DEHUMIDIFICATION ENHANCEMENTS for 100-Percent-Outside-Air AHUs

Recuperative heat exchange is an energy-efficient way to accomplish reheat while also reducing cooling capacity

Author's note: While this series of articles (Part 1 appeared in the September 2000 issue of HPAC Engineering*) is written from a 100-percent-outside-air standpoint, most of the dehumidification technologies are applicable to systems that handle both outside air and return air.*

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Recuperative heat exchange is a universal technology applicable to vapor-compression, direct-expansion, and chilled-water air-handling-unit (AHU) coils; heat-powered desiccant-dehumidification equipment; dehumidifiers; supermarket, ice-rink, and natatorium air-conditioning and dehumidification systems; and packaged 100-percent-outside-air conditioners.

This installment discusses five types of recuperative sensible-heat exchangers that are used to prevent overcooling while still meeting the dehumidification needs of a conditioned space. The energy aspects of this technology are explained in great detail. The reason for this is that many owners and designers are under the incorrect assumption that there are no penalties associated with the use of hot-gas or condenser-water reheat. This is not to say that one should always use some form of recuperative heat exchange in preference to hot-gas or condenser-water reheat. It simply is to say that owners and designers should be aware that there is a more energy-efficient way to accomplish reheat while also reducing the required cooling capacity.

Also addressed in this installment are the four penalties associated with ordinary "new-energy" reheat and a technology that is used to avoid one of those penalties: reheat using hot refrigerant gas.

RECUPERATIVE DEHUMIDIFICATION

Recuperative-dehumidification enhancements are good solutions for 100-percent-outside-air cooling units. Five such enhancements are:

1) Coil-loop run-around precooling and reheating coils (water or glycol).

2) Heat-pipe run-around precooling and reheating coils.

3) Air-to-air flat-plate heat exchangers for precooling and reheating.

4) Rotary-wheel heat exchangers for precooling and reheating.

5) Refrigerant liquid subcooling/air-reheating coil.

Each of the first four enhancements involves one heat-transfer device located upstream from the main cooling coil and one heat-transfer device located downstream from the main cooling coil. The upstream device precools air as it enters the main cooling coil, while the downstream device reheats the air by the same enthalpy change as it leaves the main cooling coil. Other than a small increase in fan energy to overcome the added air friction of the precooling and reheating sections and a fractional-hp pump for the coil-loop enhancement, no external energy is used. (If the heat-transfer devices are active for only a small portion of the annual operating hours, consider bypass dampers to reduce the annual energy impact.)

The first four enhancements can be applied to any type of primary cooling coil: chilled water, chilled glycol, or refrigerant. If the primary coil is of the refrigerant type, then the performance of the refrigeration system must be verified at mild- and cool-weather entering-air conditions to ensure that the refrigeration system will operate without compressor cycling or liquid slugging and with proper oil return. Suction temperatures above 30 F are necessary to prevent frost or ice accumulation on the main cooling coil.

The performance of 100-percent-outside-air recuperative-dehumidification enhancements varies from a maximum temperature change at peak cooling conditions to no temperature change at an outside temperature of approximately 50 F. This performance usually is acceptable because the latent load of the outside air declines with outside temperature.

Applications must be analyzed to determine if additional reheat (from hot refrigerant gas, electric heating coils, thermal heating coils, or in-space heat sources) is required to maintain acceptable space conditions. Supplementary reheat coils, if required, must be located downstream from the recuperative-dehumidification reheat coil.

Heating, recuperative-reheat, and conventional reheat coils must be separated from the main cooling coil to allow condensed moisture to drain

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from the main cooling coil without being re-evaporated by radiant or conducted heat. The main cooling coil must be selected at a coil face velocity at least 150 fpm below the maximum cataloged face velocity to ensure that moisture does not carry over onto a reheat coil (liquid water carryover onto an active reheat coil results in additional energy consumption and humidification).

AHU fans and motors (if the motor is in the air stream) should be located downstream from the recuperative-reheat system for optimum effectiveness. If a supplementary reheat coil is used and its leaving-air temperature is above 100 F, then the fan motor must be

Ordinary Reheat

Ordinary reheat is not an efficient technology. It is included here to establish a basis of comparison for dehumidification technologies that are more energy-efficient.

To comprehend the advantages of "enhanced" dehumidification systems, it is vital that owners and HVAC designers understand the four penalties of ordinary-reheat systems, which are:

1) The first cost of the cooling-generation plant, associated auxiliaries, and electrical service is increased.

2) The first-cost premium of reheat coils includes increased electrical service and/or heating-distribution piping.

3) The owner pays the annual operating cost of the additional sensible cooling of air.

4) The owner pays the annual operating cost of reheating air.

Although ordinary reheat may be necessary as a final supplement to other forms of reheat, it should not be used alone or first as a means of humidity control.

Review applicable building-energy codes prior to designing or installing a "new-energy" reheat system. Reheat systems using "new" energy are restricted under many states' building-energy codes.

Figure 1 is a psychrometric chart for a room with a 12-ton sensible-heat gain, a 7.7-ton latent-heat gain (87 lb or 84 pt of water per hr), a 19.7-ton total-room heat gain, a 60-percent sensible-heat ratio, and 5000 cfm of outside air, which equates to a 21-ton outside-air load. The grand-total load is 40.7 tons, assuming that the HVAC equipment can condition 10,000 cfm of air to a 62-F dry bulb (DB) temperature and a 49-F dew point (DP).

Unfortunately, the constraints associated with the physics of cooling and dehumidifying air result in a cooling coil with a 50-F DB temperature and a 49-F DP. Although air at this temperature has enough moisture to absorb 87 lb of water vapor per hr, the 50-F air will overcool the space, causing the thermostat to shut off the cooling and stop further moisture removal. To absorb both the sensible and latent (moisture) gains of the space, an ordinary-reheat system must utilize 39 kW of reheat. This 39 kW causes an 11-ton increase—from 40.7 to 51.7 tons (39 kW [3412 Btu per kWh] / [12,000 Btu per ton-hr] = 11.09 tons)—in the grand-total cooling load. At an incremental cost of $550 per ton, the 11-ton increase adds $6050 in first cost (penalty No. 1).

The other three penalties associated with ordinary reheat for this example are:

- The 39-kW reheat coil (assuming electric) requires electrical circuits and possibly an incremental increase in switch-gear and distribution equipment. At an incremental cost of $50 per kW, this adds $1950 in first cost.
- If the reheat coil is energized for dehumidification purposes 1500 hrs per year, an annual operating penalty of $3510 will result, assuming an average electricity cost of 6 cents per kWh.
- The cooling-generation plant must produce an additional 16,634 ton-hrs of cooling per year, which results in an annual operating penalty of $998, assuming an average electricity cost of 6 cents per kWh and a plant cooling factor of 1 kW per ton.

The load in this example could be managed with either of the following technologies: (1) vapor-compression (mechanical) cooling and reheat or (2) drying with a desiccant followed by cooling. At dew-point temperatures above 45 F, cooling with reheat generally is preferred to desiccant dehumidification because of the lower first cost, simplicity, longer life, and nearly equal or lower operating cost.

It is important to note that actual annual operating costs could double or triple, particularly if the electric-rate structure involves high demand charges or ratchet provisions.

The preceding analysis did not include the costs of additional cooling-coil heat-transfer surface, the reheat coil, or the additional fan energy required because of extra air friction. Although these should be included in a detailed analysis, they were omitted here for clarity and because enhanced-dehumidification options also involve additional heat-transfer elements and associated air friction.

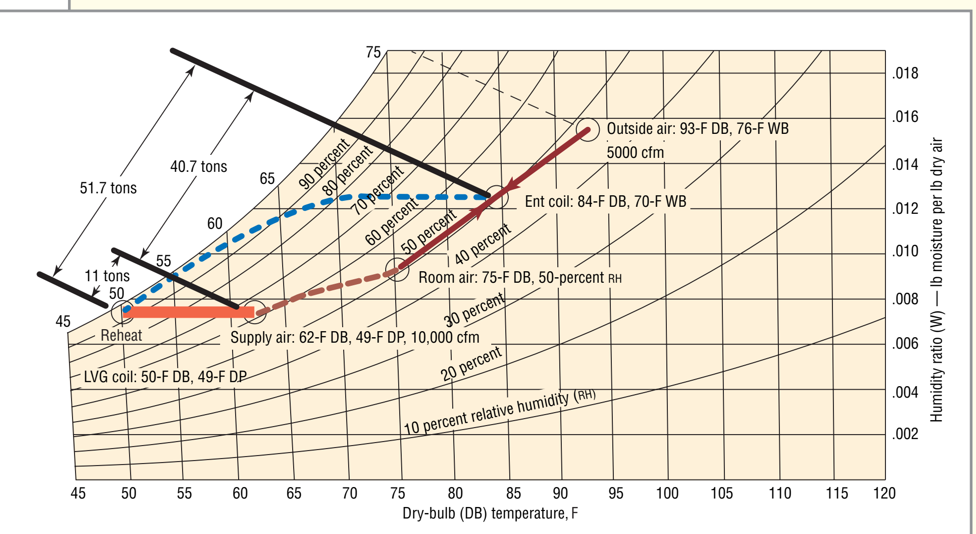

FIGURE 1. Psychrometric chart of a reheat system.

selected for reliable operation at the actual temperature conditions at the motor. It may be necessary to derate the motor and use Class F or H high-temperature motor-winding insulation. Special motors are not required for recuperative-reheat systems not equipped with supplementary reheat coils.

Because of the possibility of moisture condensing on precooling heat-transfer surfaces during part-load operating conditions, provisions for collecting and draining condensate must be made. Heat-exchange surfaces will accumulate particulate even with well-maintained filters. Surfaces should be accessible and cleanable without difficulty or high cost.

The fifth recuperative-dehumidification enhancement is superior to the other four in many respects because it achieves almost the same result with a single coil located downstream from the main cooling coil. The single coil reduces first cost, halves the air-side friction of the recuperative elements, and requires no space or modifications upstream from the main cooling coil.

With the fifth enhancement, which is applicable only to systems using refrigerant coils served by compressors, the amount of reheat is limited. If a significant temperature rise is required, this enhancement may need to be combined with one of the other four.

Details on each of the five recuperative-dehumidification enhancements follow.

COIL-LOOP RUN-AROUND PRECOOLING, REHEATING

Run-around coils for enhanced-dehumidification systems are not a new technology. They are well-described in texts from as long ago as 1939.[1,2,3,4]

The psychrometric-chart analysis of run-around coils for precooling and reheating is identical to that for ordinary reheat (see sidebar) with one exception: The precooling coil cools the entering air from 84- to 72-F dry bulb (DB); therefore, the air entering the main cooling coil is cooler, which means that the main cooling coil does not have to remove as much heat. The reheat is provided not by an external source of expensive energy, but by the heat picked up by the circulating fluid

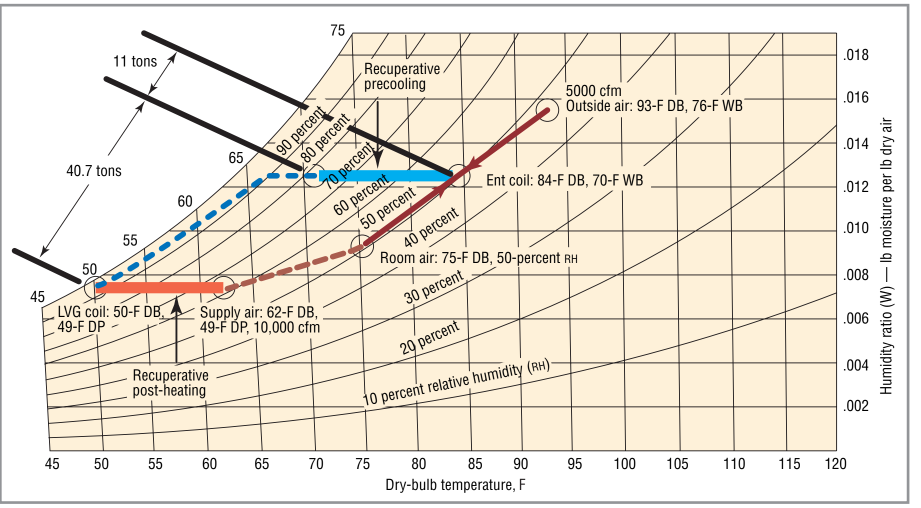

FIGURE 2. Psychrometric chart of a recuperative reheat system.

in the precoil. The cycle and savings are illustrated in Figure 2.

Figure 3 is a piping diagram showing that run-around coils require a small closed-loop piping system. When freezing is a possibility, the heat-transfer fluid is dilute ethylene glycol; at other times, it is water. The system requires a means of fluid makeup. A diaphragm compression tank normally is installed for fluid expansion. If water (not glycol) is used as the circulating fluid and chilled-water or heating-hot-water lines are in the vicinity, it is possible to achieve fill and fluid expansion with a ⅜-in. connection to the

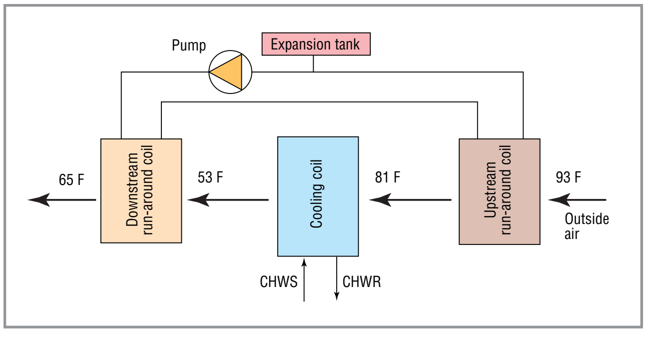

FIGURE 3. Run-around-coil piping.

chilled-water or heating-hot-water closed loop. The expansion of the fluid in the small run-around system then would be provided by the fluid-expansion equipment in the larger system. With only a single connection between them, there can be no flow between the two systems except for that induced by density forces of water at different temperatures.

The system requires a fractional-hp pump, electrical service, and controls. The recommended pump for the circuit is a 120/60/1 hermetically sealed pump that does not require a shaft seal. If a pump with a seal is used, the seal should be mechanical rather than packed to minimize or eliminate leakage. The closed-loop piping system is close-coupled and confined to the immediate vicinity of the two coils. Once the circulating fluid is charged into the system, there is little possibility of leakage; therefore, the fluid-makeup system can be a hose connection or a funnel fill valve. Coils and piping must include manual air vents at high points to vent air at the time of initial filling.

The piping connections to each coil must be arranged for "counterflow." The lines between the two coils (and the coil headers if exposed to ambient air) must be insulated to prevent external heat transfer. The pump should be located in the warm-fluid line. All of the air passing through the air-handling unit must pass through both coils. Any deviations from these guiding principles will cause a loss in performance.

Advantages. Advantages of run-around coils are:

- They can be widely separated and arranged in any position. If desired, a single precooling coil can be used in combination with multiple reheat coils.
- They carry the certification of the Air-Conditioning and Refrigeration Institute (ARI) and are available from at least 10 manufacturers.
- Because they are mass-produced

using machinery, labor contributes little to their cost.

• They are, for all practical purposes, commodity items and, therefore, relatively inexpensive.

• Their selection can be made by the manufacturer or by the manufacturer's coil-selection program using software on a personal computer.

• The precooling and reheat function can be controlled by pump on-off cycling or valve control.

• The preheat coil can be piped to a third coil in the exhaust-air stream to capture heat for preheating outside air during the winter.

Disadvantages. Disadvantages of run-around-coil systems are:

• Possible freezing if water is the circulating fluid (this can be overcome by using a dilute ethylene glycol solution selected to provide burst protection at the coldest anticipated entering-air temperature).

• A 120-v, 60-cycle single-phase electrical circuit is required for the circulating pump.

• Air trapped in the coils, pump, and piping must be vented upon initial startup to ensure effective fluid flow and heat transfer.

Figure 4 shows run-around coils at the entering and leaving sides of a specially configured unit. This unit will be used to illustrate all of the recuperative precooling and reheating concepts. It will graphically show that they perform the same function—even though some require specific physical arrangements.

HEAT-PIPE RUN-AROUND PRECOOLING, REHEATING

Although their use in dehumidification is relatively new, heat pipes have been around for decades. A heat pipe is a heat-transfer assembly that includes a heating section connected to and located slightly above a cooling section. In Figure 5, the lower cooling section is upstream from the main cooling coil, while the upper heating section is downstream. This allows for a transfer of sensible heat from the warm, humid incoming air to the cold exiting air, which reduces or eliminates the external reheat energy requirement. The air leaving the unit is warmer and dryer.

The arrangement of the equipment room and the entering- and leaving-air ductwork poses a major challenge to the side-by-side placement of the joined sections of the heat pipe or an alternate arrangement with the cooling section below the heating section. The lines between the two coils (and the coil headers if exposed to ambient air) must be insulated to prevent external heat transfer.

Advantages. The main advantages of heat pipes are:

• They have no moving parts.

• They have no external connections to either water circuits or electricity.

• They are not susceptible to damage from freezing conditions.

• They do not require a compression tank.

Disadvantages. Disadvantages of heat pipes are:

• The coils are more expensive than are run-around coils because they are not mass-produced and each of the many refrigeration circuits in heat pipes must be individually evacuated and charged with a critical amount of a volatile refrigerant.

• ARI-certified ratings are not available.

• Selection is made only by the manufacturer.

• Control is difficult and expensive (however, in many applications, control of the run-around coil or heat-pipe system is not required).

• The physical arrangement of the coils must enable gravity drainage or capillary transfer of the condensed refrigerant from the heating coil to the precooling coil.

• Multiple reheat coils are not available.

• If heat pipes are installed in an AHU, then the AHU's coil section must be shipped to the heat-pipe manufacturer or the two heat-pipe sections must be joined by field-installed piping, with each circuit tested, evacuated, and charged by the manufacturer at the job site. (For small AHUs, a precharged wrap-around heat pipe is available.)

AIR-TO-AIR FLAT-PLATE HEAT EXCHANGERS

Flat-plate heat exchangers consist of a series of flat or nearly flat heat-exchange surfaces arranged in such a way that alternating air passages are connected to one air stream with remaining passages connected to the second air stream. Figure 6 illustrates

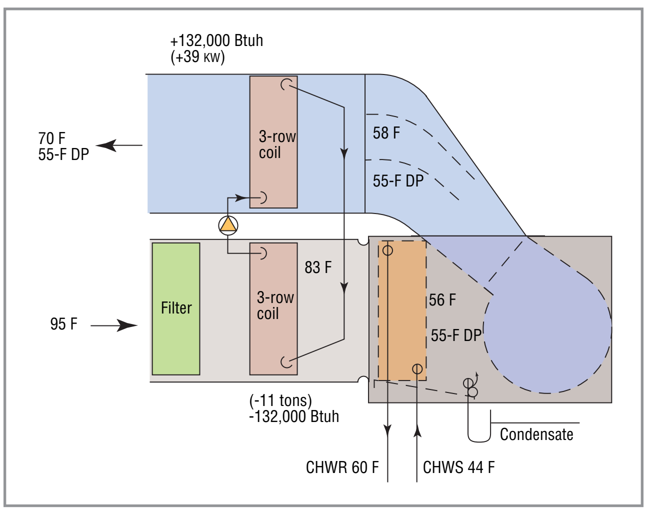

FIGURE 4. Run-around coil.

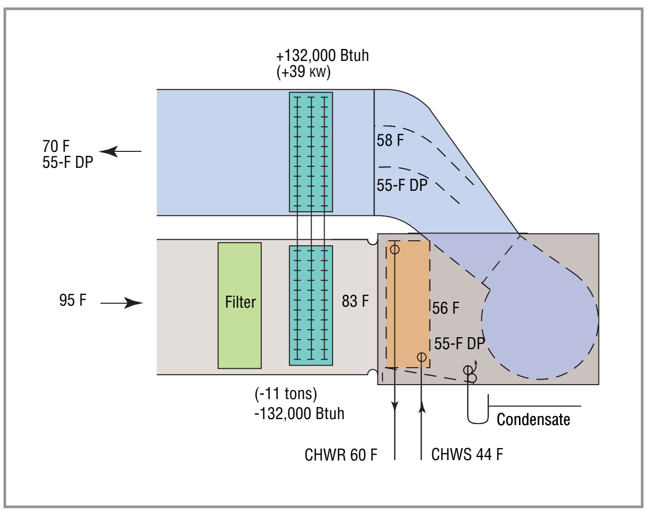

FIGURE 5. Heat-pipe coil.

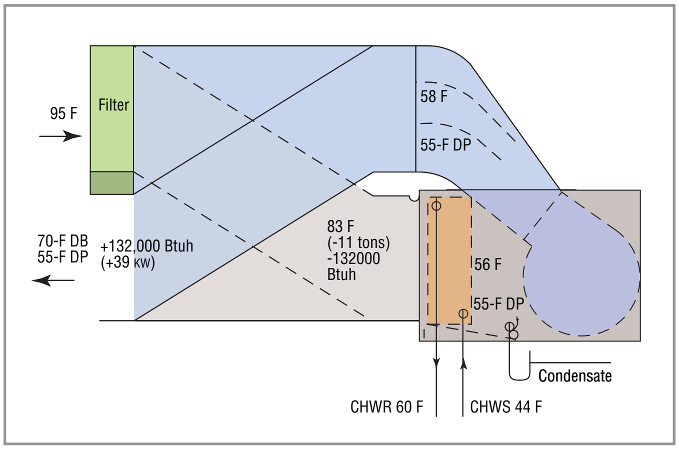

FIGURE 6. Air-to-air heat exchanger.

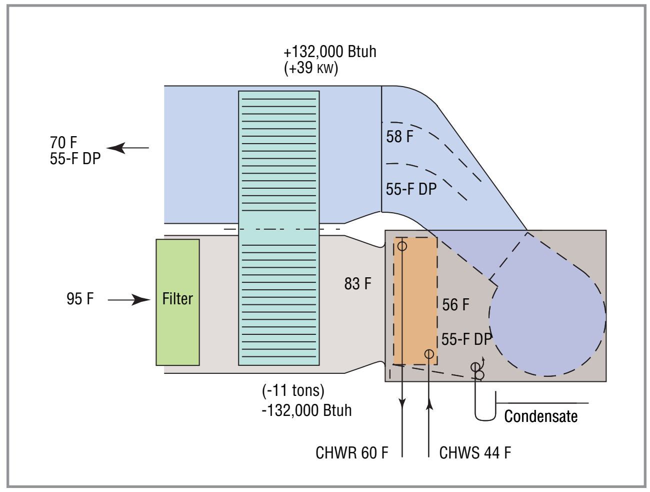

FIGURE 7. Rotary-wheel heat exchanger.

the recuperative application of the air-to-air flat-plate heat exchanger. The precooling section should be sloped in the direction of air flow to a condensate drain.

Advantages. The main advantages of flat-plate heat exchangers are:
- They have no moving parts.
- They have no external connection to water circuits, ethylene glycol, refrigerant, or electricity.
- They have no heat-transfer fluids that are subject to freezing.

Disadvantages. Disadvantages of flat-plate heat exchangers are:
- Control is impossible unless bypass dampers are used.
- The physical arrangement of their external components is more restrictive than that of the other recuperative-dehumidification enhancements because of the requirement of alternate air streams in cross-flow or counter-flow arrangements.
- ARI-certified ratings are not available.
- Some leakage or cross flow may occur if the sealant at the edge of plates is not perfect.

ROTARY-WHEEL HEAT EXCHANGERS

The rotary-wheel heat exchanger usually consists of a honeycomb (fluted) aluminum rotor. An 8-in.-wide corrugated layer of aluminum sheet and an 8-in.-wide flat aluminum sheet are wound around a hub to create an 8-in.-deep rotor (depth varies by manufacturer) with diameters up to about 8 ft. The rotor usually is encased in a housing (cassette) that includes seals at the wheel periphery and at the sectional divider between air streams. The rotor housing is ducted to the two air streams as shown in Figure 7. One-half of the rotor picks up heat from the warm air stream. As the rotor rotates at about 20 rpm, this heat is transferred to the cool air stream.

Advantages. The main advantages of rotary-wheel heat exchangers are:
- There is no water, ethylene glycol, or refrigerant charge.
- Control is easy.
- They have no heat-transfer fluids that are subject to freezing.

Disadvantages. Disadvantages of rotary-wheel heat exchangers are:
- A restricted physical arrangement of inlet and outlet air streams.
- The requirement of 120-v, 60-cycle single-phase power to a fractional-hp motor.
- ARI-certified ratings are not available.
- The media in the rotor may be susceptible to clogging.
- Some drive systems have been unreliable or have required high maintenance.
- The life of the rotor may be shorter than that of other options.
- Leakage between air streams reduces effective air quality and performance. The initial leakage rate may be acceptable; however, the wearing of seals, etc. can result in increased leakage.
- Condensation may be detrimental to some types of rotors and media.

REFRIGERANT LIQUID SUBCOOLING/AIR REHEATING

Reheating a cooled air stream using heat from liquid refrigerant en route to a direct-expansion cooling coil is quite desirable from an efficiency standpoint, as it requires only a single coil to accomplish what the previous arrangements do with two heat-transfer devices. Figure 8 illustrates this dehumidification enhancement.

The temperature of the refrigerant liquid supplied to a direct-expansion coil often is in the 90- to 115-F range. The reheat coil uses this warm liquid to reheat the cold air stream while simultaneously subcooling the liquid refrigerant. The subcooled liquid refrigerant then enters the direct-expansion coil and, because it is subcooled, increases the latent and total capacity of the cooling coil.

Figure 9 shows compressor-condenser capacity with and without subcooling as well as evaporator-cooling-coil capacity. The reheat energy is free and the penalties of increased refrigeration or the expense of additional cooling energy are avoided. The net effect of this cycle is identical to that of the run-around enhancements with two beneficial exceptions: (1) A precooling coil is not required and (2) the row depth of the reheat coil is less than that of the heat pipe or run-around coil.

A limitation of this method is the small amount of heat available. For example, in an R-22 system with liquid refrigerant entering the reheat coil at 95 F and leaving at 55 F, the total amount of heat available is 2000 Btu per ton-hr. Assuming an air-circulation rate of 350 cfm per ton, this results in a 5.2-F rise in air temperature across

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the reheat coil. With 100-percent outside-air systems at less than 200 cfm per ton, the temperature rise is approximately 10 F. If the reheat from this coil is not sufficient, an additional heating coil using some other form of energy is required. This adds to the first cost, the space required, and the control complexity.

A 5-F rise in air temperature in a 350-cfm-per-ton system may appear small; however, when this system is retrofitted to an existing unit, the amount of moisture removal increases by approximately 50 percent because of the combined effects of greater moisture removal per minute by the cooling/dehumidifying coil and longer run time attributed to the increase in supply-air temperature by the reheat coil.

Figure 8 shows the piping of the refrigerant-liquid/reheat coil. The reheat coil is part of the refrigerant-liquid line, with the additional refrigerant charge equal to the volume of the reheat-coil tubes and additional piping. Some manufacturers balk at installing a liquid-subcooling/air-reheating coil in a system (the effect of the coil on the refrigeration system is the same as that of an additional 20 or 30 ft of liquid line in a 60-F room). If a winter heating source is located upstream from the refrigerant-liquid-reheat coil, then the refrigerant circuit must be checked to ensure that the refrigerant has a path to the receiver and is not blocked by isolation valves. If the liquid-refrigerant coil is isolated by line valves during the winter, then high pressures could be a problem.

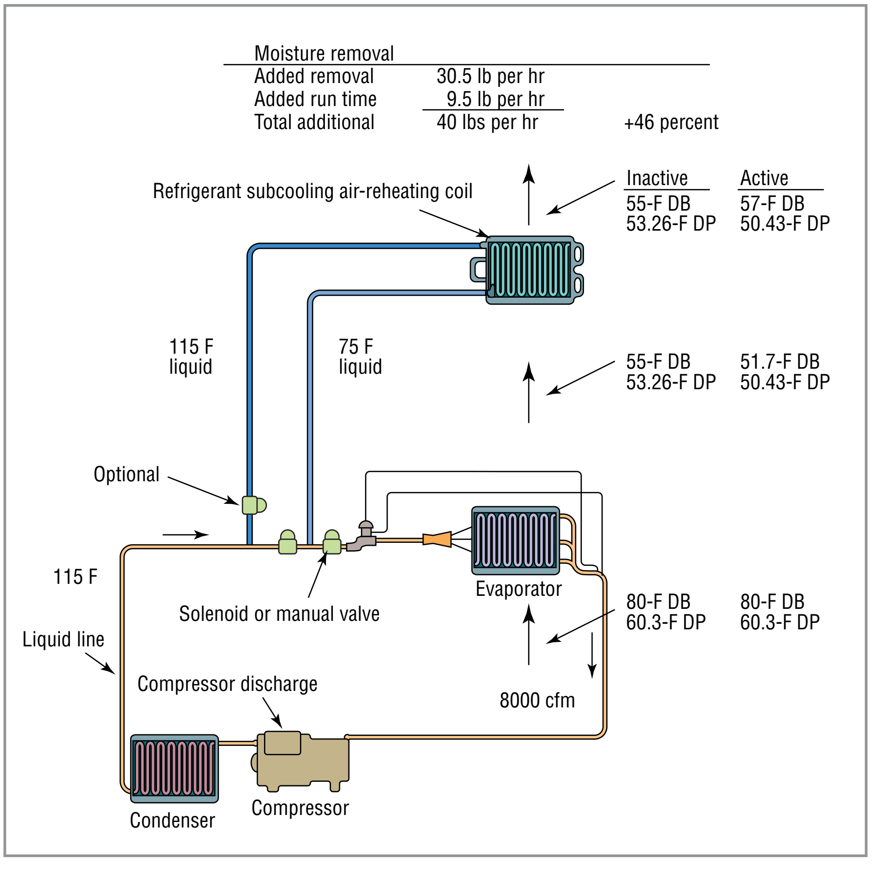

FIGURE 8. Liquid subcooling/air reheating.

Advantages. The advantages of refrigerant-subcooling/air-reheating dehumidification are:

- There are no water circuits to freeze or ethylene-glycol charges to maintain.
- Electrical connections are not required.
- Controls are not required for most systems.
- Only a single coil is required in the air stream leaving the main cooling coil.
- Air resistance is approximately half of that of the previous enhancements.

Disadvantages. Disadvantages of refrigerant-subcooling/air-reheating dehumidification are:

- The cost of the additional refrigerant charge and, in retrofit applications, the isolation, evacuation, and recharging of the refrigerant circuit.
- Possible bursting pressures if relief provisions are not made when the coil is located downstream from the heating apparatus.
- Concerns about refrigerant migration and inventory management, particularly in heat-pump refrigeration cycles.
- Controls, if required, add expense.

REFRIGERANT-HOT-GAS OR CONDENSER-WATER REHEAT

Intuitively, reheating a cooled air stream using hot discharge gas from a refrigerant compressor makes sense. However, it mitigates only the last of the four penalties of ordinary reheat systems mentioned in the sidebar. The refrigeration plant still must be larger by the amount of reheat. Also, the owner must pay the increased operating cost of the amount of cooling canceled by the reheat.

Refrigerant hot gas or condenser-water reheat is inferior to the other dehumidification enhancements, particularly when reheat is required on peak design days. This is because it requires a larger cooling-generation system and increased cooling-system operating costs. If reheat is required only on mild days and reheat from liquid refrigerant is not a viable solution, this enhancement can be considered along with the recuperative-dehumidification enhancements discussed previously.

Designers of refrigeration systems using hot gas for reheat are cautioned that the design is not as simple as it first appears. When the reheat coil is reheating, the cycle is obvious. When the control no longer requires reheat, the reheat coil will be at a low refrigerant pressure and the coil will fill with condensed liquid refrigerant. When the control again calls for reheat, this liquid refrigerant must be displaced for the reheat coil to function. The system must incorporate a larger refrigerant-storage vessel and additional refrigerant charge to accommodate the liquid refrigerant that is alternately stored in the reheat coil.

Designers have tried numerous ways, including check valves at the reheat-coil outlet, to circumvent this problem. If the check valve holds, the reheat coil will be under very low pressure and invite leaks. Most valves have a small leakage rate, which, in this case, means that the system still must be designed with the extra refrigerant charge and receiver. Some designers suggest bleeding a small amount of hot gas to the reheat coil when reheat is not required. This accomplishes nothing. The coil remains filled with liquid refrigerant. Some designers vent the reheat coil to compressor suction pressure when reheat is not required. Although this can be an acceptable solution, it adds the risk of refrigerant-liquid floodback damaging the compressor when the system changes from reheat to no reheat.

A variation of hot-gas reheat involves the use of the warm water leaving a water-cooled refrigerant condenser for reheat. This simplifies the refrigerant cycle and is a better alternative if the refrigerant cycle is water-cooled. However, penalties 1, 2, and 3 from the sidebar still apply.

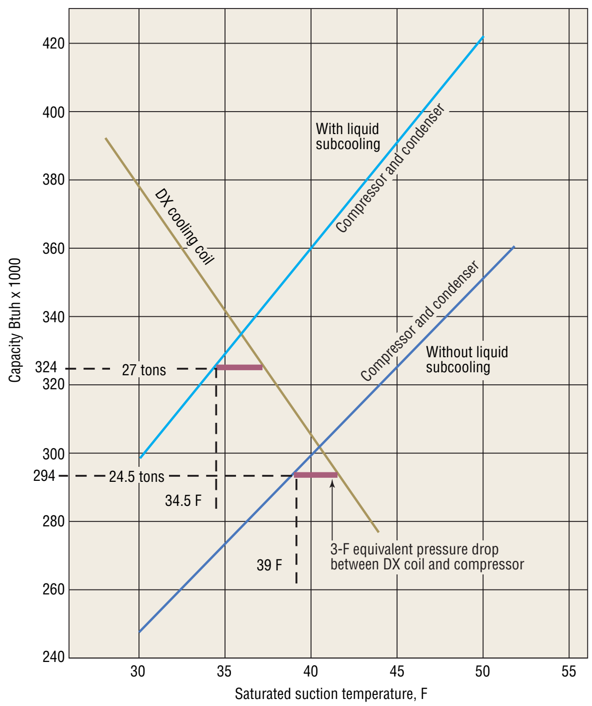

FIGURE 9. Subcooling impact on cooling capacity.

CONCLUSION

In many cases, the solution to indoor-air-quality and energy-efficiency problems can be found in 60-year-old technologies. The inventors of these technologies were motivated not so much by the cost of energy, but by the need to reduce compressor size to the limited range of available refrigeration compressors and to keep electrical motor size to a minimum because of the limited peak power available from the electrical utilities of the 1930s.

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The third and final installment of this series will cover passive desiccant enthalpy heat exchangers, heat-powered active desiccant dehumidifiers, and self-contained or packaged vapor-compression dehumidifiers. ■