ASHRAE Standard 90.1 Energy Requirements

Wrap-Around Heat Pipes In Humid Climates

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Designing a building's HVAC system requires designers to meet or exceed minimum outdoor air requirements, maximize energy savings, and meet all state and local codes. Most states and local codes have adopted ASHRAE/IES Standard 90.1, *Energy Standard for Buildings Except Low-Rise Residential Buildings*. This article reviews the ASHRAE Standard 90.1 requirements for air energy recovery for ventilation systems and reviews one product that is listed in Section 6.5.6 as an exception to the required energy recovery system—the wrap-around heat pipe.

A variety of energy recovery devices can be selected to meet the requirements of Standard 90.1, including enthalpy wheels and fixed plate heat exchangers. In certain applications, wrap-around heat pipe may offer designers a lower-cost solution and reduced energy consumption. It is primarily applicable to use in "humid" climates (ASHRAE/DOE Climate Zones 1A, 2A, 3A, 3C and 4A).

Importance of ASHRAE Standard 90.1

The U.S. Green Building Council (USGBC) has adopted ASHRAE Standard 90.1-2010 as the baseline for energy modeling. All LEED projects must at a minimum meet the energy requirements set forth in Standard 90.1. Nearly all states' locally enforced energy codes are either directly or indirectly tied to what is laid out in Standard 90.1. Per the Department of Energy, *Figure 1* maps out which U.S. states and territories have adopted which version of 90.1.

Each state can individually decide what version of Standard 90.1 it will enforce and how much of the standard it will use. The Alabama Building Commission, for example, simply enforces Standard 90.1 as published. In Georgia, however, the Department of Community Affairs enforces the 2009 version of the International Energy Conservation Code (IECC), which is tied directly

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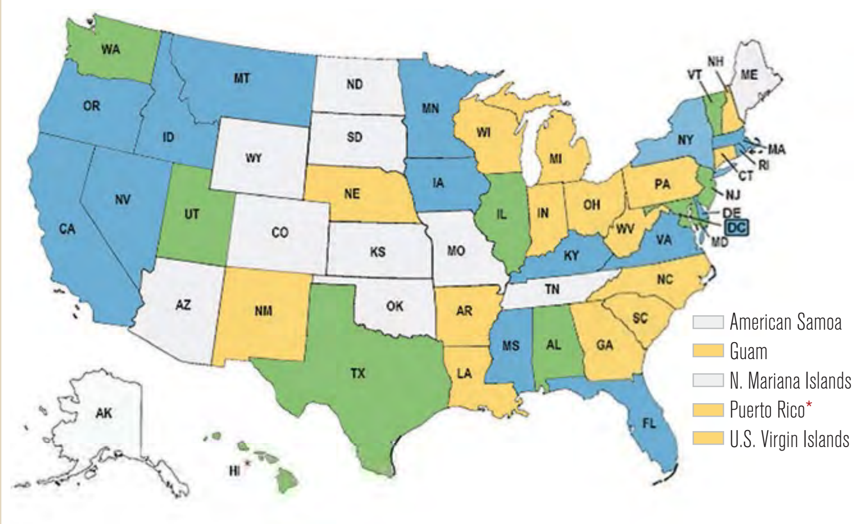
to 90.1. The Florida Building Code is directly tied to IECC 2012, which is tied to Standard 90.1-2010. Tennessee has not yet adopted 90.1, but Nashville and Knoxville have adopted the 2012 version of IECC, and Chattanooga has adopted IECC 2009. Even though the energy code may vary from state to state, they are all based on Standard 90.1 in some way.

Designers should check their local state codes. At the time of publication, the Department of Energy is trying to get all states to adopt Standard 90.1-2013. Some locales are now referencing the IECC 2015. The change in code requirements may change the energy recovery requirements.

FIGURE 1 ASHRAE Standard 90.1 adoption by state. (Courtesy https://www.energycodes.gov/adoption/states)



Humidity Control

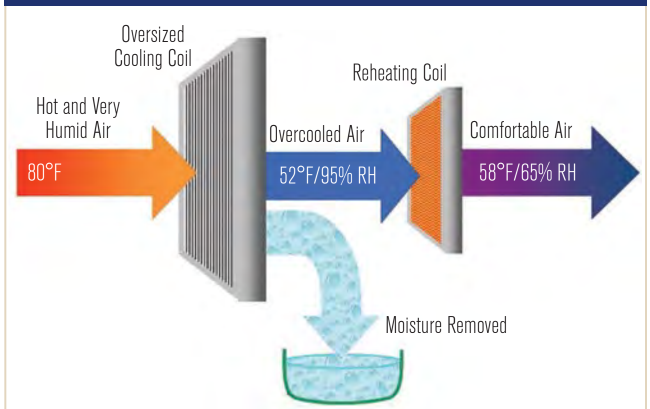
ASHRAE Standard 62.1 provides guidelines on how to ensure proper indoor air quality (IAQ) and focuses on ventilation, but Section 5.9.1 of the 2013 edition pertains to dehumidification and requires the following:

Occupied-space relative humidity shall be limited to 65% or less when system performance is analyzed with outdoor air at the dehumidification design condition (that is, design dew point and mean coincident dry bulb temperatures) and with the space interior loads (both sensible and latent) at cooling design values and space solar loads at zero.

Most comfort-cooling designs in humid climates have a relative humidity (RH) setpoint of 50% when in cooling mode, providing a safety factor to this Standard 62.1 requirement. When conditions turn to cooler outdoor temperature and high humidity, a humidistat may require the cooling coil to operate to reduce the space humidity level. In this situation, the space temperature may become too low, and the system may require reheat. The common solution to this problem is shown in *Figure 2* and involves the use of reheat to allow the reduction of the RH of the air coming off the cooling coil by adding heat to the space.

This is also a very common strategy for part-load temperature control, allowing the cooling coil to maintain proper dew point of the air to control humidity in the space, while downstream reheat is used to control the temperature.

FIGURE 2 Dehumidification control via reheat.



Standard 90.1-2013 addresses dehumidification in Section 6.4.3.6, which states the following:

Humidity control shall prevent the use of fossil fuel or electricity…to reduce RH below 60% in the coldest zone served by the dehumidification system.

Section 6.5.2.3 further prohibits this strategy of cooling with reheat by stating:

Where humidity controls are provided, such controls shall prevent reheating, mixing of hot and cold airstreams, or

FIGURE 3 Basic heat pipe process.

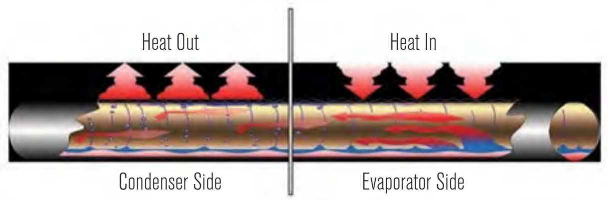


FIGURE 4 Side-by-side heat recovery heat pipe module.

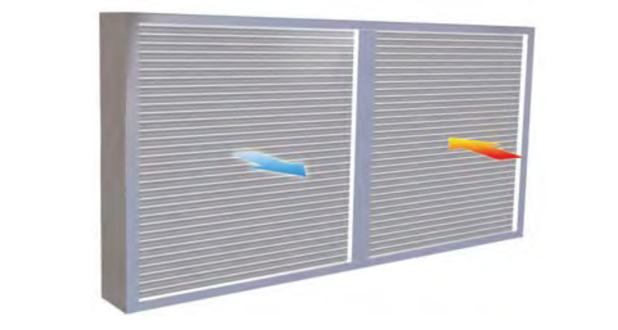
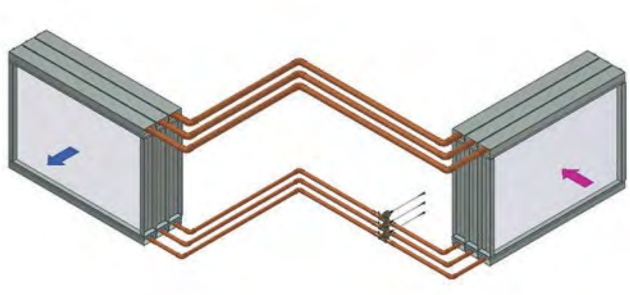


FIGURE 5 Split passive heat recovery heat pipe.



other means of simultaneous heating and cooling of the same airstream.

Included in Section 6.3.2 of Standard 90.1-2010 is the following:

i. The system controls shall not permit reheat or any other form of simultaneous heating and cooling for humidity control.

These guidelines limit the options available to designers to effectively control humidity levels by using reheat. However, exceptions are provided in Section 6.5.2.3. Exception 5 in the 2013 edition allows the following:

At least 90% of the annual energy for reheating or for providing warm air in mixing systems is provided from a site-recovered (including condenser heat) or site-solar energy source.

Site-recovery of waste heat may be available for DX systems that produces hot gas reheat that can be used to reheat the air off the cooling coil. But, what is the solution using a system that does not have hot gas reheat, such as a chilled water system?

Wrap-Around Heat Pipes

One solution to a system requiring cooling with reheat is a wrap-around heat pipe. A heat pipe is a tube, or a grouping of tubes, that uses phase change in a refrigerant to passively transfer heat from one end to the other, as shown in *Figure 3*.

The liquid refrigerant will remove heat from the warm airstream (or the evaporator side), phase change to a vapor creating a pressure differential within the tube that carries that vapor to the other end where the refrigerant then gives off that heat to the cooler airstream (or the condenser side) and phase changes back to a liquid. The liquid is then pushed back to the other end by the vapor, and the cycle repeats as long as there is a temperature differential from one side of the heat pipe to the other.

The only requirement for a heat pipe to function is a temperature difference between the two ends of the circuits. No power is required to make this happen other than the increase in fan energy required to overcome the static pressure losses through the heat pipe coils.

Heat pipes are sensible heat transfer devices and are quite often used for basic air-to-air heat recovery (*Figure 4*) to pretreat the incoming air as either preheat or precooling, especially when cross contamination between those two airstreams is a concern.

In some instances, provided the distance between is not too great, split passive heat pipes can be used even when those airstreams cannot be adjacent (*Figure 5*).

A wrap-around heat pipe is a version of a split heat pipe. A wrap-around heat pipe does more than just pretreat the entering air. The refrigerant still removes heat from the incoming air and phase changes to a vapor, but instead of simply dumping that heat into an exhaust airstream, the heat pipe circuits redistribute that heat as reheat (*Figure 6*).

The precooling of the air either reduces the load required of the cooling coil or enhances dehumidification by allowing the cooling coil to do more latent heat removal and further depress the dew point; or it provides both functions.

FIGURE 6 Wrap-around heat pipe.

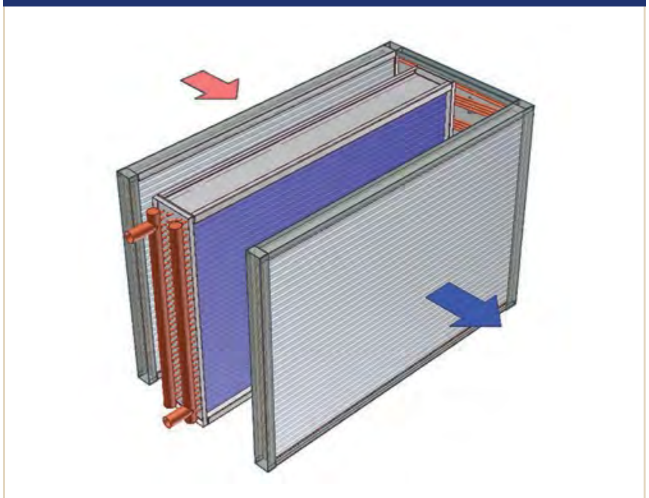
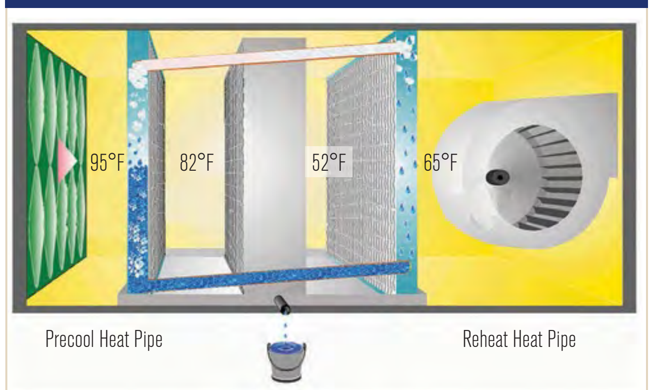


TABLE 1 Two-row vs. four-row performance.

NUMBER OF HEAT PIPE ROWS	CONTROLLABLE?	REHEATED AIR TEMPERATURE WHEN 95°F	REHEATED AIR TEMPERATURE WHEN 85°F
Two	No	65°F	62°F
Four	Yes	69°F	65°F

FIGURE 7 Two-row wrap-around heat pipe conditions.



The reheat it provides qualifies as "site-recovered" as allowed under ASHRAE Standard 90.1-2013 Exception 5 in Section 6.5.2.3.

Site-Recovered Heat for Reheat

The 2013 edition of Standard 90.1 requires at least 90% of the total reheat needed throughout the year be site-recovered. Heat pipes are sensible-only devices, and the performance of a heat pipe is dependent on the entering air conditions. The hotter the entering air, the larger the temperature difference between that air and the air leaving the cooling coil. A higher entering air temperature will, therefore, lower the entering air temperature (to the cooling coil) and reheat the discharge air to a higher temperature.

Therefore, if a wrap-around heat pipe is sized to provide higher design reheat on the hottest (humid) day of the year, it may not provide adequate reheat at lower entering air conditions. Because lower-than-design conditions occur over a majority of the year, they may prevent the system from meeting the Standard 90.1 requirement for 90% site-generated heat recovery.

Sizing the heat recovery system for the majority of operating hours (i.e., "shoulder" days) and controlling refrigerant flow, typically using solenoid valves, is an effective way to solve this dilemma.

A properly sized system will have more heat transfer surface (more coil rows and/or closer fin spacing). See *Table 1*.

EXAMPLE: If the cooling coil is to condition 100% outdoor air down to 52°F (11°C) and 65°F (18°C) is the desired temperature off the reheat portion of the heat pipe, a two-row wrap-around heat pipe will recover the 13°F (7.2°C) necessary on a design summer day of 95°F (35°C) to make that happen (*Figure 7*). However, this will only occur when it's 95°F (35°C) outside. When it's 85°F (29°C) outside, the heat pipe will only reheat up to 62°F (17°C), requiring another 3°F (1.7°C) of supplemental heat. Additional rows of the heat pipe may be required as the outside air gets cooler.

Increasing the heat pipe from two rows to four rows will allow for more heat to be recovered and it can then deliver 65°F (18°C) air when it's 85°F (29°F) outside, no supplemental heat required.

Control of Reheat

The excess reheat capacity necessary for the majority of operating hours may cause the space to overheat when the outdoor air is higher. Solenoid valves used to control refrigerant flow can modulate the reheat and maintain discharge air temperature requirements.

Example of a control sequence using solenoid valves:

When the setpoint (or return air temperature) is exceeded by *x* degrees (2°F [1.1°C] is common), stage the first circuit off. If after *x* minutes, the setpoint is still exceeded (5°F [2.8°C] is common), stage the second circuit off and so on, until all stages are closed. Then, reverse the sequence as air gets too cold. When all valves are open, and it's still too cold, add supplemental reheat.

See *Figure 8* for a schematic of the required control. It's essentially the opposite sequence of staged electric reheat. The valves are energized to shut the heat pipes off when required to meet the space temperature requirements. The valves can be open when heating to the space is required.

Comparison of Wrap-Around and Exhaust Air Energy Recovery

Section 6.5.6 of both Standard 90.1-2010 and 2013 relates directly to energy recovery and 6.5.6.1 is

FIGURE 8 Sample control schematic for wrap-around heat pipe with four stages of controllability.

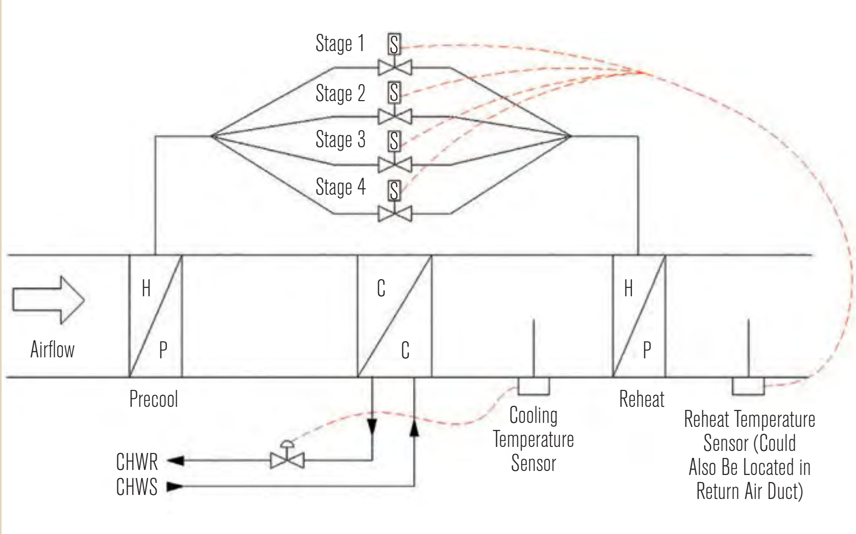


FIGURE 9 Airflow tables for energy recovery requirements.

TABLE 6.5.6.1-1 Exhaust Air Energy Recovery Requirements for Ventilation Systems Operating Less than 8000 Hours per Year

Zone	% Outdoor Air at Full Design Airflow Rate							
	≥10% and <20%	≥20% and <30%	≥30% and < 40%	≥40% and < 50%	≥50% and < 60%	≥60% and < 70%	≥70% and < 80%	≥80%
	Design Supply Fan Airflow Rate, cfm							
3B, 3C, 4B, 4C, 5B	NR	NR	NR	NR	NR	NR	NR	NR
1B, 2B,5C	NR	NR	NR	NR	≥26000	≥12000	≥5000	≥4000
6B	≥28,000	≥26,500	≥11000	≥5500	≥4500	≥3500	≥2500	≥1500
1A, 2A, 3A, 4A, 5A, 6A	≥26,000	≥16,000	≥5500	≥4500	≥3500	≥2000	≥1000	>0
7,8	≥4500	≥4000	≥2500	≥1000	>0	>0	>0	>0

NR—Not required

TABLE 6.5.6.1-2 Exhaust Air Energy Recovery Requirements for Ventilation Systems Operating Greater than or Equal to 8000 Hours per Year

Zone	% Outdoor Air at Full Design Airflow Rate							
	≥10% and <20%	≥20% and <30%	≥30% and <40%	≥40% and <50%	≥50% and <60%	≥60% and <70%	≥70% and < 80%	≥80%
	Design Supply Fan Airflow Rate, cfm							
3C	NR	NR	NR	NR	NR	NR	NR	NR
1B, 2B, 3B, 4C, 5C	NR	≥19,500	≥9000	≥5000	≥4000	≥3000	≥1500	>0
1A, 2A, 3A, 4B, 5B	≥2500	≥2000	≥1000	≥500	>0	>0	>0	>0
4A, 5A, 6A, 6B, 7, 8	>0	>0	>0	>0	>0	>0	>0	>0

NR—Not required

specific to air-to-air energy recovery. Standard 90.1-2013 states the following:

Each fan system shall have an energy recovery system when the system's supply airflow rate exceeds the value listed in Tables 6.5.6.1-1 and 6.5.6.1-2, based on the climate zone and percentage of outdoor airflow rate at design conditions. Table 6.5.6.1-1 shall be used for all ventilation systems that operate less than 8,000 hours per year, and Table 6.5.6.1-2 shall be used for all ventilation systems that operate 8,000 or more hours per year. Energy recovery systems required by this section shall have at least 50% energy recovery effectiveness. Fifty percent energy recovery effectiveness shall mean a change in the enthalpy of the outdoor air supply equal to 50% of the difference between the outdoor air and return air enthalpies at design conditions. Provision shall be made to bypass or control the energy recovery system to permit air economizer operation as required by Section 6.5.1.1.

The tables referenced in the Section 6.5.6 exerpt and the related Climate Zone map are *Figures 9* and *10*, respectively.

Section 6.5.6.1 of Standard 90.1-2010 states:

Exhaust Air Energy Recovery. Each fan system shall have an energy recovery system when the system's supply air flow rate exceeds the value listed in Table 6.5.6.1 based on the climate zone and percentage of outdoor air flow rate at design conditions. Energy recovery systems required by this section shall have at least 50% energy recovery effectiveness. Fifty percent energy recovery effectiveness shall mean a change in the enthalpy of the outdoor air supply equal to 50% of the difference between the outdoor air and return air enthalpies at design conditions. Provision shall be made to bypass or control the energy recovery system to permit air economizer operation as required by 6.5.1.1.

Depending on where you are and how much outdoor air is needed for proper ventilation, air-to-air energy recovery is required. Energy recovery must be at least 50% effective in terms of enthalpy. To better understand effectiveness, reference *Figure 11* and *Equation 1* below, as defined in AHRI Standard 1060-2013, *Performance Rating of Air-to-Air Exchangers for Energy Recovery Ventilation Equipment.*

FIGURE 10 U.S. map of climate zones.

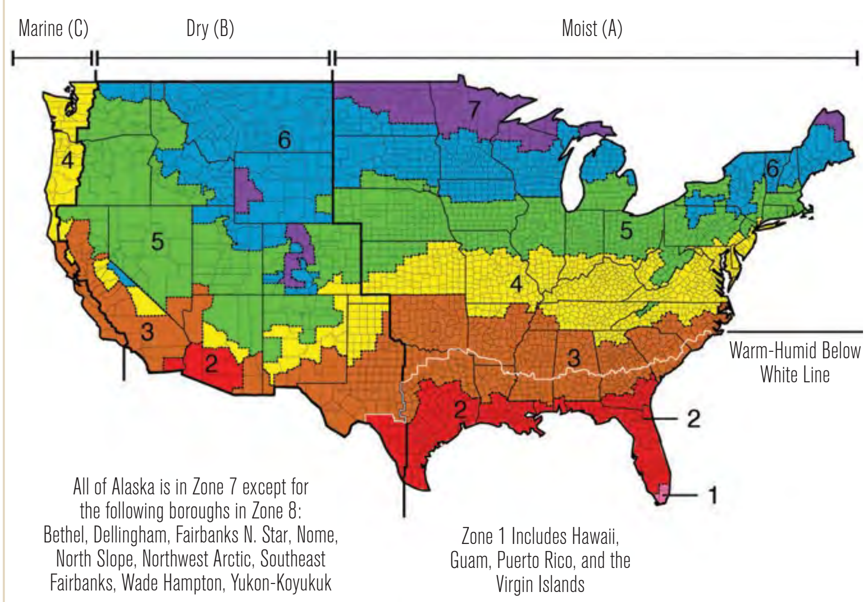
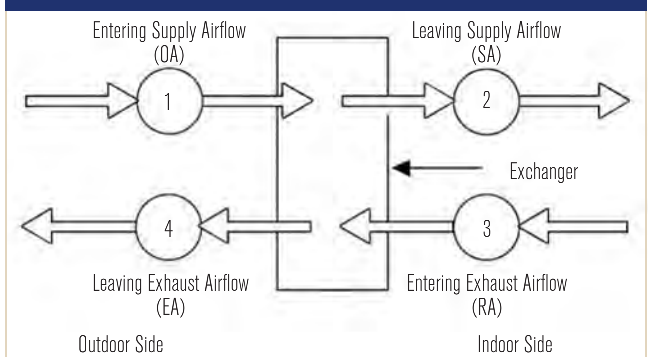


FIGURE 11 Airflow locations for energy exchanger.



Total effectiveness:

$$\varepsilon = (h_1 - h_2)/(h_1 - h_3) \quad (1)$$

where

h = enthalpy at the respective location as noted above

If airflows aren't equal, this ratio is multiplied by the ratio of the supply airflow to the minimum airflow.

Several devices are available that can meet this minimum 50% effectiveness requirement. Enthalpy wheels are the most common devices used but carry with them some concerns. Designers should consider that the exhaust duct must run adjacent and ideally counter to the outdoor air duct.

Fixed plate heat exchangers are another option. They typically will not require additional power, but do require the exhaust and outdoor air ducts to be adjacent as well.

Section 6.5.6 does provide some exceptions in both the 2010 and 2013 version to the section's energy recovery requirement. One of those (Exception i in the 2010 version and Exception 9 in the 2013 version allows the following as an acceptable alternative:

Systems requiring dehumidification that employ energy recovery in series with the cooling coil.

The term "in series" implies that the energy must be both recovered and redistributed within the same system. That is exactly how a wrap-around heat pipe functions. Because its sole purpose is to aid with dehumidification, this exception allows wrap-around heat pipes to be used in lieu of having to recover any energy from the exhaust air and thus having to run the exhaust air duct alongside the outdoor air duct at all. DX systems can provide hot gas from the condenser coils as reheat, which will also meet Exception 9, but this article focuses on comparisons made based on chilled water systems.

TABLE 2 Enthalpy wheel vs. wrap-around heat pipe performance.

ENERGY RECOVERY DEVICE	EFFECTIVENESS	REHEATED AIR TEMPERATURE	TOTAL STATIC PRESSURE*	TOTAL POWER CONSUMED**
ENTHALPY WHEEL	71%	N/A	2.20 in. w.g.	4.4 kW
FOUR-ROW HEAT PIPE	46%	72°F	0.70 in. w.g.	1.3 kW

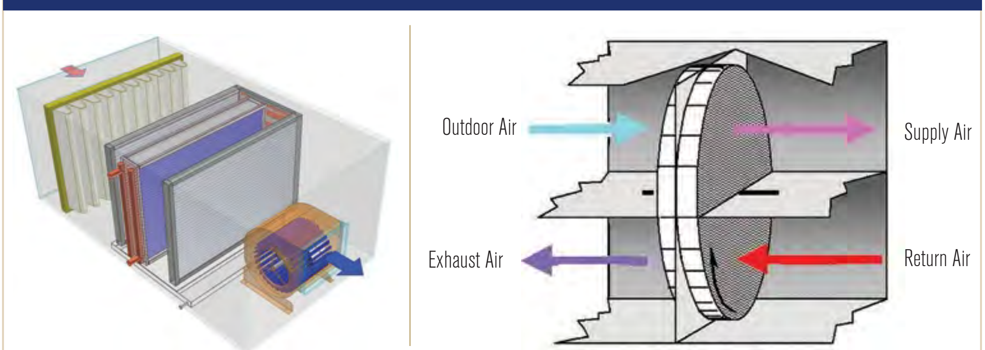
Assumes 100% OA at 95°F, 52°F off the cooling coil, 70% fan efficiency and 90% fan motor efficiency.
*Total static pressure (TSP) for the wheel is the sum of static pressure losses associated with both the outdoor and exhaust portions of the wheel; TSP for the wrap-around heat pipe is the sum of static pressure losses associated with both the precool and reheat modules.
**Total power consumed for the wheel includes the additional supply and exhaust fan power required to overcome static pressure losses, as well as motor hp required to rotate the wheel; total power for the wrap-around heat pipe is only the additional fan power required to overcome static pressure losses at the precool and reheat modules.

TABLE 3 Enthalpy wheel vs. wrap-around heat pipe energy savings.

ENERGY RECOVERY DEVICE	COOLING SAVINGS	HEATING SAVINGS	ELECTRICAL PENALTY	NET ANNUAL SAVINGS
ENTHALPY WHEEL	$3,600	$11,300 Preheat	$3,900	$11,000
4-ROW HEAT PIPE	$3,900	$8,850 Reheat	$1,150	$11,600

Assumes chiller efficiency is 15 EER, electricity costs $0.10/kWh and hot water costs $1.50/therm.

FIGURE 12 Examples of a single-path AHU with wrap-around heat pipe (left) and dual-duct ERV with enthalpy wheel (right).



Tables 2 and *3* examine a 10,000 cfm (4719 L/s) system of 100% outdoor air in Atlanta and compare the performance and associated energy savings for each an enthalpy wheel and a four-row wrap-around heat pipe. *Figure 12* shows how each device is typically arranged—the wrap-around heat pipe in a single-path AHU, the enthalpy wheel within two counterflow airstreams. In this example, the air handler is a chilled water dedicated outdoor air system (DOAS) where its sole purpose is to precool and dehumidify the ventilation air and deliver neutral-temperature air to the space (or deliver pretreated air to other air handlers).

An enthalpy wheel preconditions the air by recovering both sensible and latent heat in both cooling and heating modes, respectively. A heat pipe, on the other hand, only preconditions the air in cooling mode while recovering sensible heat, but it will then redistribute that sensible heat as reheat.

Wrap-around heat pipes are not just solutions for 100% outdoor air systems. Section 6.5.6 of Standard 90.1 requires energy recovery for systems all the way down to 10% outdoor air. For simplicity, this example will examine a system conditioning 100% outdoor air.

The net savings for the wheel are the sum of the net precooling and net preheating savings, minus the annual electrical penalty for the additional fan power due to static pressure as well as the motor. This example also assumes 10% leakage at the wheel. The net savings for the heat pipe are the sum of the net precooling and net reheating savings, minus the annual electrical penalty for the additional fan power only. No additional power is required for the heat pipe.

Using Atlanta weather bins as an example to compare a 10,000 cfm (4219 L/s) enthalpy wheel ERV to a single duct 10,000 cfm (4219 L/s) wrap-around heat pipe, *Table 3* shows that despite the wheel providing more free cooling as well as free preheating when it's cold outside, the wrap-around heat pipe will in fact offer more energy savings. This is because in Atlanta, there are more cooling hours where reheat is needed as well as more power consumed by the wheel.

Also of interest here is that despite the wheel being more effective, the cooling savings from the heat pipe are higher. Despite the enthalpy wheel's ability to recover 54% more energy than the heat pipe, it's doing so less often because it will only precool the outdoor air when its enthalpy is greater than that of the return air. The heat pipe, in contrast, precools whenever the outdoor air is warmer than the leaving air off the cooling coil, which in this case is 52°F (11°C)—well below the return air temperature. It can then be surmised that in cooler climates, the results shown in *Table 3* lean more favorably to the wheel, while in warmer climates, they lean more favorably to the heat pipe.

Capital Cost

When it comes to capital cost, the inclusion of an ERV versus the cost of adding a wrap-around heat pipe to an air handler is actually very similar. Each could be budgeted at roughly $1.50 per cfm, or $15,000. That does not include additional savings achieved by not having to run exhaust duct or multiple ducts to the outdoor air or the additional electrical circuit required. Also the reduction in maintenance costs or longer lifespan of the wrap-around heat pipe should be considered.

Conclusion

Designers should be knowledgeable on the various requirements within ASHRAE Standard 90.1 and how each state has implemented those requirements into its own respective building code.

When evaluating energy recovery, several devices are available, each having its pros and cons.

When the system requires dehumidification and calls for a fair amount of reheat, the wrap-around heat pipe should be considered. When used for dehumidification, the wrap-around heat pipe acts as energy recovery "in series" with the cooling coil and provides an acceptable alternative to mandatory air-to-air energy recovery.

The more reheat the system requires, the more it will precool the air, and the more the wrap-around heat pipe will ultimately save. The heat pipe should be selected based on the greater number of part-load hours rather than fully loaded hours. To optimize those savings, designers should consider making the heat pipe circuits controllable. ■