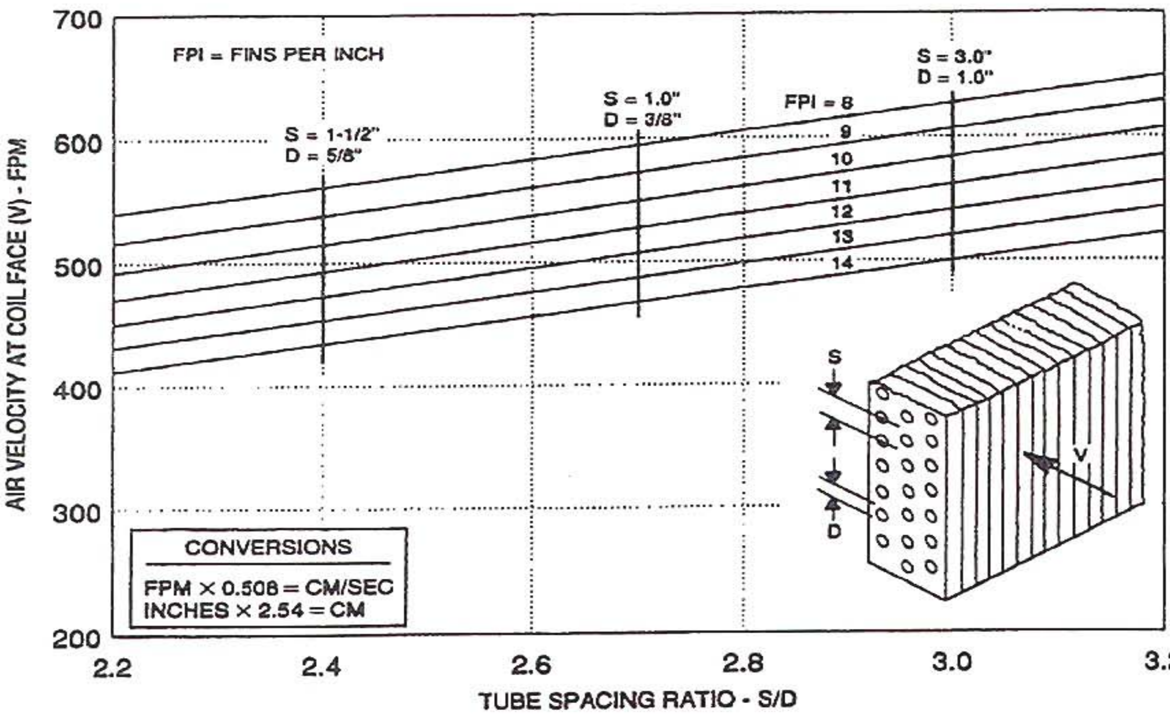


FIGURE 18.8.1 Coil face velocity above which condensate carryover occurs, typical cooling coil.

different characteristics, but the variables and their general relationships remain the same. For a specific coil design, applicable data—in various forms—are usually available from the coil manufacturer.

Cooling coil design arrangements that permit condensate to be carried down stream are unsuitable for HVAC applications. Large drain pans extended to protect the floor from condensate carryover are of little value. The floor still becomes wet, as do fan surfaces and other downstream components, creating serious cost and health problems for building owners-users, see Secs. 18.8.4 and 18.8.7.

Condensate carryover "eliminators," placed at the leaving (trailing) edge of the coil, are unsuitable as a preventive measure. They introduce appreciable air pressure losses that increase energy consumption. In addition, they not only create costly maintenance problems, but their wet surfaces promote the growth of health threatening fungi and bacteria.

Condensate Drips from Sloped Coils. Sloped cooling coils allow condensate to drip away from the coil surfaces. At low slope angles, surface tension may be adequate to retain the condensate and allow it to drain into the condensate pan. However, foreign deposits on the coil can easily destroy the effects of surface tension and cause dripping to occur.

While the air velocity entering the coil tends to reduce dripping, when the fan is operating, it is not a reliable force to prevent condensate dripping.

Extending the condensate drain pan to catch condensate drips introduces another equally serious condition—large drain pans—discussed in Sec. 18.8.4.

Under no circumstances should an air filter be placed beneath a sloped coil. A wet filter forms an ideal place for the growth of contaminating organisms.

Condensate drips from cooling coils and their detrimental effects are easily avoided, by utilizing only vertically oriented coils.

Condensate Drips from Coolant Lines. Noninsulated coolant lines that are exposed to conditioned air, inside the cooling air flow path, form condensate that will drip onto the floor and components—damaging equipment and contaminating the HVAC system.

Condensate drips from coolant lines and their detrimental effects are easily avoided by simply applying proper insulation to all exposed lines.

18.8.3.2 Economic Factors

Changes in cooling coil design for the purpose of reducing air velocity and the potential for condensate carryover will almost certainly add some cost to the HVAC unit. That is, reducing the air velocity at the coil face (to reduce condensate carryover) from 600 to 500 ft (150 m) per min can be expected to increase coil cost by about 15 percent. This, however, is a small cost compared to the potential savings.

For example, preventing condensate carryover removes any possible justification for extending the condensate pan more than a few inches downstream of the coil. Thus, the cost of fabricating and installing a large stainless steel condensate pan is eliminated.

Far more significant, however, are the savings that accrue as a result of preventing condensate from being blown onto the HVAC components and duct work, downstream of the cooling coil. Easily recognized by the building owner-user, these savings appear in the form of reduced maintenance, reduced property damage, reduced indoor air contamination, and longer equipment life.

The hardware costs for eliminating sloped coils depend upon the angle of slope involved. Costs for insulating coolant lines are minimal to insignificant. Regardless of initial costs, however, highly sloped coils and noninsulated coolant lines represent unacceptable design compromises.

18.8.3.3 Suggested Statements for Specification

1. The condensate cooling coil shall be designed to accommodate the maximum air flow of the HVAC unit, with a condensing rate of at least 0.013 lb (90 gr) of water per pound of dry air, without allowing condensate carryover.
2. All cooling coils shall be installed vertically, without slope.
3. All coolant lines in the air-handling unit must be insulated unless they pass directly over the condensate drain pan.

18.8.4 CONDENSATE DRAIN PAN

A properly designed drain pan is essential to the successful removal of condensate from a HVAC system. Pans that allow condensate to stand and stagnate form an ideal growth haven for the proliferation of biological and microbial agents—disease causing organisms. When condensate stagnation occurs, the HVAC system becomes a source of air contamination and poses a threat to human health.

The major considerations involved in designing a satisfactory drain pan include the following:

1. Condensate flow rate;
2. Drain ports—position, type, and size;
3. Condensate drainage provisions; and
4. Pan material.

18.8.4.1 Critical Design Factors

Condensate Flow Rate. The rate of condensate flow from a HVAC unit is determined by the total cooling capacity and how this capacity is divided between latent heat and sensible heat. Sensible heat ratio at which a HVAC system must operate may vary from near 0 to 100 percent of the total cooling capacity, depending upon a number of variables. These variables include the (a) amount of internally generated moisture—human, animal, and equipment; (b) amount of infiltration; (c) amount of outdoor ventilation air; and (d) the absolute humidity (humidity ratio) of the outdoor air.

Figure 18.8.2 shows how sensible (and latent) heat ratios affect the amount of condensate removed from cooling air. To determine the condensate flow rate for a given system, simply enter Fig. 18.8.2 with the operating sensible heat ratio at the nominal rate cooling capacity. For example, a system rated at 60 tons operating at a sensible heat ratio of 0.80 will remove about 0.30 gal (1.1 L) of condensate per min. The same system operating at a sensible heat ratio of 0.30 will remove about 1.05 gal (4 L) of condensate per min.

The shaded areas in Fig. 18.8.2 indicate typical operating ranges of sensible heat ratio for various levels of outdoor ventilation air.

Drain Ports. Drain port position, type, and size all affect how deep condensate stands in the drain pan. Each of these factors affects the potential for stagnation. Even slight variations can have an appreciable effect on the minimum level at which condensate stands in the pan.

Drain Port Position. Condensate drain ports may be positioned on a pan wall or in the bottom of the pan. For most effective drainage, ports must be flush with the bottom of the pan.

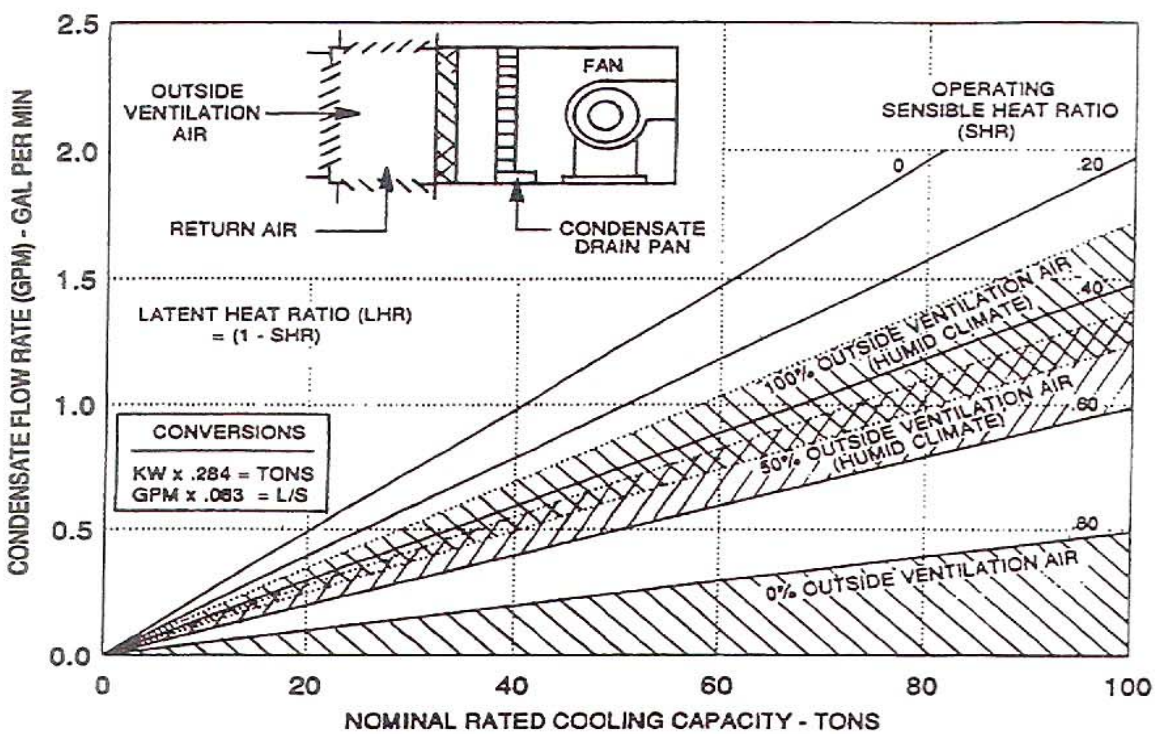


FIGURE 18.8.2 Condensate flow rate as a function of nominal ton rating and operating sensible heat ratio.

Drain Port Type. Male drain connections are more desirable than female connections. A female connection requires an internal drain connection fitting which reduces the flow area. This restriction blocks condensate flow and catches debris. In addition, in a pan wall drain port, this restriction raises the depth that condensate stands in the pan.

Drain Port Size. The drain port size depends upon the condensate flow rate, whether the port is in a side wall or in the bottom of the pan, and what condensate depth can be tolerated in the pan.

Condensate Drainage Provisions. In order for condensate to flow from a particular drain pan, under the force of gravity, it must rise to a predetermined depth. This level depends upon two forces: surface tension of the water and the water level (head) necessary to provide the required flow rate.

Recent test data (Ref. 1) indicate that about $^1/_8$ in (3.2 mm) of water is required to overcome surface tension and permit condensate flow. Thus, independent of the position, type, and size of the drain port, condensate—when present—will stand in the pan at some finite depth. The total depth, of course, increases in proportion to the condensate flow rate.

Figure 18.8.3 shows how condensate depth in a level pan varies with the condensate flow rate for different port sizes and positions. As shown, a bottom drain port provides better drainage than does a side wall port. Neither drain port arrangement, however, allows for complete drainage from a level pan. That is, condensate will remain in the pan, at some depth, as long as moisture is being removed from the circulated air. If allowed to "back-up" into the pan and stagnate, condensate—at any depth—promotes the growth of biological and microbial agents that contaminate the HVAC system.

Although a bottom drain port affords better drainage than does a wall drain port, either can be used successfully if properly integrated with the condensate pan design.

The importance of proper pan drainage and the avoidance of condensate stagnation has been recognized for years. For example, ASHRAE Standard 62–1999, paragraph 5.11 (Ref. 2) includes the following statement: "Air handling unit condensate pans shall be designed for self-drainage to preclude the buildup of microbial slime" (see Ref. 2). In this context, self-drainage is taken to mean that condensate shall flow from the pan in such a way that no stagnant water remains to support the growth of contaminating organisms (microbial slime).

One means of assisting self-drainage is to slope the condensate drain pan in the direction of the drain port. However, it is generally not practical to add enough slope to prevent condensate from covering a large area of the drain pan, during the cooling operation. *How sloping the pan in one direction by $^1/_4$-in per ft (20 cm/m)—in combination with other pertinent variables*—affects the amount of pan area covered with condensate is shown in Fig. 18.8.4. Doubling this slope, of course, reduces the condensate coverage by one-half, while reducing the slope by one-half, doubles the area covered by condensate.

Although a sloped pan enhances flow, a portion of the pan will remain covered with condensate, see Fig. 18.8.4. Under these circumstances the pan width—the distance the pan extends downstream of the cooling coil—is critical in preventing stagnation of condensate and precluding the growth of microbial slime.

Figure 18.8.5 illustrates the problems created by wide pans, often designed to catch condensate carryover from cooling coils. In such a pan, it is inevitable that a considerable amount of condensate will stagnate even if the pan is sloped, see Fig. 18.8.6. *The quantity of stagnant condensate in a wide pan can, of course, be reduced by sloping the pan in both directions. But stagnant condensate is only one of the problems posed by wide pans. The primary purpose of a large pan is to catch condensate droplets* blown off the cooling coil. Even if no condensate stands in the pan, condensate droplets, deposited on the floor of the pan, are held in place by surface tension and promote the growth of various unhealthy fungi and bacteria. *Condensate carryover must be eliminated.*

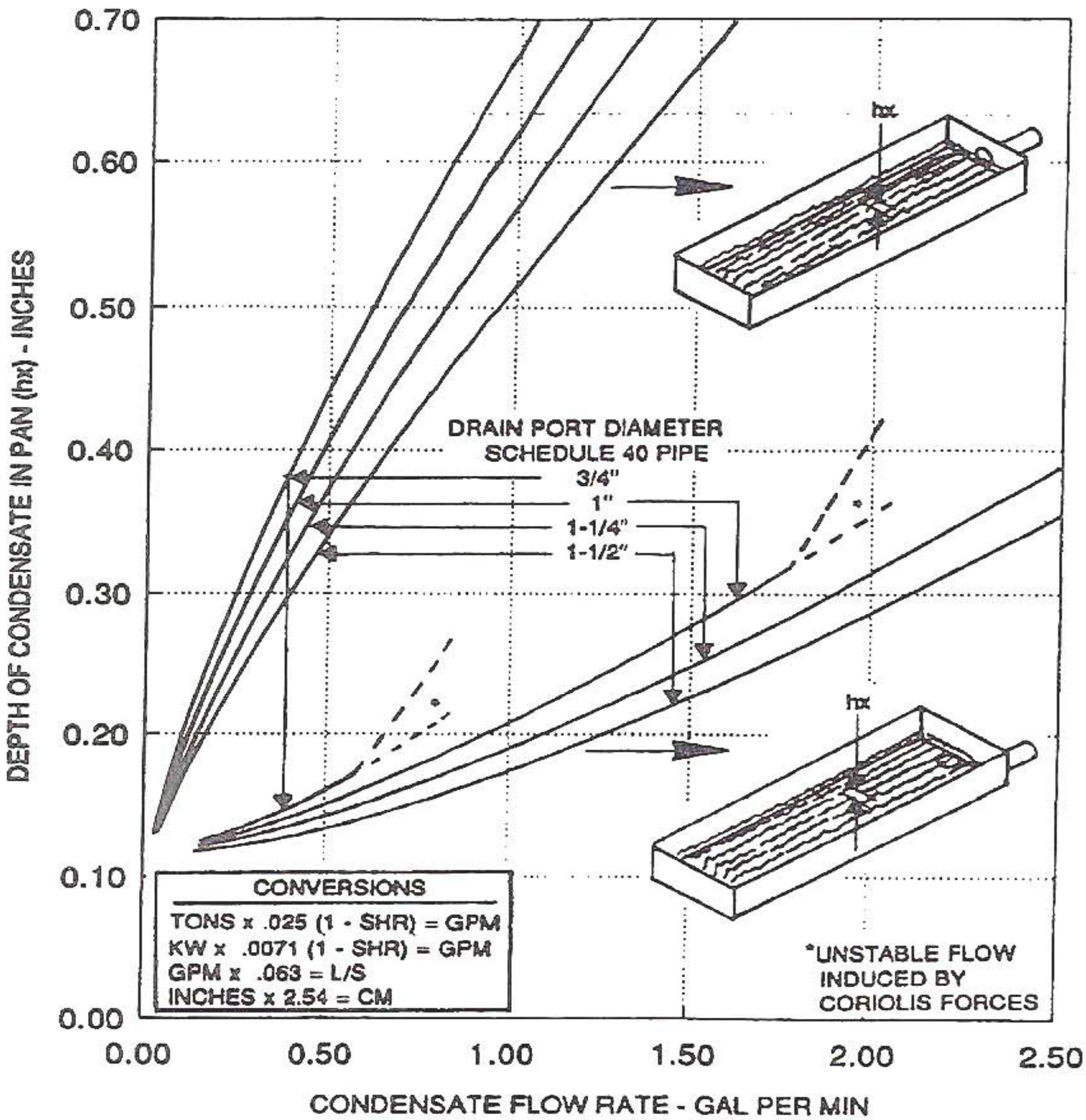


FIGURE 18.8.3 The effect of drain port size and position on condensate flow rate under the force of gravity.

In order to avoid condensate stagnation and droplet deposits, pan width must be limited to ensure that condensate leaving through the drain port will flow continually over the total surface of the floor of the pan.

Figure 18.8.7 suggests pan widths suitable for units with various condensate flow rates, and for port sizes commonly used for side wall drain ports. These same width and drain port size relationships may also be used, conservatively, for selecting pans with bottom floor drain ports.

Greater pan widths and smaller drain port sizes increase the potential for condensate stagnation and system contamination.

Pan Materials. The condensate drain pan may be constructed of either metallic or non-metallic materials, but it is important to avoid iron-based materials that are subject to rapid

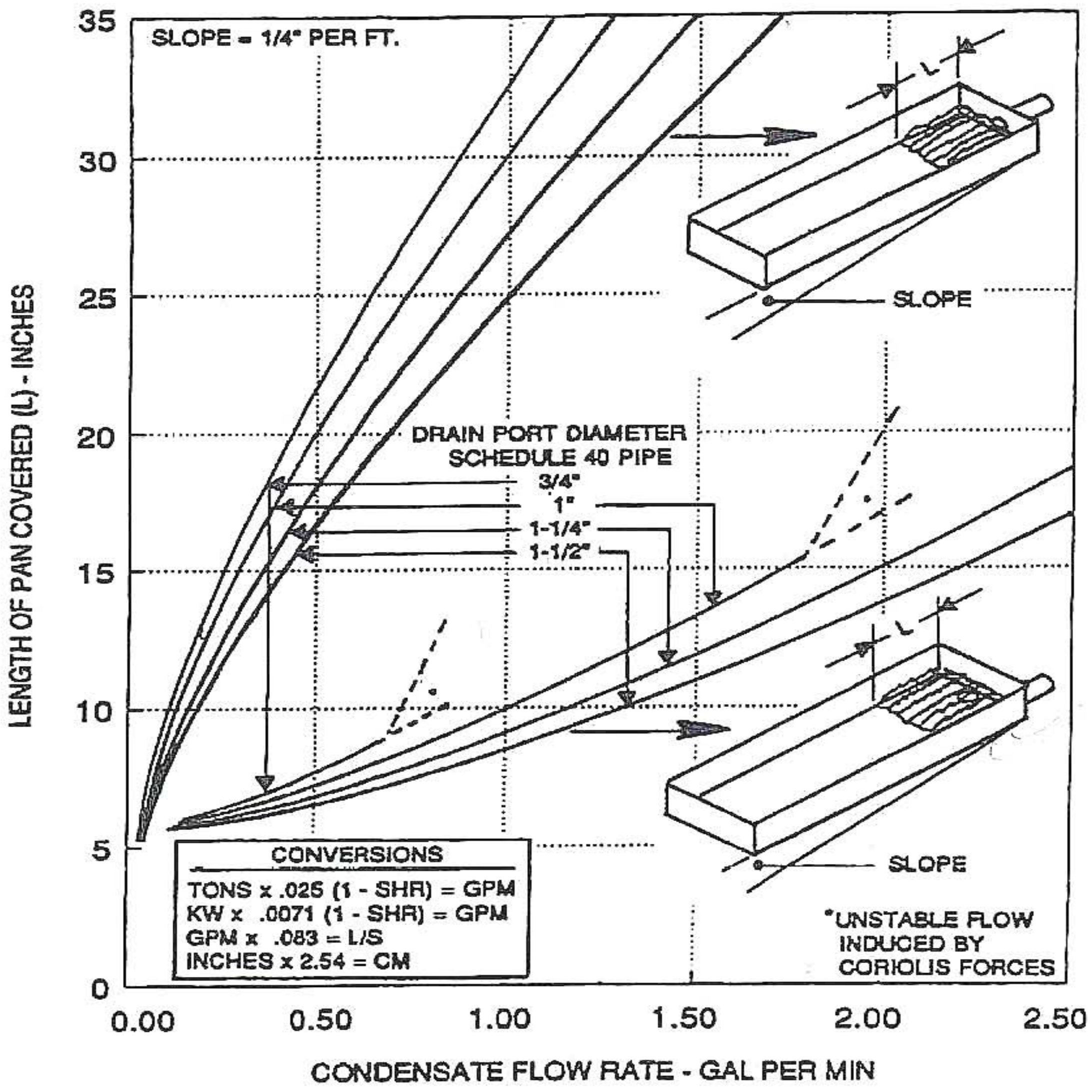


FIGURE 18.8.4 The effect of pan slope on the area covered by condensate.

oxidation in the presence of water and humid air. This is because iron is known to accelerate the growth of *Legionella pneumophilia*, the bacteria that causes Legionnaire's disease. Although *Legionella pneumophilia* has been found in the condensate pans of some HVAC units, no outbreak of Legionnaire's disease has been attributed, officially, to these conditions. Investigators often give two questionable reasons why the HVAC unit is not a threat to the generation and spread of this disease causing bacteria.

First, it is argued that the condensate temperature is too low for sufficient multiplication of the bacteria to occur. Generally speaking this may be the case. However, *Legionella pneumophilia* has been found in water temperatures ranging from 42.3° to 145°F (5.7° to 63°C). Condensate temperatures, typically around 55°F (13°C), are well within this range. Moreover, in the presence of certain iron concentration levels, the multiplication rate of this bacteria increases more than 200 times (Ref. 3, p. 4). In any case, this potential health threat dictates that if an iron-based material is to be used in construction of the condensate pan, it must be stainless steel.

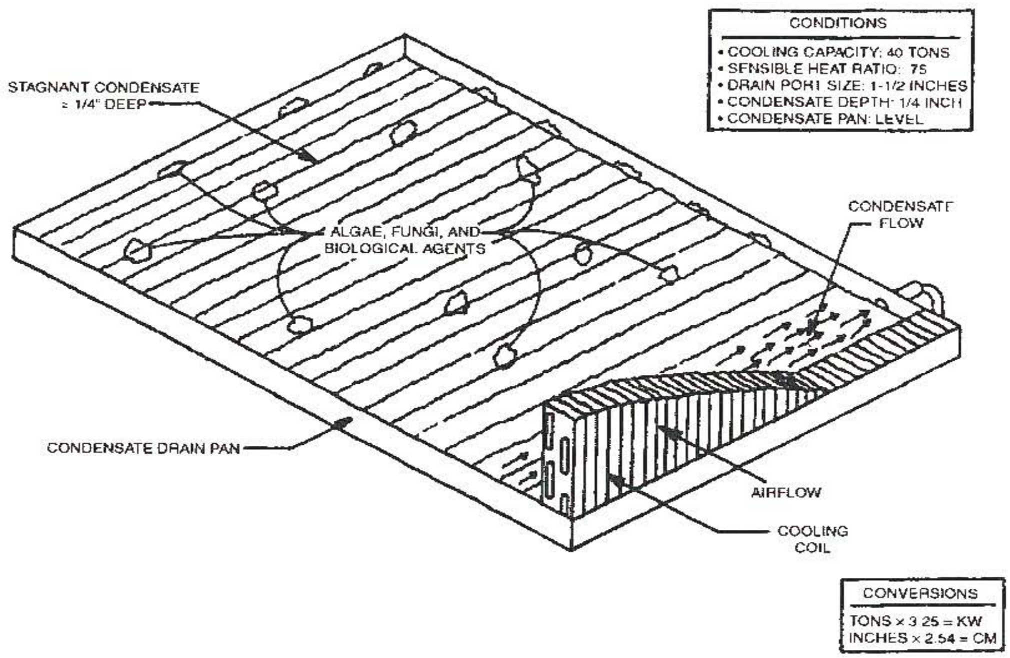


FIGURE 18.8.5 Contamination problems created by wide drain pans.

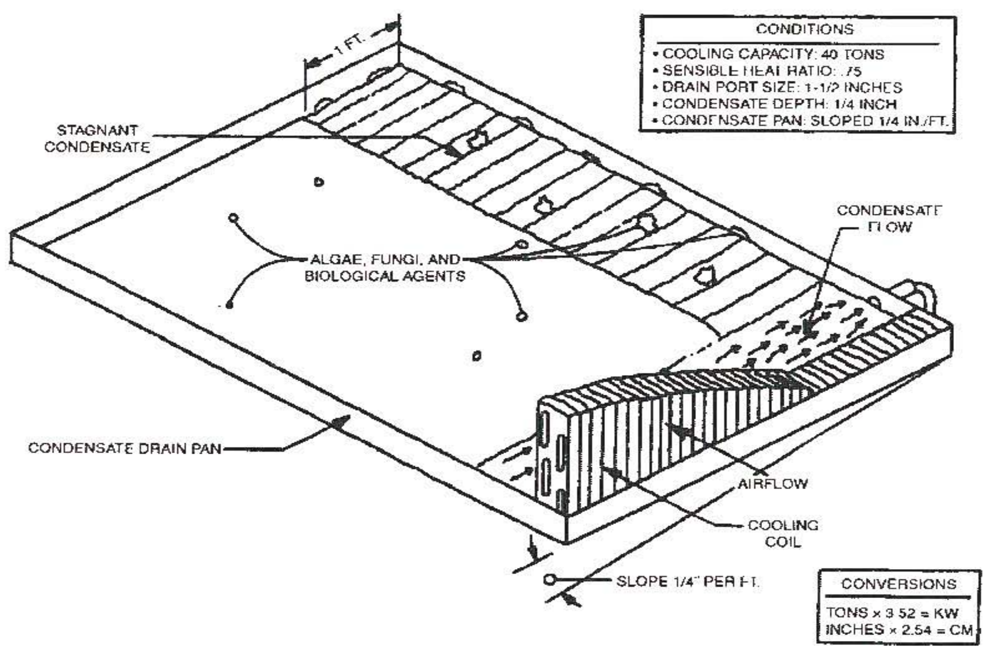


FIGURE 18.8.6 Effects of pan slope on condensate flow rate and contamination.

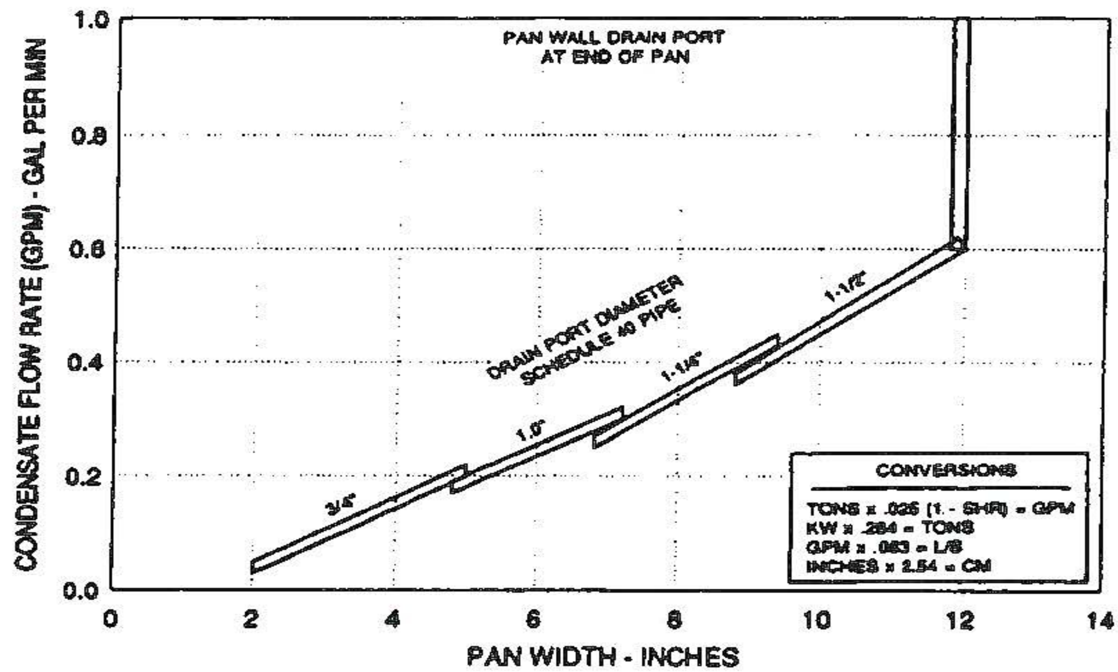


FIGURE 18.8.7 Pan widths suitable for units with various flow rates and for commonly used port sizes.

Second, it is contended that there is no mechanism for aerosolizing the bacteria, a condition essential for its dissemination. Contrary to this contention, as shown in Sec. 18.8.7 of this chapter, a very effective aerosolizing mechanism does exist and frequently operates inside the HVAC unit. This fact emphasizes the importance of utilizing a pan material that avoids high iron concentrations in the condensate.

18.8.4.2 Economic Factors

Incorporating the above design features in the condensate pan has little effect on the initial cost of the HVAC system. In fact, a smaller pan reduces material and fabrication costs.

An internally sloped drain pan necessitates a slightly higher enclosure for the pan and cooling coil; hence, some added cost will be incurred. However, in many systems, the desired pan slope may be achieved by tilting the HVAC unit toward the condensate drain port. This can usually be done without compromising the performance of the system and at little or no cost.

In any case, the added costs of a self-draining stainless steel condensate pan is dwarfed by subsequent savings in terms of reduced maintenance, equipment damage, and fewer human health problems.

18.8.4.3 Suggested Statements for Specifications

1. The condensate drain pan shall be constructed of 18 gauge* stainless steel. It shall have a depth of no more than 2 in* (5 cm), enclose the base of the cooling coil, and extend no more than 10 in* (25 cm) downstream.

---

*Typical values only.

2. A 1-in* (2.5 cm) stainless steel drain pipe, with a male pipe thread shall be connected to the end of the pan wall, flush with the bottom of the pan, and extended 2 in* (5 cm) from the wall.
3. The floor of the condensate pan shall be sloped $^1/_4$-in per ft (2 cm/m) toward the drain port. The slope may be effected by sloping the pan internally or by externally tilting the entire HVAC unit toward the drain port. External tilting, if employed, shall not affect the performance of the HVAC unit nor the manufacturer's warranty.

18.8.5 HUMIDITY AND TEMPERATURE IN AIR SUPPLY SYSTEM

High relative humidity and low temperature in the HVAC air supply system can result in serious degradation in indoor air quality, and considerable damage to exposed hardware components. Good design practices dictate that these factors be considered carefully in HVAC system design.

18.8.5.1 Critical Design Factors

The conventional HVAC unit provides air cooling and moisture removal by reducing the dry bulb temperature of the air it handles. Passing through the cooling coil, the temperature is reduced to a dewpoint equal to or below that of the indoor air. This process reduces the humidity ratio (moisture in the air) but the average relative humidity is increased typically to about 95 percent. Figure 18.8.8 illustrates the cooling process where the cooling load on

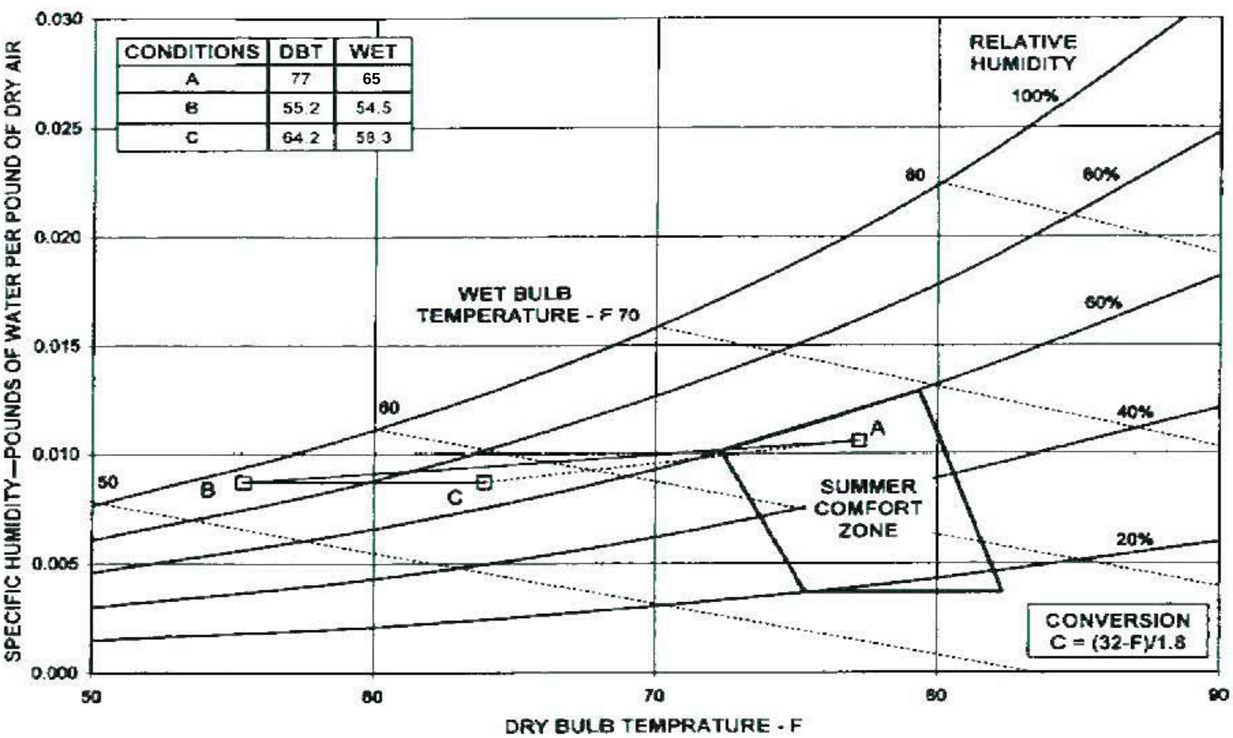


FIGURE 18.8.8 Psychrometric chart showing cooling and reheat process paths.

the system is 25 percent latent heat and 75 percent sensible heat: a sensible heat ratio (SHR) of 0.75. Point A represents the indoor conditions. Point B represents the condition of the air entering the supply system; where the relative humidity is 95 percent and the dry bulb temperature is 55.2°F (13°C). In a tightly sealed and well insulated air supply system, the relative humidity and dry bulb temperature of the air remain essentially constant as it passes through the supply system.

Humidity Conditions. High relative humidity conditions, as shown in Fig. 18.8.9 (Ref. 4), are conducive to and support the growth of contaminating organisms, including bacteria, viruses, fungi, etc. The relatively low air temperature may suppress rapid growth of organisms and air movement may prevent accumulation of contaminates. However, this condition can degrade indoor air quality, and it represents a potential health hazard which must be carefully considered in HVAC system design.

One simple, but often expensive, way to reduce relative humidity in the supply air is to provide reheat. As illustrated in Fig. 18.8.8, an increase of about 9°F (5°C) in the air supply temperature—path B to C—decreases the relative humidity to 70 percent. At this lower relative humidity the growth of bacteria, viruses, and fungi is greatly reduced, see Fig. 18.8.9.

Temperature Conditions. Inside the air supply system, low temperature air has no particular adverse effect on indoor air quality. Its effect occurs inside the conditioned space, at the air supply grille. Cold supply air often reduces the temperature of the grille below the dewpoint of the indoor air. When this happens, condensate can form on exposed surfaces of the grille. There, it promotes the growth of contaminating organisms, including mold, mildew, and other fungi. The discoloration frequently observed on supply grilles is often caused by these conditions and not always by dirty air filters, as is sometimes suggested.

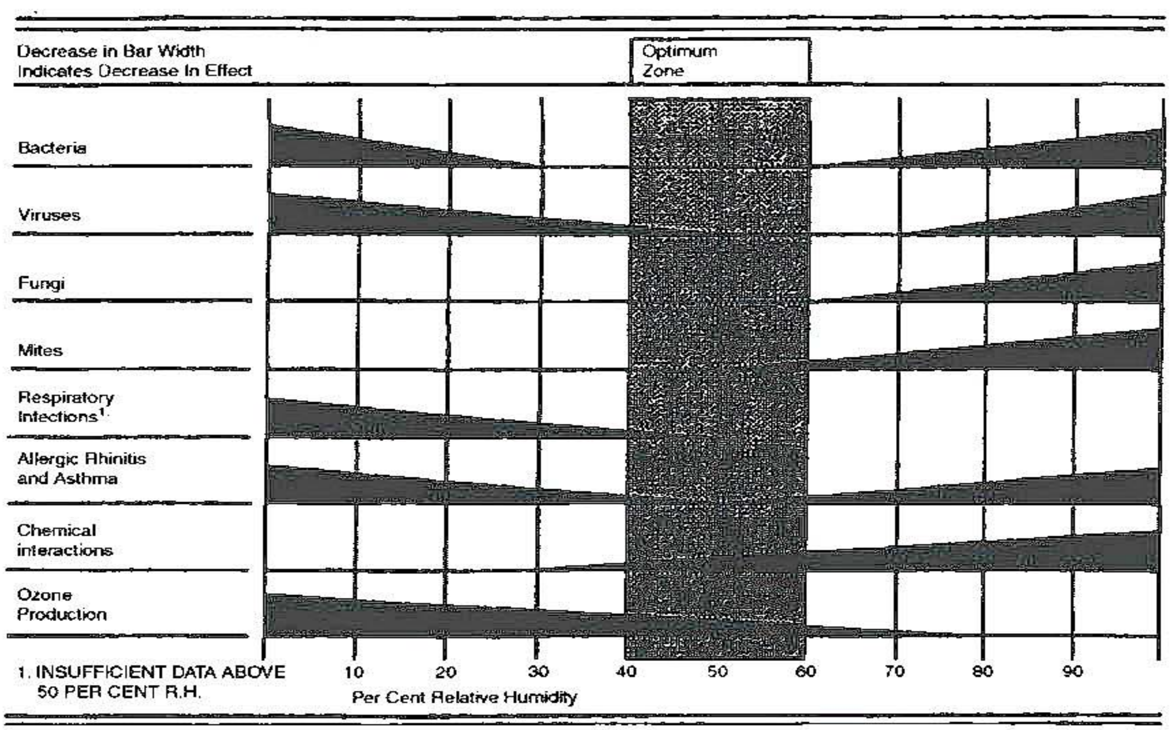


FIGURE 18.8.9 Optimum relative humidity ranges for health. (Reprinted by permission from ASHRAE Transactions, 1985, Vol. 91, Part 1B.)

To minimize this problem, consideration must be given to both supply air temperature and grille design.

The factors that affect air supply temperature are indicated in Fig. 18.8.10, for a typical design condition. Here, the supply air temperature is shown as a function of the SHR of the system, at various values of indoor wet bulb temperature and relative humidity. Also shown, for the various conditions, is how much the supply air temperature is below the dewpoint of the indoor air.

The difference between the indoor air and dewpoint temperatures, shown in Fig. 18.8.10, varies with indoor operating conditions. Lower indoor dry bulb temperatures reduce the differences. Higher indoor dry bulb temperatures and lower wet bulb temperatures increase the differences. For any specific design, these differences can be determined through the use of the psychrometric charts in Appendix A of this handbook.

Low temperature air does not *always* cause condensate to form on air supply grilles. At any particular temperature level, condensate formation depends upon specific features of the grille design. Some of the most significant features include the following:

1. Thermal conductivity of the grille material,
2. Jet velocity of the supply air, and
3. Amount of grille surface area exposed to the indoor air and not washed by the supply air.

Materials applicable to grille fabrication with the lowest and most desirable thermal conductivity characteristic are listed in order as follows: plastics, steel, aluminum, and copper.

High jet velocity causes air supply grilles to cool to a low temperature, which increases the potential for condensate formation. Flush mounted ceiling grilles that provide long

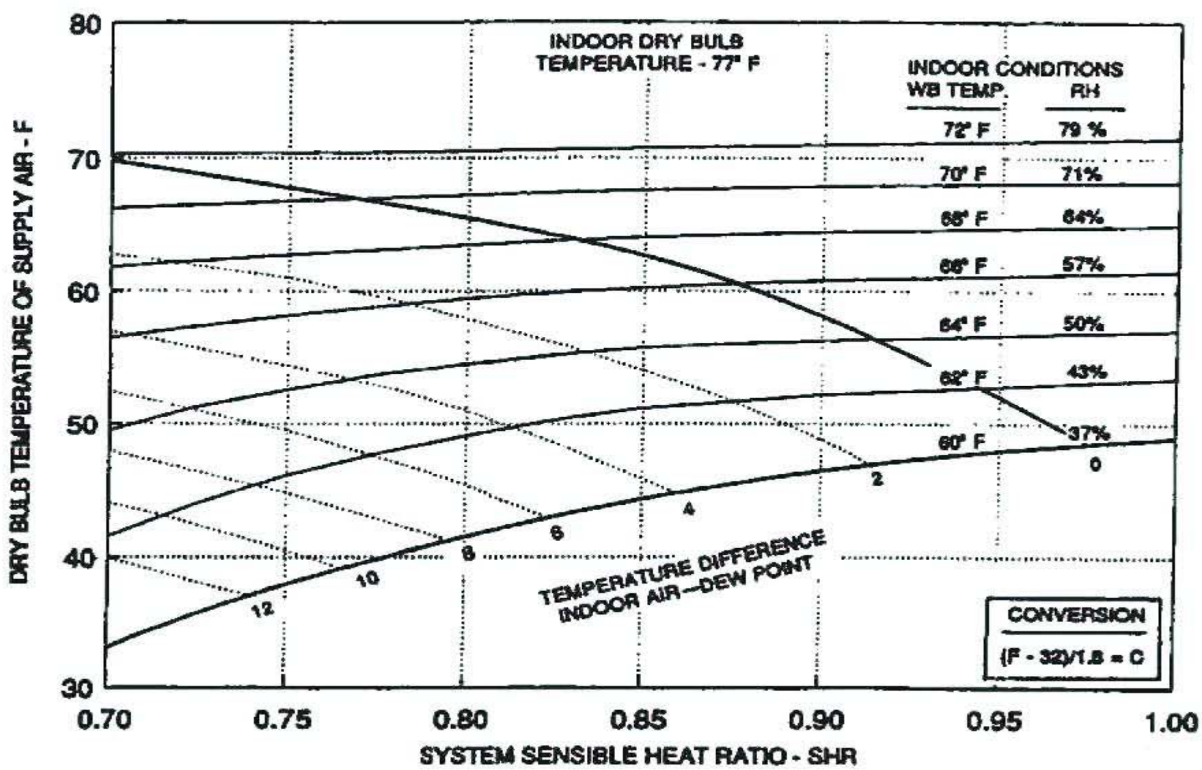


FIGURE 18.8.10 Effects of system sensible heat ratio and indoor wet bulb temperature on temperature of supply air.

throw distances usually operate with high jet velocities. Ceiling mounted concentric supply grilles, with short throw distances, often operate with low jet velocities.

Large grille surface areas exposed to indoor air increase the potential for the formation of condensate. Large unwashed surfaces usually accompany flush mounted ceiling grilles that discharge in one direction only. Ceiling mounted concentric grilles usually exhibit small areas of unwashed surfaces.

The condensate formation characteristics of the various types of air supply grilles are generally not available. However, grille manufacturers are cognizant of this problem. They realize that certain designs are superior to others, and they can aid designers in coping with the subtleties of this problem. In the meantime, designers should take advantage of the grille design fundamentals reviewed above when selecting supply air grilles from production units.

18.8.5.2 Economic Factors

The costs associated with high relative humidity and low temperature inside the air supply system can be appreciable.

The cost of degraded indoor air quality is difficult to establish. In most cases, it cannot be determined with any degree of accuracy. It is real, however, and could result in costly health care and other health related problems.

The cost of equipment damaged by high humidity and low temperature is much more tangible. The effects of high humidity will become evident in damage to air handling equipment and other downstream hardware. The cost of grille maintenance and damage caused by low air temperature will be both visible and definable.

Remedies to the air supply problem may not be expensive. There may be little or no hardware costs associated with selecting a supply grille of superior design.

Reheat, if provided with electricity or fossil fuel, involves appreciable initial costs plus significant and continuing operating costs. For this type of application, a heat pipe system may be attractive. The technology is mature. The initial costs are not exorbitant, about 30 percent of the cost of the basic air handler. There is no significant continuing operating cost, and maintenance costs are minimal.

18.8.5.3 Suggested Statement for Specifications

The HVAC system shall provide conditioned air to the air supply system at a relative humidity no greater than 70 percent and the dry bulb temperature shall be sufficiently high to prevent condensate formation on supply grille surfaces during all operating conditions.

18.8.6 POSITION OF FAN IN AIR HANDLER

The position of the fan in an air handler system can be a significant factor in condensate control. It directly affects internal airflow conditions and can seriously degrade air handler performance.

The flow condition of the air approaching the fan inlet is critical, as is the condition of the air leaving the fan exit.

Air flow conditions at the fan inlet are influenced by (a) the direction at which air enters the fan compartment, (b) hardware located in the airstream that can alter flow direction, and (c) how the approaching air interacts with the rotating fan blades. The airstream may be simply distorted, or it may contain highly harmful vortices. Vortices may be initiated by (a) fan blades and swirling flow at the inlet, (b) flow disturbances caused by obstructing hardware, or by (c) interactions between airstreams of different velocities. These conditions degrade fan efficiency. The interactions are complex, but in some cases their effects can be approximated using information from the Air Movement and Control Association (Ref. 5). The lower fan efficiency caused by these air flow conditions may be acceptable, in some cases. However, any combination of conditions that allows condensate to be entrained and spread into the HVAC system cannot be tolerated.

Air discharged from the fan leaves the exit at a high velocity with a greatly distorted velocity profile. In order to avoid excessive losses in fan system efficiency and achieve a reasonably uniform flow condition, a suitable extension to the exit duct must be provided. Failure to provide a suitable diffuser not only results in reduced efficiency, it can introduce unacceptable local air velocities that entrain condensate and spread it onto components inside the HVAC system.

18.8.6.1 Critical Design Factors

The factors that influence fan efficiency affect all types of air handlers in a similar way. Their effects on condensate problems, however, differ depending upon whether the air handler is a *draw-through* or a *blow-through* type unit. In the draw-through unit, only those conditions ahead of the fan inlet are important to condensate control. In the blow-through unit, the extreme air velocity profile at the fan exit is the primary cause of serious condensate problems.

Draw-Through Air Handler. In a draw-through air handler, air is drawn through the cooling coil into the compartment that houses the fan and its inlet. Condensate is precipitated by the coil and collected in a pan inside the fan compartment. Thus, air entering the fan compartment is exposed to condensate both in the coil and in the condensate pan. Generally, the average velocity of the air passing into and through this compartment is too low to entrain condensate. However, certain fan and surrounding hardware arrangements can distort flow conditions and create local air velocities sufficiently high to entrain condensate and propel it into the fan inlet.

Published data and analytical techniques available to designers are not adequate to ensure that a selected fan position and adjacent hardware arrangements will be free of condensate entrainment and associated problems. Thus, successful design requires a considerable appreciation of the flow conditions that cause distorted airflow, along with substantial judgment. In some designs, full scale or model testing may be necessary.

Some of the various airflow conditions that create distorted local flow velocities, including vortices, are illustrated in Fig. 18.8.11. Here, a centrifugal fan with the inlet facing the cooling coil is depicted. Changing the position of the fan by 90° presents a different airflow pattern, but the fundamental airflow considerations remain the same.

In this illustration, air enters the fan inlet at 2500 ft/min (762 m/min) and the effect extends upstream from the inlet. The lines of constant velocities shown were computed, based on still air surrounding the fan, assuming no upstream flow distortion (Ref. 6).

These values are somewhat lower than what will be experienced in practice, because the system airflow adds a velocity component. This component increases the peak velocity and distorts the profile, as indicated by the dashed line in Fig. 18.8.11, for velocities of 600 and 1000 ft/min (182 and 305 m/min). Although less than precise, these results provide useful information for the designer. For example, if the cooling coil is placed closer than about 0.80 diameters of the inlet, the coil may be exposed to an air velocity of 600 FPM (182 m/min), which will likely cause condensate entrainment and carryover. On the other hand, at an

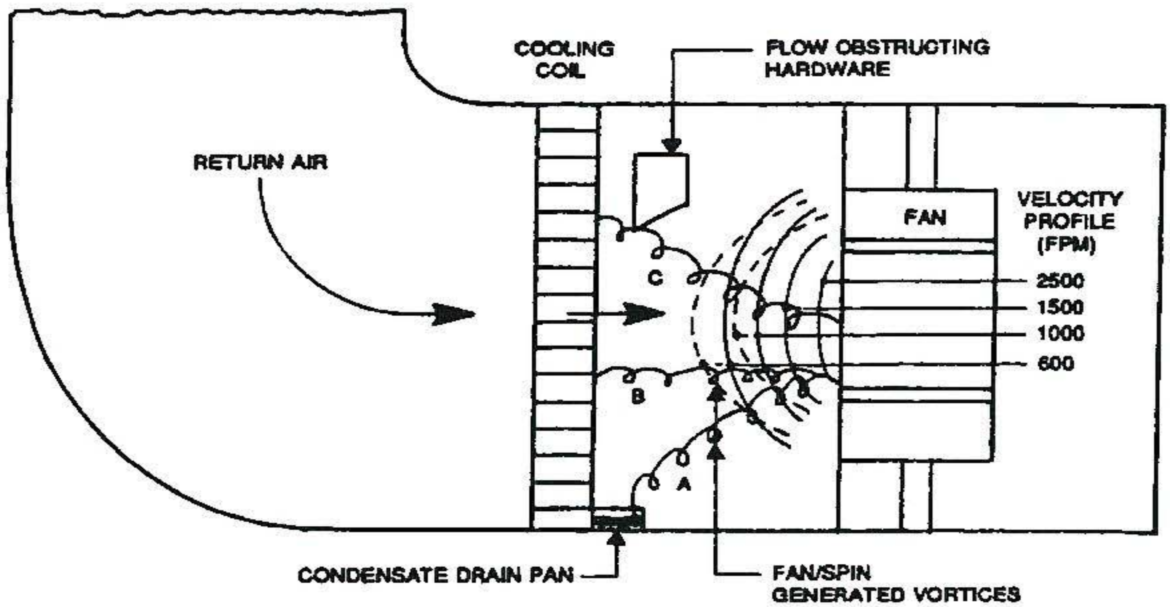


FIGURE 18.8.11 Air flow conditions that create distorted local flow velocities, including detrimental vortices—draw-through unit (Ref. 6).

distance greater than 1.5 diameters, condensate carryover (due to the fan alone) is unlikely to occur.

Vortices can create an even more serious problem. The spiral lines symbolize vortices and show how condensate can be entrained by the air and ingested into the fan inlet. Lines A and B indicate vortices generated by fan blades and externally induced spin or swirl (distortion). Line C indicates how a vortex may be created by obstructing hardware in the airstream. Eliminating airflow distortion, whether caused by obstructing hardware, unequal entering velocities, or other conditions can essentially negate the possibility of damaging vortices.

Blow-Through Air Handler. The highly distorted velocity profile of air discharged from the fan of a blow-through air handler imposes significant constraints on the position of the fan relative to the cooling coil. The distance between the fan and coil must be adequate to eliminate flow distortion and reduce the air velocity sufficiently to avoid condensate entrainment and carryover. As indicated in Fig. 18.8.12, for a centrifugal fan, the required distance from the coil may be 2 to 5 equivalent duct diameters.

Shorter diffuser duct lengths introduce both undesired duct losses and unfavorable velocity profiles, and cause condensate carryover. Baffles used to reduce flow distortion often introduce unacceptable pressure losses and low fan system efficiencies.

18.8.6.2 Economic Factors

A fan positioned in an air handler such that it entrains condensate and propels it into the HVAC system creates a costly situation for the building owner-user. The cost of service calls, maintenance, shortened equipment life, and property damage can be excessive. Health problems, resulting from contamination caused by condensate entrained and deposited on internal surfaces of the system, add to the owner-user costs.

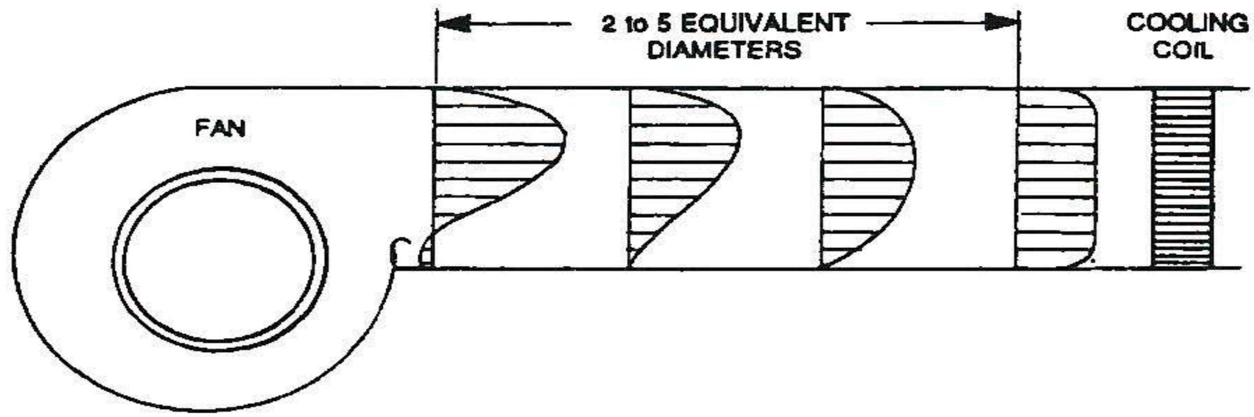


FIGURE 18.8.12 Velocity profiles at fan discharge and at cooling coil entry—blow-through unit.

The extra costs added to ensure that an air handler is free of fan induced condensate problems are due primarily to two factors: Loss in fan system efficiency and the designer's use of precautionary design features. Fan efficiency, for example, may be compromised by adding baffles to reduce flow distortion—particularly in the fan discharge airstream. This adds to operating costs. Also, flow distortion caused by complex interactions of the airstream with internal components cannot be precisely defined. Thus, the designer may add space and distance—walls, floor, ceiling—that may not be needed, in order to ensure that high velocity air and condensate entrainment are avoided. Whatever this cost, however, it is minimal compared to the cost incurred when condensate is entrained by the airstream and deposited on the internal components.

18.8.6.3 Suggested Statement for Specifications

The fan shall be positioned in the air handler so that local air velocities and induced vortices do not entrain condensate and propel it onto components in the HVAC system.

18.8.7 SEAL ON THE CONDENSATE DRAIN LINE (DRAW-THROUGH SYSTEMS)

An effective and reliable seal on the condensate drain line of a draw-through HVAC system is essential for successful condensate removal and for keeping the system dry inside.

In a properly designed HVAC system, all the condensate removed from the circulated air collects in a pan below the cooling coil. From there, it is drained to a selected condensate disposal place.

Achieving suitable drainage, however, can be very difficult, depending upon the type of HVAC unit involved. In this regard, there are two basic types of units: the "blow-through" and "draw-through." These designations stem from the relative positions of the air-circulating fan and the cooling coil.

In the blow-through type unit, the fan is located upstream and blows air through the cooling coil. As a result, the air pressure surrounding the condensate drain pan is positive (above ambient). The positive pressure alleviates somewhat the problems of condensate removal. Even with this advantage, however, the condensate trap is not a suitable device for controlling condensate removal. Many of the inherent problems with a condensate trap remain. Flow blockage and flooding are common, and dry traps at start-up often allow condensate to blow onto floor surfaces creating hazardous and health threatening conditions.

Condensate removal from draw-through units is much more critical. In this type unit, the fan draws air through the cooling coil, creating a negative (below ambient) pressure condition in the drain pan compartment. This condition produces two very adverse effects: (a) it impedes, or may even prevent, the drainage of condensate and (b) it effects ingestion of air and other gases from outside the unit. To avoid the health problems and property damage caused by these conditions, *a seal must be provided in the condensate drain line*, which permits condensate to flow freely and precludes ingestion of outside air or other gases.

Operating a draw-through HVAC unit without an effective seal on the condensate drain line causes serious problems (Refs. 8 and 9) including the following:

1. Negative pressure in the condensate drain pan area impedes the flow of condensate and frequently causes flooding and overflowing that damage the HVAC unit and surrounding property.
2. Inrushing air which in some cases may exceed hurricane velocities creates a geysering effect that propels condensate into the system and keeps it wet inside. The results are property damage and a growth haven for health threatening bacteria, mold, yeast, mildew, and other fungi.
3. The blowing of condensate can also create an aerosol mist—a known mechanism for spreading Legionella pneumophila: The disease that killed 34 Legionnaires at a Philadelphia hotel in 1976. A study of this incident, which strongly implicates the condensate drain system as the most likely source of the disease, is provided in Sec. 18.8.11.
4. Outside air, which may be polluted with carbon monoxide or other contaminates, can be drawn into the system and spread throughout the conditioned space.
5. Condensate flooding due to flow blockage by debris and algae growth.

The consequences of the above problems are illustrated in Fig. 18.8.13. These consequences are clearly unacceptable and dictate that an effective and reliable seal be included on every draw-through HVAC unit. Regarding this matter, ASHRAE Standard 62–2001, Ventilation for Acceptable Indoor Air Quality, paragraph Addendum 62t (Ref. 7), states: "*For configurations that result in negative static pressure at the drain pan relative to the drain outlet (such as a draw-through unit), the drain line shall include a P-trap or other sealing device designed to maintain a water seal while allowing complete drainage of the drain pan, whether the fan is on or off.*"

18.8.7.1 Critical Design Considerations

Within the industry, three different types of devices are being used to form condensate drain seals for draw-through HVAC systems: (a) condensate (water) traps, (b) condensate pumps, and (c) a fluidic flow control device—the latter a recent technological development.

Each of these devices exhibits unique physical and operating characteristics and provides a different level of effectiveness and reliability.

Condensate Trap

Description. The condensate trap is widely used as a seal in condensate drain lines. It is usually mounted outside the HVAC unit, as indicated in Fig. 18.8.14.

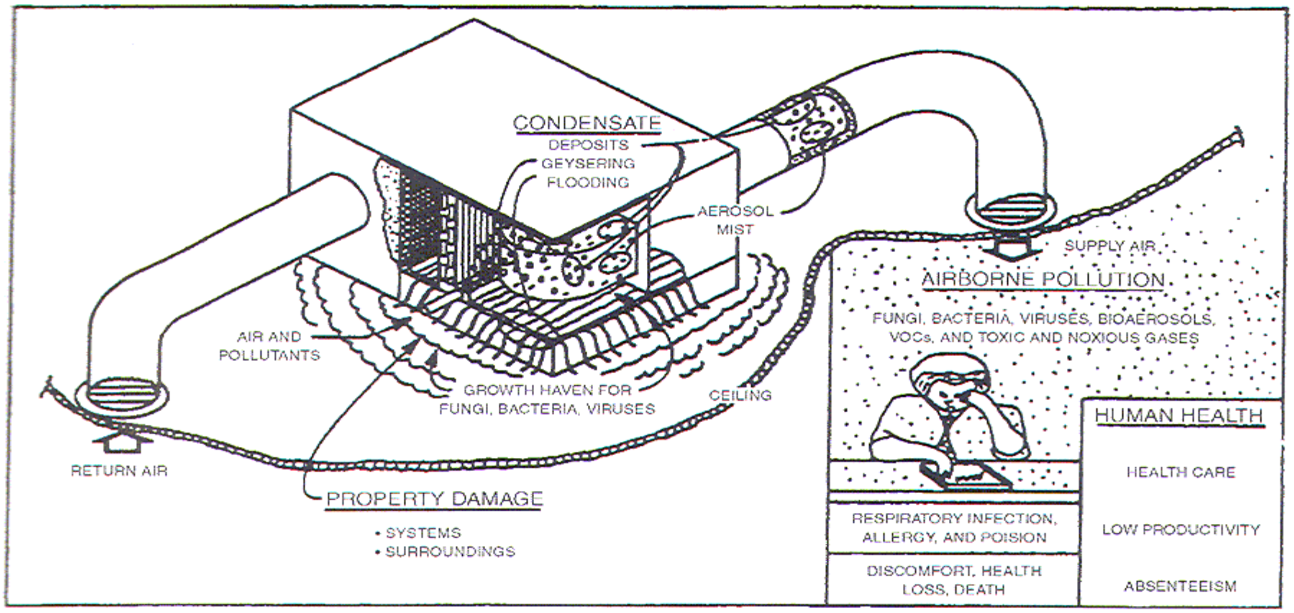


FIGURE 18.8.13 Consequences of no seal or a dysfunctional seal on the drain line of a draw-through HVAC unit.

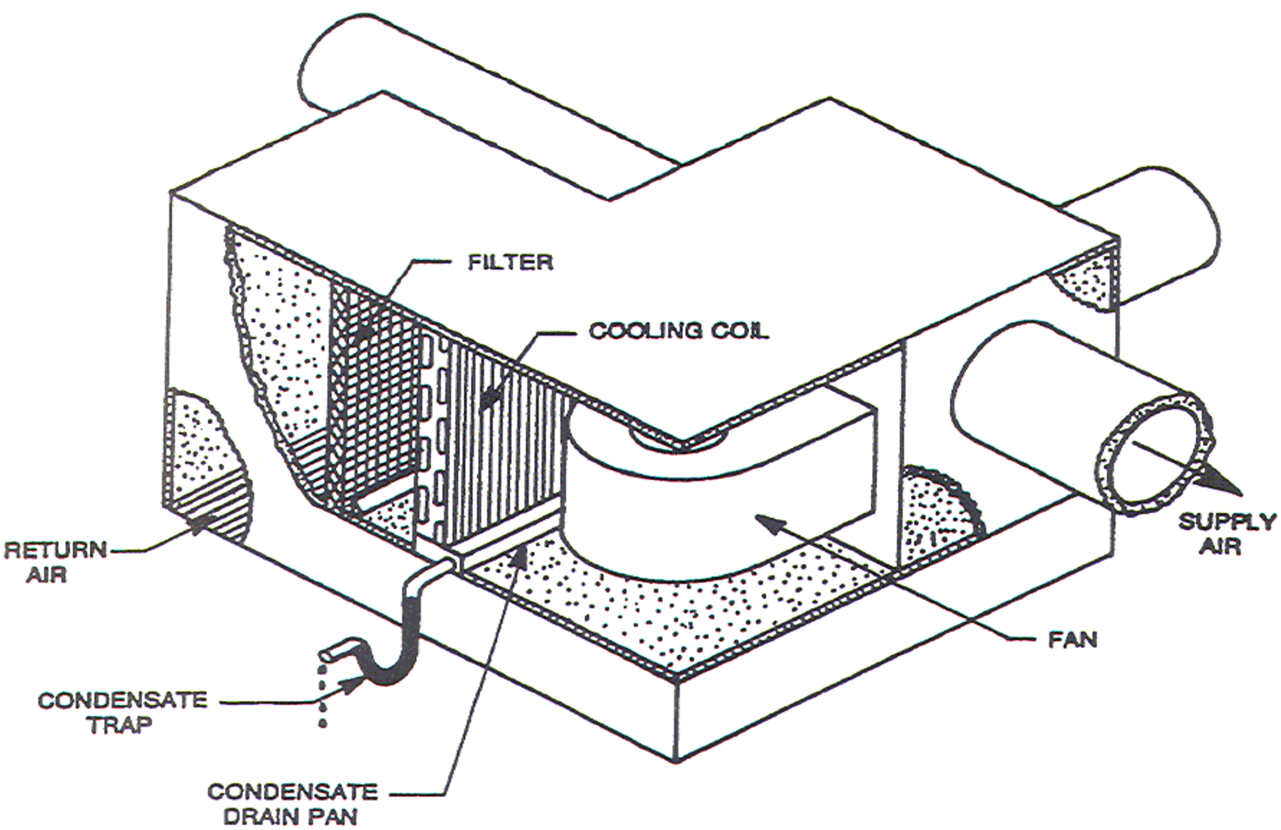
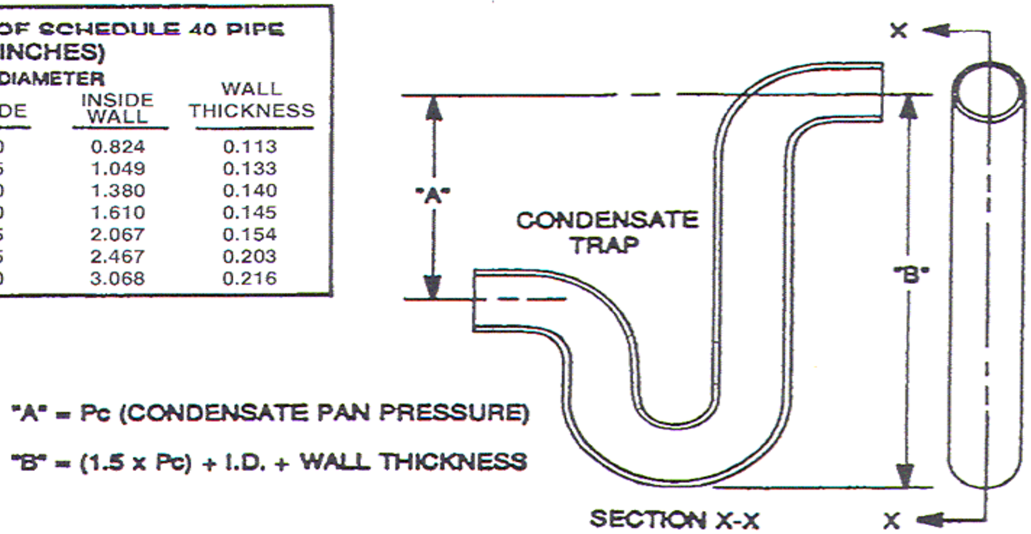


FIGURE 18.8.14 Conventional condensate trap in operation.

The seal is formed by gravitational forces acting on trapped water and a water column. The trap depth and water column depth necessary to form a seal depend upon the pressure inside the drain pan compartment. For any compartment pressure, the required trap depth and water column depth remain fixed. However, the total depth varies with the diameter and thickness of the trap wall. Figure 18.8.15 defines the required seal trap geometry for various drain pan pressures and trap diameters. Trap geometry established in accordance with Fig. 18.8.15 ensures a positive seal, allows drainage, and prevents condensate from standing in the condensate pan due to negative pressure, providing the trap is filled with water. Unfortunately, in practice these geometric dimensions have only academic value,

DIMENSIONS OF SCHEDULE 40 PIPE (INCHES)

NOMINAL SIZE	DIAMETER OUTSIDE	DIAMETER INSIDE WALL	WALL THICKNESS
3/4	1.050	0.824	0.113
1	1.315	1.049	0.133
1-1/4	1.660	1.380	0.140
1-1/2	1.900	1.610	0.145
2	2.375	2.067	0.154
2-1/2	2.875	2.467	0.203
3	3.500	3.068	0.216



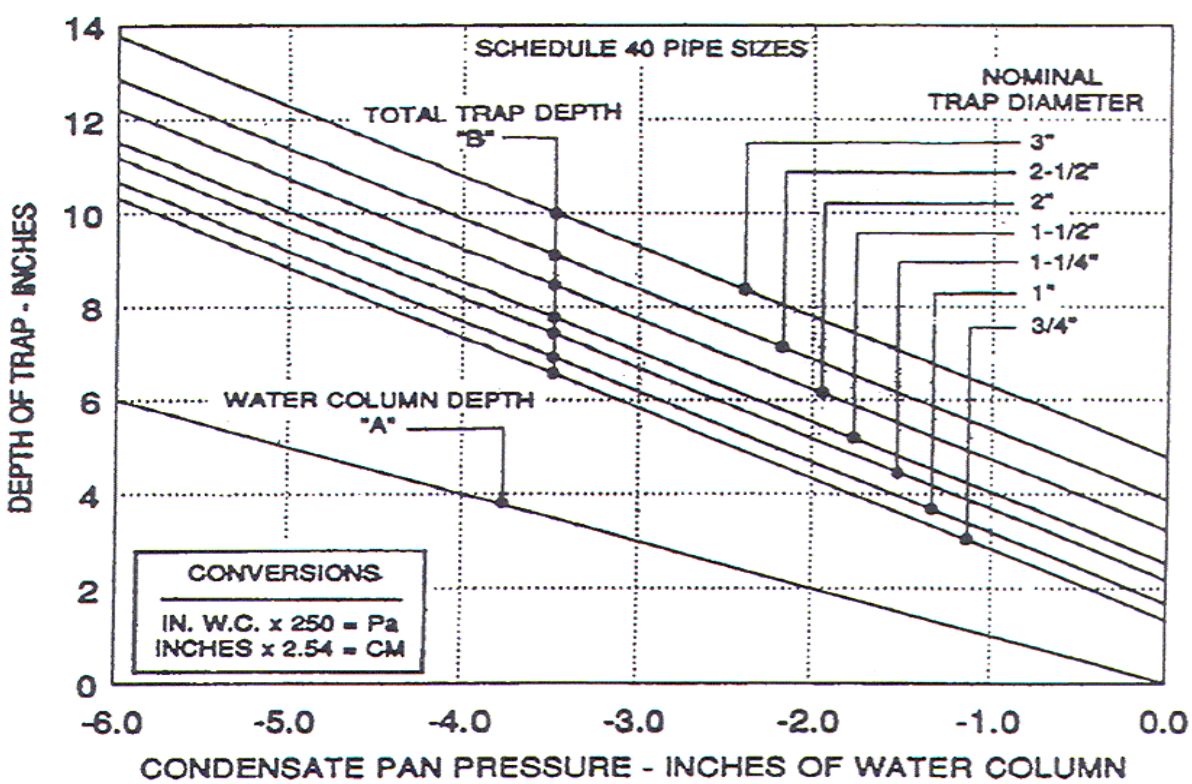


FIGURE 18.8.15 Dimensions of a properly designed condensate trap.

and are not generally applicable to actual operating systems. Any significant reduction in water level destroys the seal. For example, evaporation during periods when there is no flow of condensate (shutdown periods and winter heating) renders traps ineffective. Evaporation rate from traps is typically more than 1 in per month.

To overcome the effects of evaporation and allow an effective seal to be formed, trap depth must be greater than the values shown in Fig. 18.8.15. In some geographic locations, it may be necessary to increase the trap depth several inches over the values shown, in order to prevent so-called "dry trap syndrome." Dry traps permit the ingestion of outside air (possibly contaminated), allow condensate blowing onto internal components, and can cause flooding at start-up of cooling operations. In addition to dry trap syndrome, traps are inherently susceptible to freeze damage in outside locations and to flow blockage and pan overflow caused by trapped debris and algae growth.

Generally, condensate trap seals stocked by supply houses are unsuitable. A photograph of two such devices is shown in Fig. 18.8.16. In this figure, trap (a) provides a seal, but has no depth for water column. Thus, during system operation, it allows water to stand in the drain pan at a depth at least equal to the pan pressure, in inches of water. Trap (b) provides a water column and a seal over a limited range of internal pressures, but its adaptability to any particular application must be assessed by the designer. Under no circumstances should trap selection be left to the installer.

Effectiveness and Reliability. Under *ideal* conditions, the condensate trap can form an effective seal for the condensate drain line. However, a conventional trap exhibits so many failure modes that *its reliability is generally unacceptable for use as a drain line seal*. This situation has been recognized for years. Indeed, in 1996 the informative language in BRS/ASHRAE 62-1989R (Ref. 10) contained the following statement:

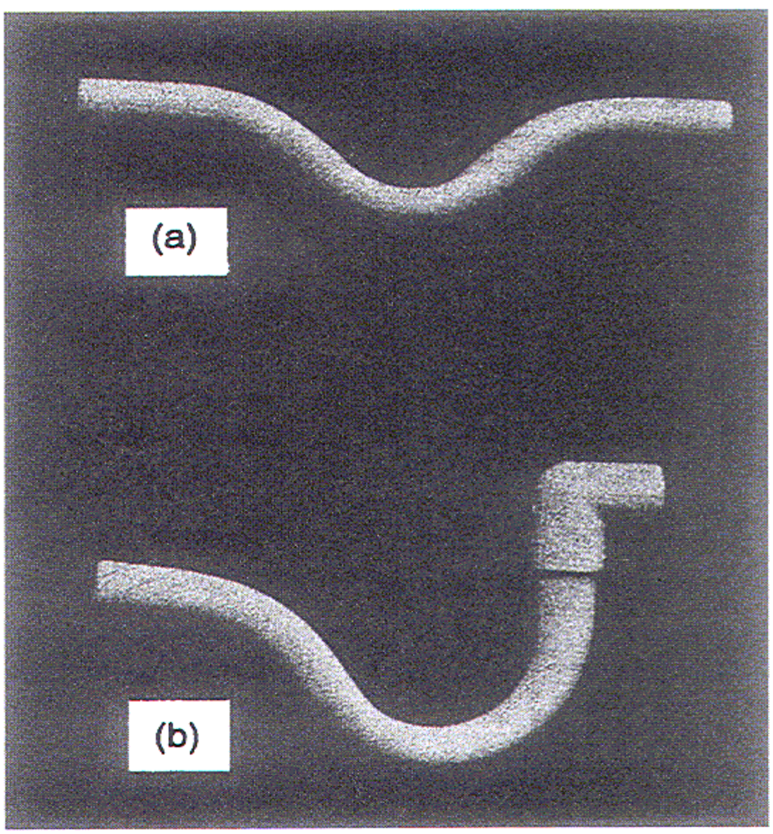
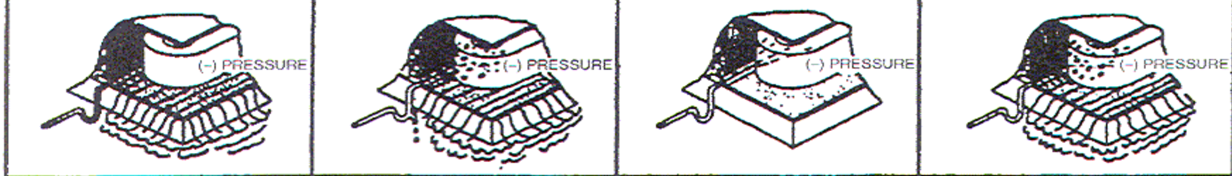


FIGURE 18.8.16 Condensate traps typically available at supply houses.



BLOCKED TRAP	FREEZE DAMAGED TRAP	EMPTY TRAP (Winter operation)	EMPTY TRAP (Cooling start up)
Cause: Algae growth and trapped debris	Cause: Installed in low temperature environment	Cause: Evaporation during non-cooling periods-no seal present	Cause: Evaporation during non-cooling periods-no seal present
Likely Consequences: • Overflow of condensate • Damage to unit and surroundings • Pollution of system and conditioned air • User Costs: Property damage, health care, excessive maintenance, and litigation	Likely Consequences: • Seal destroyed • Ingestion of outside air which may be polluted • Overflow of condensate • Blowing of condensate into unit and ductwork • Formation of aerosol mist • User Costs: Property damage, health care, excessive maintenance, and litigation	Likely Consequences: • Ingestion of outside air which may be polluted • User Costs: Health care and litigation	Likely Consequences: • Ingestion of outside air which may be polluted • Overflow of condensate • Blowing of condensate into unit and ductwork • Formation of aerosol mist • User Costs: Property damage, health care, excessive maintenance, and litigation

FIGURE 18.8.17 Some trap failures, causes, and consequences (Ref. 8).

"*Condensate traps exhibit many failure modes that can impact on indoor air quality* [and property damage*]. *Trap failures due to freeze-up, drying out, breakage, blockage, and/or improper installation can compromise the seal against air ingestion through the condensate drain line. Traps with insufficient height between the inlet and outlet* [and other trap design deficiencies*] *on draw-through systems can cause the drain to back up when the fan is on, possibly causing drain pan overflow or water droplet carryover into the duct system. The resulting moist surfaces can become sources of biological contamination* [and associated property damage*]. *Seasonal variations, such as very dry or cold weather, may adversely affect trap operation and condensate removal.*" Many of the most common failure modes, which are inherent in the condensate trap, are discussed in Ref. 11. A few of the more serious causes of these failures, and their consequences are summarized in Fig. 18.8.17.

Some of the most critical failure modes of the condensate trap can be alleviated by incorporating the following design features and maintenance procedures:

1. A water replenishing system to ensure that the trap provides a seal under all operating conditions;
2. Heating provisions, to prevent water in the trap from freezing during winter operations, in outside locations (The use of freeze plugs for protection against trap damage caused by freezing temperatures should be avoided. The maintenance effort for replacing plugs after freeze-ups is impractical to implement effectively); and
3. Mandatory maintenance procedures to ensure that traps are (a) inspected frequently for flow blockage, (b) filled with water prior to each cooling start-up, and (c) thoroughly cleaned or replaced at least annually (and filled with water after each action).

These added trap design features and the defined maintenance procedures will alleviate significant trap failure modes. But they introduce others. Both the water replenishing and water heating systems are subject to failure. And, even "mandatory" maintenance procedures are difficult to enforce. The designer must evaluate all these factors when considering the trap as condensate drain seal.

*Added by the authors.

Condensate Pump

Description. There are two basic types of condensate pumps: positive displacement and centrifugal. They require external power (usually electrical) to provide condensate removal. Pumps are used primarily where there is insufficient depth for the installation of a gravity dependent drain system or where condensate must be discharged to a level above the drain pan. When used for condensate removal, pumps are usually placed inside the condensate drain pan.

The configuration of condensate pumps differs greatly among types and manufacturers. Some designs fit better into condensate drain pans than others. In most instances, however, the condensate pan must be equipped with a suitable water sump.

The physical dimensions of a particular pump, of course, depend primarily upon the manufacturer and the volume of condensate it must handle. The maximum condensate flow rates from various size HVAC units, operating under specific cooling conditions, are shown in Fig. 18.8.2.

In operation, the rate of condensate removed by a HVAC unit varies from some maximum value to zero. To accommodate this variation, an on-off switch—which usually operates with a float—must be provided.

Effectiveness and Reliability. The condensate pump provides an effective and positive way to remove condensate from the drain pan of a HVAC unit. The positive displacement pump provides a firm seal and prevents the ingestion of outside air under all operating conditions. The centrifugal pump does not provide a firm seal when the pump is not operating. However, depending upon the particular design and installation, it may restrict air ingestion to an acceptably low level.

Condensate pumps are well developed and have been used successfully in certain applications. Their long term reliability, however, must be questioned. They depend upon moving parts that must operate in a cold and humid environment. The pump must handle condensate that often carries significant quantities of debris, which can interrupt pumping action and prevent flow. The on-off switch required to control condensate flow is exposed to the same hostile environment, and is subject to frequent failures.

Fluidic Flow Control Device

Description. The fluidic flow control device was developed primarily to provide a seal on the condensate drain line of draw-through HVAC units. However, a condensate flow control device for blow-through units, based on the same operating principles, is available. It is discussed separately in Sec. 18.8.12.

The fluidic flow control device is simple and has no moving parts. In draw-through system applications the desired seal is formed by a unique combination of hydraulic and pneumatic forces, readily available in the HVAC unit. One key feature of the device is that it uses air as a seal instead of water. Thus, it negates the problems associated with a water seal (Ref. 12).

The operating principles of the fluidic flow control device are illustrated in Fig. 18.8.18.

During both heating and cooling operations, the air seal is formed as follows: Fresh air from the fan discharge is supplied to point (a) at a pressure slightly above atmospheric. Some of the air flows away from the HVAC unit, thus preventing ingestion of outside air. A portion of the fresh air returns to the HVAC unit, passing through points (b) and (c). The quantity of air returning to the unit is minimized by the high pressure loss in the mitered elbows. This pressure loss plus the air flowing through the bypass connected at point (c), ensures that the air entering the condensate drip pan will not produce blowing and geysering and an aerosol mist.

Condensate flows through the device without being trapped. At the same time, the counterflow of condensate and air creates a pulsing action that ensures free passage of debris. Hence, the potential for freeze-up and flow blockage—common problems with traps—are nil.

A typical field installation of the fluidic flow control device is shown in Fig. 18.8.19.

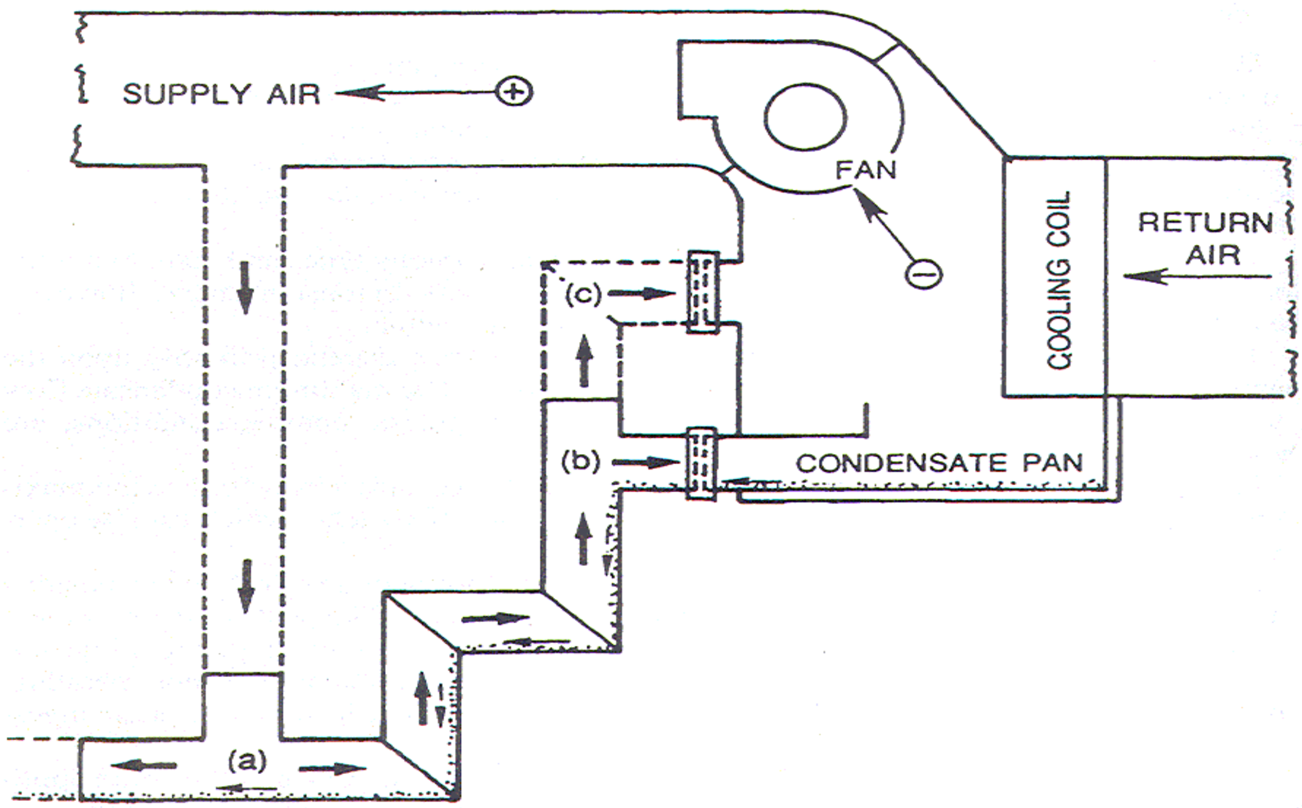


FIGURE 18.8.18 Operating principles of the fluidic flow control device.

The fluidic flow control device is a patented product manufactured and marketed by Trent Technologies, Inc., under the trade name CostGard Condensate Control Device. Detailed performance and installation data are available from the manufacturer.

The product, made from polyvinyl chloride (PVC) material, is available in sizes suitable for HVAC units up to 100 tons of cooling capacity and –5.0 in (127 mm) water column at the condensate drain outlet. Figure 18.8.20 shows how the physical dimensions of the device vary with system cooling capacity and drain pan pressure.

Effectiveness and Reliability. The fluidic flow control device provides an effective and reliable seal for condensate drain lines during all cooling and heating conditions. Its effectiveness and reliability (see Refs. 8, 11, and 12) stem from unique characteristics and features incorporated in the design which:

1. Allow condensate to flow freely and unimpeded from the air-conditioning unit;
2. Prevent air (which may be contaminated) from being drawn into the system through the condensate drain pipe during heating and cooling start-up operations (when p-traps are usually empty).
3. Prevent condensate in the drain pan from being blown into the air conditioning unit and the duct work (during both normal and start-up operations);
4. Remove the condensate drain system as a source of an aerosol mist;
5. Eliminate condensate overflow caused by trap blockage and negative pressure inside the system;
6. Are not affected by algae growth;
7. Are not affected by condensate evaporation (as are traps);

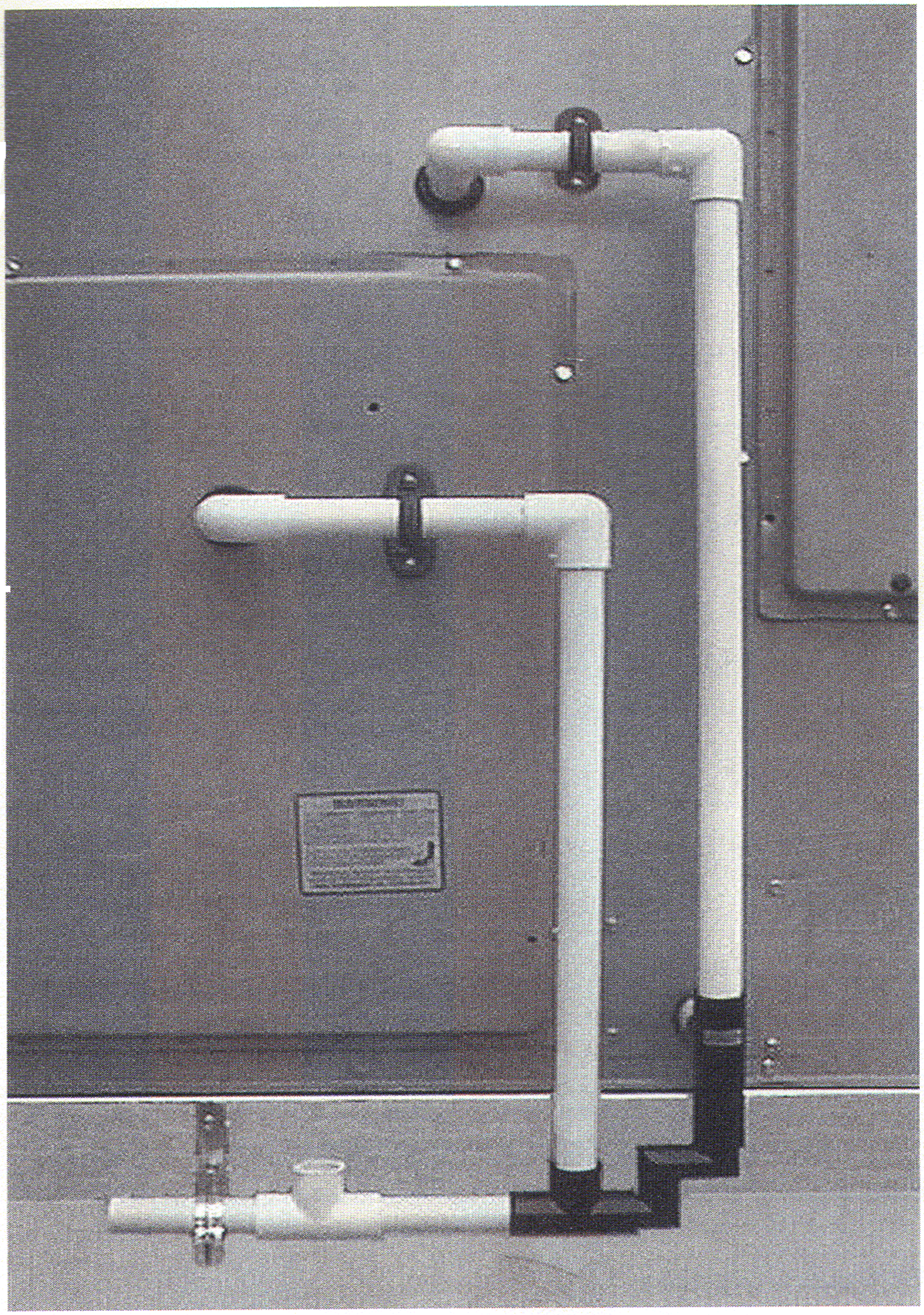
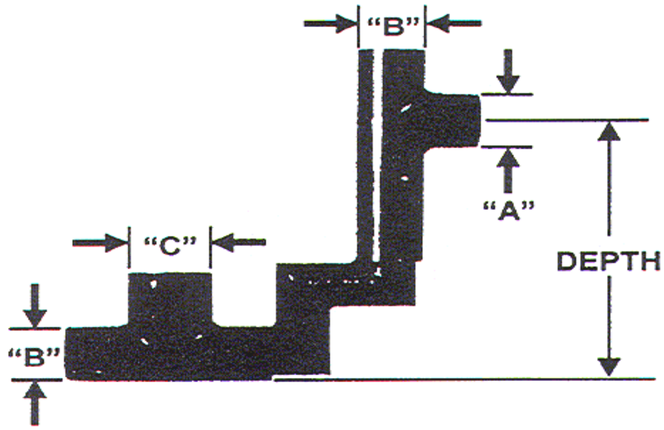


FIGURE 18.8.19 Typical field installation of the fluidic flow control device on a York Predator unit.

8. Preclude damage from freezing temperatures;
9. Include no moving parts; and
10. Are self-cleaning and self-regulating.

The device is essentially free of failure modes, has been in use for many years with no failures.



NOMINAL RATED TONS	-PORT SIZE- NOMINAL DIAMETER		
	"A"	"B"	"C"
1 to 30	3/4" to 1"	3/4"	3/4" to 1"
1 to 100	3/4" to 2"	1"	1-1/4"

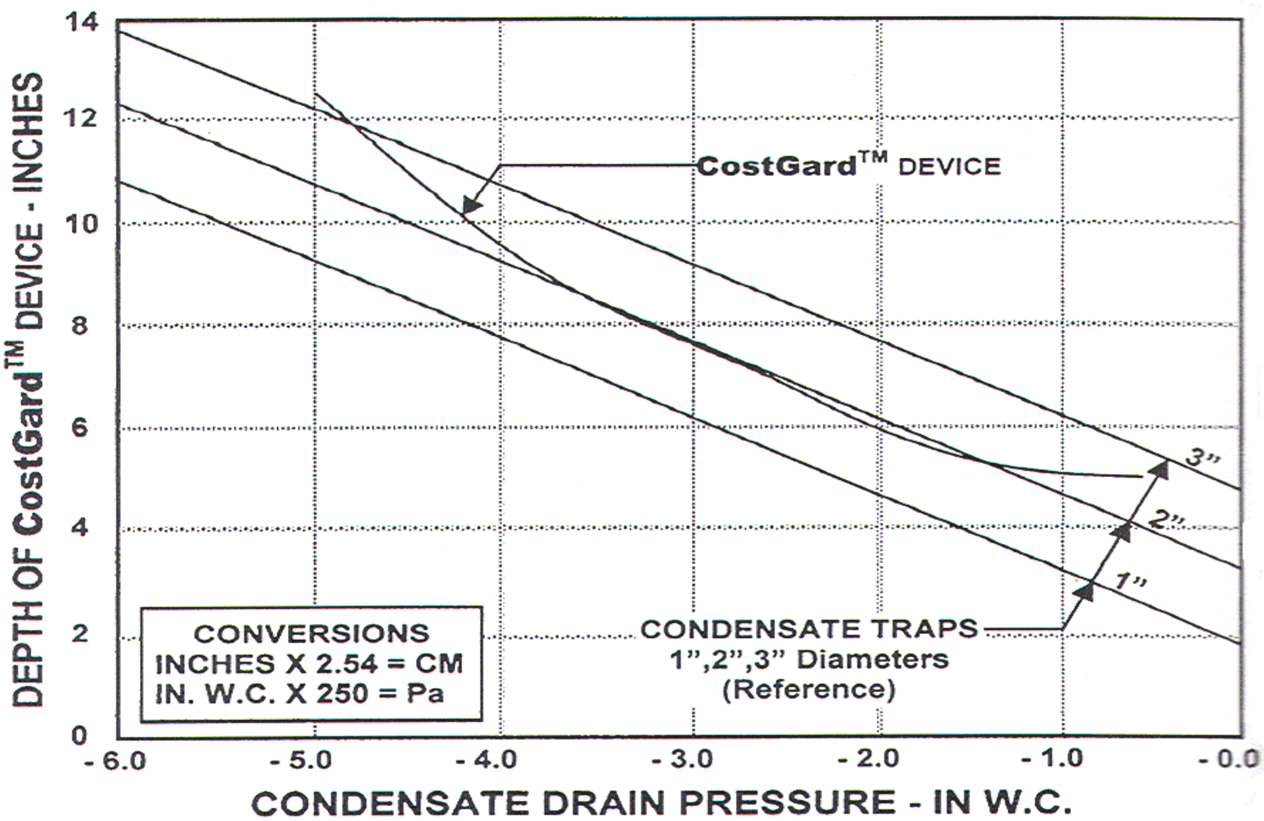


FIGURE 18.8.20 Physical dimensions of the **CostGard** condensate control device.

18.8.7.2 Economic Factors

Economic factors are paramount in the selection of a seal for condensate drain lines. Both the initial costs and operating costs are important.

Of the three types of seals discussed, the initial cost of the conventional condensate trap is lowest, and the condensate pump is the highest. The initial cost of the fluidic flow control device falls in between. However, total costs, which include both initial and operating costs are not at all related to the initial costs.

Despite the low initial cost of the conventional condensate trap, its operating and total costs are extremely high. This is because of excessive service calls, expensive maintenance effort, damage to surrounding property, and shortened equipment life. Although less visible and definable than others, the effect of the condensate trap on indoor air quality and health related costs may far exceed other operating costs.

Adding a water replenishing system and a heating device addresses two major failure modes of the condensate trap—empty traps and freeze damaged traps. But they introduce other failure modes, add to the initial costs, and contribute little, if anything, to increasing reliability and reducing system operating costs.

The cost of a condensate pump installed in a HVAC drain system, including special condensate drain pan designs, is greater than the cost associated with either of the other drain line seals. Years of field experience, however, indicates that with the fluidic control device, these costs are nil.

18.8.7.3 Suggested Statements for Specification

The seal on the condensate drain line of draw-through HVAC systems shall be designed to:

1. Allow condensate to flow freely and unimpeded from the air-conditioning unit;
2. Prevent air (which may be contaminated) from being drawn into the system through the condensate drain pipe during both heating and cooling start-up operations (when p-traps are usually empty).
3. Prevent condensate in the drain pan from being blown into the air-conditioning unit and the duct work during both normal and start-up operations;
4. Remove the condensate drain system as a source of an aerosol mist;
5. Eliminate condensate overflow caused by trap blockage and negative pressure inside the system;
6. Not be affected by algae growth;
7. Not be affected by condensate evaporation (as are traps);
8. Preclude damage from freezing temperatures;
9. Have no moving parts; and
10. Be self-cleaning and self-regulating.

18.8.8 CONDENSATE DRAIN LINES

The condensate drain line, which extends from the drain seal to the condensate disposal place, is the last link and a critical component in the condensate removal system. It can be, and frequently is, the source of serious condensate problems.

For successful drainage, this line must be carefully defined and clearly specified by the system designer. Under no circumstances should this responsibility be left to the installation contractor.

18.8.8.1 Critical Design Factors

An acceptable drain line is simply one that has adequate flow capacity and offers minimum potential for flow blockage. The following factors are critical to the design: diameter, length, routing, drainage slope, supports, and materials.

The diameter of the drain line must be equal to or greater than the exit diameter of the drain seal device. The line length should be the minimum possible, following the shortest path to the condensate disposal place (the shorter, the better). It should include the least possible number of elbows.

The line must be sloped away from the drain seal at a rate of *no less* than $^1/_8$-in/ft (1 cm/m). Solidly fixed drain line supports must be provided at intervals which ensure that a uniform slope is maintained to avoid dips in the line that can trap condensate and debris.

Drain lines may be constructed of PVC, copper, or steel piping. PVC and steel pipe must be Schedule 40 or heavier. Copper pipe must be Type L or heavier.

To avoid excessive dips in the drain line and prevent shifting of position, fixed supports should be provided as follows: PVC, 2 to 3 ft (0.6 to 0.9 m); copper, 4 to 6 ft (1.2 to 1.8 m), and steel 8 to 10 ft (2 to 3 m) intervals.

Clearly, a long and meandering condensate drain line requires careful engineering design and proper installation which adds appreciable cost to the system. Where possible, consideration should be given to eliminating the drain line entirely. For example, in rooftop installations, condensate flowing from the drain seal may be dumped onto the roof. Any potential roof problems caused by this arrangement should be assessed against the cost of installing the drain line and the probable condensate drainage problems caused by the use of a drain line.

18.8.8.2 Economic Factors

The cost of the condensate drain line depends primarily on the type of pipe used. The unit cost of the pipe and the cost of installation are both important.

The unit cost of pipes differ substantially. The cost of PVC pipe is one-half to one-third that of steel. The cost of steel pipe is one-half to one-third that of copper. It follows then that copper pipe is four to six times more costly than PVC.

Installation costs consists of labor plus the material required for supporting the drain line. The cost of labor involved in assembling PVC pipe is minimal. It consists of connecting slip joints with PVC cement, for which little labor is involved. The closely spaced pipe supports required, however, add to both labor and material costs. Even so, a condensate drain line of PVC costs considerably less than either steel or copper.

The cost of labor required to assemble a copper drain line far exceeds that of one constructed of PVC. Each connection must be soldered and the necessary equipment must be transported to the installation site. However, the costs of material for pipe supports and the cost of installing them are only about one-half that for PVC pipe.

The cost of labor necessary for assembling a steel drain line is even greater than for copper. Each connection must be threaded and screwed together. Equipment for cutting threads must be transported to the installation site. These factors plus heavy pipe impose an extraordinary amount of labor on the installer. The cost of pipe supports and material are minimal.

In summary, when both pipe and installation costs are included, a drain line system with PVC pipe is the lowest of the three. The cost of systems constructed with steel and copper pipe are about the same. The installation of copper is less, but the higher cost of copper pipe tends to offset the higher installation costs of steel pipe. In any particular application the cost difference between copper and steel systems may vary, depending upon the experience of the contractors involved.

Building owners-users sometimes prefer one material over others. Also, in some instances, local codes may prohibit the use of PVC. However, all three of the mechanical codes used in the United States permit the use of PVC.

18.8.8.3 Suggested Statements for Specifications

1. The diameter of the drain line must be equal to or greater than the exit diameter of the drain seal device. The line length should be the minimum possible—following the shortest path to the condensate disposal place. It should include the least possible number of elbows.

2. The line must be sloped away from the drain seal at a rate of no less than $^1/_8$-in/ft (1 cm/m).
3. Drain line supports must be fixed solidly in place and provided at intervals which ensure that a uniform slope is maintained and that any dips formed in the line do not trap condensate and debris.
4. Drain lines may be constructed of PVC, copper, or steel piping. PVC and steel pipe must be Schedule 40 or heavier. Copper pipe must be Type L or heavier.
5. To avoid excessive dips in the drain line and prevent shifting of position, fixed supports should be provided as follows: PVC, 2 to 3 ft (0.6 to 0.9 m); copper, 4 to 6 ft (1.2 to 1.8 m), and steel 8 to 10 ft (2 to 3 m) intervals.

18.8.9 SYSTEM REMEDIATION

Suitable condensate control is achieved and an acceptable HVAC maintenance program can be implemented only when condensate is confined to (a) surfaces of the cooling coil, (b) a small and properly sloped condensate drain pan, and (c) a well-drained system through which condensate flows freely and never stands nor stagnates.

Confining condensate to these three areas allows the system to operate virtually free of excessive maintenance, property damage, and health-threatening biological growth. When condensate is confined in this manner, the required system maintenance consists of rather simple periodic scheduled procedures: inspecting, cleaning, and flushing the drain system (pan, seals, and lines).

Unfortunately, far too many systems now in operation are not designed to restrict the spread of condensate, and are not amenable to reasonable maintenance.

A successful maintenance program for these systems must begin with an assessment of the capacity of each to *confine condensate to the cooling coil, drain pan, and drain system*. Anytime condensate spreads beyond these areas, system remediation is necessary to ensure that condensate is properly confined, under all operating conditions.

System deficiencies that allow the spread of condensate beyond the cooling coil and the drain system include the following:

- Condensate carryover from cooling coils
- Condensate drips onto internal HVAC system components
- Unsuitable drain pan designs
- Very low supply air temperatures
- Improper fan position inside the air handlers
- Ineffective seals on condensate drain lines
- Unsuitable installation of condensate drain lines

When these deficiencies are present, no amount of system maintenance can prevent equipment damage, surrounding property damage, and health-threatening biological growth. *Scheduled maintenance has only limited value*. It occurs after property damage has been done and biological growth has had its effect. Moreover, the damaging effects begin all over as soon as system operation is resumed. The design considerations necessary to avoid these conditions in future systems are provided in Sec. 18.8.2.

Whenever the above deficiencies appear in any system, they must be remedied before a meaningful maintenance schedule can be defined and implemented. The following paragraphs suggest suitable remedies and define a drain system that can be maintained with reasonable routine and preventive maintenance programs.

Specific system deficiencies that preclude the implementation of a feasible maintenance program, along with remedies to these deficiencies are reviewed below.

18.8.9.1 Condensate Carryover from Cooling Coil

Condensate carryover in any observable quantity is incompatible with a practical and acceptable system maintenance program. Damage and contamination begin when carryover occurs, neither will wait for the next scheduled maintenance action.

Condensate carryover occurs when the velocity of the air passing through the cooling coil is sufficient to entrain condensate and blow it off the coil. Any time the system components or other surfaces downstream of the cooling coil become wet, condensate carryover is a possible cause that must be assessed. The presence of carryover can best be established by visual observation (portholes, fiber optics, etc.) downstream of the coil, during the cooling operation when the latent heat load (water removal) is high. The entire surface of the coil must be viewed in order to determine the cause and location of the deficiency. Uniform carryover indicates one deficiency, carryover in local areas indicates other deficiencies. The three most common causes of condensate carryover are (a) unsatisfactory coil design, (b) dirty cooling coils, and (c) distorted air velocity profile entering the coil.

Unsatisfactory Coil Design. Coil design is unsatisfactory when condensate carryover appears somewhat uniformly over the entire face of a *clean* cooling coil. The following design parameters determine the cooling coil condensate carryover characteristics: airflow of the air handler; height and width of the cooling coil; size and spacing of the coil tubes; and thickness and spacing of fins on the tubes. Figure 18.8.1 illustrates, for a typical coil design, the relationship among these parameters. The air velocity at the coil face, shown in this figure, is determined by dividing the air handler airflow by the face area of the coil.

Problem Definition. When condensate carryover, due to coil design, occurs in a particular system, it can be remedied only by changing one or more of the parameters included in Fig. 18.8.1. Generally, in existing systems, it is not practical to make significant changes in coil geometry. Thus, the most practical way to eliminate condensate carryover is to reduce air velocity at the coil face; that is, reduce airflow.

Remedies. Reduced airflow can be achieved most effectively by changing fan speed, which involves either a change in size of pulleys or a change in the motor speed, if the motor speed is variable.

It is often possible to reduce airflow without causing system problems. Many times HVAC systems are oversized. In such cases, reduced fan speed introduces no penalty in cooling performance. Moreover, total cooling capacity is relatively insensitive to airflow. For example, a reduction in airflow of 20 percent typically reduces total cooling capacity by about 5 percent at the rated point. Sensible cooling capacity is reduced more, but latent cooling capacity is increased. Even in those instances where the total cooling capacity is compromised by reduced airflow, the best choice may be to accept this compromise and eliminate the serious property damage and health problems associated with condensate carryover.

In installations where the coil design is similar to that shown in Fig. 18.8.1, the reduction in air velocity needed to eliminate carryover can be approximated as follows: Compute air velocity at the coil face in feet per minute by dividing the airflow (CFM) by the face area (square feet—height times width) of the cooling coil. With the coil face velocity, enter Fig. 18.8.1 at the spacing ratio and fin spacing determined from coil measurements. The difference between this point and the point where carryover is indicated by Fig. 18.8.1, indicates the reduction in velocity and, therefore, the airflow reduction required to eliminate carryover. At best, however, this process provides only a starting point. The proper airflow reduction is that which eliminates condensate carryover, a condition that must be determined by visual observation or other suitable means.

The installation of moisture "eliminators" downstream of the coil is not a viable method for preventing carryover. Eliminators add significantly to the pressure loss in the system and, therefore, reduce airflow. In addition, they introduce another potential growth place for biological contaminates.

Dirty Cooling Coils. Condensate carryover may sometimes be observed in systems where the cooling coil design is entirely satisfactory. The cause may be dirty coil surfaces. Carryover may occur in limited local areas of the coil because dirt does not always collect uniformly on the cooling coil.

Problem Definition. Dirt and other foreign material deposited on the surfaces of cooling coils can reduce the area for airflow and increase the air velocity sufficiently to effect condensate carryover. Unrelated to condensate carryover, dirty coils have other adverse consequences. They reduce heat transfer and decrease system efficiency.

Remedies. Within the industry, the most widely endorsed solution to dirty coil conditions is maintenance program that involves periodic coil cleaning. When properly defined and performed regularly, coil cleaning can be adequate to avoid carryover resulting from dirty coils. But, coil cleaning is a costly and time-consuming process. Furthermore, in many existing systems, the cooling coils are so inaccessible and cleaning is so difficult that it is often deferred until a major problem arises.

Probably the most dependable and cost-effective way to maintain coils in an acceptably clean condition is to utilize filters with adequate capacity to remove particles that accumulate on the coil; thereby, avoiding the need to perform frequent cleaning. Available data (Ref. 13) indicate that filters with dust spot efficiency ratings (as defined in Ref. 14) of 25 percent (or AHSRAE MIRV 7 Filter) or higher can virtually eliminate dirty coils and the airflow problems they cause. Of course, to be effective a filter must be placed in an essentially air tight holder, otherwise bypassed particles can reach the coil and be deposited on the surfaces.

Distorted Air Velocity Profile Entering the Cooling Coil. Air entering the cooling coil with a nonuniform velocity profile can cause carryover even when the average face velocity is below where carryover would occur, as indicated in Fig. 18.8.1. Carryover caused by this condition can be defined by visual observation. And, the location and source of the distorted airflow can be identified and corrected.

Problem Definition. In draw-through systems, distorted airflow can be generated; for example, when air enters a short-coupled return plenum at right angles to the coil. In blow-through systems the coil may be subjected to a very adverse velocity profile created at the fan discharge. Carryover of this type is evidenced by concentration in local areas of the coil, where airflow distortion occurs.

Remedies. Carryover caused by distorted airflow may be remedied by installing longer plenums and/or turning vanes. Properly installed turning vanes and longer, more efficient diffusers not only improve the velocity profile, they can significantly reduce pressure losses. Turning vanes and longer plenums require more space, additional hardware, and added costs. Nevertheless, in certain cases, major changes may be necessary to eliminate the detrimental spread of condensate if an effective maintenance program is to be achieved.

18.8.9.2 Condensate Drips onto Internal HVAC System Conponents

Any HVAC system that allows condensate to drip onto internal surfaces and components is subjected to internal damage and the growth of contaminating organisms. Sloped cooling coils and noninsulated coolant lines (refrigerants or water) are often the source of condensate drips. Systems that exhibit these qualities must be modified, because routine scheduled maintenance does not protect against these conditions, nor does it remedy the causes.

Drips from Sloped Cooling Coils. Sloped cooling coils included in some HVAC systems are prone to drip condensate onto surfaces outside the condensate drain pan.

Problem Definition. Condensate that drips from a slanted coil onto surfaces outside the drain pan creates destructive and contaminating conditions. At small slope angles, surface tension may be adequate to retain the condensate and allow it to drain into the condensate pan. However, foreign deposits on the coil can easily destroy the effects of surface tension and cause dripping to occur.

Air velocity entering the coil tends to reduce dripping from a coil that is sloped rearwardly (from the top), when the fan is operating. But it is not a reliable force for preventing condensate dripping.

Remedies. Extending the condensate drain pan to catch condensate drips is not a viable solution. It introduces another equally serious condition, large drain pans, discussed in Sec. 18.8.9.3. ("Unsuitable drain pan designs"). In order to ensure adequate condensate control and a dry system that is free of harmful contaminates, sloped coils must be kept clean at all times and the fan should not be turned off during the cooling period. The air filter must never be placed below the cooling coil, where dripping condensate creates conditions conducive to the growth of health threatening organisms. Filters mounted below the coil must be moved upstream to eliminate a major source of system contamination. Slanted coils increase the susceptibility of systems to internal wetness and contamination; therefore as a minimum, a more stringent and high frequency maintenance program is necessary for these systems.

Drips from Noninsulated Coolant Lines. All too frequently, existing HVAC units have noninsulated coolant lines that pass through the cooling airflow passage, causing condensate drips along their paths.

Problem Definition. Condensate that drips on surfaces outside the drain pan causes damage to the HVAC system and creates conditions conducive to health-threatening biological growth.

Remedies. This condition, much too common in current systems, is simple to remedy. It can and must be eliminated by applying suitable insulation to all bare coolant lines.

18.8.9.3 Unsuitable Drain Pan Designs

Condensate drain pans in many HVAC systems now in the field are so configured that the necessary maintenance effort varies between very difficult and impractical to perform. Among the most troublesome features are (a) large drain pans, (b) primary drain port location, and (c) internal baffling. Systems that exhibit these characteristics must be modified before a reasonable maintenance program can be implemented.

Large Drain Pans. Systems that make use of large condensate drain pans (often extended downstream of the cooling coil to protect against condensate carryover)—cannot confine the spread of condensate within the boundaries necessary to permit successful maintenance.

Eliminating condensate carryover, as discussed earlier, will not keep large condensate pans dry and free of damage and biological growth.

Problem Definition. As condensate forms and drains into the pan, it will stand there at some finite depth. If the drain pan is level—as is common for systems now in the field—condensate will cover the entire pan. The precise depth at which condensate stands depends upon the pan geometry, and the rate at which condensate is drained from the pan. Typically, the depth varies between about $^1/_8$ in (3 mm) and 1/2 in (12 mm) (or greater). See Fig. 18.8.3.

During system operation, condensate in the drain pan will flow from the area below the cooling coil to the drain port, leaving the remainder—in fact most—of the condensate in a stagnant state. There it becomes a growth haven for contaminating organisms, as illustrated in Fig. 18.8.5. A photograph of one such result is shown in Fig. 18.8.21.

FIGURE 18.8.21 Photo showing contamination in wide drain pan.

Remedies. For HVAC units now in the field, sloping the drain pan by tilting the HVAC unit is one way to reduce the pan area covered with stagnant condensate. Figure 18.8.6 illustrates the effect of sloping a drain pan in one direction. Sloping the pan in both directions, of course, further reduces the area of stagnant condensate. Hence, with sufficient slope in two directions, it is possible to virtually eliminate stagnate condensate in the pan.

Sloping the pan, however, by no means makes a large pan an acceptable remedy for condensate carryover. Carryover droplets deposited on the pan will not drain readily to the drain port. Instead, they will be held in place by surface tension providing another potential source of biological contamination. In reality, the large drain pan serves no useful purpose. It is not a solution to condensate carryover, a condition that must be prevented, as discussed earlier.

The equipment damage and contamination problems caused by large drain pans now in the field can be remedied by simply reducing the pan size to that required to catch the condensate and accommodate the flow in the drain pan. The length of the pan must be sufficient to cover the base of the cooling coil. The pan area is then fixed by pan width—the distance the pan extends away from the cooling coil. The width of the drain pan must be sufficient to accommodate the maximum condensate flow rate, yet not so wide as to allow condensate to stagnate. Pan widths considered acceptable for systems with various cooling capacities and condensate drain sizes are shown in Fig. 18.8.7.

The most effective way to reduce large pans to a suitable size depends upon the specific system involved. Where possible, the most desirable pan is one constructed of durable nonmetallic material or stainless steel. Often, however, the most practical way to effect pan size

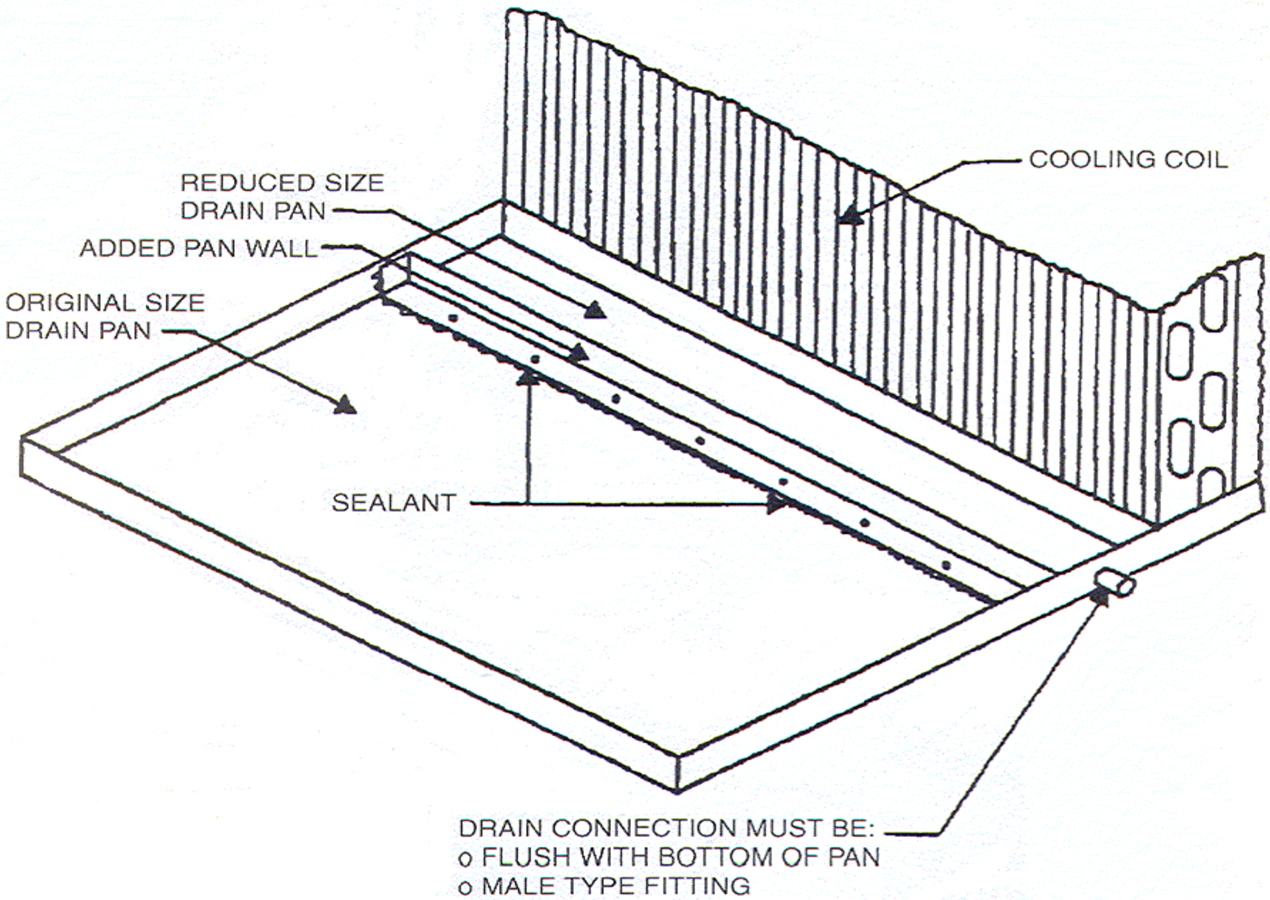


FIGURE 18.8.22 Drain pan reduced in size.

reduction is to install a wall inside the current drain pan, as illustrated in Fig. 18.8.22. In some cases, it may be necessary to relocate the drain port and place it at the end of the pan as indicated.

If the pan and attachments already in place are constructed of ferric metals, they must be replaced or treated with durable (long-life) protective coatings. This is because under some conditions the presence of iron accelerates the growth of certain harmful bacteria. (See Ref. 3.)

Condensate drainage can be enhanced, and protection against the formation of water puddles can be realized by tilting the HVAC unit toward the drain port, as discussed above. A slope of $^1/_4$-in/ft (2 cm/m) is usually adequate. However, the unit should be tilted only with the approval of the equipment manufacturer.

Large pans modified as defined above will permit condensate to be confined within boundaries that allow practical maintenance and ensure a minimum of property damage and biological contamination.

Primary Drain Port Location. Proper drain port location is essential to adequate drainage and condensate control.

Problem Definition. Drain ports located above the bottom of the drain pan inherently prevent complete drainage of condensate. Water standing in the pan below the drain port level collects and retains debris, supports the growth of biological agents, and contaminates the system. Frequent cleaning and maintenance are required to prevent serious property damage and human health problems. Moreover, location of the drain port above pan floor level makes cleaning and scrubbing unduly difficult and time consuming. Maintaining such a pan free of contaminates is not realistically feasibile.

Remedies. An acceptable maintenance program dictates that drain ports be flush with the bottom of the drain pan. Whenever feasible, the drain port should be placed in the bottom floor of the drain pan, to further improve drainage. See Figs. 18.8.3 and 18.8.4.

Baffles in Condensate Drain Pans. The drain pans in some draw-through HVAC packaged units now in the field are equipped with internal baffles. Evidently, these are intended to prevent condensate from blowing into the system where it can cause damage to internal components and promote health-threatening biological growth. In most draw-through systems—in the field today—condensate blowing is a serious problem. The problem arises when no seal has been installed or when the seal depends upon a trap that is dry; for example, during initial system start-up, or start-up for summer cooling. (Traps become dry in winter due to evaporation and/or freeze-plug expulsion.)

Problem Definition. During the above operating conditions, baffles can reduce, although they rarely eliminate, condensate blowing when no drain seal is present. But they present a significant maintenance problem. More surface area is exposed to condensate and the potential for system contamination is magnified. And because of the small air and water passages in baffles, condensate pans seldom drain well and condensate flow is often blocked by debris. Frequent cleaning of baffled systems is therefore imperative. Yet, the interior of baffle arrangements are so inaccessible that reasonable maintenance procedures are usually not feasible.

Remedies. The implementation of a practical maintenance program requires the removal of troublesome baffles and the use of a reliable and effective drain seal that eliminates the condensate blowing, for which the baffles were initially installed. See Sec. 18.8.9.6 "Ineffective seals on condensate drain lines" in the following pages.

18.8.9.4 Very Low Supply Air Temperatures

Low supply air temperatures present a special problem in condensate control, which occurs too frequently to be ignored. The problem appears in the form of damage to and biological contamination of air supply grilles.

Air Supply Grilles. In buildings where the latent heat load is high, the dry bulb temperature of the air leaving the cooling coil is usually below the dewpoint temperature of air in the conditioned room.

Problem Definition. Whenever supply air reduces the supply grille temperature to the dewpoint temperature inside the room, condensate can form on the surfaces of the grille. Deposited there, it causes the formation of molds and other fungi that discolor, damage, and contaminate surfaces of the grille. Systems that allow formation of condensate on supply grille surfaces require constant attention and must be modified to be amenable to a realistic maintenance program.

Remedies. There are three possible solutions to this problem: (a) change in grille design, (b) increase in cooling airflow rate, and (c) addition of cooling air reheat.

The internal and external geometry as well as the material of construction determine how resistant a supply grille is to condensate formation. Some grille manufactures are aware of the problem and can be helpful in selecting designs that are the least susceptible to condensate formation.

An increase in airflow rate will increase the supply air temperature and reduce moisture formation on supply grilles. Many times it may be possible to increase airflow sufficiently to avoid this problem and still provide adequate system performance. This possibility should always be considered, anytime condensate is found on air supply grilles. (The effect of increasing airflow on condensate carryover from the cooling coil must be evaluated when increased airflow is considered.)

Providing reheat to cooling air is an effective way to avoid condensate formation on supply air grilles, but it is usually an inefficient and a costly process. There are, however, other reasons for using reheat. If needed for other purposes, adding reheat may offer an acceptable method of eliminating condensate on supply grilles.

More details on what can be done to avoid condensate formation on supply grilles are provided in Sec. 18.8.5.

18.8.9.5 Improper Fan Position Inside Air Handlers

Fans improperly positioned within an air handler often cause condensate problems that cannot be remedied by routine maintenance. Poorly located fans can (a) cause condensate to be entrained directly from surfaces of the cooling coil or (b) generate vortices that ingest condensate from either the drain pan or the cooling coil.

Condensate Entrainment. Air entering the fan inlet is accelerated to a velocity much higher than that in the coil plenum. This condition generates a high velocity core that extends well beyond the fan inlet.

Problem Definition. If fans are placed too close to cooling coils, the high velocity core will extend into the coil, entrain condensate, and blow it onto downstream components.

Remedies. In instances where the fan draws condensate directly from the coil, the separation distance must be increased in order to alleviate the problem. Section 18.8.6 provides information on the separation distance necessary to avoid condensate entrainment.

Vortex Ingestion. Airflow distortion developed upstream of fan inlets can interact with fan blades and generate troublesome vortices. The presence of vortices is most readily confirmed by visual observations.

Problem Definition. Vortices touching the coil surfaces or condensate in the drain pan can carry streams of condensate into the fan. From there, it is spread onto downstream components causing damage to equipment and promoting the growth of biological contaminates.

Remedies. Vortices can usually be eliminated by installing properly designed turning vanes.

18.8.9.6 Ineffective Seals on Condensate Drain Lines

Ineffective seals on condensate drain lines of draw-through systems is a major cause of equipment damage, surrounding property damage, and system contamination. In fact, dysfunctional drain seals appear to be the primary cause of biological growth in HVAC systems.

An ineffective drain seal can be identified in a number of ways (Table 18.8.1).

The consequences of operating a draw-through HVAC system with an ineffective drain seal are summarized in Fig. 18.8.13. These consequences are clearly unacceptable and dictate that every draw-through HVAC unit be equipped with an effective and reliable condensate drain seal.

Within the industry, three different types of devices are being used to form condensate drain seals for draw-through HVAC systems: (a) condensate (water) traps, (b) condensate pumps, and (c) a fluidic flow control device—the latter a recent technological development.

Each of these devices exhibits unique physical and operating characteristics and provides a different level of effectiveness and reliability.

Condensate traps. The condensate trap is widely used as a seal in condensate drain lines. It is usually mounted outside the HVAC unit, as indicated in Fig. 18.8.14. The seal is formed by gravitational forces acting on trapped water and a water column.

TABLE 18.8.1 Determining Seal Effectiveness

Symptom	To determine seal effectiveness
Outside air is drawn into HVAC unit during normal operation.	Place soap bubbles or a small flame at the drain exit, or at any open port (downstream of the drain seal). If either the bubbles or flame is drawn into the system, the seal is ineffective and unsatisfactory.
Outside air is drawn into HVAC unit when the fan is operating with the drain pan, trap,* and drain system dry.	Place soap bubbles or a small flame at the drain exit, or at any open port (downstream of the drain deal). If either the bubbles or flame is drawn into the system, the seal is ineffective and unsatisfactory.
Condensate stands in the drain pan during the cooling operation.	Determine the depth of condensate in the drain pan. If it exceeds the level shown in Fig. 18.8.3 the seal is ineffective and unsatisfactory.
Condensate is blown from the drain pan during cooling system start-up, or normal operation, and condensate is spread onto internal surfaces.	View conditions of the drain pan and cooling coil through port holes or other means.

*Unless the seal is equipped with a water replenishing system.

Problem Definition. Properly configured, as described in Sec. 18.8.7, the conventional condensate trap can provide a seal under *ideal* circumstances. Even when configured properly, however, the trap exhibits numerous failure modes and is so unreliable that it is ineffective and is unsuitable for use on a draw-through HVAC system.

Some failure modes are inherent when using the condensate trap: (a) flow blockage—pan overflows; (b) trap freeze damage (in outside locations)—seal destroyed; (c) evaporation of condensate—seal destroyed. The causes of these failures and the destructive consequences are summarized in Fig. 18.8.17.

In addition to inherent deficiencies, traps are susceptible to design deficiencies and unwise field practices, which add failure modes and further decrease trap reliability and effectiveness.

Reference 10 presents a comprehensive summary of failure modes that plague the condensate trap, and torment building owners/users.

Remedies. The methods available for improving trap effectiveness and reliability are limited.

Trap flow blockage is virtually impossible to avoid. Because traps trap water, they likewise trap debris, which eventually blocks flow. In addition, the cool water in the trap promotes the growth of algae, a condition that almost ensures periodic flow blockage. Annual cleaning of traps is one possible way to overcome flow blockage. However, because of prolific growth of algae and the drying-out and hardening that takes place during winter months, trap cleaning is not always effective. The best approach is to replace traps annually.

Trap freeze-up and seal destruction, in outside locations, can be avoided by applying heat to the condensate during freezing periods. Although such a system requires a heating element and a sensor device, it can be effective and reasonably reliable, but not cost free. The use of freeze plugs, often employed to prevent trap damage, is an unsuitable choice because when expelled they destroy the seal and render traps ineffective until the plugs are replaced. Further, in many applications, it is not feasible for maintenance personnel to replace freeze plugs after each freeze-up. Thus, after thaw-out the seal is lost until plugs are replaced and traps are filled, often months later. Evaporation of condensate from traps, which begins as soon as the cooling operation and condensate-flow ceases, can be overcome by using a water replenishing system. The control of water flow may be affected by a continual drip arrangement, an on/off timer, or level sensor. In any case, a water replenishing system adds cost and decreases reliability. For successful operation in outside locations (where freezing occurs), a water replenishing system must be equipped with methods for keeping the water above freezing temperature.

Condensate traps should be used as drain seals only as a last resort. Even when water replenishing and condensate heating systems are employed, systems must be monitored carefully—a very expensive procedure.

Condensate Pumps. Condensate pumps are usually installed in the condensate drain pan, inside a suitable water sump. They are used primarily where there is insufficient depth for the installation of a gravity dependent drain system or where condensate must be discharged to a level above the drain pan. Pumps provide a positive and effective seal during all phases of operation. External power (usually electrical) is required. To accommodate variations in condensate flow, an on-off switch, which is usually operated by a float, must be provided.

Problem Definition. Although they are well developed and have been used successfully in special applications, the long-term reliability of condensate pumps must be questioned. They depend upon moving parts that operate in a cool and humid environment. Pumps must handle condensate that often carries significant quantities of debris, which can interrupt pumping action and cause flooding. The on-off switch used to control pump operation is exposed to a somewhat hostile environment, and is subject to frequent failures.

Condensate pumps may be damaged when exposed to freezing conditions. Freezing, generally, does not destroy the seal, but it can result in pump failure and condensate overflow whenever cooling operation begins. Because they usually require considerable space inside the drain pan, pumps are not often used as replacements for condensate traps.

Remedies. Acceptable pump reliability can be achieved by implementing an aggressive maintenance and monitoring program. It must include periodic cleaning of debris from the sump, and replacement of aging and deteriorating electrical and mechanical components. In outside locations, freeze damage can be avoided by providing a heating system to maintain water in the sump at a temperature above freezing.

Fluidic Flow Control Device. The fluidic flow control device is a recent advancement in drain seal design. It was developed specifically for use on the drain lines of draw-through HVAC units, to be free of the failure modes common to traps and pumps. The device is connected to the condensate drain port much like a conventional condensate trap. The desired seal is formed by a unique combination of hydraulic and pneumatic forces, available in the HVAC unit. It has no moving parts. A key feature of the device is that it uses air as a seal instead of water. Thus, it negates the problems associated with a water seal. The operating principles of the fluidic flow control device are illustrated in Fig. 18.8.18 and described in Sec. 18.8.7.

Problem Definition. Installation procedures for the device are new to HVAC service personnel, and the effort required is slightly more than that required to install a conventional condensate trap (although, less than that required for installing a trap with a condensate heater and a water replenishing system). Not all existing systems are adaptable to installation of the new device. For example, units that are too close to the floor to allow installation of a trap, cannot accommodate the fluidic control device either, without major changes.

Remedies. Detailed step-by-step installation procedures, including a pictorial guide, are available to assist service personnel with their first installation. Subsequent installations become routine. Once installed, the device operates virtually void of maintenance effort and free of the many problems caused by the condensate trap, in that it:

1. Allows condensate to flow freely and unimpeded from the HVAC unit;
2. Prevents air (which may be contaminated) from being drawn into the system through the condensate drain pipe during heating operations, cooling operations, and cooling system start-up operations (when p-traps are usually empty);
3. Prevents condensate in the drain pan from being blown into the air-conditioning unit and the duct work (during both normal and start-up operations);
4. Removes the condensate drain system as a source of an aerosol mist;
5. Eliminates condensate overflow caused by trap blockage and negative pressure inside the system;
6. Is not affected by algae growth;
7. Is not affected by condensate evaporation (as are traps);
8. Precludes damage from freezing temperatures;
9. Includes no moving parts; and
10. Is self-cleaning and self-regulating.

18.8.9.7 Unsuitable Installation of Condensate Drain Lines

Condensate drain lines, which extend from the drain seal to the condensate disposal place, can be—and frequently are—the source of serious condensate problems. Drain lines receive less design, installation, and maintenance attention than any component of the HVAC system. As a result, line failures are significant contributors to property damage, equipment damage, and system contamination.

An acceptable drain line is simply one that has adequate flow capacity and offers minimum potential for flow blockage. The critical design factors are basic geometry and the support system for the drain line.

Drain Line Geometry. Unsatisfactory drain line geometry is a common cause of drain line flow blockage that results in condensate overflow problems.

Problem Definition. Small diameter, long and meandering, non-sloped and deflected drain lines are major causes of drain line blockage. Lines that are too small are easily blocked by debris and algae growth. Long lines are more susceptible to flow blockage, because there are simply more places for blockage to occur. Meandering lines with elbows are highly prone to flow blockage. Non-sloped drain lines retain condensate along with debris. Retained or standing condensate supports the growth of algae, which restricts and blocks flow. The effect of drain line blockage, which occurs all too often, is flooding and the overflow of the condensate pan. The consequences are damage to equipment and surrounding property plus contamination of the HVAC unit and the surroundings.

Remedies. The diameter of the drain line must be equal to or greater than the exit diameter of the drain seal device. When more than one HVAC unit drains to a common line, the area of the common line must be increased proportionally, at the downstream point where the additional HVAC drain line enters. The line length should be the minimum possible, following the shortest path to the condensate disposal place (the shorter, the better). And it should include the least possible number of elbows. The line must be sloped away from the drain seal at a rate of *no less* than $^1/_8$ in per ft (1 cm/m).

Drain Line Support. A firm fixed drain line support system is essential to ensure satisfactory condensate drainage.

Problem Definition. Condensate drain lines are often located in areas of high maintenance activity; for example, building roof tops. In this environment, if lines are not securely fixed they can be broken or damaged, by careless personnel, and permit condensate to be drained to unwanted places. Damage to drain lines frequently destroys the condensate drain seal (a very common occurrence). A destroyed condensate drain seal results in all the property damage and contamination problems discussed in Sec. 18.8.9.6.

A fixed support system is also required to ensure that the drain line maintains a satisfactory slope and prevents line defections sufficient to create harmful secondary traps. Any amount of line defection allows condensate to collect at the low point, where it promotes the growth of algae and increases the potential for flow blockage. Deflections greater than one diameter of the drain line create a much more detrimental situation. In systems with a conventional condensate trap, a trap formed by a dip in the drain lines forms an airlock, which will block condensate flow and cause the pan to flood and overflow.

Remedies. To avoid excessive deflection of the drain line, prevent shifting of position, and ensure a satisfactory slope, fixed supports should be provided at distances no less than the following: PVC (Schedule 40 pipe), 2 to 3 ft (0.6 to 0.9 m); copper, 4 to 6 ft (1.2 to 1.8 m). and steel 8 to 10 ft (2.4 to 3 m) intervals.

18.8.10 SYSTEM MAINTENANCE

HVAC systems that are wet, dirty, and contaminated inside are often attributed to poor maintenance. Most often this is not the case. Systems with one or more of the deficiencies defined in Sec. 18.8.9 are commonplace. These deficiencies allow condensate to penetrate into places where successful maintenance is at best impractical.

In new system designs, these deficiencies can be avoided by applying the design procedures provided in Sec. 18.8.2.

In existing systems the remediation procedures outlined in Sec. 18.8.9, System remediation, can rid these systems of the deficiencies that prevent successful maintenance.

In reality, however, it is not practical to design around or remedy the inherent deficiencies and the nonmaintainability characteristics of the condensate trap. Table 18.8.2, prepared in the form of a routine and preventive maintenance program, shows why it is not possible for the conventional condensate trap to provide an acceptable drain seal. In summary, this is because the trap:

1. Requires frequent periodic cleaning to remove algae and debris, in order to prevent condensate flow blockage and overflow, resulting in system contamination and property damage
2. Must be filled with water frequently,
   a. During noncooling periods—e.g., winter—to prevent the ingestion of potentially toxic and noxious gases, and
   b. Prior to each cooling system start-up, to prevent drenching and/or flooding that contaminate and damage the system interior and surroundings
3. Is not suitable for use during winter cooling in outdoor locations where the temperature is below freezing, because of flow blockage and trap destruction.

Although it is possible by routine and preventive maintenance to minimize the damage caused by trap blockage, the procedure is costly, because traps must be cleaned or replaced frequently, requiring a significant maintenance effort.

Overcoming evaporation, which destroys the drain seal, during non-cooling periods and at system start-up time for cooling, places an enormous burden on maintenance personnel. Filling each condensate trap with water, frequently, to avoid gas ingestion, drench

TABLE 18.8.2 Routine and Preventive Maintenance Program for Conventional Condensate Trap

Trap located indoors or outdoors, with outdoor temperatures above freezing

1. Frequency and time of inspection and service:
   (a) For systems that provide summer cooling and winter heating during cooling operation:
   - Annually—at initial system start-up for cooling
   - Semiannually—at initial system start-up and at second system start-up if facility is shut down annually for a week or more, e.g., schools

   During Heating operation:
   - Biweekly, between cooling system shutdown and the beginning of winter heating

   (b) For systems that provide summer cooling and winter cooling
   - Semiannually—at 6-mo: intervals (one inspection must be made at system start-up, following an annual shutdown of facility for a week or more, e.g., schools
2. Maintenance effort required:
   (a) At each annual inspection (and semiannually if need is indicated)
   - Physically remove flow-blocking algae and/or debris, or replace trap
   - Flush with water
   - Treat with EPA approved biocide and
   - Fill trap with water and add biocide tablets

   (b) At each biweekly inspection
   - Fill with water and add biocide tablets if need is indicated.
3. Equipment and material needed:
   (a) Internal pipe scraper
   (b) New trap
   (c) Water hose
   (d) Biocide
4. Estimated time required:
   (a) Annually and semiannually:
   - 5 min per inspection + (25 min travel time to and from maintenance shop and system site)
   - 0 to 60 min per time serviced + (25 min travel time to and from maintenance shop and system site)

   (b) Biweekly:
   - 5 min, per time serviced + (25 min travel time to and from maintenance shop and system site)

Trap located outdoors, with outdoor temperatures below freezing

1. Frequency and time of inspection and service:
   (a) For systems that provide summer and winter cooling and winter heating during cooling operation:
   - Not possible to maintain drain seal with a trap during winter cooling under these conditions—flowing condensate will freeze in trap, block flow, and damage trap

   (b) During heating operation:
   - Not possible to maintain drain seal with a trap during winter heating under these conditions—unless the trap is filled with water, it will not hold a seal and when filled, water will freeze and block condensate flow

problems, and condensate flooding places impractical demands on maintenance organizations, even in indoor locations.

For example, using information in Table 18.8.2, it has been estimated that the maintainance effort for a typical system located indoors—used for both heating and cooling—is about 6 h per year per unit.

In outdoor locations, where outdoor temperatures are below freezing, it is virtually impossible to implement an effective trap filling program. Freezing condensate will destroy the trap, rendering it ineffective until it is replaced and refilled with water. Freeze plugs are of little value; even if they protect the trap, they destroy the seal.

TABLE 18.8.3 Routine and Preventive Maintenance Program for CostGard Condensate Drain Seal located indoors or outdoors, temperatures below or above freezing

1. Frequency and time of inspection and service:
   (a) For systems that provide summer cooling, winter heating, and cooling
   - Annually—during cooling operation, when condensate is flowing
2. Maintenance effort required:
   (a) If condensate is not flowing freely during cooling operation and/or condensate is standing in the pan more than the operating level indicated in Fig. 18.8.3, at drain outlet:
   - Check for debris inside the device. If present, physically remove and flush inside with water
   - Check operating pressures per manufacturer's instructions

   (b) Otherwise, no effort is required.
3. Equipment and Material Needed:
   (a) Water hose
   (b) Pressure gauge
4. Estimated time required:
   (a) Less than 5 min per inspection + (25 min travel time to and from maintenance shop and system site)
   (b) 0 to 30 min per time serviced + (25 min travel time to and from maintenance shop and system site)

The maintainability of the condensate trap can be made feasible by utilizing a water replenishing system and a condensate heating system, to ensure a water-filled trap and prevent freezing in outside locations. This does not, however, eliminate all the maintenance problems of the conventional trap and it introduces others. The system is subject to the same trap blockage from algae growth and debris, as is the conventional trap. In addition, both the water replenishing and the condensate heating systems require some type of control and usually utilize moving parts. Such systems require appreciable maintenance, which is often much too great for a practical drain seal.

The fluidic flow control device identified under Sec. 18.8.7 provides an effective and reliable drain seal, which eliminates all the problems caused by the condensate trap, and is virtually maintenance free.

Table 18.8.3 shows a routine and preventive maintenance program for the CostGard condensate drain seal. As shown, the projected maintenance effort is small. The only effort for which a finite time is stated is that for scheduled inspections. Experience shows that the time required for servicing these systems is minimal. The estimated time for maintenance service varies from zero to a few minutes. Accordingly, in any particular installation, maintenance experience may indicate that the inspection and service frequencies stated in the table can be decreased significantly, thus reducing the effort and cost.

18.8.11 LEGIONNAIRES' DISEASE: PHILADELPHIA REVISITED

18.8.11.1 Background

More than a quarter century has passed since 34 persons died from Legionnaires' disease allegedly contracted in a Philadelphia hotel. In an effort to find the cause of this catastrophe, federal, state, and local agencies launched one of the most extensive investigations in medical history. The best public documentation of what went on during the investigation is provided in the records of U.S. Senate and U.S. House of Representatives Hearings (Refs. 15, 16) on Legionnaire's disease.

Somewhere between 100 and 200 medical professionals participated in this investigation, for a period of several months. Because most of the investigative effort went into searching for what infected the victims, that is what was found. About five months after the outbreak in Philadelphia, the culprit was identified. It was a very tiny bacterium discovered, in pathologic specimens taken from victims, by Dr. Joseph McDade of the U.S. Center for Disease Control (CDC), Atlanta. The bacterium was named *Legionella* and legionellosis became the medical name of the disease.

It was also determined that *Legionella* causes illness only when it penetrates to the deep portion of the human lungs. For this to happen, it was concluded that the bacteria must be airborne in an aerosol, likely in very small water droplets.

From the viewpoint of medical science, the discovery of *Legionella* was clearly a brilliant achievement and a major success for the medical profession. Unfortunately, in the Philadelphia investigation, **the source of the Legionella was never determined and the spreading mechanism was not identified**.

Thus, a remarkable research effort and discovery has done little in terms of human health benefits and lives saved. The following statement from the January 1997 issue of the *ASHRAE Journal* (Ref. 17, p. 27) well summarizes the current situation:

"Despite two decades of ever increasing information about many aspects of legionellosis, the disease seems to be as common as ever producing tens of thousands of cases and thousands of deaths each year."

In outbreaks of legionellosis—following the discovery of *Legionella*—of which there have been many, the bacteria have been found somewhere at most of the affected sites. Cooling towers and potable water systems, because they are frequently contaminated with legionellae, are often alleged to be the source of the bacteria. However, how the bacteria are spread from these sources to the victim's lungs is not at all clear. In some instances, it has been postulated that *Legionella* aerosolized in cooling towers was airborne for several hundred meters, where it resulted in human illnesses and deaths. Still, other observers contend that the aspiration of water from potable water systems is the primary mode by which legionella is spread. Neither of these arguments is very convincing.

18.8.11.2 Missing Information

In the Philadelphia investigation, little attention was given to the role of the air handlers, as the possible source of the bacteria and as the mechanism for spreading them. Reports of the investigation defined only the location of the air handlers, type of refrigerant used in the systems, type of air filters in each unit, location of the water chilling equipment, and the source and approximate percentage of outside air used by each unit.

The details necessary for assessing how the air handlers could contribute to the growth and spread of the disease causing agents were not sufficiently defined, or at least not in public documents. For example, nothing was reported regarding the following important factors: Type and size of air handlers; geometry of the cooling coils; the geometry, condition, and contents of the drain pans; and the type of drain traps (seals), if any. Although samples of water for testing were taken from the chiller system, potable water system, and cooling towers, there is no evidence that condensate samples were taken from the drain pans of the air handler.

18.8.11.3 Hindering Myths

Despite the obvious potential for contamination inside an air handler, two industry myths have hindered critical investigation of air handlers as the source of legionellosis outbreaks.

These myths are (1) the conditions inside air handlers, including the condensate drain pan, will not support the growth and proliferation of *Legionella* and (2) there is no mechanism for creating the aerosol necessary for transporting the bacteria. Contrary to these myths, examination of available information suggests that air handlers were indeed the likely source of legionellosis outbreaks in Philadelphia, as well as at others locations.

Myth 1. Legionella cannot grow and proliferate in condensate drain pans. The first myth is that *Legionella* cannot grow and multiply in a condensate drain pan because the water temperature is too low. While the growth rate of *Legionella* is found to be greatest in water where the temperature is near 98.6°F (37°C) (Ref. 18), it survives at much lower temperatures. In fact, legionella has been found, in water at temperatures varying between 42°F and 145°F (5 to 70°C) (Ref. 3, p. 168) and it will grow and multiply at temperatures as low as 60°F (7°C) (Ref. 3, p. 300).

Legionella can be found almost anywhere there is water and suitable nutrients (e.g., dirt and biological growth). Its presence has been reported in numerous places, including the following: cooling towers, humidifiers, evaporative condensers, evaporative coolers, condensate drain pans, water fountains, spas, potable water systems, outdoor ponds, ice makers, and many other places (Ref. 18, p. 19).

In a typical air handler, operating at design conditions, the temperature of the air leaving the cooling coil is near 55°F (14°C). Under these conditions, the temperature of condensate in a free flowing drain pan is about 60°F (15°C). However, under part-load conditions, condensate temperatures change markedly. When coolant flow is reduced in response to reduced cooling loads, the temperature of the condensate will increase. Under such conditions, condensate temperatures of 70°F have been measured. *Legionella* is said to proliferate between 68°F and 113°F (Ref. 20).

The growth-rate of the *Legionella* bacteria is relatively low in water at temperatures of 60°F to 65°F. However, in the presence of iron (e.g., rusty pans) the growth-rate may increase more than 100 times (Ref. 3, p. 4). Accordingly, even at relatively low temperatures, there is a potential for high growth-rates and great concentrations of *Legionella*, in drain pans of air handlers. Thus, among the millions of HVAC systems in this country, many are undoubtedly infested with high concentrations of legionellae.

***Myth 2. There is no mechanism present to aerosolize and spread* Legionella.** The second myth stems from the assumption that the only mechanism present for generating an aerosol inside the air handler is the conditioned air flowing over the surface of the condensate in the drain pan. Typically, this velocity is no greater than 600 ft per minute (fpm). According to the Kelvin-Hemholtz instability limit (Ref. 3, p. 51), water will not be aerosolized from the surface until the velocity reaches 1400 fpm (7 m/s). Thus, it can be correctly concluded that the 600 fpm is too low to create an aerosol.

There is, however, another means, not widely recognized, whereby condensate in the drain pan can be and frequently is aerosolized. It is common to draw-through air handlers—the most common type used in public, commercial, and industrial applications. In this type system the static pressure inside the drain pan is always negative. Unless the condensate drain ports are equipped with seals, air will be ingested. And during operation, the level of the condensate will rise in the pan and the velocity of the entering air can entrain and aerosolize the condensate. The negative pressure in condensate drain pans varies among systems. Typically, these pressures range from about –0.50 to –5.00 in of water column (in wc). Without a seal on the condensate drain line, water will stand in the pan at about 0.50 and 5.00 in, respectively. For these conditions, the velocity of the air entering the drain port will vary from about 2000 fpm (23 mph) to about 6200 fpm (70 mph), respectively.

Figure 18.8.23 shows how the negative pressure inside the drain pan compartment affects the velocity of the entering air, when no seal is present or when the seal (usually a

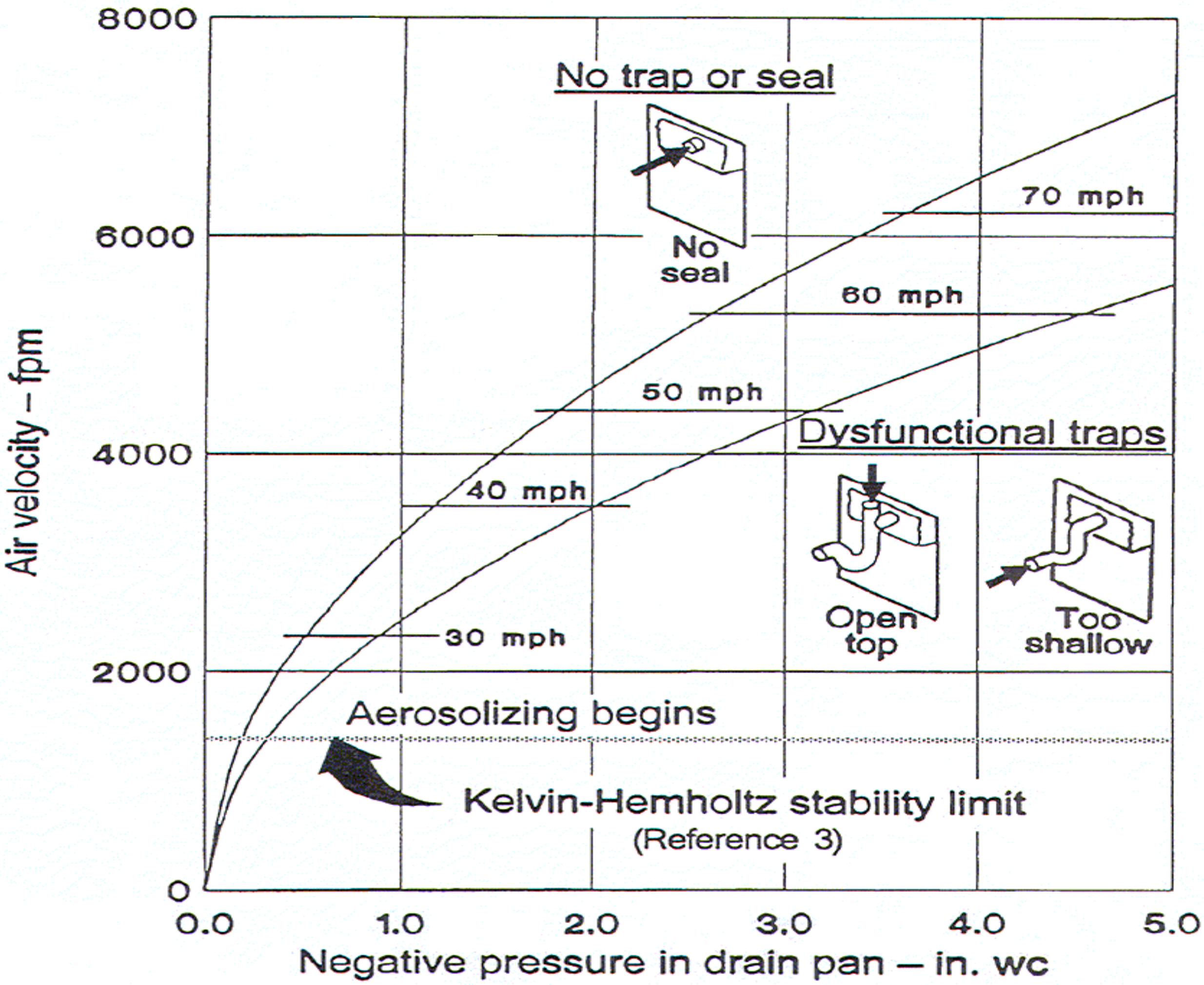


FIGURE 18.8.23 Velocity of air entering the condensate drain pan through a missing or dysfunctional trap.

condensate trap) is dysfunctional. As shown here, for a range of operating pressures, the air velocity in both cases is well above that where aerosolizing begins. Systems operating without adequate drain seals are common, nationwide.

18.8.11.4 Aerosol Generation

Condensate in a drain pan of a draw-through HVAC system will usually be aerosolized whenever the system is operated without a drain seal or with a dysfunctional trap. The seriousness of the condensate trap problem has been known to qualified professionals for years. In fact, in 1999 a statement to this effect was included in the informative language in BSR/ASHRAE Standard 62–1989R (Ref. 10). It reads as follows:

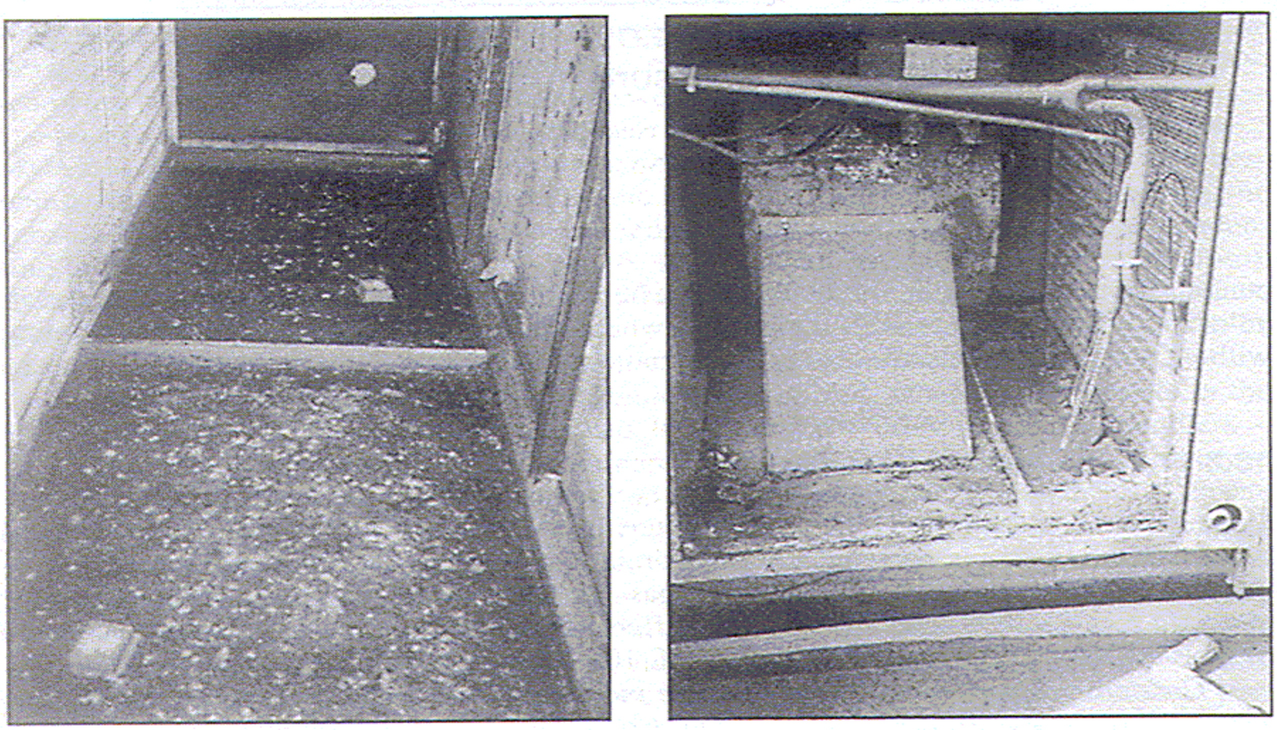
"*Condensate traps exhibit many failure modes that can impact on indoor air quality. Trap failures due to freeze-up, drying out, breakage, blockage, and/or improper installation can compromise the seal against air ingestion through the condensate drain line. Traps with insufficient height between the inlet and outlet* [poor design] *on draw-through* *systems can cause the drain to back-up when the fan is on, possibly causing drain pan overflow or water droplet carryover into the duct system. The resulting moist surfaces can become sources of biological contamination. Seasonal variations, such as very dry or cold weather, may adversely affect trap operation and condensate removal."*

These hazardous conditions are readily observable by anyone interested enough to visit and inspect the air handlers in almost any public, commercial, or industrial facility. Examples of what to expect during such a visit are depicted in Figure 18.8.24. Generally, these air handlers will be of the draw-through type, operating without adequate drain seals—no traps or dysfunctional traps—on the condensate drain lines.

During the past ten years we have visited scores of public, commercial, and industrial facilities in the central and southern parts of this country. And we have inspected hundreds of HVAC systems during the cooling seasons. With very few exceptions, the systems were of the draw-through type. Most were wet, dirty, and visually contaminated inside with various forms of biological growth, due to no seal or a dysfunctional trap. The wetness of internal walls and air supply ducts, which was frequently observed, attests to the fact that air entering the drain port was blowing and aerosolizing the condensate.

Others have reported similar conditions. For example, one report of a NIOSH investigation included the following comment: "*In a building where the air handling units' fans were down-stream from 'chiller' decks,* [draw-through systems] *stagnant water had spawned thick layers of microbial slime* (Ref. 20)." Almost certainly some of the air handlers in the Philadelphia hotel were in this condition.

Contrary to what many in the industry contend, these conditions are not the result of poor maintenance. They are, instead, the result of system design deficiencies—primarily the use of the condensate trap. Under the most favorable conditions, satisfactory maintenance of a conventional condensate trap is neither realistically feasible nor practical. Under other conditions, satisfactory maintenance is virtually impossible. The maintenance effort



(a) Drain pan - large air handler (b) Drain pan - packaged hvac unit

FIGURE 18.8.24 Common conditions of drain pans—rusty and contaminated.

required for maintaining a condensate trap is summarized in Sec. 18.8.10. Evidently, no such maintenance program was in place at the Philadelphia hotel.

In view of the deplorable conditions of air handler drain systems, which have prevailed in the field for years, the potential for the widespread growth and aerosolizing Legionellae is obvious. Under such conditions, the illnesses and deaths of thousands from legionellosis should surprise no one.

18.8.11.5 The Philadelphia Story

Despite the discovery of *Legionella*, the results from the extensive Philadelphia investigation provides little help in determining the source and in reducing the number of persons affected by legionellosis. However, the evidence is strong and consensus is that exposure to the bacteria occurred in the hotel lobby and that transmission was by air. Hence, the air handler serving the center of the lobby is strongly implicated.

Comments reported in the senate hearings (Ref. 16) support this observation. For example, hotel staff members reported periods of "*poor flow of cooling air*" during the investigation. Also, in the same document, it was reported that, "*The dysfunction of the air handling system that serves the center of the lobby two weeks after the convention might indicate that the system was working imperfectly earlier.*"

In addition to the above comments, there are other factors that point to and implicate the air handler serving the lobby. This air handler had been in operation for 22 years. Like air handlers of this vintage, it likely exhibited several characteristics that are conducive to the growth and spreading of legionellae. That is, it almost certainly (1) was the draw-through type; (2) depended upon a condensate trap to prevent air ingestion and permit condensate drainage; and (3) incorporated a large, deep drain pan, constructed of common steel.

Draw-through systems inherently create a negative pressure in the drain pan area. As stated in ASHRAE Standard 62-89R, quoted above, the condensate trap is subject to numerous failure modes, which frequently destroy the drain seal. When there is no seal on the drain line, the negative pressure holds backs the condensate and causes it to stand in the pan. The air rushing through the dysfunctional trap at high velocity entrains and aerosolizes the condensate. The standing and stagnant condensate enriched with iron from a rusty steel drain pan form a fertile place for the growth and proliferation of legionellae. Once the contaminated condensate is aerosolized inside the air handler, the bacteria are swept quickly into the conditioned space. The transmission is thorough and complete, since all the air in a conditioned space, typically, passes through the air handler 5 to 10 times per hour. All these conditions were likely present in the air handler serving the central lobby of the Philadelphia hotel.

Figure 18.8.25 shows a sketch of the envisioned air handler configuration, and its location relative to the hotel lobby. It also summarizes the likely conditions of the air handler and the conditioned space. The proximity of the air handler to the lobby ensures that contaminates from the air handler enter the lobby in high concentrations. One could hardly visualize more favorable conditions for spreading the legionellae bacteria.

18.8.11.6 Eliminating the Source of Legionellosis

Legionellosis is a serious life threatening disease. The discovery of *Legionella* has done little, or nothing, to reduce the incidence of this terrible malady. It has been estimated that about 8000 to 9000 persons in the United States die annually from this disease (Ref. 17, p 22). Efforts to reduce the number of victims have been remarkably unsuccessfully, ostensibly, because the real sources of legionellosis have not been identified. Even so, there is

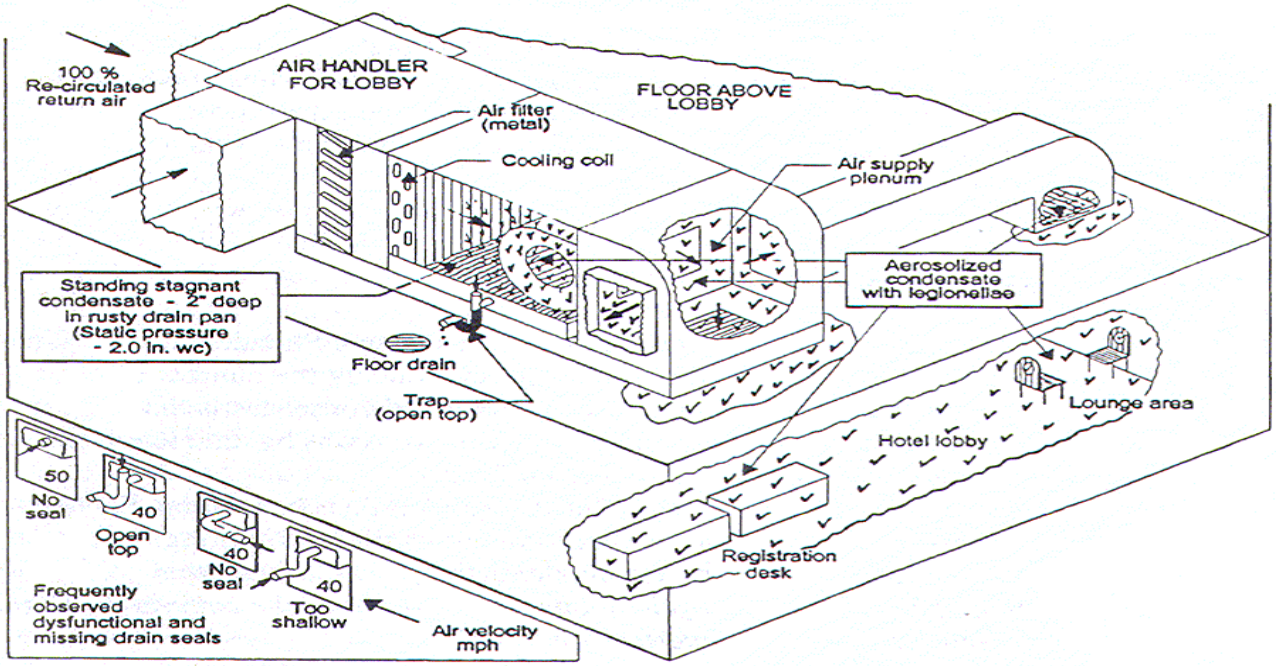


FIGURE 18.8.25 Envisioned features and condition of the air handler serving the central area of the hotel lobby.

no concerted effort, within the industry, to find the sources of the disease. An investigative effort comparable to that being devoted to leukemia (about 11,000 deaths annually) or that devoted to investigating airline crashes (an average of much less than 200 causalities annually) could well identify the source and virtually eliminate these deaths in a short period of time. A comprehensive engineering program plan for defining and eliminating sources of legionellosis is long overdue.

In the meantime immediate action should be taken, on both new system designs and on systems now in operation, using what is already known. For example, we know that *Legionellae* are everywhere. They are often present in condensate drain pans. They thrive in standing contaminated water, grow in condensate at temperatures common to drain pans, and their growth is accelerated many fold in the presence of iron (rusty pans).

Drain pans constructed of stainless steel or of other non-corrosive material can virtually eliminate iron as a factor. Sloped drain pans can prevent condensate puddles and local stagnation. But neither is a remedy for standing, stagnant condensate and the aerosolizing action caused by dysfunctional condensate traps.

Aerosolizing of condensate from drain pans can be prevented in different ways. In the design phase, one way is to select air handlers in which the drain pan is placed under positive pressure, instead of negative pressure (draw-through systems). This, of course, is not possible for the millions of draw-through systems now in service. For these and newly designed draw-through systems, the obvious remedy is an effective and reliable condensate drain seal. The commonly used condensate trap meets neither of these criteria. In fact, the condensate trap is the current problem, not the remedy. In some applications, the condensate pump can effect suitable condensate removal and provide a seal against air ingestion. However, it also exhibits many failure modes, which render it unreliable.

An effective drain seal, for draw-through systems, is essential to preventing stagnant condensate and to eliminating aerosolizing as a source of legionellosis. But an effective drain seal does much more for indoor air quality. It precludes the ingestion of outside air or other gases, when the trap is dry, and therefore prevents contaminates such as sewer gas and carbon monoxide from being drawn into the system. It also prevents flooding at start-up for cooling, when the trap is empty. In addition, by preventing the aerosolizing of condensate, an effective drain seal removes the primary source of internal system wetness. In so doing, it eliminates the accompanying biological growth, which contaminates HVAC components and supply air ducts. This virtually removes the draw-through HVAC system as a contributor to Sick Building Syndrome and Building Related Illness.

In the interest of their clients and building occupants as well as themselves, system designers would be well advised to place increased emphasis on finding an effective and reliable drain seal for draw-through HVAC systems. Clearly, providing an effective drain seal is as important, if not more important, as is providing suitable air ventilation and acceptable humidity control. It therefore warrants equal consideration by the designer.

The mechanics of fluid flow associated with draining condensate from the drain pan of a draw-through air handler are not simple. Nevertheless, system designers should have the basic technical understanding needed to evolve or select a suitable drain seal for the draw-through systems they design. The conventional condensate trap is simply not an acceptable option.

The design and selection of condensate drain seals is treated in Sec. 18.8.2. It reviews traps, condensate pumps, and defines one new drain seal, which is effective, reliable, and suitable for draw-through systems. Ingenious designers may, of course, evolve other equally suitable drain seals.

18.8.11.7 Conclusions

There is a critical need for effective and reliable condensate drain seals for draw-through HVAC systems. In fact, it is safe to say that the spread of legionellosis will not be diminished, nor will Sick Building Syndrome and Building Related Illnesses be reduced appreciably, until draw-through HVAC systems are equipped with effective and reliable drain seals. Moreover, until then, we cannot be assured that another outbreak of legionellosis, like the one in Philadelphia, will not occur.

18.8.12 FLUIDIC FLOW CONTROL—BLOW-THROUGH DRAIN SYSTEMS

In blow-through type HVAC systems, unlike draw-through systems, the fan blows air through cooling coils, creating a positive pressure (above ambient) in the drain pan. The positive pan pressure is favorable to condensate removal, and ingestion of outside air through the drain line is not possible. But, the control of condensate flow is essential. And, as with draw-through systems, a condensate trap is unsuitable for this purpose. This is because it is subject to dry trap syndrome, trap flow blockage, and freeze-up in outside locations.

During noncooling periods when the trap is dry (dry trap syndrome), a relatively large quantity of air may be discharged through the trap. Depending upon the drain size, this could compromise somewhat the overall efficiency of the HVAC system.

In addition, during start-up for cooling—with an empty trap—the discharged air often reaches velocities sufficient to entrain condensate in droplet form and spread it to unwanted places. The velocity at which condensate begins to entrain is about 1400 ft per min (fpm) (430 m/min). The velocity of the air discharged from an empty trap is usually much above that value. For example, at a pan pressure of 1 in (25 mm) of water, (near a minimum value found in practice) the air velocity of discharge is about 2500 fpm (780 m/min). At 5 in (12.5 cm) of water, the velocity approached 6000 fpm (1800 m/min) (near hurricane velocity). At best, the resulting wetness creates a nuisance and at worst it may cause wet floor accidents, property damage, and contamination of local surfaces.

Like a trap on a draw-through system, the trap also collects debris and supports algae growth, which cause frequent flow blockage, condensate pan overflow, and associated damage.

In cold climates, traps placed in outside locations can be damaged by freezing temperatures and their effectiveness destroyed, thus producing an empty trap and all the problems discussed above.

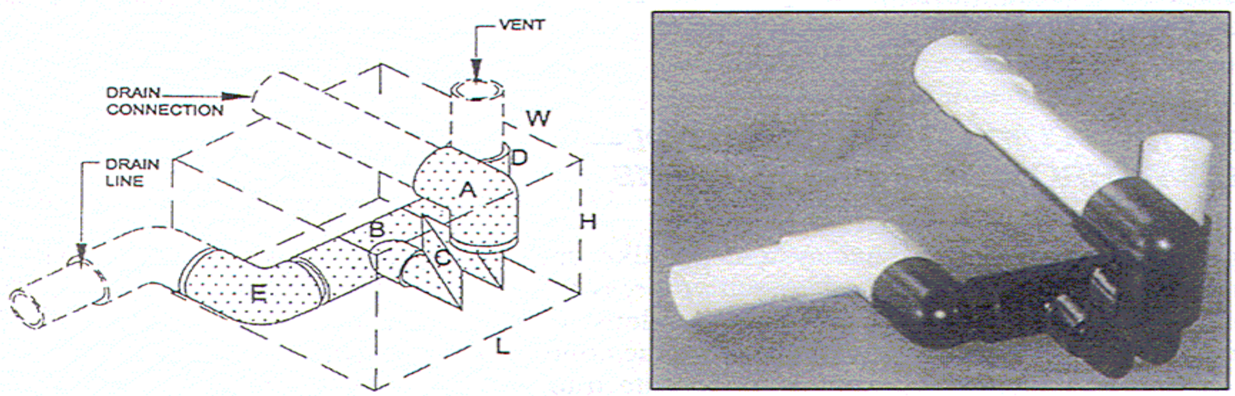
The fluidic flow control device negates or eliminates the problems created by the condensate trap.

An isometric drawing, a photograph, and the characteristics of the fluidic flow control device for blow-through systems are shown in Fig. 18.8.26.

Referring to Fig. 18.8.26, the device operates as follows: Condensate and air (two-phase flow) leaving the drain pan enters part A of the fluidic flow control device. Both fluids then pass through the mitered elbow array, into part B. From there, the condensate and a portion of the air pass into part E and on to the condensate disposal place. The remainder of the air passes into part D and out through the vent.

As the fluids pass through the mitered elbows, there is little resistance to condensate flow. Indeed, condensate flow is accelerated by the air flow and flows freely through the device. At the same time these elbows restrict airflow such that the velocity leaving the unit is far too low to cause entrainment and blowing of condensate. In addition, the air turbulence in the mitered elbows creates a scrubbing effect, which prevents blockage by debris and algae growth.

PRODUCT CHARACTERISTICS



MODEL NUMBER	HVAC CAPACITY	PAN PRESSURE LIMIT	DIMENSIONS			DRAIN DIAMETER
			L	W	H	
B20-12-30	to 30 tons	2 in. wc	6.5"	5.5"	3" to 5"	3/4" to1-1/4"
B45-20-30	to 100 tons	5 in. wc	8.0"	8.0"	3" to 10"	1.0" to 2.0"
			Other orientations are possible			

FIGURE 18.8.26 Fluidic flow control device for blow-through systems.

Two models of the fluidic flow control devices are available. Together, they can accommodate systems with cooling capacities up to 100 tons, and with positive pressures up to 5.0 in (12.5 cm) of water column. The table in Fig. 18.8.3 summarizes the performance and geometric characteristics of the fluidic flow control device.

REFERENCES

1. Unpublished test data from the Department of Mechanical Engineering, University of New Orleans and Trent Technologies, Inc. laboratory, July, 1996.
2. 1999 ASHRAE 62-1999, Ventilation for Acceptable Indoor Air Quality, © American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc., www.ashrae.org, Para. 5.4.
3. G. W. Brundrett, *Legionella and Building Services*, Butterworth-Heinemann Ltd., London, 1992.
4. E. M. Sterling, A. Arundel, and T. D. Sterling, "Criteria for Human Exposure to Humidity in Occupied Buildings," *ASHRAE Transactions*, Vol. 91, Part B, 1985, pp. 611–622.
5. *Fans and Systems*, AMCA publication 201-90, Air Movement and Control Association, Arlington Heights, IL, 1990, p. 47.
6. "Industrial Ventilation," *A Manual of Recommended Practice, 22nd ed.*, American Conference of Governmental Industrial Hygienists, USA, 1995, pp. 3-6–3-8.
7. 2001 ASHRAE 62-2001, Ventilation for Acceptable Indoor Air Quality, Addendum 62t, © American Society of Heating Air Conditioning Engineers, Inc., www.ashrae.org, Para. 5.11.3.
8. W. Trent and C. Trent, "Indoor Air Quality and the Condensate Trap," paper presented at the Ninth Symposium on Improving Indoor Air Quality in Hot and Humid Climates, Arlington, Texas, May 19–20, 1994.
9. J. Cummings et al., "Uncontrolled Air Flow in Non-Residential Buildings," Final Report FSEC-CR-878-96, Florida Solar Energy Center, Cocoa, FL, April 15, 1996, pp. 14–15.
10. 1996 BSR/ASHRAE 62-1989R, Ventilation for Acceptable Indoor Air Quality, © American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc., www.ashrae.org, Para 5.6.
11. W. C. Trent, "The Condensate Trap: A Costly Failure," *Air Conditioning, Heating, and Refrigeration News*, Feb. 21, 1994, p. 3.
12. W. Trent and C. Trent, "Consideration in Designing Drier, Cleaner HVAC Systems," *Engineered Systems*, Aug. 1995, p. 38.
13. T. C. Ottney, "Particle Management of HVAC Systems," *ASHRAE Journal, 35*, American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc., Atlanta, GA, July 1993, pp. 26–34.
14. 2000 ASHRAE Handbook-HVAC Systems and Equipment. © American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc., www.ashrae.org, p. 24.11, Table 3.
15. U.S. Senate, *Hearings before the Subcommittee on Health and Scientific Research of the Committee on Human Resources, 95th Congress, 1st Session on Follow-Up* Examinations on Legionnaire's Disease, November 9, 1997.
16. U.S. House of Representatives, *Hearings before the Subcommittee on Consumer Protection and Finance of the Committee on Interstate and Foreign Commerce, 94th Congress, 2nd Session*, November 23 and 24, 1976.
17. J. Millar, G. Morris, and B. Shelton, "Legionnaire's Disease: Seeking Effective Prevention," *ASHRAE Journal*, Jan. 1997.
18. ASHRAE, *Legionellosis: Position Paper*, ASHRAE, Atlanta, GA, June 25, 1998.
19. J. Coleman, "Considerations to Prevent Growth and Spread of Legionella in HVAC Systems," *American School and Hospital*, June 1999.
20. V. Bishop, D. Custer, and R. Vogel, "The Sick Building Syndrome: What It Is and How to Prevent It," *National Safety and Health News*, Dec. 1985.