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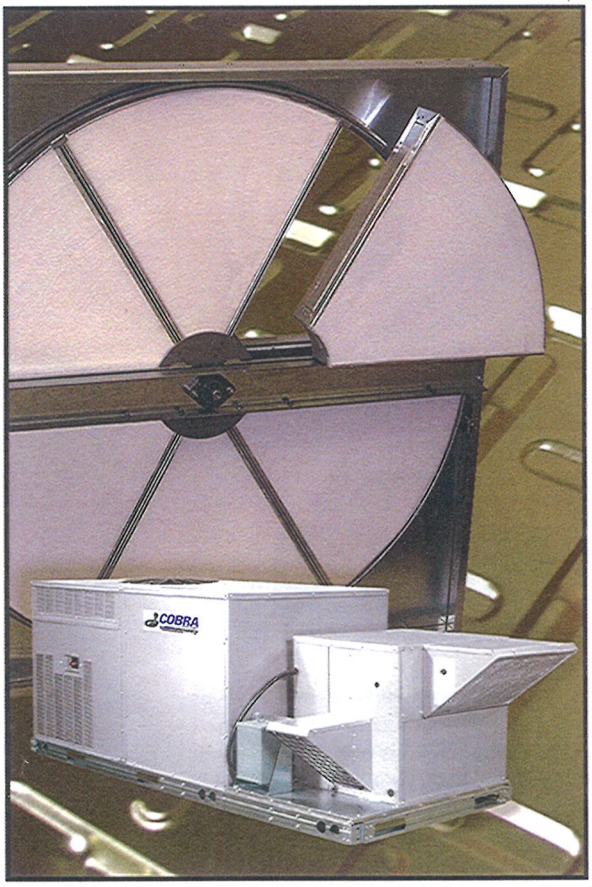


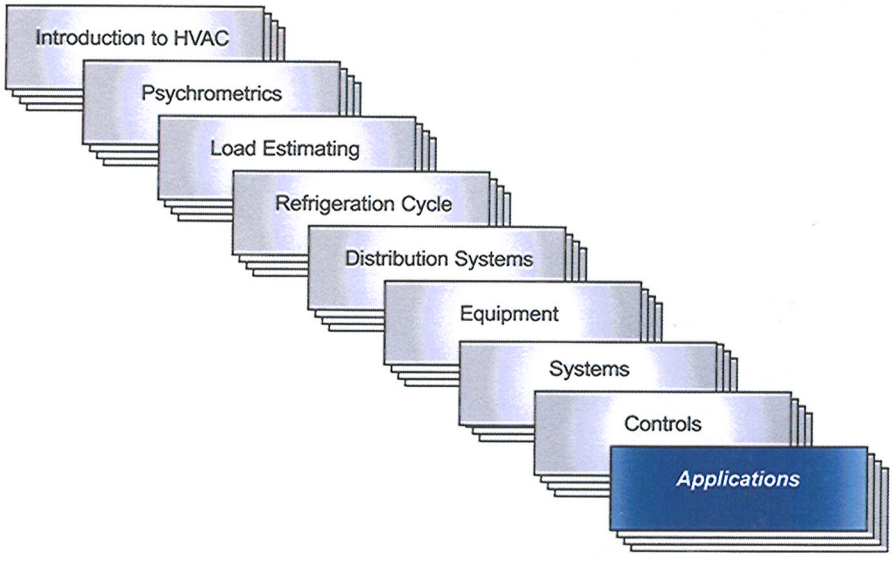
APPLICATIONS

Air-to-Air Energy Recovery

Technical Development Program

Technical Development Programs (TDP) are modules of technical training on HVAC theory, system design, equipment selection and application topics. They are targeted at engineers and designers who wish to develop their knowledge in this field to effectively design, specify, sell or apply HVAC equipment in commercial applications.

Although TDP topics have been developed as stand-alone modules, there are logical groupings of topics. The modules within each group begin at an introductory level and progress to advanced levels. The breadth of this offering allows for customization into a complete HVAC curriculum – from a complete HVAC design course at an introductory-level or to an advanced-level design course. Advanced-level modules assume prerequisite knowledge and do not review basic concepts.



This TDP module deals with the methods and product types that are available for air-to-air recovery of energy in comfort air-conditioning applications. The recovered energy is transferred from the building exhaust airstream to the building ventilation airstream. This transfer can result in energy savings and potential downsizing of the HVAC equipment. Upon completion of this module, the reader should have a specific understanding of the types of energy recovery technology, the best fit for each type, and how to identify recovery opportunities in comfort heating and cooling applications.

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Printed in Syracuse, NY

CARRIER CORPORATION
Carrier Parkway
Syracuse, NY 13221, U.S.A.

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Introduction

As shown in Figure 1, there are several reasons to use energy recovery in HVAC system design. To begin with, recovery can offset some of the increased operating costs associated with heating and cooling the ventilation air. Annual savings in energy can become very significant as fuel costs continue to rise.

Since current ventilation air requirements have been increased over previous levels, the size of the HVAC unit has also increased. The result of increased ventilation levels should be improved indoor air quality. The use of energy recovery can downsize the HVAC equipment, resulting in savings in installed cost. Lastly, compliance with local codes may require the use of energy recovery in the system design.



Figure 1

Why Use Energy Recovery?

Recovery

Heat and energy recovery are different. Heat recovery is the sensible transfer of temperature. Energy recovery involves sensible and latent (moisture) transfer. Not all recovery devices can exchange both heat and energy.

There are several energy recovery options available in the industry. The correct solution often depends on the location, the application, and the project requirements. It is the purpose of this TDP module to help the designer understand the available energy recovery options and to recognize when energy recovery is justified. The reader will also learn which type of product or system is the best fit for different applications.

Air-to-air types of recovery devices will be discussed in this TDP module. For air-to-air types, the transfer of heat or energy occurs between the ventilation airstream and the exhaust airstream. Most recovery products on the market require these two airstreams to be in close proximity. An energy recovery device during winter operation is shown in Figure 2.

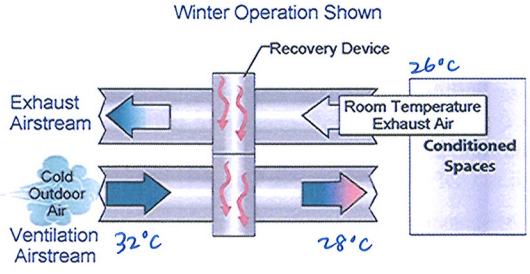

Figure 2

Air-to-Air Recovery

This TDP will make use of the psychrometric chart to illustrate the recovery process. We will also demonstrate how the major types of heat recovery products differ functionally. Since recovery may be a *heat* exchange only (change in dry bulb temperature) or an *energy* exchange (change in sensible and latent), a basic knowledge of psychrometrics is required

for this TDP module. Consult TDP-201, Psychrometrics, Level 1: Introduction for an explanation of chart use.

We will discuss the codes and standards that influence the energy recovery industry and review the applicable methods of product certification. This TDP will also include a selection procedure using software for an energy recovery wheel. A calculation will then be performed showing operating cost savings and payback for using energy recovery.

Ventilation Air

Ventilation is the process of introducing outside air to occupied spaces in a manner and quantity that ensures good mixing throughout the space. The continuous supply of good quality outside air during occupied hours provides the necessary dilution of indoor pollutants, odors, and airborne bacteria to reduce occupant discomfort and complaints. A well-designed and ventilated area will result in high levels of human productivity and health.

Ventilation with outdoor air reduces the level of indoor pollutants. As shown in Figure 3, each doubling of the ventilation rate results in a 50 percent reduction in the concentration of air pollutants. For one air change per hour, pollutant concentrations are reduced by a factor of five.

Prior to the energy crisis of the 1970s, energy recovery was of little concern, and mechanical ventilation rates were lower than are used today. Mechanical ventilation was also supported by the natural exchange of outdoor air and indoor air. Because of this, IAQ (indoor air quality) levels were acceptable.

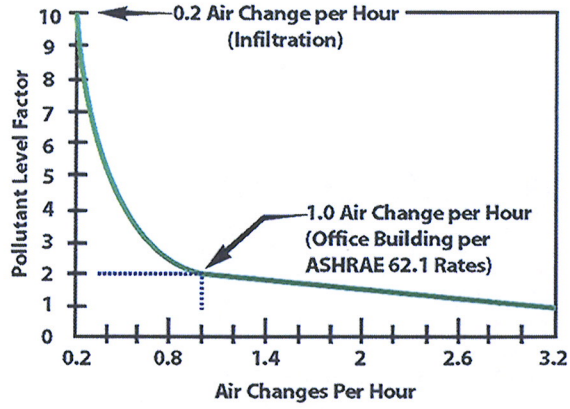

Figure 3

Dilution Principle

When energy costs rose, the effort to retain the heated and cooled air became more important. Tighter buildings were constructed to limit natural exchange of air. This lack of air exchange led to IAQ problems. The off-gassing of indoor contaminants from machines and furnishings caused an increase in Building Related Illness and Sick Building Syndrome. These terms are explained in detail in TDP-902, Indoor Air Quality.

Off-gassing is caused by the increased use of plastics and adhesives (synthetics) in building materials and furnishings. Because of the relatively lower ventilation rates (by today's standards), the VOCs (volatile organic compounds) were not being removed.

The realization of the impact that IAQ, and therefore ventilation, has on occupant satisfaction and energy consumption led to ASHRAE (American Society of Heating, Refrigerating, and Air-Conditioning Engineers) requirements.

ASHRAE Requirements

The ASHRAE organization has established a history of recommending minimum ventilation rates beginning in the 1930s and continuing to the present time. See Figure 4. Outside air introduction is recognized as essential to human health and productivity.

The ASHRAE organization has established indoor ventilation rates based on dilution. These are related to air changes/occupancy and have become accepted as good design practice in occupied spaces.

ASHRAE Standard 62.1-2004 calls for minimum ventilation rates to result in human comfort and adequate odor dilution.

See TDP-902, Indoor Air Quality for a detailed discussion on this topic.

ASHRAE Standard 90.1 includes requirements for energy recovery based on system capacity and the amount of ventilation air used. See the ASHRAE Standard 90.1 section on page 52 for more details.

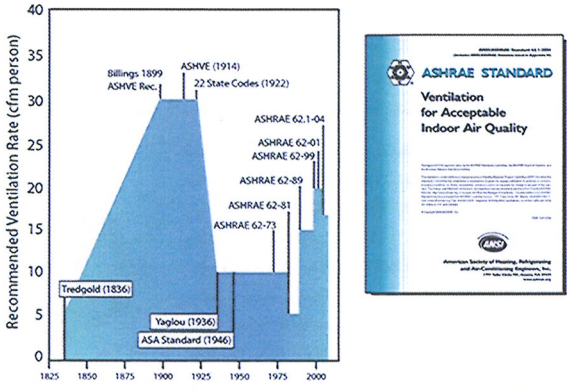

Figure 4

Evolution of Minimum Ventilation Rates

even no occupant, also need to provide OA.
(based on m^2)

Humidity

Humidity directly affects the comfort level in the conditioned space as shown in Figure 5. The application of energy recovery can affect the relative humidity and result in more comfortable conditions.

Another equally important factor that is directly related to humidity levels is occupant health. Humidity that reaches excessive levels for even short periods of time can create an environment that promotes the growth of fungi and bacteria. Human exposure to fungi and bacteria can cause serious health issues.

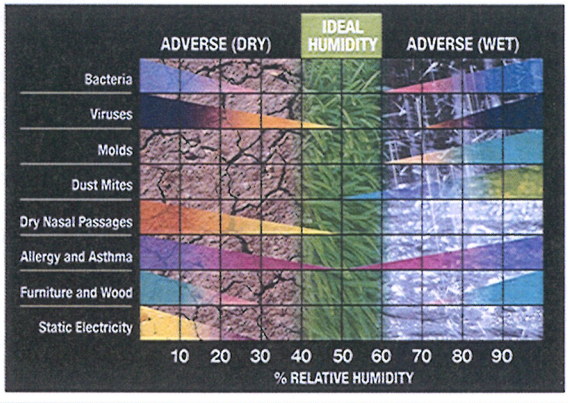

Figure 5

Why Correct Humidity is Important

HVAC Equipment and Humidity Control

Increasing ventilation air amounts to comply with ASHRAE 62.1 ventilation levels increases the latent load during the cooling season, making humidity control more difficult. With elevated ventilation amounts, sensible heat ratios (SHR) of 0.60 to 0.65 may result. The sensible heat ratio is the ratio of sensible heat to total heat that a coil is required to remove in order to offset the heat gains. Total heat is the sum of sensible and latent heat. The latent component of heat contains the moisture load. A packaged rooftop unit without an energy recovery device has about a 0.75 to 0.80 SHR capability.

The addition of an energy recovery unit, as shown in Figure 6, can offset the latent load from the ventilation air, thus shifting the SHR back to what the packaged unit can normally handle.

The evaporator coil is responsible for moisture removal. The deeper the coil, the greater the potential to remove moisture. With deeper coils, there is less air that passes through the coil untreated. A deeper coil also provides greater heat transfer area and colder surface temperatures are possible. This results in greater condensing of the moisture from the airstream.

As an example, a packaged rooftop unit typically has an evaporator coil of 3 or 4 rows depth. Applied equipment like central station air-handling units can come equipped with 6 or 8 row coils. For that reason, applied equipment has been considered better for applications involving high latent loads. However, energy recovery may allow for the use of packaged DX (direct expansion) systems on applications where applied equipment had been used.

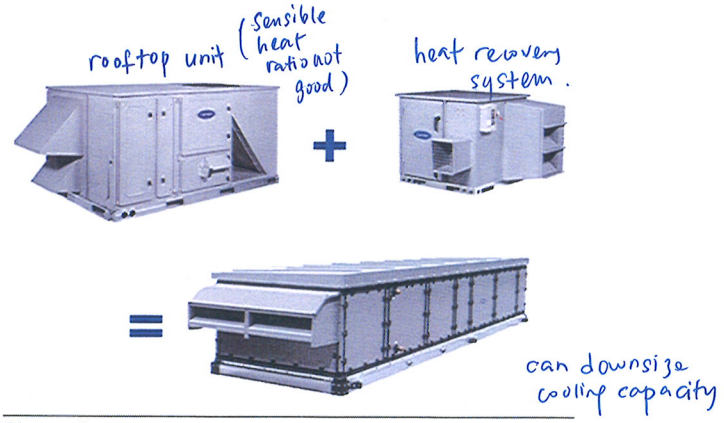

Figure 6

Packaged Unit and Recovery Unit Equals Applied

Packaged DX Systems

Energy recovery may allow packaged DX systems to be used on applications previously reserved for applied equipment.

Year round, ventilation air is introduced to the system. In the summer, the energy recovery device removes moisture from the ventilation air prior to it entering the air-conditioning unit. Because of the energy recovery device, the latent load imposed on the air-conditioning equipment is reduced. This allows a conventional packaged unit to be able to introduce the required ventilation air per ASHRAE requirements, while handling the remaining latent load adequately such that indoor humidity levels are maintained.

During winter operation, the energy recovery device acts as a humidifier, increasing the humidity of the incoming ventilation air.

Energy recovery ventilator (ERV) is a term used to describe an energy recovery device (such as a wheel) packaged with ventilation and exhaust fans in a housing, ready to install next to a rooftop unit.

Figure 7 shows a comparison of the SHR of a typical building load with the SHR of a combination unitary air conditioner (rooftop unit) and ERV. The SHR of the unitary unit without the ERV is shown by the dotted line. Notice the SHR of the unit without the ERV is much higher, indicating less ability to handle latent cooling requirements.

The chart shows that using the ERV can provide a very close match up of unit SHR to building load SHR across two cities of different humidity conditions. The mismatch of SHR capability and building loads due to increased amounts of ventilation air has been eliminated by the addition of energy recovery.

Shoulder refers to part-load operation.

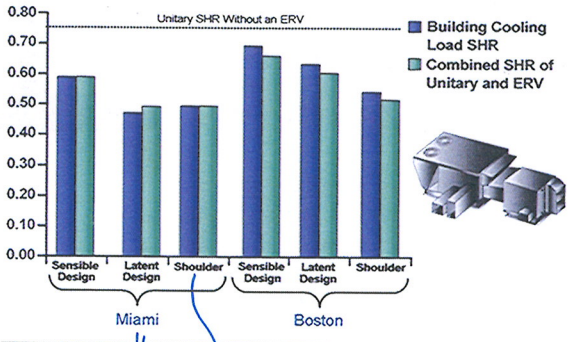

Figure 7 close to singapore part load operation

SHR Comparisons

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Equipment Capacity and Part Load

For moisture to be removed effectively, the cooling coil must be kept operative as long as possible. Condensation of the moisture from the airstream onto the coil only occurs while the cooling coil is operating. Since ventilation air must be provided continuously during the occupied cycle, humidity control problems can occur when the cooling coil is not operating.

When the cooling system is cycled excessively, moisture may evaporate off the wetted surface of the coil back into the airstream. This contributes to moisture build-up in the space. See Figure 8.

An oversized system can cause excessive cycling. This can lead to a cold, clammy feeling in the space. On packaged equipment with a single step of capacity, excessive cycling is common. Multiple steps of capacity help avoid excessive cycling since the system can more closely match load with capacity.

Load Condition	Design Load Sunny Day	Part-Load Condition
Occupancy	100%	20%
Outdoor Air Condition	95 db, 76 wb	80 db, 71 wb
Supply Air Cfm Cooling Coil Dewpoint	15,000 53.5°F	15,000 65.5°F
Room Conditions	75 db 48% rh	75 db 71% rh

Figure 8 Discharge air temp control

Humidity Build-Up at Part Load

Refrigeration systems sized for a peak load day will operate at part load most of the time. While they may be able to maintain sensible control, they often lose control of the humidity in the space. It is imperative that HVAC cooling systems be sized properly to avoid this problem.

The addition of energy recovery helps remedy oversized equipment issues by allowing a downsizing of the HVAC equipment.

Identifying Potential Applications for Heat or Energy Recovery

Energy recovery can be used for both new and retrofit applications. There are three potential application types: (1) process, (2) combination process and comfort, and (3) comfort. See Figure 9.

An example of a process application is the capture of sensible heat from the process exhaust airstream and the transfer of heat to the manufacturing process. For example, a coil modified for use in a high temperature exhaust stack could transfer heat from hot flue gas to make hot water required for manufacturing in the same plant. In process applications, exhaust temperatures may be extremely high, sometimes in excess of 1000° F.

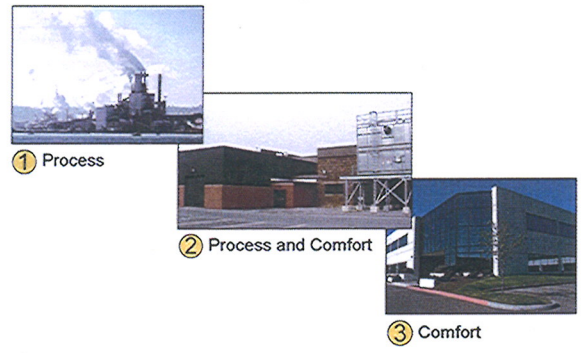


Figure 9

Recovery Application Types

Focus Applications

This TDP module will concentrate on comfort heat and energy recovery applications.

In most combination process and comfort applications, only the transfer of sensible heat occurs. An example would be waste heat transferred to make-up or ventilation airstreams. This is often a heating-only application with no energy recovery during summer.

Comfort applications differ from other categories in that both sensible and latent heat are often transferred. In comfort applications, the recovery device transfers sensible heat from the warmer airstream to the cooler airstream. The device may also transfer moisture from the airstream with the higher moisture level to the airstream with the lower moisture level. The directions of moisture and heat transfer are not necessarily the same.

Comfort applications can involve a sensible-only process as well as a process where moisture is transferred. Depending on the project specifics and the climate, however, a sensible-only transfer may make more sense.

There are many possible comfort applications of air-to-air energy recovery. Any building with comfort conditioning requiring relatively high levels of ventilation air is a likely candidate. See Figure 10. In addition, a clean exhaust airstream is required in order for transfer to take place with the ventilation airstream. If the internal loads are normal to low, then the ventilation cooling becomes a significant portion of the total load. This means the air-conditioning unit must be sized to handle the ventilation air

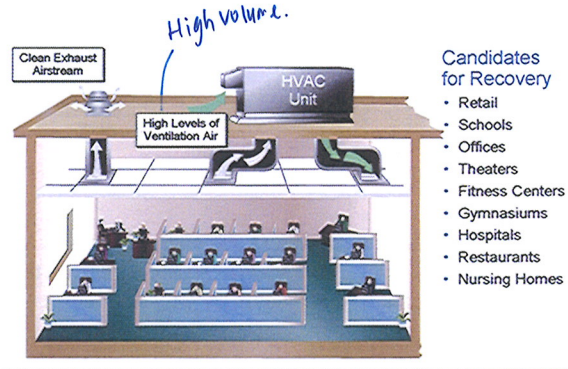


Figure 10

Identifying Potential Recovery Applications

load while also responding to the internal loads. The issues discussed earlier regarding equipment capacity, part load, and humidity control become concerns.

Buildings with a significant amount of occupants are good candidates for heat or energy recovery because of the corresponding ventilation amounts required by ASHRAE 62.1. Below is a list of applications where recovery is used:

- Schools and universities
- Gymnasiums
- Office buildings
- Hospitals
- Restaurants
- Fitness centers
- *Nursing homes*
- *Correctional facilities*
- Retail shopping centers
- *Operating rooms*
- Churches
- Dormitories
- *Bars*
- Movie theaters
- *Casinos*
- *Bingo halls*

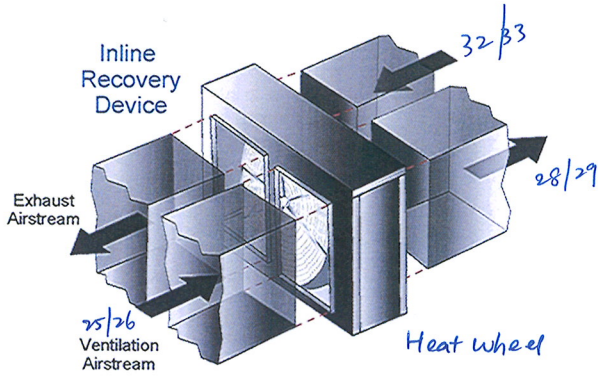


Figure 11

Ideal Arrangement for Energy Recovery Device in the Airstream

The italicized applications in the above list require special considerations when selecting a recovery method. For instance, some of these applications have severe cleanliness requirements and great care must be taken to prevent contamination between the incoming (ventilation) and the outgoing (exhaust) airstreams. An ideal arrangement of airstreams is shown in Figure 11. Some recovery products do not require that the exhaust and the ventilation airstream to be in close proximity to one another. We will discuss this in the Types of Heat and Energy Recovery Technology section of this TDP. In fact, keeping them apart can be desirable if cross-contamination must be avoided. Listed below are some applications where cross contamination is often a concern:

- Laboratory fume hood exhaust
- Industrial applications with fumes or smoke (e.g., welding operations)
- Public bathroom exhausts
- Designated smoking areas
- Industrial applications with toxic or noxious exhaust
- Restaurant kitchens
- Specialized hospital treatment areas

Suitable for Recovery

A general rule of thumb is: if the air is being exhausted from an occupied space, it is suitable for recovery.

In these situations, the airstreams often must be physically isolated to ensure there is no cross-contamination. This will often limit the option for recovery to a sensible heat transfer only.

If it is process air, kitchen hood exhaust, auto exhaust, print hood exhaust, paint booth exhaust, or lab hood exhaust, it will not be acceptable for use in all types of recovery products.

Any exhaust stream that has high levels of pollution, irritating odors or chemicals, or biological hazards is considered problematic. The "quality" of air being exhausted from the space and used for energy recovery is classified below. (This information can be found in ASHRAE 62.1-2004 Addendum Y.)

Class 1: "Air with low contaminant concentration" - offices, classrooms, conference room, etc.

Class 2: "Air with moderate contaminant concentration, mildly offensive odors or sensory-irritation intensity" - toilet exhaust, locker room, dry cleaning, commercial laundry, etc.

Class 3: "Air with significant contaminant concentration or significant offensive odor or sensory-irritation intensity" - daycare sickroom, general chemical/biological labs, machinery rooms, etc.

Class 4: "Air with highly objectionable fumes or gases or containing potentially dangerous particles, bioaerosols, or gases at a concentration high enough to be considered harmful" - laboratory hoods, copy machine exhaust, paint spray booth, etc.

The information in ASHRAE 62.1-2004 states that you can use class 2 or 3 air for energy recovery, as long as cross leakage is less than either 10 percent when using class 2 air or 5 percent when using class 3 air through the recovery unit. Cross leakage typically pertains to a wheel recovery device and will be discussed later in this TDP.

Deciding on Energy Recovery

The following rules will help decide when to utilize energy recovery. This list can be used for the vast majority of potential heat or energy recovery applications for comfort heating and cooling:

- Identify what situations may be good recovery candidates. For instance, if the exhaust systems can be routed together into a single location, a single recovery system can be used.
- Locate the ventilation air intake and the building exhaust. Based on their proximity, determine which recovery technologies fit best.
- Based on the quality of the exhaust airstream, determine if cross-contamination is a concern.
- Consider the corrosive and fouling effect of the exhaust airstream. If it is excessive, the energy recovery type that best fits may still require special coatings or treatment.
- Estimate the cost of the system with and without the energy recovery device.
- Factor in the first cost benefit of any downsizing of the heating and cooling system because of energy recovery.
- Consider to what degree extra maintenance is required. Factor in the capabilities of the staff at the facility where energy recovery is being considered.
- Determine the start-up and commissioning costs and consider the time involved to place the system into effective use.

Principles of Air-to-Air Energy Recovery

Air-to-air recovery is the process of capturing and transferring sensible (and sometimes latent) heat between the building exhaust air and the incoming building ventilation airstreams. See Figure 12.

Airstream Designations

The exhaust airstream is composed of return air from the room(s) ducted into the recovery unit. From there, it passes through the recovery process, exchanges heat, and is then exhausted outside. The dry bulb and relative humidity condition of the return airstream entering the recovery unit are the same as the room conditions, unless it has picked up some heat gain or loss in the ductwork.

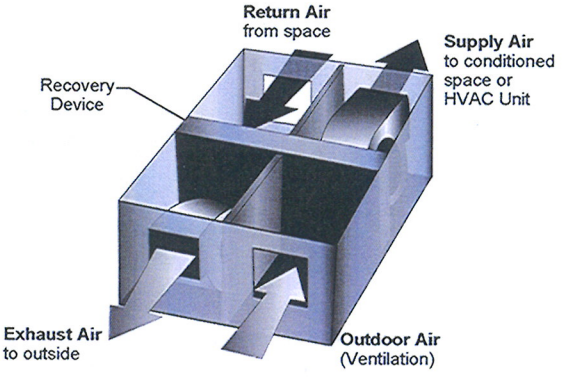


Figure 12

Airstream Designations

Regeneration

The return airstream is sometimes called the regeneration airstream because it is the source of energy used to preheat, precool, humidify, or dehumidify the ventilation airstream.

The airstreams involved with an energy recovery process can be broken into four designations: outdoor air, supply air, return air, and exhaust air. The outdoor air is airflow entering the recovery medium. This is also called the ventilation air. The supply air is air entering the conditioned space. Return air is the air exiting the space. Lastly, the exhaust air is the air leaving the recovery medium. These terms will become important later on when discussing flows and leakage.

Sensible and Total Recovery

Sensible recovery is the transfer of heat between the exhaust and ventilation airstreams. It is strictly a dry bulb temperature change and is driven by a temperature gradient between the two separate airstreams. See Figure 13. This is accomplished by every type of recovery design such as the matrix in an energy wheel, the metal conduction in a plate exchanger, the liquid temperature exchange in a runaround loop, or the fluid evaporation and condensation in heat pipes.

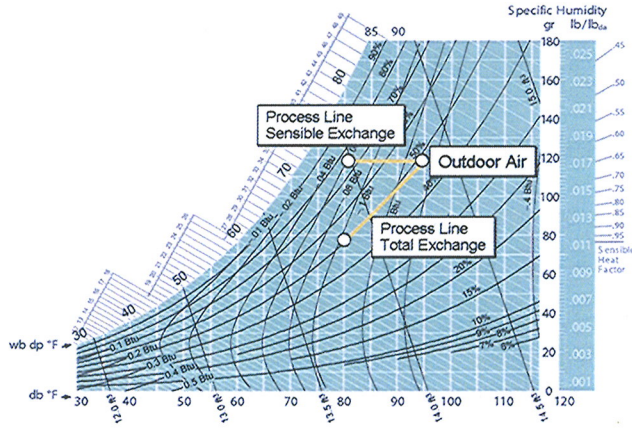


Figure 13

Sensible and Total Recovery

Total recovery is the change in temperature and moisture level of the ventilation airstream as it passes through the recovery device, as shown in Figure 13. As an example, using an energy wheel in summer operation, a desiccant coating helps remove the water vapor molecules from the humid ventilation air and transfer them to the relatively dry exhaust air. A desiccant is a substance used to attract and hold moisture. Desiccants will be discussed further in this TDP.

Moisture transfer is driven by the differential partial pressures of the two airstreams. This same process can serve to humidify the dry outside air in the winter mode of operation.

Transfer of heat always occurs from a higher temperature to a lower temperature. Energy recovery also transfers moisture from the higher moisture airstream to the lower one. The process works in both summer and winter to reduce the ventilation load on the HVAC system. As we will see later, this can result in reduced unit size and energy consumption. In all cases, the transfer of sensible only, or sensible and latent heat, should be accomplished with minimal leakage between the two airstreams.

The role of moisture (latent) heat transfer is very important in recovery applications. If the ventilation airstream is very hot and humid, and it is preconditioned in the summer by transferring sensible heat only from the building exhaust, then moisture will still enter the building. This may result in occupant discomfort. Also, nothing will be done to alleviate the latent load on the main air-conditioning unit.

Total Energy Recovery

When both sensible and latent transfer have occurred, this is total energy recovery.

As an example, let's say a 30-ton rooftop unit is required for a certain application. No energy recovery was incorporated into the design. Now the decision is made to use energy recovery. This has resulted in a downsize of the rooftop unit to 25 tons. The reduction in ventilation air latent load due to the recovery device allows the downsizing of the unit. We will work through an actual example showing this in the Psychrometric Example of Heat and Energy Recovery section and also the Selection Example with Economic Analysis section of this TDP.

Passive and Active Recovery

Passive energy recovery is the most common type of recovery. A passive recovery device, such as an energy recovery wheel, uses the temperature difference in the two airstreams to transfer energy. The term "passive" is used because no new energy is required to accomplish the heat transfer. Passive recovery can occur through capillary action and gravity. See Figure 14. Examples of passive heat recovery devices are heat pipes, wheels, and plate heat exchangers.

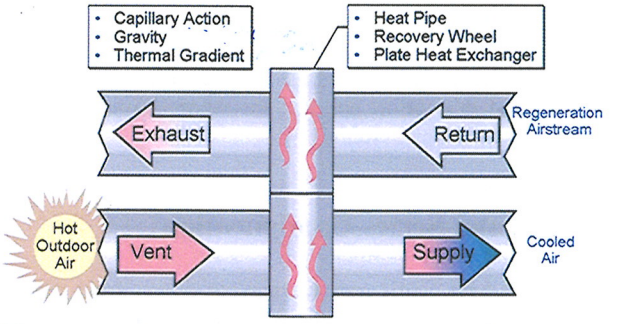


Figure 14

Passive Recovery

Active energy recovery requires new energy in the process. For example, in the case of an active energy recovery wheel, new energy in the form of heat is used in the exhaust airstream to regenerate and dry the wheel. This new energy would typically be a gas or electric heating source producing air approximately 150° F or higher to enter the wheel. Recycled waste heat can also be used to preheat.

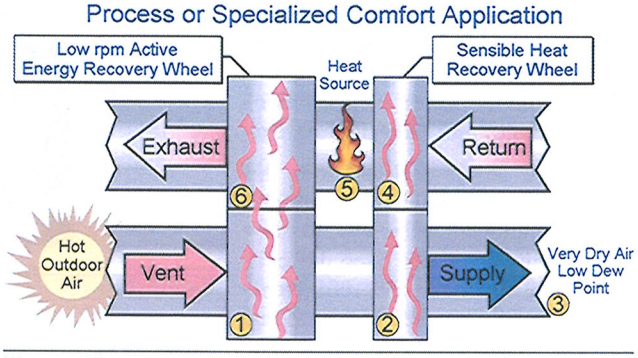


Figure 15

Active Recovery

Active energy recovery is often accomplished by a heat-powered, active-desiccant dehumidifier. See Figure 15. These devices use an energy wheel. Their total energy consumption is higher than a passive energy recovery device, but the resultant ventilation air after the recovery process has a lower dew point. The wheels in an active design are much deeper and have a higher airside pressure drop than passive recovery wheels. A typical active recovery wheel may have a pressure drop approaching 2 in. wg versus a passive wheel at less than 1 in. wg. Active recovery wheels contain different amounts of desiccant, revolve slower, and must withstand much higher temperatures than a standard passive energy recovery wheel.

Active recovery wheels operate in the following way (step numbers correspond to step numbers on Figure 15):

1. Moisture is removed from the hot, humid, outdoor air by the active recovery wheel and the moisture is transferred to the exhaust air.
2. The sensible heat of the outdoor air is removed by the sensible wheel.
3. Very dry (low dew point) air exits the sensible wheel. This air may be cooled by a cooling coil (not shown) to deliver cold dry air to the space.

4. Heat is transferred to the return airstream from the sensible wheel.
5. A source of heat energy, usually gas or electric, heats the air entering the slow-turning, active recovery wheel to a high temperature, usually 150 to 250° F.
6. Moisture is driven off the active wheel by the heat source and the air is exhausted.

Active energy recovery can be applied on more specialized applications. It can be used for projects that require "deep dehumidification" such as when dew point temperatures of 45° F or below are necessary. Active energy recovery is often used to dehumidify and remove moisture from a process airstream. Some typical applications are industrial drying processes, supermarkets, ice rinks or other facilities where low humidity control is important. Active energy recovery can also be used in comfort applications where lower than normal temperature air is desired or in dedicated ventilation systems.

Parallel and Series Configuration

Parallel heat configuration transfers energy from one separate airstream to another. Energy wheels, run around loops, outdoor air heat pumps, and many heat pipe configurations use parallel configuration.

Series heat recovery transfers heat from an upstream location in the same airstream to a downstream location. Figure 16 shows an example of parallel configuration and Figure 17 shows an example of series configuration. Both examples use a heat pipe system.

In the series configuration, the first section of heat pipes is positioned in the ventilation airstream. In summer, warm air passes over the heat pipes and vaporizes the refrigerant. This preconditions the air by cooling it. Heat is transferred to the second section of heat pipes located downstream of the cooling coil. This section tempers the air off the cooling coil by reheating it. This is also known as a wraparound heat pipe arrangement.

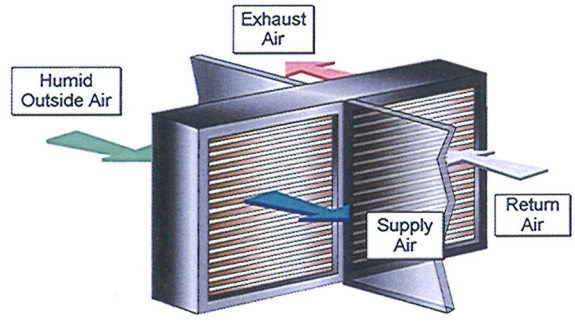


Figure 16

Parallel Configuration
(Reproduced with permission of Heat Pipe Technology, Inc.)

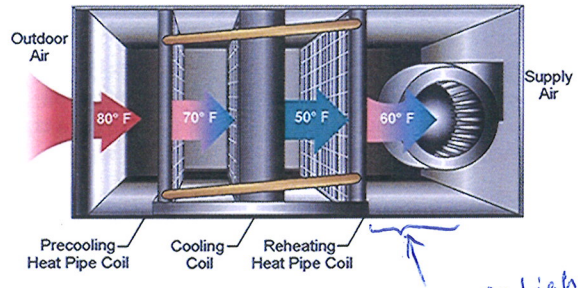


Figure 17

Series Configuration
(Reproduced with permission of Heat Pipe Technology, Inc.)

temp is higher but RH lower

Series Arrangement

A series arrangement does not accomplish heat or energy recovery. It simply transfers heat from one location to another.

Effectiveness

Effectiveness is a term used to describe the ability of the energy recovery device to change the condition of supply air. The higher the effectiveness, the more heat or energy transfer has taken place.

Efficiency is used to describe the effectiveness of the whole system, not just the recovery unit. For instance, if the ventilating unit is bringing 1000 cfm of air into the building and only exhausting 750 cfm of air through the recovery unit, then 25 percent of the energy that could be recovered is lost. This brings into focus the importance of balanced airflows, which will be discussed later in detail.

If the exhaust and the supply airflows are equal, the effectiveness and the efficiency are the same thing. ARI Standard 1060 has defined parameters used to measure effectiveness of wheel, plates, and heat pipes. The Standard defines sensible and latent effectiveness for each design and manufacturer. Certification testing is used to confirm manufacturers' published data.

The effectiveness values for certification conditions are established in the lab. The effectiveness for other conditions can be reasonably predicated using the certification test data.

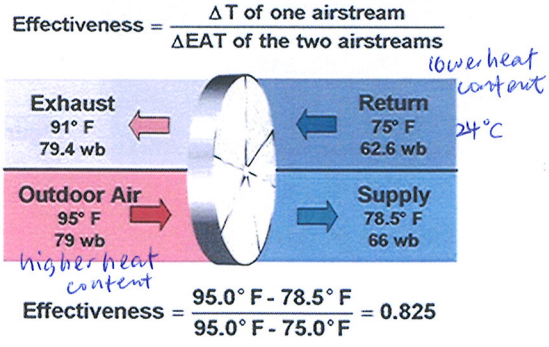


Figure 18

Summer Effectiveness

Sensible effectiveness can be calculated with the following formula:

$$\text{Effectiveness } (\varepsilon) = \frac{\Delta T \text{ of one airstream}}{\Delta \text{ EAT of the two airstreams}}$$

We will calculate the summer and winter sensible effectiveness for the heat exchanger shown in Figures 18 and 19.

Summer

$$\text{Ventilation } \varepsilon = \frac{95.0^\circ \text{ F} - 78.5^\circ \text{ F}}{95.0^\circ \text{ F} - 75.0^\circ \text{ F}} = 16.5^\circ \text{ F} \div 20.0^\circ \text{ F} = 0.825$$

$$\text{Exhaust } \varepsilon = \frac{91.0^\circ \text{ F} - 75.0^\circ \text{ F}}{95.0^\circ \text{ F} - 75.0^\circ \text{ F}} = 16.0^\circ \text{ F} \div \div 20.0^\circ \text{ F} = 0.80$$

Now let's do the winter calculation:

$$\text{Exhaust } \varepsilon = \frac{70.0^\circ \text{ F} - 22.0^\circ \text{ F}}{70.0^\circ \text{ F} - 10.0^\circ \text{ F}} = 48.0^\circ \text{ F} \div \div 60.0^\circ \text{ F} = 0.80$$

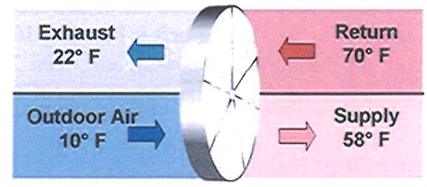
$$\text{Ventilation } \varepsilon = \frac{58.0^\circ \text{ F} - 10.0^\circ \text{ F}}{70.0^\circ \text{ F} - 10.0^\circ \text{ F}} = 48.0^\circ \text{ F} \div 60.0^\circ \text{ F} = 0.80$$

Effectiveness is not adjusted to account for any effect on the supply air conditions as a result of potential leakage from the exhaust airstream. The formal test set up to find and measure effectiveness is outlined in ASHRAE Standard 84. Net effectiveness, however, is a term used to reflect the potential effect of any leakage from the exhaust air. The formulas for effectiveness and net effectiveness are found in ARI Standard 1060. Both ASHRAE Standards 84 and ARI 1060 will be discussed later in the TDP.

Total Effectiveness

If the recovery device has sensible and latent recovery capability, typically both total effectiveness and sensible effectiveness are calculated.

$$\text{Effectiveness} = \frac{\Delta T \text{ of one airstream}}{\Delta EAT \text{ of the two airstreams}}$$



$$\text{Effectiveness} = \frac{58.0^\circ F - 10.0^\circ F}{70.0^\circ F - 10.0^\circ F} = 0.80$$

Figure 19

Winter Effectiveness

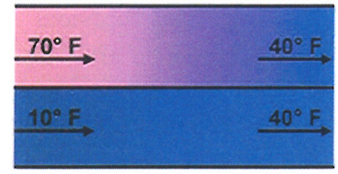
Direction of Airflow

How well energy is transferred is a direct result of the design of the heat exchanger. The physical construction, geometric layout, and thermal properties of the materials used all affect heat transfer. Direction of airflow through the heat exchanger plays an equally important role and can be broken down into several categories.

Parallel flow is the most undesirable of the configurations and is not used in most situations. For parallel flow, the exhaust and the supply airstreams will be moving in the same direction through the heat exchanger. This results in a maximum possible recovery effectiveness of 50 percent. See Figure 20.

Two more effective methods of air-to-air energy recovery are counterflow and crossflow. In counterflow, the exhaust and supply airstreams flow in opposite directions. See Figure 21. Inlets for the flows are at opposite ends of the exchanger. Counterflow effectiveness is higher than parallel flow and typically 70 to 80 percent effectiveness is common.

50% Maximum Theoretical Efficiency

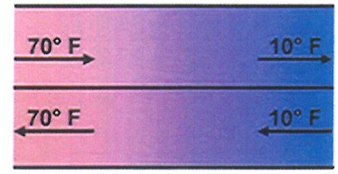


$$\frac{70 - 40}{70 - 10} = \frac{30}{60} = 50\%$$

Figure 20

Parallel Heat Transfer

100% Maximum Theoretical Efficiency



$$\frac{70 - 10}{70 - 10} = \frac{60}{60} = 100\%$$

Figure 21

Counterflow Heat Transfer

Crossflow describes the design in which the exhaust and supply airstreams flow perpendicular to each other in the shape of "X." Similar to counterflow, crossflow effectiveness is higher than parallel, typically 50 to 70 percent.

Airflow Balance

Since an air-to-air recovery device depends on the exhaust air for its source of recovered energy, any reduction in exhaust airflow compared to ventilation airflow results in a reduction of energy recovery. Significantly unbalanced airflows are the enemy of highly effective air-to-air energy recovery systems.

Airflow Balance

As a rule of thumb, any time the exhaust airflow is less than 50 percent of the ventilation airflow, the building is not a good application for recovery.

On the chart in Figure 22, balanced flow effectiveness is the 1:1 ratio represented by the vertical axis. Flows that are less than 1:1 (exhaust air is the numerator) are represented by the horizontal axis. The upper three lines show the effectiveness of three different recovery devices when the airflows are balanced: one device is 80 percent effective (bold), one device is 70 percent effective (medium), and one device is 60 percent effective (dotted). The lower set of curves show effectiveness for the same three devices accounting for the impact of flow imbalance. This chart applies to any air-to-air exchanger.

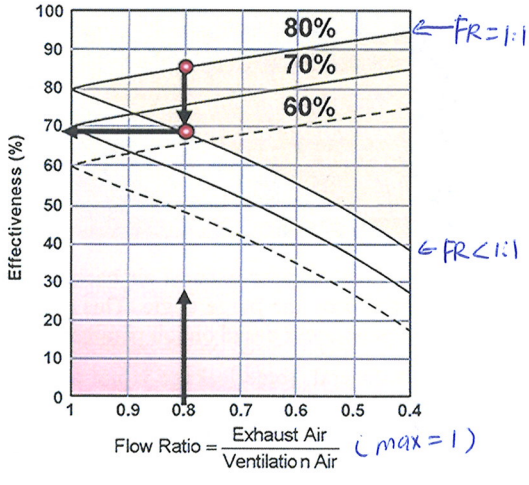


Figure 22

Impact of Unequal Flows

As an example, let's assume we have a recovery application where the exhaust air is 80 percent of the ventilation air amount. Let's also use a device whose effectiveness with balanced (equal) flows has been established at 80 percent, represented by the bold line. The goal is to see the effect of unequal flows. The flow ratio is the exhaust airflow divided by the ventilation airflow. We would enter the chart at a flow ratio of 0.8 for this example and intersect the bold line representing our 80 percent effective unit. The recovery of the exhaust air is 86 percent. However, since only 80 percent of the exhaust energy is available, the net effectiveness drops to 69 percent (0.8 * 86 percent = 69 percent), which can be read from the lower line.

When a project has unequal ventilation and exhaust airflows, the actual effectiveness percent of the exhaust airstream goes up, but due to the lower airflow, the overall value of the recovery process drops. This is accounted for automatically in the manufacturer's selection and evaluation software. This is true for all air-to-air energy recovery units.

Air Leakage, EATR, and OACF

Air leakage can occur in both the incoming ventilation air and the leaving exhaust air. There are two types of possible leakage. Seal leakage results from pressure differences between opposing airstreams. This can happen in a plate heat exchanger if the partition is not airtight. Shown in Figure 23 is a wheel exchanger where leakage is occurring at the point where the wheel and partition between the airstreams meet. Refer to the section on Heat and Energy Wheels for a discussion of fan location and effect on leakage. Carry-over is the next form of leakage and is a function of the recovery device design type. Carry-over is a characteristic exhibited only by wheels and refers to air that is carried from one airstream to another as a result of wheel rotation.

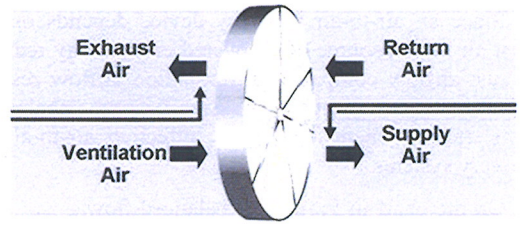


Figure 23

Leakage

Leakage

One of the best ways to keep exhaust air from contaminating the ventilation air is to design the system so that the ventilation air is at a higher pressure than the exhaust air.

On wheels, some amount of air leakage is common and manufacturers have designed ways to minimize the effects. For instance, where leakage from one airstream to another may be an issue, a purge section is available to eliminate nearly all of the leakage. The function of the purge on a wheel is to remove any dirty air trapped in the wheel media as it rotates from one airstream to another. The purge can cause the flushing of exhaust air carry-over by the matrix using incoming ventilation air. The purge forces trapped exhaust air back to the exhaust stream. The amount of flushing required is determined by the purge angle. This purge angle is the angle of rotation over which this purge effect must occur based on job parameters.

In general, some leakage is not a problem unless the exhaust airstream contains odors or harmful gasses that could contaminate the incoming ventilation airstream. Purge is only encouraged when the design calls for an absolute minimum of leakage since the purge increases the required amount of incoming air. See Figure 24.

If contamination between the adjoining airstreams is a serious concern, consider either using a recovery device other than a wheel or locating the airstreams remote from each other.

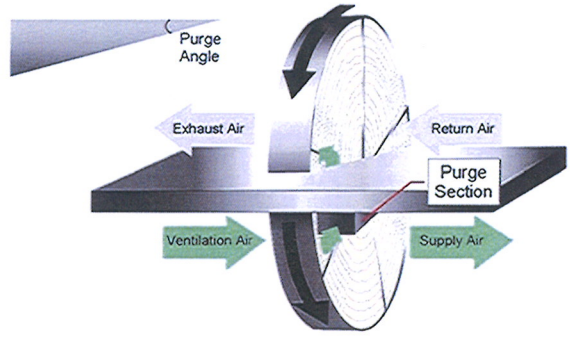


Figure 24

Purge

- not for toilet.
- used for bigger volume.

ASHRAE Standard 62.1-2004 Addendum Y, Acceptable Cross Leakage for Energy Recovery Applications, provides clear and much needed clarification to airstream recirculation issues and air classification categories. With respect to recovering energy from exhaust air, the amount of acceptable exhaust air cross leakage is clearly quantified based on the contaminant concentrations of the exhaust.

Contamination

Exhaust air transfer ratio is the percentage of exhaust air that leaks into the ventilation air.

There are two terms used in the energy recovery industry to measure leakage in both airstreams. For wheels, leakage from exhaust to ventilation is exhaust air transfer. Exhaust air transfer ratio (EATR) is the percentage of exhaust air in the ventilation air. If there is no leakage between airstreams, the EATR will be zero. When it is desirable to reduce EATR, a mechanical purge or a different fan arrangement is used in rotary wheels. Exhaust air transfer occurs because of seal leakage and the pumping action of the wheel. In permeable membrane plate exchangers, the leakage is pressure driven through the energy transfer media.

For the example in Figure 25, if the EATR for this wheel is 0.4 percent and the ventilation air passing through the wheel is 5000 cfm, then the leakage from exhaust to supply would be 20 cfm:

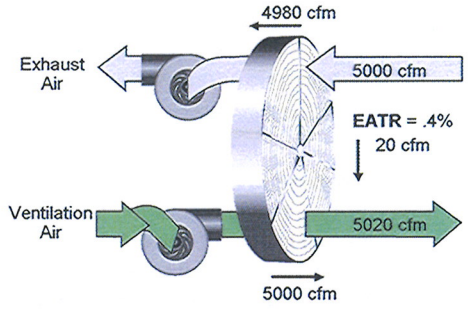


Figure 25

Exhaust Air Transfer Ratio

$$5000\ \text{cfm} * \frac{\text{EATR}}{100} = 5000\ \text{cfm} * \frac{0.4}{100} = 5000\ \text{cfm} * 0.004 = 20\ \text{cfm}$$

For wheels, the OACF is the ratio of the flow in the outdoor air plenum to the flow in the supply air plenum. See Figure 26. The OACF is generally greater than 1, indicating that some of the outdoor air entering the recovery unit will not actually reach the building. Under certain pressure situations, the value may be less than 1, but the OACF is rarely much less than 1.

For example, if the OACF on our example is 1.08, that means that some of the ventilation air on the upstream side of the wheel is leaking back to the exhaust airstream before ever going through the wheel. In this case we can find the OACF as follows:

$$\frac{\text{Upstream Airflow}}{\text{Downstream Airflow}} = \frac{5420}{5020} = 1.08$$

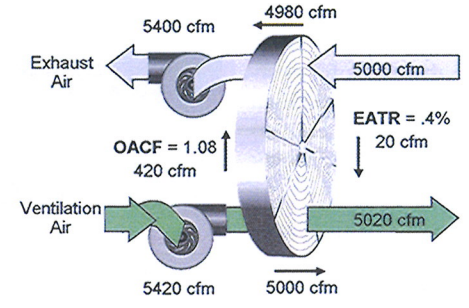


Figure 26

Outdoor Air Correction Factor

The supply and exhaust fans must be sized to take into account the airflow variations resulting from the EATR and OACF values.

Correct Fan Sizing

The supply and exhaust fans must be sized to take into account the airflow variations resulting from the EATR and OACF values.

Since total leakage is a small amount of the total airflow in a system, it generally does not cause problems. This is true even when the exhaust air is bathroom exhaust. In comfort-to-comfort applications, exhaust airstream leakage into the supply airstream is not really considered contamination. In bathroom exhaust applications, the exhaust stream is highly diluted. Five percent cross-contamination is not sufficient to produce detectable odors.

Frost Prevention of Heat Exchangers

In many climates utilizing recovery applications, the outside air temperatures can be below freezing. Moisture in the exhaust airstream can condense on the surface of the air-to-air exchanger if the temperature at the exchanger assembly falls below the dew point of the exhaust air. If the exchanger surface gets cold enough, (below 32° F) there can be the formation of frost and possibly ice.

For actual freezing to occur, the exchanger surface temperature must be slightly lower than 32° F. This can lead to the blockage of ventilation airflow, increased airside resistance for the fans to overcome, and a less effective heat exchange process. The exchanger may need to be shut down to allow it to thaw. However, shutting down the heat exchanger means that no ventilation air is being introduced into the building. This may not be allowable depending on the application. In some rare cases, damage to the air-to-air recovery device can occur from the expansion of water into ice.

The likelihood that frosting may occur can be determined with the psychrometric chart as shown in Figure 27. Frosting may occur if the straight line drawn between the winter outside air condition and the room return (exhaust air condition) intersects the saturation curve. The lower the exhaust air temperature is in relative humidity, the less of a chance there is of intersecting the saturation curve. If there is no intersection, frosting cannot occur.

As an example, let's determine the frost potential for a recovery wheel that is handling a 75° F db 45 percent rh exhaust air winter condition. Winter design is –5° F outside.

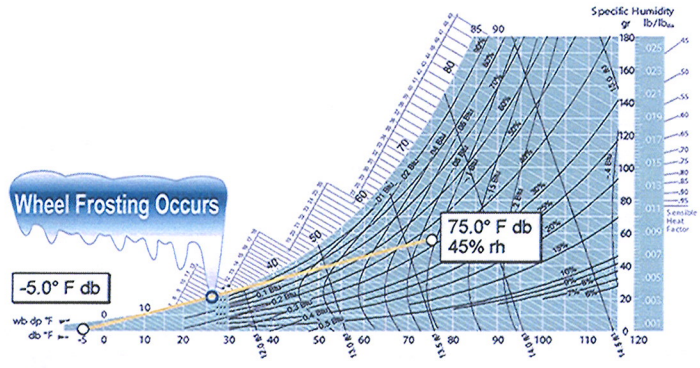


Figure 27

Psychrometric Determination of Frosting

Frosting

Exchanger temperature conditions, effectiveness, physical layout, and hours of occurrence all factor into the possible formation of condensation, frost, and freeze-up of condensate.

As we draw a line between our two conditions, the intersection of the saturation curve is at 26° F. This confirms frosting can occur.

There are a variety of variables that affect when and how much frost may result. Frosting depends on the humidity of the exhaust air (indoor relative humidity) and corresponding outdoor air temperature, but it also depends on the type of exchanger involved.

Shown here in Figure 28 is a generic graph that represents the relationship between exhaust (indoor) humidity and outdoor temperature for two types of recovery: a wheel and a fixed-plate exchanger.

Frost formation on an air-to-air exchanger depends on two parameters: the indoor relative humidity and the outdoor temperature, which are shown on the axes of the graph in Figure 28. The relative humidity of the exhaust airstream and the outside air temperature of the air entering the exchanger determine the frost threshold.

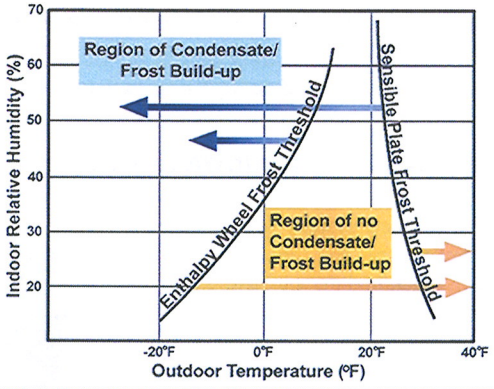


Figure 28

Frost Occurrence on Wheel and Plate Exchangers

The two lines on the graph represent two different air-to-air technologies. The area to the right on the graph is frost-free operation. In the area to the left on the graph, frost control would be required. As shown in the graph, plate type exchangers have a higher frost threshold than energy wheels.

Several methods of frost control are currently employed for recovery systems. The method used depends on the air-to-air technology chosen. Fixed devices such as plates and heat pipes often recycle warm exhaust air through the ventilation section to prevent frost.

One method of frost prevention shown is in Figure 29. A plate heat exchanger utilizes a damper that keeps the air away from the coldest spot on the heat exchanger. This keeps frosting from occurring.

A common method for frost prevention used on several types of energy wheels preheats the outdoor air or reheats the exhaust air. This keeps the straight line between the two conditions from intersecting the saturation curve as shown on the psychrometric chart (Figure 27), thus preventing the possibility of frosting. In small systems, electric preheat frost control is very effective. As systems get larger, either bypass or exhaust air preheat are effective means of keeping the wheel from frosting.

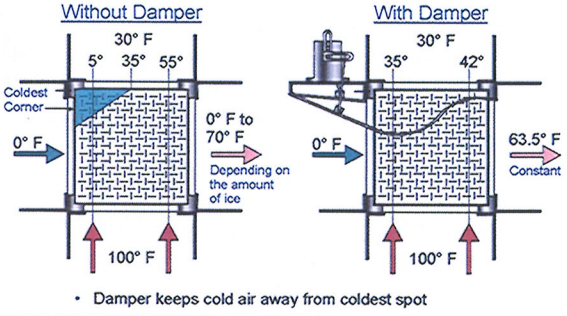


Figure 29

Plate Exchanger with and without Damper
(Reproduced with permission of American Energy Exchange, Inc.)

Another frost prevention method used with wheels utilizes a variable frequency drive (VFD) to slow the wheel rpm, thus reducing heat transfer rate at the extremely cold outdoor air conditions.

Of all these methods, the ventilation air and exhaust air preheat options are the most energy efficient when applied to a recovery wheel since they allow it to operate with peak energy recovery effectiveness at very low temperatures. In the case of the exhaust air frost control, 70 percent or more of the heat energy added to the exhaust air is recovered in heating outdoor air supply.

Additional data on frost control on the various energy and heat recovery product types is detailed under the section dedicated to each type.

Coupled and Uncoupled Systems

A coupled system is defined as a system where the energy recovery unit is attached to or inside of the main HVAC unit chassis. See Figure 30.

In a coupled system, the recovery device and the base unit power can often be conveniently supplied from a single source. This is an advantage over uncoupled systems.

An uncoupled system is a combination of an HVAC unit with a separate energy recovery unit. On the uncoupled system diagrams shown in Figures 31 and 32, the preconditioned ventilation air can be delivered through a separate duct and diffuser system directly into the conditioned space. The recovery unit can be placed anywhere a convenient combination of exhaust air and ventilation air can be brought together. An uncoupled system can be applied when it is not possible or advantageous to have the recovery device inside or attached to the main HVAC unit chassis. An uncoupled arrangement also does not interfere with the main unit's economizer operation.

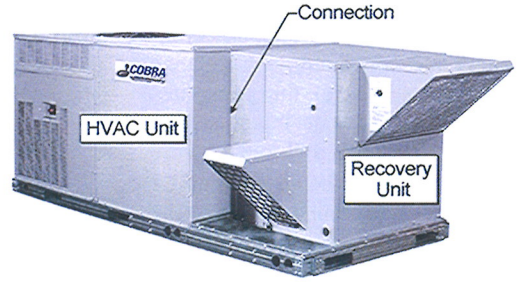


Figure 30

Coupled System

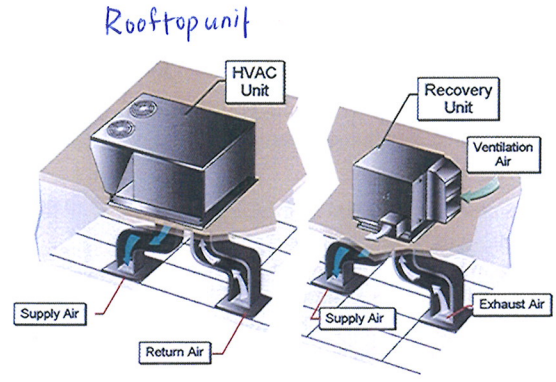


Figure 31

Uncoupled System

There is an advantage to an uncoupled system when it comes to ventilation air delivery to multiple spaces. With the uncoupled approach, each room's ventilation supply can be balanced to the amount necessary to comply with ASHRAE 62.1 requirements.

For instance, in the large office shown in Figure 32, the ventilation air is 120 cfm, or 23 percent of the total room airflow. This is because of the heavy people load. In the one-person office, only 20 cfm of ventilation air is required, which is less than 10 percent of the room airflow.

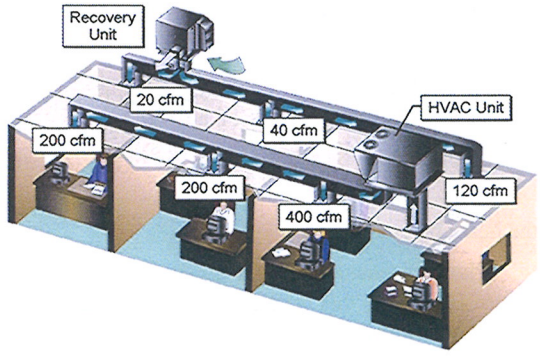


Figure 32

Uncoupled System Ventilation

With a coupled recovery system, there may be over-ventilation or under-ventilation of some of the rooms when several rooms with different airflow requirements are served by the same unit. This is because the ventilation air mixes with the return air into a common airstream. The ventilation air is a straight percentage of the total air delivered by the rooftop. Rooms that require more airflow due to their thermal loads automatically get more ventilation air also, even if they do not require it.

Filtration

It is recommended that the incoming ventilation air be filtered prior to passing through the heat or energy recovery device. Filtering the exhaust air prior to entering the exchanger is also good practice. If the airstream contains grease, special filters should be used accordingly. It is important to ensure a clean supply of filtered air for both airstreams in order for the heat or energy exchanger to maintain its effectiveness. If filters are not provided as part of the manufacturer's packaged recovery product, they must be supplied by the installing contractor. See Figure 33.

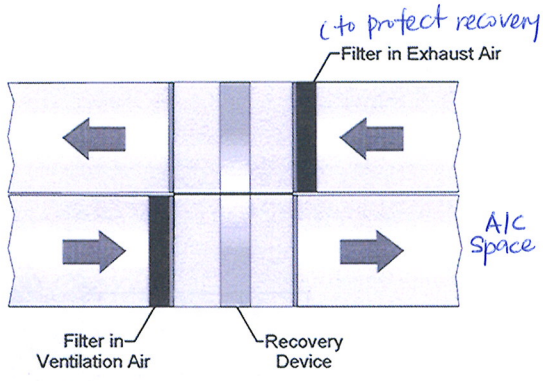


Figure 33

Filtration Requirements

Psychrometric Examples of Heat and Energy Recovery

Now that we have examined the principles of air-to-air recovery, we will establish the basics for understanding the process of heat and energy recovery using the psychrometric chart. The reader should refer to the TDP-201, Psychrometrics Level 1: Introduction prior to reading this section in order to be familiar with the psychrometric chart, its uses, and properties of air.

First we will define some important terms related to psychrometrics that are also important in the heat and energy recovery processes.

When a recovery device causes a temperature change in an airstream and there is no change in moisture level, this is called a sensible heat process. Some recovery units capture sensible heat only. These are referred to as *heat* recovery units. Common examples of sensible-only recovery units are runaround loops, heat pipes, fixed-plate heat exchangers, and heat wheels.

When a recovery device transfers *energy,* there is also a change of moisture level to the airstreams. This is called a latent change. A combination sensible and latent change is also called an enthalpy or total heat content change. That is why some energy recovery devices that recover both sensible and latent heat are referred to as enthalpy or total heat devices.

The following example shows the sensible cooling effect on the ventilation airstream as a result of heat exchange with the exhaust air. See Figure 34. Notice that the ventilation air has undergone a dry bulb temperature reduction of 15° F from 95° F entering to 80° F leaving air after passing through the heat recovery unit. We are using 1250 cfm of ventilation air in our example.

The winter mode is shown in Figure 34 for the same system. The outdoor air has been heated from its initial condition of 15 to 50° F by the recovery device.

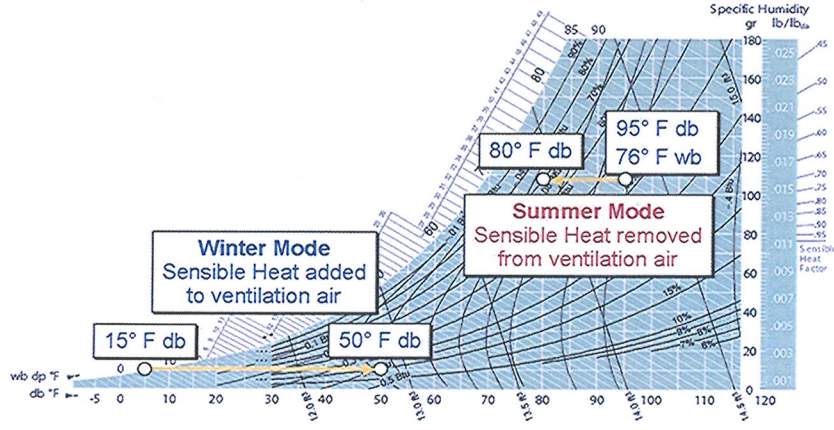


Figure 34

Process Line for Sensible Heat Recovery

We can calculate the amount of heat added in winter with the sensible heat equation. The equation for sensible heat is:

$qs = 1.1 * cfm * (\Delta T)$

Where:

qs = Btuh of the sensible heat process

1.1 = constant for air

ΔT = difference in leaving and enterng dry bulb conditions (T_1-T_2)

T_1 = 50° F db leaving air

T_2 = 15° F db entering air

For this example, the amount of recovered heat added to the air in winter is:

$Qs = 1.1 * 1250 * 35 = 48{,}125$ Btuh

Cooling Mode Example, No Recovery

To continue our discussion of psychrometrics, we will now analyze the mixing of air. This is important as it will allow us later to see the impact of adding recovery to an air-conditioning unit that recirculates some of the return air and mixes it with the incoming ventilation air. Mixed air systems comprise the majority of applications, however, recovery is also applied to 100 percent outdoor air systems, also known as dedicated outdoor air systems.

Mixed Air Systems

Mixed air systems comprise the majority of applications. However, recovery can also be applied to 100 percent outdoor air systems. In fact, ASHRAE 90.1 requires recovery on many systems using large amounts of outdoor air. See the ASHRAE 90.1 section for details.

For our example we will use the cooling mode with a system that mixes ventilation air with the return air.

In the cooling mode, outdoor air (point A, 95° F db [dry bulb]/76° F wb [wet bulb]) is mixed with building return air (point B, 75° F db, 50 percent rh) and the resulting mixture lies on a straight line between the two points (point C). The air then enters the cooling coil to be conditioned at that same point.

The location of the mixture between the two points is dependent on the amount of outdoor air versus the amount of return air. Since in many air-conditioning systems the outdoor air amount tends to be 1/4 to 1/3 of the total amount of air, the mixture will usually be located 3/4 or 2/3 of the distance toward the return air condition. This mixed air temperature entering the coil has not involved any recovery at this point.

Let's determine the mixed air condition and then find the total resulting tonnage of a rooftop unit *with no heat recovery* working at the following conditions:

- Outdoor air is 95° F db and 76° F wb
- Room design is 75° F db and 50 percent rh
- Total airflow required is 5,000 cfm
- Ventilation air required 25 percent (1250 cfm)
- Rooftop unit will deliver 55° F leaving air

Plotting the points on Figure 35 and using a scale to find the mix point 25 percent of the distance between A and B, we see the resulting properties of the mixture are 80° F db and 66.4° F wb. For this example we are making a simplified assumption that air leaves the cooling coil saturated at 55° F. In reality, there is some amount of bypassed air. See TDP-614, Coils: Direct Expansion, Chilled Water, and Heating, for a discussion of bypass factor. This represents a point ¾ of the way towards the room design. This mixture reflects the condition of air as it enters the cooling coil. Since air leaves the cooling coil at 55° F, we can calculate the total capacity required for the rooftop unit with the equation:

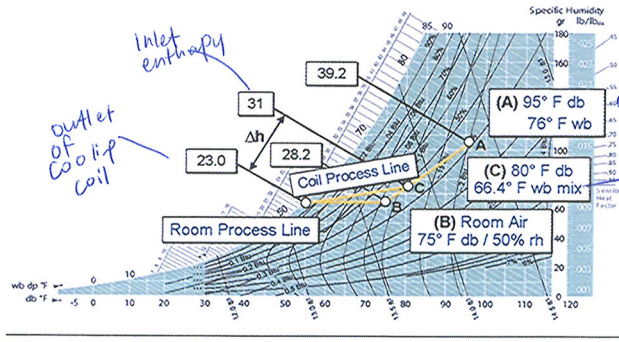


Figure 35

Cooling Load with No Recovery

$$qt = 4.5 * cfm * (\Delta h)$$

Where:

qt = total Btuh of the process

4.5 = constant for air

Δh = difference in entering and leaving enthalpy h_1-h_2

h_1 = entering air enthalpy (31 Btu/lb)

h_2 = leaving air enthalpy (23 Btu/lb)

Total Btuh required = 4.5 * cfm * Δh

= 4.5 * 5000 * (31-23)

= 180,000 Btuh or 15.0 tons

In this example, the enthalpy (total heat content) of the air mixture entering the cooling coil was 31 Btu/lb and as a note, the outside air enthalpy was 39.2 Btu/lb. At this point a 15-ton rooftop unit would be chosen to provide cooling.

Cooling Mode Example with Energy Recovery

If we utilize a recovery unit, the resulting air mixture temperature entering the rooftop unit cooling coil will be lower. In summer, the outdoor air will be cooled and dehumidified by the passive transfer of energy from the recovery unit. The energy is coming from the airstream passing through the wheel, which is at room design of 75° F db and 50 percent rh.

This in turn will reduce the amount of cooling and heating required of the rooftop unit. The result will be a downsizing in base unit capacity and an associated first cost and operating cost savings from the original 15-ton unit selection, which had no recovery.

For our example let's use an energy wheel at 70 percent effectiveness that is direct coupled to the rooftop unit. The ventilation air for the rooftop unit enters through the energy wheel. The building exhaust airstream exits through the energy wheel. The energy wheel unit (ERV) contains a separate supply and exhaust fan to move the two airstreams through the wheel assembly and filters.

This process is represented on the psychrometric chart in Figure 36. For purposes of this discussion, the sensible and latent recovery process results in the condition of the ventilation air coming off the wheel to be 70 percent of the distance between the exhaust airstream (75° F db, 50 percent rh) condition and the outside air (95° F db, 76° F wb). In our example, the point will lie on the straight line connecting the points as shown. This makes an assumption that the sensible and latent effectiveness are equal. In reality the point could lie close to, but not exactly on, the straight line between the two points if the sensible and latent effectiveness are not exactly equal. Typically they are very close to being equal.

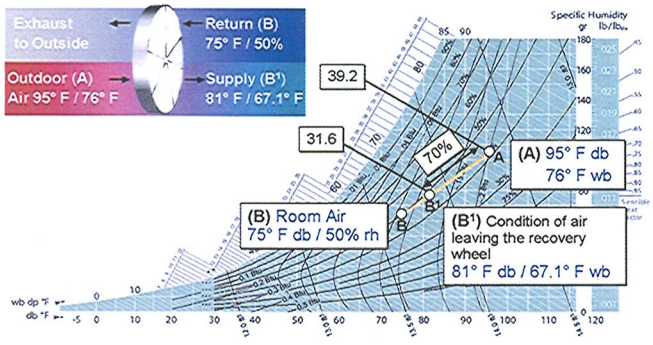


Figure 36

Cooling Load with Energy Wheel

On the graph, this new point's condition is 81° F db and 67.1° F wb. This condition reflects an enthalpy change of 39.2 Btu/lb – 31.6 Btu/lb or 7.6 Btu/lb for the 1250 cfm of ventilation air. This new point is the condition of the ventilation air after recovery has reduced its dry bulb and wet bulb temperatures. Now, when it is mixed with the return air, the resulting condition entering the coil will be even lower.

The reduction in tonnage of the ventilation air load as a result of recovery can be calculated.

$$\text{Reduction in tons} = \frac{4.5 * cfm * \Delta h}{12{,}000}$$

Where:

4.5 = constant for air

1,250 = ventilation air cfm

Δh = difference between entering and leaving ventilation air enthalpy (h_1-h_2)

h_1 = 39.2 Btu/lb (entering ventilation air enthalpy)

h_2 = 31.6 Btu/lb (leaving ventilation air enthalpy)

$$\text{Reduction in tons} = \frac{4.5 * 1{,}250 * 7.6}{12{,}000} = 3.5 \text{ tons}$$

In this example, it looks as if we could downsize the rooftop unit from a 15-ton unit to a nominal 12 1/2-ton unit by adding recovery. Let's go ahead and figure out the final entering coil conditions and exact tonnage requirement for the downsized rooftop unit and complete the entire process on the psychrometric chart as shown in Figure 37.

The resulting entering conditions for the unit with recovery can be found by doing a mixture. Air exiting the energy recovery wheel at point B^1 is 81° F db 67.1° F wb, and will mix with room air. The mixture will be ¾ of the way between the two points. The new mixture entering the coil of the rooftop will be 76.5° F db / 63.9° F wb reflecting energy recovery.

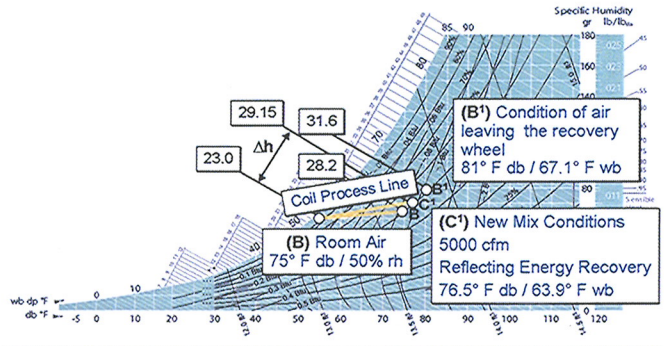


Figure 37

Cooling Load with Recovery

With a lower entering wet bulb condition of 63.9° F, the 12 1/2-ton unit will produce a slightly different capacity than if it had no recovery and the entering wet bulb of the mixed air were higher.

Notice in Figure 37 the slope of the coil process line has changed. It has flattened out reflecting a shift to a higher sensible heat factor. The sensible heat factor is the ratio of sensible heat to total heat. The latent component of the total heat has been reduced by the recovery device. That allows the rooftop unit's 3-row coil to more adequately handle the space relative humidity requirements as a result of the recovery wheel preconditioning the ventilation air.

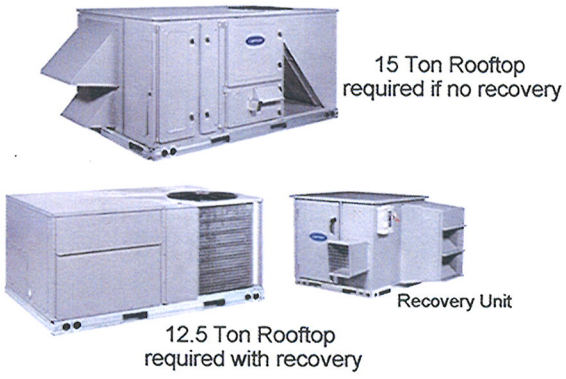


Figure 38

Downsizing the HVAC Unit

Downsizing the unit can be an important cost savings. See Figure 38.

Heating Mode Example, No Recovery

Let's take a look at the same rooftop unit and examine the psychrometrics of the heating mode. We will first size the heat with no recovery. See Figure 39.

The outdoor design in winter for our example is 15° F (point C). Room design is 70° F db and 25 percent rh (Point A). The unit airflow is 5000 cfm, which was established from the cooling loads in the space. The 25 percent ventilation air mixes with the room return air resulting in a heating coil inlet temperature of 56.25° F (Point B).

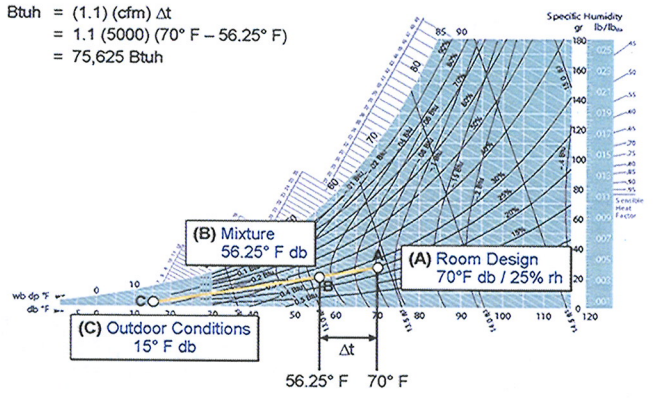


Figure 39

Heating Load without Recovery

Heat capacity in the rooftop unit will have to overcome the ventilation air load required to bring this airstream up to room design plus any normal heat losses in the space. For purposes of simplification so we can concentrate on the psychrometrics of heat recovery, we will disregard space heat losses.

Let's assume an electric heater will be used. Its capacity can be found by the sensible heat equation:

Btuh = 1.1 * cfm * ΔT

Where:

ΔT = the difference between entering and room design air temperature (T_1-T_2)

T_1 = 70° F (room design)

T_2 = 56.25° F (mixed air temperature)

Btuh = 1.1 * 5,000 * (70° F- 56.25° F)

= 75,625

We can convert the Btuh into kW using the conversion

$$\frac{3412 \text{ Btuh}}{\text{kW}}$$

kW = 75,625/3,412 = 22.2

A 25 kW heater would normally be selected.

Heating Mode Example with Energy Recovery

We will use an effectiveness of 70 percent on heating mode for our example, therefore, the recovery wheel will bring the outdoor air to within 70 percent of the distance from the outdoor air condition of 15° F towards the room (exhaust) air condition of 70° F and 25 percent rh. This new condition, point B^1, is 53.5° F db and is on the line between the two points and reflects the addition of energy recovery. See Figure 40.

Air at this condition will mix with room design temperature air and this mixture will enter the heating coil.

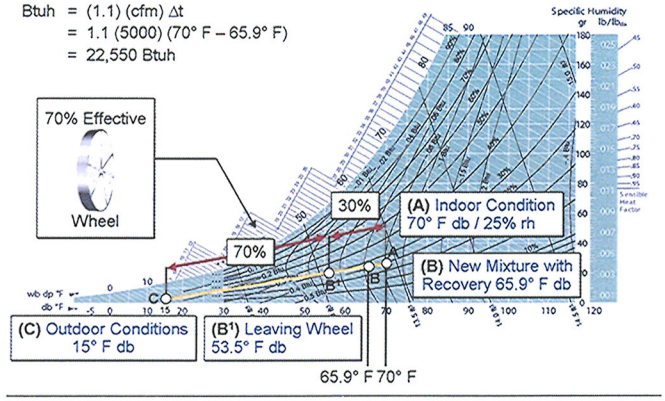


Figure 40

Heating Load with Recovery

The new mixture condition entering the heating coil is 65.9° F (Point B). We arrived at that figure by finding the point 3/4 of the distance toward the room condition point. This point reflects a mixture of 25 percent outdoor air and 75 percent room air.

The required electric heater capacity reflecting the use of recovery would be:

Btuh = 1.1 * cfm * Δ T

= 1.1 * 5,000 * (70° F – 65.9° F)

= 22,550

kW = 22,550/3,412 = 6.6

A 10 kW heater would be selected, which is less than half the size required without recovery.

If our return air condition had been 70° F db and 70 percent rh (unusually high relative humidity) (point 2) as shown in Figure 41, instead of 70° F db and 25 percent rh, then the process line would have intersected the saturation curve resulting in frosting. By preheating the exhaust air prior to it entering the recovery wheel (point 3 in Figure 41), we move the process line off the saturation curve and avoid the potential for frosting of the exchanger.

Return/Exhaust Air Reheat

Instead of preheating the return air, preheating the outdoor air is another method to avoid frosting.

Shown in Figures 42 is a psychrometric plot reflecting various outdoor weather conditions representing the ventilation air entering an energy recovery wheel.

The ventilation air temperature leaving the wheel at design conditions lowers the difference between the outdoor air and the room design as we saw in our example. This is the case both summer and winter.

Energy recovery has shrunk the psychrometrics into a smaller area. As the ventilation air conditions exiting the energy wheel mix with their respective room design conditions, the resulting entering coil conditions are much closer to room design. This results in smaller calculated heating and cooling equipment and less energy consumption.

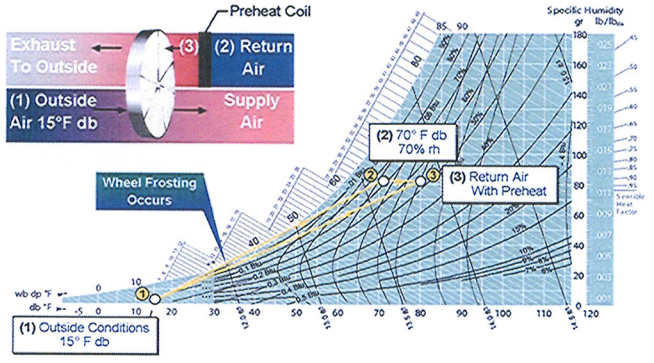


Figure 41

Return/Exhaust Air Preheat

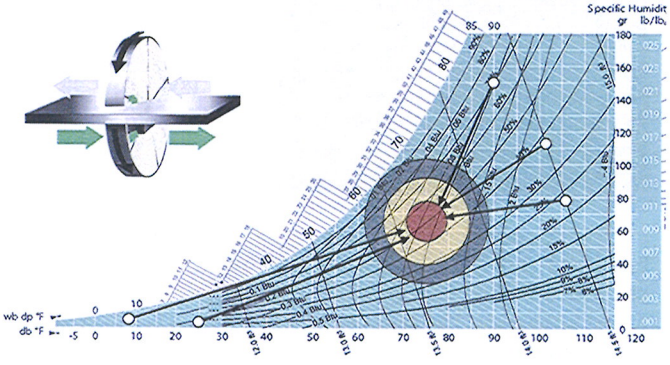


Figure 42

Energy Recovery Wheel Performance

Types of Heat and Energy Recovery Technology

Following is a discussion of seven types of heat and energy recovery technology. Listed in Appendix A is a comparison chart from ASHRAE that summarizes most of the types discussed in this TDP module.

Runaround Loops

A runaround loop (or coil energy recovery loop) is a heat recovery system. It is distinct from other recovery equipment discussed in this TDP, such as wheels or fixed-plate heat exchangers, because it can be located throughout the building in pieces. Runaround systems circulate a fluid (usually a glycol mixture) between two air-streams to transfer heat using standard finned tube coils. See Figure 43. In the winter, the warm exhaust air from the building is transferred to the circulating fluid, which warms the supply airstream containing incoming cold (ventilation) air. In summer, the fluid is circulated through the cool exhaust air coil and it precools the incoming warmer supply air.

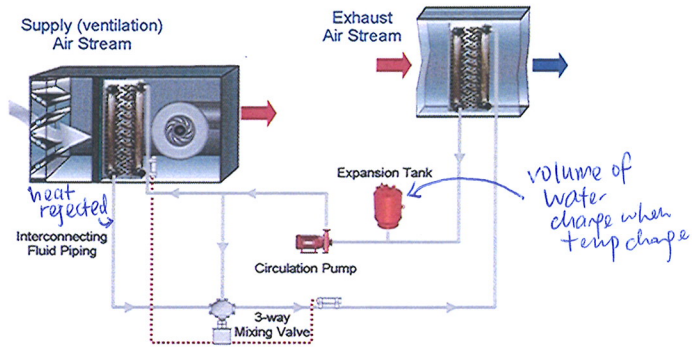


Figure 43

Runaround Loop

Runaround Loops

Two important features of runaround loops are that the airstreams do not need to be next to one another and there are no cross-contamination issues.

The supply air coil may be located in an air handler in a precool or preheat position. Multiple supply and exhaust coils may also be installed in various exhaust and supply ducts. The runaround loop piping connects the coils, which is a major advantage of this approach to heat recovery.

The major components of the system are a pump, expansion tank, interconnecting piping, exhaust and supply coils, and controls, which include a 3-way valve. Notice that the pump is positioned so that heat from the pump enters the fluid of the ventilation coil. This maximizes winter efficiency. The pump circulates the fluid between the coils in a closed loop. The expansion tank is necessary for thermal expansion and pressurization of the fluid.

Runaround loops have approximately a 55 to 65 percent sensible effectiveness in transferring heat from exhaust to ventilation. The airside pressure drop of the coils is typically 0.6 to 1.5 in. wg. The coils are often 6 or 8 row coils with face velocities between 350 and 550 fpm. The best life cycle selections for a runaround loop favor those which maximize heat transfer by using deep row coils and 14 fin-per-inch (fpi) spacing as opposed to 8 fpi fin spacing. Airside pressure drop will be greater, resulting in increased fan energy to move air through the coils. First cost is higher but heat transfer is highest.

Frost Prevention

The 3-way valve in a runaround system is used for capacity control and for frost prevention.

Runaround loops are very flexible and well-suited to industrial applications or comfort applications with remote ventilation and exhaust ductwork.

Runaround loops are a natural fit for medical facilities and laboratories that may have a contaminated airstream. If the airstreams are located next to each other, and the exhaust is not contaminated, consider instead an energy wheel or another recovery method. Runaround loops cannot transfer any moisture between the airstreams, so they are only capable of sensible recovery.

In both new buildings and renovations, a runaround loop can fit the layout and reduce the maximum required heating and cooling capacity while providing ongoing operating cost savings. In new projects, this can result in both boiler and chiller downsizing.

Runaround loops can be sized for small airflow applications (under 300 cfm). Coils are available to fit almost any size requirement.

The selection of a runaround system is typically made by a computerized coil selection program. The coils rows and fins per inch are selected based on maximizing heat transfer at design conditions while keeping a reasonable airside and fluid side pressure drop and pump size.

Selection Program

The selection of a runaround system is typically done by a computerized coil selection program.

Selection often involves several iterations to find the correct balance between exhaust coil(s) and supply coils. The selection procedure is further complicated when multiple exhaust coils are a factor. Typically, a 6-row coil strikes a good balance with first cost and efficiency.

Capacity Control

Capacity control is usually accomplished by a 3-way mixing valve. Some designs incorporate a VFD on the pump, but that is not as common. The mixing valve is used to bypass water to make sure the supply airstream is kept from getting too warm or too cold. This can happen during periods of mild weather outside.

The 3-way valve is also used for frost prevention control. Frost is capable of forming on the exhaust coil. The fluid temperature entering the exhaust coil can be kept high enough to prevent frosting. Typically, this means at 32° F, the mixing valve is repositioned to mix the heated fluid coming out of the exhaust coil with the fluid exiting the supply coil. That serves to elevate the temperature entering the exhaust coil and prevents frost formation.

Maintenance

Maintenance requirements are not extensive but routine pump inspection is important. Coil surfaces should be kept clean to optimize heat transfer. Filters should be checked on a regular basis.

The fluid solution must be checked periodically. If an antifreeze solution is used, make sure it is maintained at the proper concentration. The system also requires a periodic check of the electrical power, motor controls, 3-way valve, and temperature controls.

Fixed-Plate Heat Exchangers

There are many different configurations and sizes of fixed-plate heat exchangers. They can be used residentially or commercially. Many come in a modular design that can be configured to fit the exact application requirements. The heat transfer core of a fixed-plate heat exchanger is made from alternate layers of plates, formed and sealed at the edges to create two adjacent, but separate, airflow paths. The most distinct advantage of fixed-plate heat exchangers is that there are no moving parts. Sensible heat transfer across the plates from one airstream to the next is passive in that it is driven by the thermal gradient only.

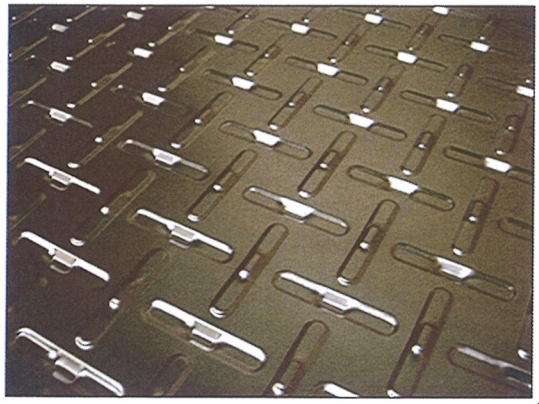


Figure 44

Plate Design
(Reproduced with permission of American Energy Exchange, Inc.)

Aluminum is a popular fixed-plate construction material because of its durable nature and good heat transfer properties. However, polymers or steel are also used depending on the manufacturer and application.

Sensible Heat Applications

Fixed-plate heat exchangers transfer sensible heat only.

Airstreams are separated by folding or welding the plate edges to form separate air paths. Spacing of the air paths is accomplished by molding integral dimples or ribbed patterns into the plates. See Figure 44 for an example of the plate design pattern. External separators are also used. Fixed-plate heat exchangers can be manufactured so there is little or no leakage between the airstreams. However, air leakage can occur outside of the fixed-plate exchanger such as within the air-handling unit casing if the exchanger is not 100 percent sealed around the perimeter.

Crossflow is the most common arrangement for heat transfer. Counterflow and parallel-flow exchangers are also available but less widely used. See Figure 45.

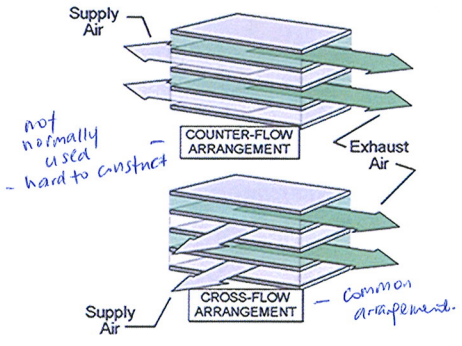


Figure 45

Counterflow and Crossflow

Fixed-plate exchangers have approximately 50 to 80 percent sensible effectiveness. Airside pressure drops range from approximately 0.35 in. wg up to 4.0 in. wg of pressure drop in each airstream on the larger sizes.

Plates are commonly 0.50 in. apart or less. Units are available in many different materials, sizes, and patterns, and are often manufactured in combinations to fit large airflow applications. Capacities range from small sizes used in residential recovery units to over 10,000 cfm modules; however, that is a common upper limit for

standard fixed-plate heat exchangers. Special combination modules can go higher. As with all air-to-air exchangers, it is important to maintain balanced airflows between the two airstreams to maximize effectiveness.

Because there is not an intermediate fluid required to transfer heat as with a runaround loop, the sensible effectiveness is relatively higher, up to 75 or 80 percent as the upper value.

However, plate-heat exchangers have an upper limit in the difference in pressure between opposing airstreams that they are capable of withstanding. Higher static applications with large high-pressure fans typically do not use plate heat exchangers for that reason.

Figure 46 shows the side view of a crossflow plate exchanger installed in the airstream. Figure 47 shows crossflow plate exchangers installed in a custom air-handling unit.

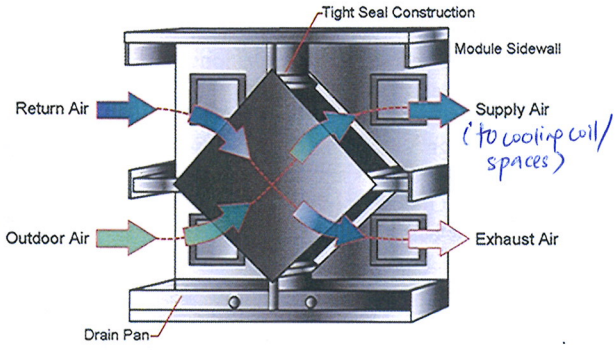


Figure 46

Plate Exchanger Crossflow Module
(Reproduced with permission of American Energy Exchange, Inc.)

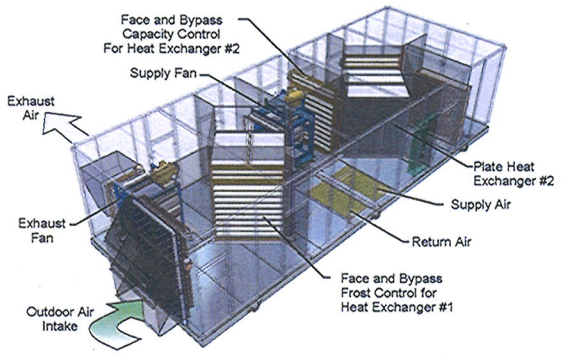


Figure 47

Plate Exchangers in Air-Handling Unit
(Photo courtesy of AnnexAir)

Membrane Type Plate Exchangers

Some fixed-plate type designs are capable of latent heat transfer also. These are referred to as *membrane* heat exchangers and are made of a water-vapor-permeable material such as a porous synthetic material. The permeability of these materials enables the fixed-plate heat exchanger design to transfer both sensible and latent heat. Membrane exchangers are not typically built in large sizes. They are used in residential and some commercial applications. Their sensible effectiveness is between 50 and 75 percent. Their total effectiveness, which includes latent, is about the same as the sensible effectiveness.

Capacity Control

On fixed-plate heat exchangers, bypass dampers are most often used. The bypass damper can be on the side or middle of the exchanger. On long exchangers, a middle bypass is recommended for good mixing. The bypass design should have approximately the same pressure drop as the exchanger. Opposed blade dampers are used for best flow regulation. See Figure 48.

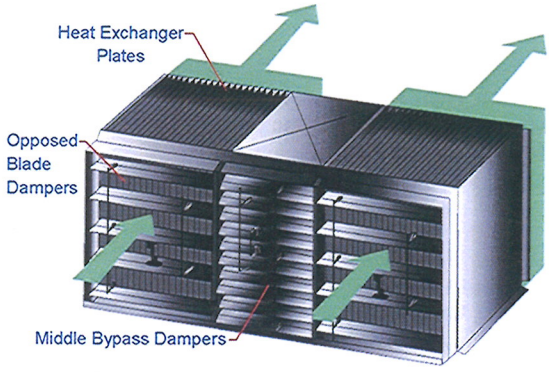


Figure 48

Fixed-Plate Heat Exchanger Capacity Control
(Reproduced with permission of American Energy Exchange, Inc.)

Heat Pipes (is not a coil) - refers to simple tube sealed on both end with refrigerant in it.

Heat pipes have the appearance of ordinary finned tube coils. However, each successive tube is independent and not connected to other tubes. Each tube is built with an internal capillary "wick" material. The tube is evacuated, filled with a fluid with a high latent heat of vaporization such as R-134a refrigerant or water, and individually sealed. The term "wick" is used to describe various forms of internal designs that promote heat transfer using the fluid. There are two common designs used for the internal wicking material: grooves and mesh. See Figure 49.

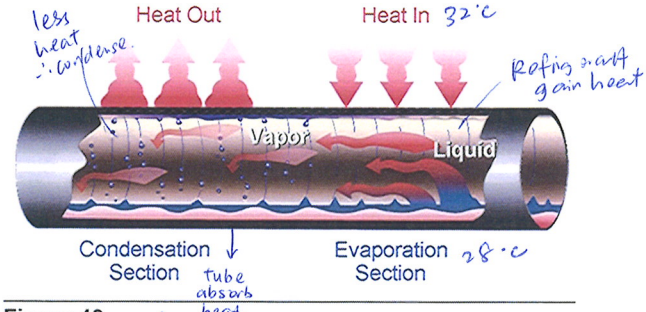


Figure 49

Heat Pipes

With the tubes installed horizontally, one-half of the heat exchanger acts like an evaporator and the other half acts as a condenser. There is a partition between them. The high-temperature airstream passes over one-half of the tubes. As the working fluid is warmed and vaporized in the evaporator half, the internal vapor pressure gradient drives the vapor to the other end of the tube. In the condenser end, the fluid releases the latent energy of vaporization as it condenses, thereby warming the low-temperature airstream. Liquid returns to the evaporator end through the internal wick material. See Figure 50.

Often, grooves are combined with a screen mesh. A screen mesh is used in the majority of the heat pipes on the market and provides a highly successful transport mechanism.

The number of screen layers and the mesh count of the screening can be varied to can be varied to suit the heat transfer desired. Axial grooves inside the tubes can be used to assist in the capillary action and transport of the heat.

Heat pipes have approximately a 45 to 65 percent sensible effectiveness. They are also most effective when the airflows are balanced. Heat pipes can be mounted in rooftop units and air handlers. They can be installed so that cross-contamination between the two airstreams is near zero.

Heat pipes for energy recovery are used when avoiding cross-contamination is critical such as in labs, operating rooms, etc. The simplicity of the heat pipe design and the lack of moving parts make heat pipes suitable for applications where maintenance may be an issue.

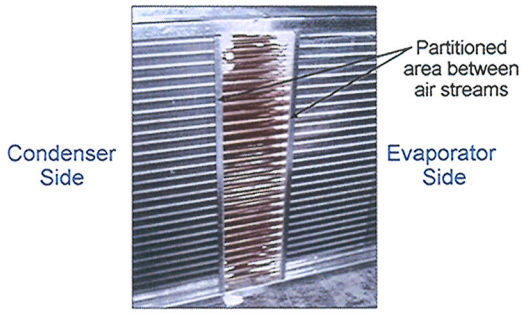


Figure 50

Heat Pipe Installation
(Photo courtesy of Heat Pipe Technologies, Inc.)

Heat Pipes

Some latent benefit is achievable, but in general, heat pipes are considered a form of sensible recovery.

Capacity Control

Heat pipes can use a tilt control mechanism or a face and bypass damper for capacity control. See Figure 51.

Tilt control reduces the heat transfer occurring within the heat pipe unit by slowing the rate by which the fluid moves back and forth within the tubes. An actuator motor tilts the entire heat pipe assembly on a pivot. The larger the tilt angle, the less heat transfer that takes place. However, the amount of tilting is limited, so this method may not be as successful on one application as another. The assembly is connected to the inlet and discharge ductwork with flexible connectors to accommodate the movement.

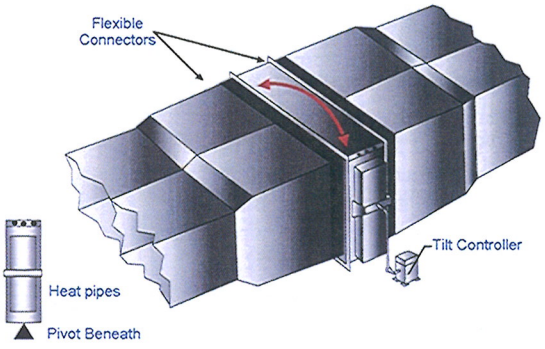


Figure 51

Heat Pipe Tilt Control

Face and bypass control works to alter the amount of air passing over one of the ends of the heat pipe. The more that end of the heat pipe is denied airflow, the greater the capacity reduction. Full face open results in full heat exchange.

Maintenance

Heat pipes require relatively little maintenance. The filters used on the inlet and discharge should be changed regularly. The coil pipes can be washed with a commercial cleaner. If a tilt mechanism is used for capacity control, it must be checked and lubricated. The canvas connections used when a tilt mechanism is employed should be checked for cracking and leaking.

Heat and Energy Wheels

In the interest of understanding the benefits of energy wheels, it is useful to understand the other technologies already discussed. The first thing to understand is that not all technologies are appropriate for every application. Each has benefits and limitations, and may be better suited to certain applications over others. For instance, energy wheels, as they are described in this section, are ideally suited to comfort-to-comfort ventilation applications. A runaround loop can be similarly effective in transferring sensible heat. On the other hand, a runaround loop can be applied successfully to harsh process application where an energy wheel should not.

Refer to the ASHRAE "Comparison of Air-To-Air Energy Recovery Devices" table in Appendix A of this TDP for a summary of the features of each recovery type.

Wheel heat exchangers are also called *heat wheels* or *enthalpy wheels*. Although many people use the phrases interchangeably, the term *heat wheel* is used to distinguish a sensible-only application. The *energy* or *enthalpy wheel* is used to distinguish a product that will accomplish sensible and latent energy transfer. In both cases, the fundamental piece of equipment is nearly identical. See Figure 52.

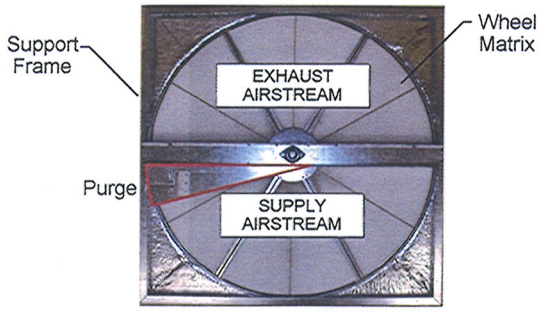


Figure 52

Energy Wheel
(Photo courtesy of AirXchange)

When a wheel is coated with desiccant, it is sometimes called a desiccant rotary regenerator. Desiccants will be discussed later. There are two types: active and passive. Active recovery uses heat energy to regenerate, while passive recovery uses exhaust air. This discussion will focus on the passive type, since that is the type commonly used in comfort cooling applications.

The exchanger is a revolving wheel filled with an air-permeable media. The media has a large internal surface area. The exchanger is positioned between two adjacent ducts with opposing flow directions. This establishes a counterflow heat exchange pattern similar to that illustrated in Figure 53. The wheel rotates between 10 and 60 revolutions per minute depending on the application. When the wheel passes through the higher-temperature airstream, the media temperature increases as heat is transferred and stored in the media material. When the wheel media rotates into the low-temperature airstream, the media is cooled and releases heat. This sensible form of heat transfer is driven by a temperature gradient between higher and lower temperature airstreams. In most comfort applications, the temperature difference is relatively small as compared to process recovery applications.

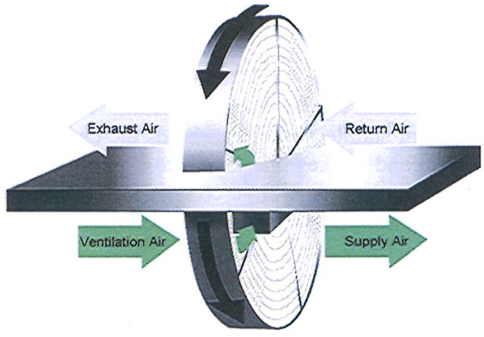


Figure 53

Heat and Energy Wheel Operation

Latent heat transfer can occur in one of two ways. First, if the temperature and humidity gradients are sufficient, water may condense on the cold media in the high-humidity airstream. Moisture droplets held in the media are carried to the low-humidity airstream where they evaporate.

Energy Wheel

In an energy wheel, heat transfer can flow in one direction and moisture transfer can occur in the opposite direction because they are driven by different mechanisms.

The second and more reliable means of moisture transfer happens when the heat transfer media in the wheel is coated with a desiccant. In the higher humidity airstream, desiccant material adsorbs water vapor molecules, which move to the surface of the desiccant by the process of vapor diffusion. The water vapor molecules ride the rotating wheel and are released (desorbed) into the lower humidity airstream. Although the overall process is considered energy transfer, the moisture adsorption/desorption process described is actually a mass transfer event. It is driven by the water vapor partial-pressure gradient between the higher humidity and lower humidity airstreams. This transfer is not dependent on the temperature gradient driving sensible heat transfer. This means that heat transfer can flow in one direction and moisture transfer can occur in the opposite direction because they are driven by different mechanisms.

Several factors affect performance of a wheel: rotating speed; physical characteristics such as size, thickness, and material; and desiccant characteristics of the material used for the matrix. Like other forms of recovery discussed in this TDP module, performance of a wheel is optimized with balanced exhaust and ventilation airflows.

The sensible effectiveness and total effectiveness are approximately 50 to 85 percent with an energy wheel. The upper values are possible with a larger, lower velocity wheel. However, increasing the physical cabinet size of the rooftop or air-handling unit may offset the benefits of increasing the wheel size.

Construction

Energy wheel design is generally similar among manufacturers. Units consist of a rotating wheel mounted on a steel metal panel that is attached to two parallel ducts. The wheel may also come packaged inside a housing with a supply and exhaust fan. Specific design and assembly features will vary somewhat. The descriptions below are typical and not to be construed as universal in the industry.

Energy recovery wheels are typically constructed with a circular, welded frame of anodized aluminum or stainless steel that holds the energy transfer media. The frame is constructed with a center hub and spokes that attach to a perimeter ring. The rim is a continuous, rolled, stainless steel band that acts as a drive component. A large, flexible drive belt encircles the wheel rim and is driven by a small electric motor (up to ½ hp). The media-wheel is supported in a flat, rectangular, sheet metal housing and rotates on a shaft held by two lubricated bearings.

Since the media wheel rotates between two adjacent airstreams, seals are installed at the wheel perimeter and at the duct penetration in order to minimize leakage between the ducts.

Larger-sized energy wheels can be manufactured with segmented wheels as shown in Figure 54. Segmented wheels are easier to handle and clean.

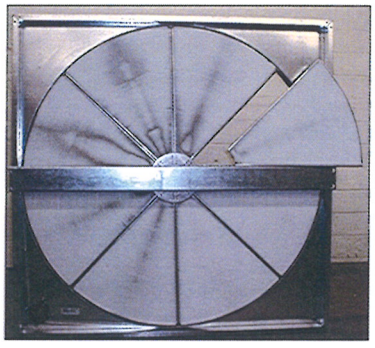


Figure 54

Segmented Wheel
(Photo courtesy of AirXchange)

Types of Matrix Material

The fundamental construction of the media is similar for both sensible-only units and combined sensible and latent units. The media used in an energy wheel, however, may incorporate a fibrous material in addition to being coated to help hold the moisture. There are two types of media: random-flow media and directionally-oriented media.

Random-flow media is made with sheets of woven wire or corrugated mesh. Multiple discs of media are assembled in layers (like pancakes), with each successive layer rotated slightly from the previous layer. This creates a random, turbulent air path through the media that encourages heat transfer.

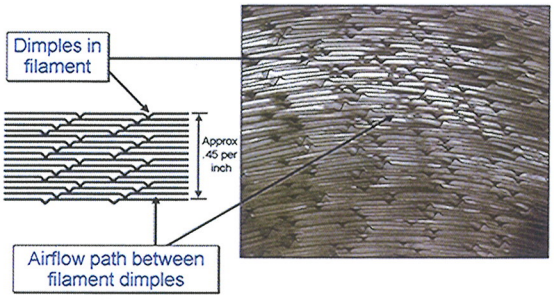


Figure 55

Directionally Oriented Media
(Photo courtesy of AirXchange)

Random-flow media requires a larger face area than directionally oriented media for the same given airflow rate and pressure drop. Random-flow media does not exhibit optimal energy transfer and should only be used in clean airstreams because it is subject to rapid fouling.

Directionally oriented media is manufactured in several different configurations. The media is constructed with small linear air passages that are aligned parallel to the flow direction. See Figure 55. Air passages are similar in performance regardless of their shape. Media material can be plastic, aluminum or other metals, paper, or other synthetic material depending on the application. Directionally oriented media is the most common media design and these "laminar flow" designs are highly resistant to clogging.

One style of directionally oriented media consists of parallel, concentric layers of lightweight polymer plastic that are wound to a precise separation and then sliced into "pies" that are contained in metal frames forming the segmented wheel discussed earlier. These frames are then retained in a stainless wagon wheel frame, which is driven, by a belt and motor-pulley. Each layer is separated from the adjacent layers by small dimples/channels that are stamped into the flat side of the filament. The dimples and channels space each layer uniformly, creating parallel openings for the air to pass through. There can be between 30 and 50 wraps per inch of media wheel radius, depending on desired recovery performance.

Desiccants

When a wheel is to be used for both sensible and latent heat transfer, a coating called a desiccant is permanently bonded to the energy transfer matrix. The desiccant allows the moisture to cling to the wheel, thus allowing the transfer of latent heat. See Figure 56.

Desiccants

An important feature of desiccants is the ability to remain reliably attached to the energy transfer matrix. All desiccants experience a decrease in their adsorption ability when dirty.

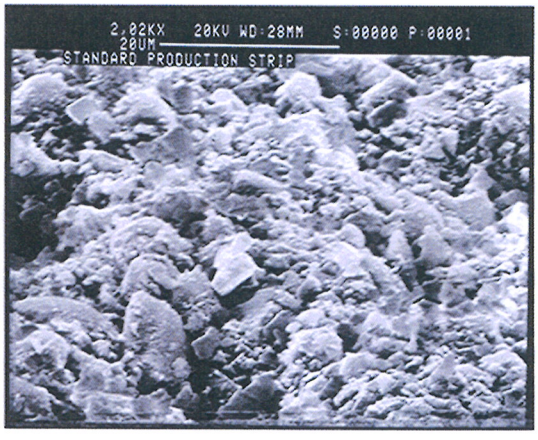


Figure 56

Desiccant Silica Gel
(Photo courtesy of AirXchange)

Several types of desiccant are available including: activated alumina, titanium silicate, lithium chloride, and aluminum oxide. Silica gel and molecular sieves are also available and are commonly used desiccants because of their ability to attract moisture, adhere to the wheel, and provide lasting performance.

Although different desiccants have different adsorption characteristics, the final performance with the wheel for the intended application is important. A desiccant will hold from 20 to 35 percent of its own weight, depending on the relative humidity of the airstream. Silica gel will hold about 35 to 40 percent of its own weight. Adsorption characteristics of various desiccants are shown in Figure 57.

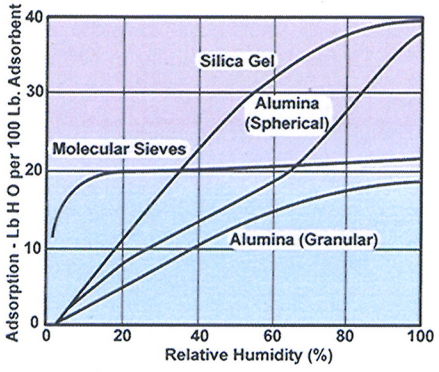


Figure 57

Adsorption of Various Desiccants

Fan Arrangements

Leakage in a wheel is influenced by the placement of the exhaust fan and supply air fan relative to the wheel. This type of cross leakage caused by fan arrangement is referred to as seal leakage. As shown here in Figure 58, placing the fans in a draw-thru supply and draw-thru exhaust arrangement can minimize cross leakage. Designing the supply side static pressure drop to be nearly equal to the exhaust side pressure drop minimizes cross leakage. In a factory-supplied ERV, this arrangement is common.

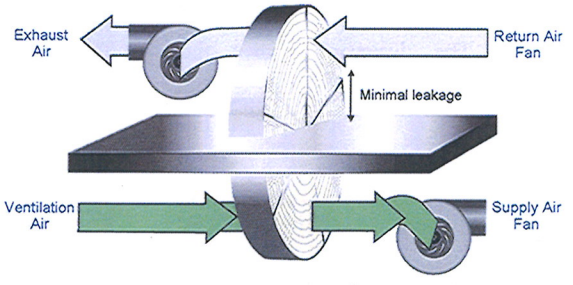


Figure 58

Draw-Thru Arrangement

In the draw-thru arrangement, airflow over the wheel is uniform because the air is being drawn through the wheel. However, a blow-thru arrangement can also be used as long as proper air distribution over the wheel can be assured. In each case, draw-thru or blow-thru, the actual direction of leakage will depend on the pressure difference between the airstreams. For instance, if in the draw-thru arrangement the exhaust fan has placed the wheel under a much greater negative pressure than the supply fan, any leakage would tend to happen from the ventilation airstream to the exhaust airstream.

One arrangement that is far less common places the exhaust fan on the same side of the wheel as the supply fan. This is shown in Figure 59. This arrangement would result in maximum leakage potential and possible contamination from the exhaust to the supply and therefore is not recommended.

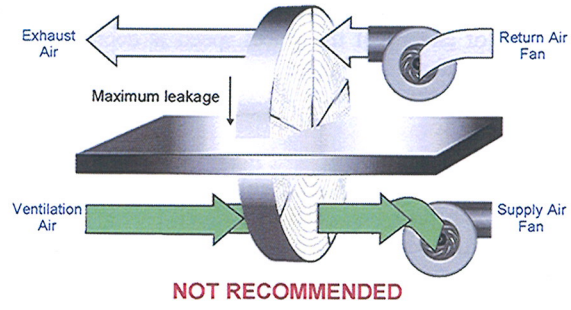


Figure 59

Blow-Thru Combined with Draw-Thru

Better Design

If both fans must be on the same side, a better design places the exhaust in a draw-thru configuration and the supply in a blow-thru configuration.

If both fans must be on the same side, a better design than what is shown in Figure 59 places the exhaust in a draw-thru configuration and the supply in a blow-thru configuration so any cross flow leakage would be from the ventilation airstream to the exhaust airstream.

It is important to understand that the airflow requirements of the supply and exhaust air fans are dependent on the resulting EATR (exhaust air transfer ratio) and OACF (outdoor air correction factor).

Capacity Control

Energy wheel control is necessary to prevent overheating the ventilation air during the winter or when cooling with an economizer. Control is also necessary in very cold weather to prevent frost accumulation on the media. The primary method of control typically used with energy wheels is bypass control.

The amount of air that is allowed to pass through the wheel determines the ventilation air temperature. A ventilation air bypass control damper blends air passing through the wheel with a side-stream flow of unconditioned outdoor air to achieve the desired temperature. See Figure 60. The damper position is adjusted to regulate the mixed air temperature downstream of the wheel. At the same time, exhaust air is bypassed around the wheel to lower the recovery amount. The bypass method provides good control of the temperature of the air coming off the wheel. Capacity control can also be accomplished using a VFD, but this method is less common.

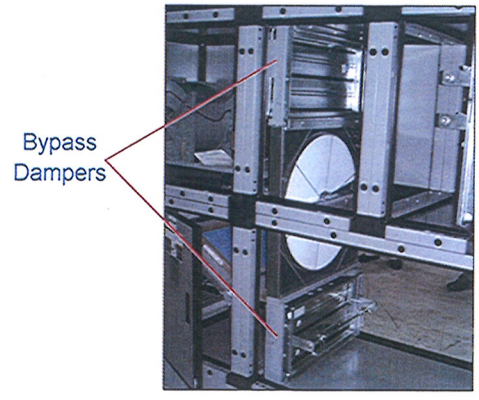


Figure 60

Wheel Bypass Damper Control

Up to a point, the energy transfer effectiveness of a rotary wheel increases with increasing wheel speed. At the optimum speed for an application, the wheel will transfer the maximum amount of energy. If the wheel speed is decreased under the same conditions, the amount of energy transfer will decrease.

Maintenance

With energy wheels, particulate accumulation is an issue. It is common practice to filter both airstreams before they enter the wheel. However, filtration is not a critical issue because of the nature of the wheel. In a counterflow installation, the wheel is self-cleaning. For instance, dust, lint, and particulates in the outdoor airstream large enough to be caught on the leading edges of the media filaments are blown away as the wheel passes into the exhaust airstream and the flow direction is reversed. Smoke, oil, aerosols, airborne grease particles and fumes are a greater source of problems than particulates. Fumes and very small particles can precipitate onto the filament surface. Over a period of time, the accumulation of a film on the filament surface will impede the moisture adsorption capability of the desiccant. Latent efficiency may diminish 20 percent or more over a period of one to three years if not cleaned.

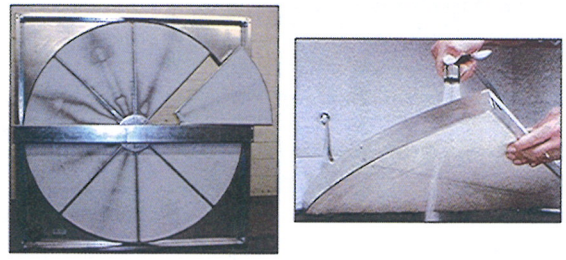


Figure 61

Segmented Wheel Cleaning
(Photo courtesy of AirXchange)

Wheels have belts and motors that will last from ten to twenty years or more. There is no schedule of replacement for these components because their failure rate is extremely low. Energy transfer matrix is also very durable and, if kept clean, will provide good service for the life of the building.

Media cleaning is an important component of regular energy wheel maintenance. See Figure 61. The wheel or wheel segments should be removed periodically and cleaned with a non-acid based coil cleaner or alkaline detergent solution. The wheel segments should be soaked in the cleaning solution and then rinsed with clean water. Excess water should be allowed to drain before replacing the wheel segments. After returning the energy wheel to service, any moisture still captured between the filaments is quickly evaporated. Polymer plastic media should never be cleaned with acid-based cleaners, aromatic solvents, or water hotter than 170° F.

Never use energy wheels on contaminated exhausts from laboratory hoods. Also, you should never use energy wheels on paint booth exhaust, in direct exhaust of automobile engines, or diesel exhausts.

Outdoor Air Heat Pumps

Outdoor air heat pumps (OAHP) are used with unitary rooftop packaged units. See Figure 62. Outdoor air heat pumps are also known as "energy recyclers" or an "energy recovery device using the refrigeration cycle."

An OAHP uses conventional air-to-air reverse-cycle heat pump technology to transfer energy from the building exhaust airstream into the ventilation air. An OAHP is the only air-to-air recovery device that uses a compressor that we will discuss in this TDP.

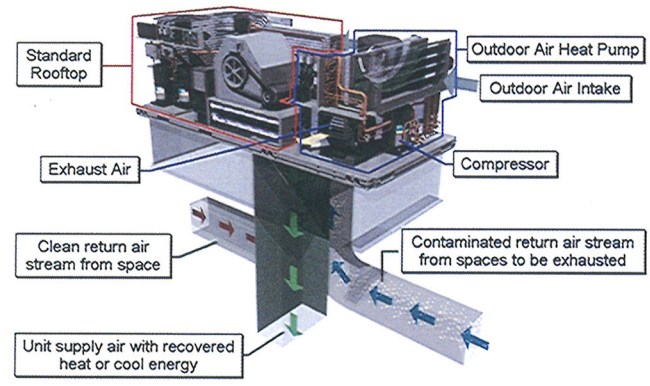


Figure 62

Outdoor Air Heat Pump (OAHP)

In the summer, the OAHP precools the ventilation air being drawn in by the fan provided in the OAHP. The relatively cool exhaust air from the building condenses the hot refrigerant gas by passing over the condenser coil of the heat pump cycle.

This precooled ventilation air from the evaporator side of the heat pump cycle can be fed directly into the return air of the base unit when the OAHP module is attached to the rooftop unit (RTU). If the OAHP is not physically attached to the RTU, it is called an uncoupled system and can still be used to precondition the ventilation air. In this arrangement, the OAHP can deliver conditioned outdoor air into the return duct going to the RTU. Refer to the Couple and Uncoupled Systems section of this TDP for more details.

In the winter the OAHP preheats the ventilation air using the reverse cycle heat pump. The relatively warmer building exhaust air is used as the heat source for the heat pump, which then heats the incoming ventilation air. A separate exhaust fan in the OAHP ejects unwanted building air during all modes of operation other than unoccupied mode. See Figure 63.

During the summer months, the heat pump is functioning as an auxiliary cooling system to the base unit cooling system. In the winter months, the COP of the heat pump will vary with outside temperature and is typically in the range of 2.0 to 2.5.

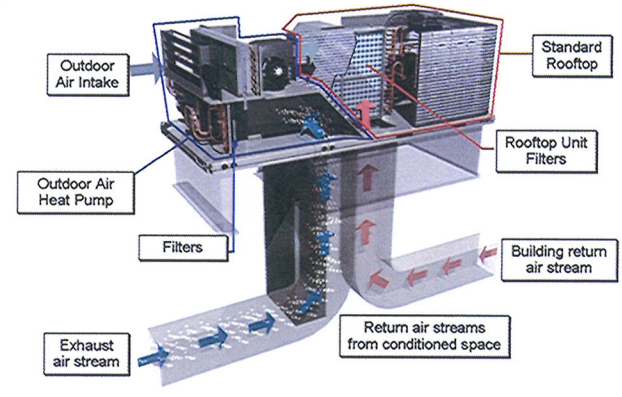


Figure 63

Outdoor Air Heat Pump Features

Capacity Control

An outdoor air heat pump can be controlled by a heat pump duty thermostat or combination thermostat and humidistat (Thermidistat™ device). The thermostat provides direct control of the OAHP, rooftop unit fans, and rooftop unit compressor in response to the programmed time schedules and temperature settings.

The signal from the humidity sensor controls the OAHP compressor to cool and dehumidify the ventilation air. In this manner, the heat pump transfers as much energy as possible from the exhaust airstream to the incoming outdoor air, given existing exhaust air conditions and airflow.

Outdoor Air Heat Pumps

In the vast majority of applications, the OAHP is coupled to the rooftop unit. Outdoor air heat pumps are limited in size and are available up to approximately 3500 cfm.

Maintenance

Typical maintenance for an outdoor air heat pump consists of cleaning the coils and a visual inspection of the interior components. Maintenance for the exhaust air heat pump is very similar to the rooftop unit to which it is directly coupled. The filters should be cleaned and/or replaced at normal intervals. Normally, the cleaning and inspection of the coils and interior components of a heat pump system is done on an annual basis; however, this can vary depending on region. Since this system uses a closed refrigeration system, it does not require the cleaning associated with a typical heat wheel.

Thermo-Siphons

A thermo-siphon is composed of a sealed system with coils or tubes and piping that contains a heat transfer fluid. Two types of thermo-siphons are used: sealed tube and coil. In a sealed tube thermo-siphon, the evaporator and the condenser are usually at opposite ends of the bundle of straight individual tubes, where the supply and return ducts are adjacent from each other. In a coil thermo-siphon, the evaporator and condenser coils are installed independently in the ducts and are interconnected by a working fluid piping. The fluid can be water or refrigerant depending on the system design. The fluid changes phase from liquid to vapor to exchange heat. The thermo-siphon is a passive process in that does not require a pump or compressor to function, so it does not consume any energy. Thermo-siphon systems transfer heat in one or both directions.

Thermo-Siphon Operation

The temperature difference and the force of gravity work to move the fluid around the system.

In a thermo-siphon system, a pressure difference is set up when a temperature difference occurs between the portions of the system where the liquid and vapor meet. Condensation occurs in the colder area and evaporation occurs in the hotter area. Gravity allows the liquid to return to the evaporator. Consequently, the system should have height difference between the coils.

Like heat pipes, thermo-siphon systems are capable of sensible heat transfer only, but they differ from heat pipes in that they depend on gravity and need a larger temperature difference to start the boiling process. Thermo-siphon systems also do not have any internal wicking material to help transport the fluid. If refrigerant is used, liquid refrigerant in the precool section absorbs heat, evaporates, and the vapor flows to the reheat section where it condenses and releases heat. The condensed fluid flows back to the precool section by the force of gravity to begin the cycle again.

An example of a thermo-siphon system would be a residential installation with solar panels and storage tank located above or beside the solar collector. See Figure 64. The thermo-siphon moves the warmed water up to the tank. The heating of the water creates a suction that moves the warm water up and the colder water down. Inside the tank, the warmer water is on top and colder water on the bottom. A continuous heating of the water occurs along with a natural circulation as long as the solar panel is receiving the sun's energy. In effect, the principle of hot water rising makes the process successful.

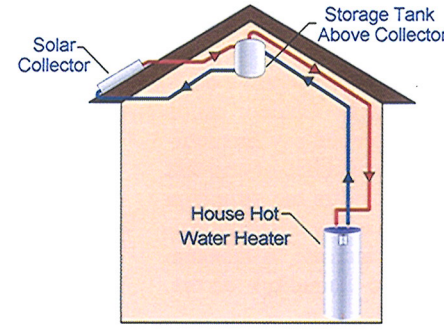


Figure 64

Thermo-siphon

Thermo-Siphon

A typical thermo-siphon installation using water would be a closed loop application with solar panels and a storage tank for residential water heating.

Thermo-siphons typically have a sensible effectiveness of between 40 and 60 percent.

Thermo-siphons are not mass produced. They are not used for recovery on typical commercial air-conditioning projects like heat pipes, run around loops, plate exchangers, and energy wheels.

Evaporative Cooling

While evaporative cooling is not considered a type of heat or energy recovery like the seven types that were just discussed, it is valuable to understand the principles involved. This is because evaporative cooling can be combined with conventional recovery technology to fit certain applications. That is why it is included in this TDP.

Two main types of evaporative cooling exist: direct and indirect.

Direct Evaporative Cooling

Direct evaporative cooling has existed for thousands of years. Ancient civilizations used to soak carpets in water and hang them up to catch a breeze at the entrance to their shelters. Many years later, fan powered water sprays helped cool factories and other facilities.

Evaporative cooling can occur when moisture is added (sprayed) into air that has a relative humidity of less than 100 percent. The lower the relative humidity of the air to start with, the greater the temperature drop when the moisture is added. Evaporative cooling technology is a versatile and energy-efficient alternative or adjunct to compressor-based cooling. See Figure 65.

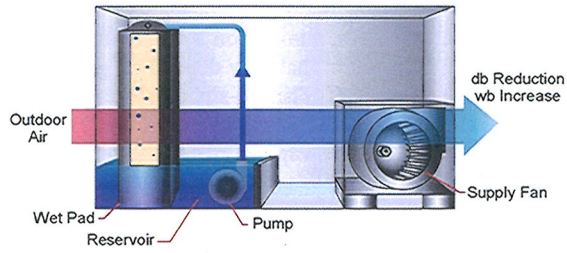


Figure 65

Direct Evaporative Cooling

The concept of evaporative cooling is quite simple. Outdoor air is sprayed with water and psychrometrically it moves along a line of constant wet bulb until it nears the saturation line. A reduction in dry bulb temperature results. An increase in moisture content (specific humidity) occurs. See Figure 66.

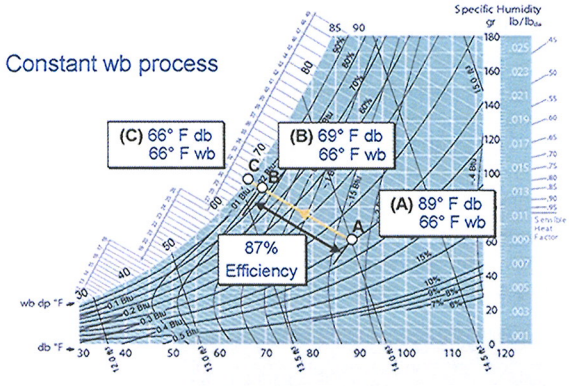


Figure 66

Psychrometrics of Direct Evaporative Cooling

With direct evaporative cooling, the dry bulb will always decrease, and the wet bulb will stay the same. The dry bulb temperature reduction that takes place with evaporative cooling will increase as the difference between entering air dry and wet bulb increases. In favorable climates (much of the western United States and other dry climates), evaporative cooling is popular for that reason.

For a further discussion of the psychrometrics of evaporative cooling, see TDP-201, Psychrometrics: Level 1: Introduction.

In modern evaporative cooling applications, moisture is added to a moving stream of outdoor air that is delivered to the indoors while an equal quantity of indoor air leaves. Pumped recirculating water wets a pad of woven fibers or corrugated paper while outdoor air flows through the pad. The pads absorb water by capillary action and serve to maximize contact between the airstream and the wet medium. To ensure that all

Precooling the Air

Evaporative cooling can also be used to precool the air that is used for standard condensing of refrigerant. This reduces the energy use of the conventional air conditioner and helps increase its equipment life and efficiency by allowing it to operate at lower condensing temperatures.

surfaces are wet, more water is usually pumped than can be evaporated. Excess water drains from the bottom of the media into a sump. An automatic refill system replaces evaporated water. Care must be taken to make sure that the recirculated water is clean and free of contamination. Similar care must be used to keep the pads from becoming contaminated. A reservoir drain is helpful in purging solids and mineral build-up.

Evaporative cooling does not use refrigerant. There are no global warming or ozone depletion concerns. It is a viable alternative to conventional mechanical refrigeration where sensible cooling only is acceptable. Evaporative cooling is an environmentally sound process.

Direct Evaporative Cooling Example

Let's calculate the dry bulb temperature reduction possible with direct evaporative cooling. See Figure 66. The air being cooled is 89° F db, 66° F wb. The efficiency of the wetted media is 87 percent. What are the final air conditions db/wb?

Temp reduction = (db – wb) * efficiency

= (89° F – 66° F) * 0.87

= 20° F

The evaporative cooling process will always lie on the line of constant wet bulb. The final conditions can be found by subtracting the wet bulb temperature from the entering dry bulb and multiplying this value by the efficiency. Had the efficiency been 100 percent, the resulting condition would have been on the saturation curve and dry bulb would equal the wet bulb.

Final air condition is 89° F – 20° F = 69° F db / 66° F wb

Indirect Evaporative Cooling

Unlike direct evaporative cooling, indirect systems cool the outdoor air without adding moisture. They are more expensive and use more energy than direct systems, but have potential uses that may not fit direct evaporative cooling.

An indirect evaporative cooling system design operates in the following way. See Figure 67. First, a direct evaporative process using water cools an incoming ventilation airstream. The airstream is then introduced to one side of an impermeable heat exchanger. This heat exchanger can be made of thin plastic plates or tubes. This airstream is called the secondary airstream and requires a separate fan to move it through the heat exchanger and then out of the building. Next, the secondary airstream via the heat exchanger cools a primary airstream (which is going to the conditioned space). The primary or conditioned airstream is much drier than the secondary because it has not been through the direct evaporative cooler.

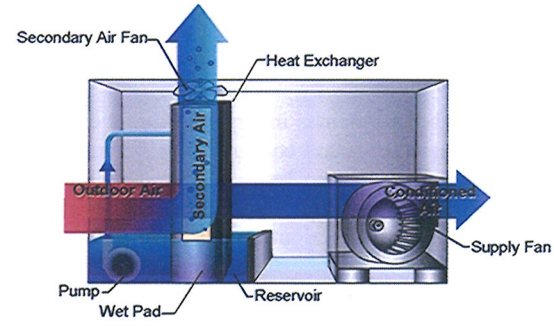


Figure 67

Indirect Evaporative Cooling

An example of indirect evaporative cooling would be water sprayed on a hot roof. The water would evaporate at the roof surface and cool the roof deck, which would then cool the indoor space below without adding moisture indoors and increasing indoor humidity. This process avoids possible contamination of the conditioned ventilation air with pollution from poorly maintained recirculated water.

Psychrometrically, since indirect evaporative cooling does not add moisture to the space, both the dry bulb and the wet bulb temperatures of the conditioned air are reduced. See Figure 68.

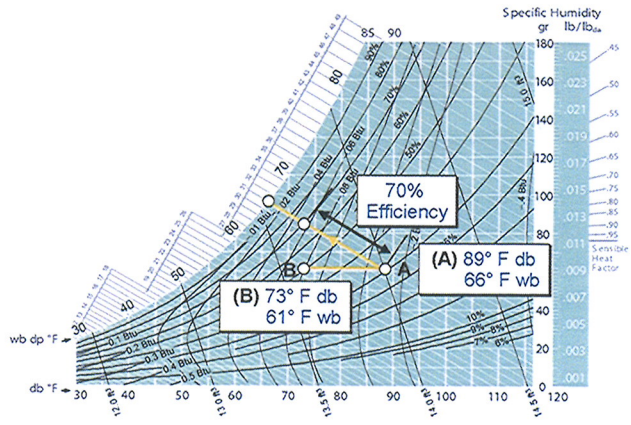


Figure 68

Psychrometrics of Indirect Evaporative Cooling

Indirect Evaporative Cooling Example

Let's calculate the dry bulb temperature reduction possible with indirect evaporative cooling. The outdoor air is 89° F db, 66° F wb. The efficiency of the indirect heat exchanger module is 70 percent. What are the final air conditions db/wb?

Temp reduction = (db – wb) * efficiency

= (89 – 66) * 0.70

= 16° F

Final air condition is 89° F – 16° F = 73° F db /61° F wb

As we said earlier, no moisture is added to the conditioned airstream, so the resulting wet bulb is located on the dry bulb line. That is the major difference between direct and indirect evaporative cooling.

Some indirect schemes incorporate direct evaporative cooling to cool a building or to supplement compressor-based cooling of outside air. In these cases, the evaporative cooler can be distant from the airstream being cooled. Cooling towers evaporatively cool the water to efficiently discharge heat that has been removed by compressor-based air-conditioning systems. Water from cooling tower outlets is increasingly used in dry climates to directly cool air in coils or in radiant cooling applications using hydronic circuits in the floor or ceiling. These indirect evaporative cooling strategies, although they are often used to cool ventilation air, do not require that an outdoor airstream pass through the building.

City Comparison – Evaporative Cooling

Shown in Figure 69 is the average July daily wet bulb and dry bulb temperature ranges for 13 U.S. cities. The dry bulb temperatures indicate the severity of outdoor-air cooling loads and (for loads with wide daily ranges) the opportunities for night ventilation cooling. In five of the cities shown (Albuquerque, Boston, New York, Salt Lake City, and Tucson), the average wet bulb range is fully below the dry bulb range, and in all five cities the wet bulb range is below 70° F. These five cities are excellent candidates for full or hybrid (integrated with compressor-based systems) evaporative cooling of commercial buildings. However, humid summer weather in these cities may favor auxiliary compressor-based cooling like the outdoor air heat pump or energy recovery wheels in series to fully treat the outdoor air load.

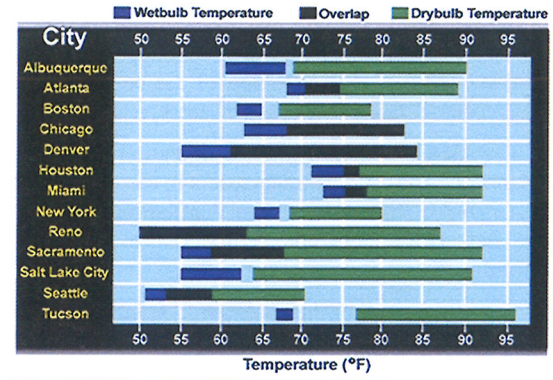


Figure 69

City Comparison – Evaporative Cooling

The five cities with wet bulb ranges extending to or below 55° F are all in the West. These cities are in regions that are ideal for evaporative cooling. However, Seattle's low dry bulb temperature range means cooling loads can usually be satisfied with outdoor air. Locations with average July wet bulb temperature ranges extending above 70° F (Atlanta, Houston, and Miami) are not good candidates for evaporative cooling of outdoor air.

Prospects for eliminating compressor-based cooling are best in high-altitude climates that have dry air and lower summer daytime temperatures, as represented by Denver in Figure 69. In very hot summer climates like Phoenix (not shown), where afternoon July wet bulb temperatures often exceed 75° F, there are times when even a good two-stage evaporative cooler cannot cool air to desired indoor temperatures without exceeding the ASHRAE relative humidity limits. However, in these climates direct or indirect evaporative cooling (or a combination with energy recovery) can usually satisfy full cooling loads for 10 months of the year. They can also be applied to ventilation air all year round. Cost effectiveness in these locales depends on local utility rates, the duration of the cooling season, cooling load patterns, and ventilation air quantities.

In summary, indirect and direct evaporative cooling of outdoor air can be energy efficient in the appropriate climates. Indirect evaporative cooling with energy recovery can extend the use of this technology to higher humidity climates or use with other technologies. Figure 70 shows the integration of indirect evaporative cooling with heat pipes.

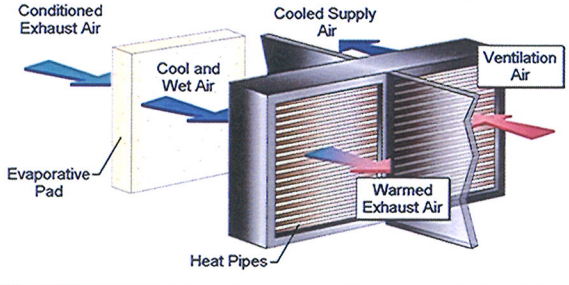


Figure 70

Indirect Evaporative Cooling with Heat Pipes

Codes, Standards, and Certification

In this section we will discuss the organizations involved in testing and certifying recovery products along with the standards that apply. The information in this section is not meant as a substitute for the current version of the code or standard. The reader is urged to reference the actual code or standard to confirm latest requirements.

The Air-Conditioning and Refrigeration Institute (ARI) is a voluntary not-for-profit trade organization made up of manufacturers in the HVAC industry. A coalition of ARI members created the Air-to-Air Energy Recovery Ventilation Section (AAERV) of ARI. The goal was to investigate and resolve various approaches to testing and presenting air-to-air energy recovery performance.

The initial work of the coalition focused on testing of various ERV technologies to ASHRAE Standard 84 (described on page 52). As a result, ARI 1060 was created for review and consideration in 1997 and reissued as ARI -1060 2001.

ASHRAE is an international organization with the goal of conducting research preparing standards and publications, and providing continuing education on heating, ventilation, air conditioning, and refrigeration systems.

ARI Standard 1060

ARI Standard 1060 - Rating Air-to-Air Heat Energy Recovery Ventilation Equipment (AAERV) is the standard of testing and evaluation of air-to-air energy recovery devices that include heat pipes, fixed-plate exchangers, and wheel exchangers. Key contributors to this standard include the major equipment manufacturers of these technologies.



Figure 71
ARI 1060 Seal

Manufacturer's certified ratings are generated for publication at the standard rating conditions shown in Table 1.

Table 1 Standard Rating Conditions		
Item	Conditions	
	Heating	Cooling
Entering Supply Temp Dry Bulb Wet Bulb	 35° F 33° F	 95° F 78° F
Entering Exhaust Temp Dry Bulb Wet Bulb	 70° F 58° F	 75° F 63° F
Leaving Supply Air Flow	100% of the rated airflow(s)	
Rate, scfm (m^3/s)	75% of the rated airflow(s)	
Entering Exhaust Air (Return Air), scfm	Same rate as Leaving Supply Air*	
Pressure Differential, for Effectiveness Tests	0.00 in. H_2O	
Pressure Differential, for OACF and EATR tests	0.00 in. H_2O [0 Pa] Manufacturer's choice of two or more of the following: -5.00, -3.00, -1.00, -0.50, 0.50, 1.00, 3.00, 5.00 in. of H_2O	

*Adjustments to balance the Leaving Supply Air and Entering Exhaust Air to equal flow rates shall be made at the Standard Rating Conditions (i.e., temperatures) just prior to data acquisition.

ARI Standard 1060

Air-to-air systems joined by field piping, such as runaround loops are excluded from ARI Standard 1060.

Air-to-air products that bear the ARI 1060 seal have been certified to meet catalogued performance. See Figure 71. Energy recovery components are certified for performance. This is assurance that the recovery capability of the product is not misrepresented. The packaged units that energy recovery components are installed in are certified to contain these components. An example would be an ERV containing an energy recovery wheel. Current certified manufacturers of components and manufacturers who include certified components in their equipment can be viewed at www.ari.org.

ARI Guideline V

ARI Guideline V

The contribution made by the energy recovery device to the efficiency of the system in which they are applied is the focus of ARI Guideline V.

In ARI Guideline V, a methodology is established to measure the impact of an air-to-air energy recovery device on equipment operating efficiency during occupied ventilation. As an example, for an energy recovery wheel, the guideline first defines the recovery efficiency of the product in terms of Btuh cooling load recovery. The guideline divides this by the energy inputs from blower motors and the motor that drives the wheel in terms of watts. The resultant Btu/Watt is the Recovery Efficiency Ratio (RER) of the air-to-air exchanger. This is somewhat analogous to EER for standard unitary equipment. However, since recovered energy may be very large versus input power to recover it, RER values may climb as high as 100 or more. See Figure 72.

Another term called Combined Efficiency (CEF) is used to describe the RER of the recovery exchanger together with the EER of the unitary system such as a rooftop. The CEF is considered to be a "system EER." The CEF demonstrates the improved efficiency of the combined system, usually from 20 to 40 percent over the base unit EER. In effect, CEF is a single number that can be used to describe the system efficiency of the base unit and the heat recovery device working together so that a comparison can be made of a unit with and without energy recovery or the same unit with various types of energy recovery.

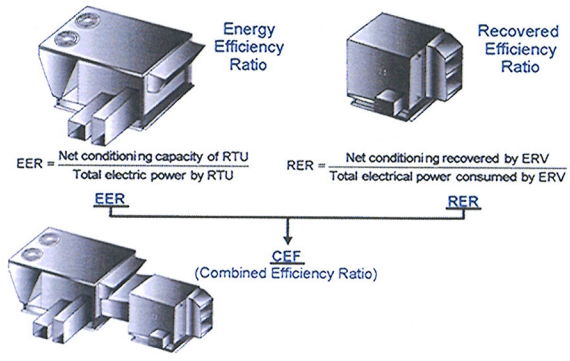


Figure 72

RER, EER, and CEF

The ARI Guideline V assists in the task of analyzing system overall efficiency regardless if the energy recovery device is part of the initial product design, stand alone, or field added. We will calculate a CEF value in our example selection in Step 5 in this TDP.

See the ARI website (www.ari.org) for download information.

ASHRAE Standard 84

ASHRAE Standard 84, Method of Testing Air-to-Air Heat Exchangers, defines a uniform method of testing for obtaining performance data. The standard also specifies the data required, calculations to be used, reporting procedures, and test equipment to be used. This standard formed the basis for ARI 1060. Independent laboratories that test energy recovery products follow the exacting procedures set forth in ASHRAE Standard 84.

ANSI, ASHRAE, IESNA Standard 90.1

As currently written, ASHRAE 90.1 2001 contains specific requirements for improved building and HVAC system operating efficiency. In this section we will discuss those ASHRAE requirements pertaining to exhaust air recovery and dehumidification controls, as these topics occur often in energy recovery applications. The ASHRAE 90.1 Standard is shown in Figure 73.

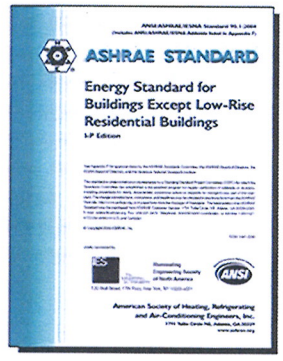


Figure 73

ASHRAE 90.1 Standard

Section 6.3.6.1 of standard 90.1 states that when a 5000 cfm and larger system has more than 70 percent outdoor air, a 50 percent effective energy recovery exchanger shall be used. This 50 percent effectiveness is defined by ASHRAE in terms of an enthalpy difference. This would lead a designer to use recovery products capable of sensible and latent recovery, such as an energy wheel, and eliminate sensible-only recovery products like heat pipes and fixed-plate exchangers. See Figure 74.

The standard, however, may be met with any energy recovery technology as long as the supply air off the exchanger has achieved an enthalpy rise of at least 50 percent of the difference between the outdoor and exhaust air enthalpy at the design conditions.



Figure 74

ASHRAE 90.1 Requirements for Recovery

In actuality, this means that a sensible-only recovery product will typically require a sensible-only efficiency higher than 50 percent in order to achieve a total enthalpic efficiency of 50 percent. This is possible in some climates but not all. Often, an energy recovery wheel is required to meet this requirement. The Standard also says that the recovery device should not interfere with the airside economizer on the base unit.

There are many exceptions to section 6.3.6.1. It does not apply to systems:

- Serving areas not cooled
- Where site recovered heat supplies a majority of the ventilation air heat
- Handling toxic or flammable air
- Serving certain kitchen hoods that handle grease

The other ASHRAE section that merits discussion involves the simultaneous heating and cooling of the air, Section 6.3.2.3.

This section places restrictions on the use of reheating applications for comfort cooling. However, there are exceptions. Please consult the Standard for a list of all the exceptions.

Reheating is acceptable if:

- At least 75 percent of the energy for reheating is provided from a site-recovered energy source. Examples would be hot gas reheat, condenser heat, or solar heat.
- The system is capable of airflow reduction of at least 50 percent from design levels (variable air volume systems) before any reheating takes place.
- It is being used for special applications like museums, hospital applications, and some process applications.

It is the intent of ASHRAE to encourage the practical application of energy conserving techniques and products. In all cases, however, local codes will have jurisdiction.

ASHRAE 62.1

ASHRAE 62.1 Standard (Ventilation for Acceptable Indoor Air Quality) will be adopted by states in their individual building codes. It describes methods for assuring good indoor air quality through the proper introduction of ventilation air and other topics related to IAQ. The purpose of ASHRAE 62.1 is to define minimum ventilation rates and to help achieve an indoor air quality that makes the majority of humans comfortable. See Figure 75.

Dilution is intended to lower all indoor chemical and pollutants to levels that are considered acceptable for occupants. Constant dilution to ASHRAE minimums is required for good IAQ.

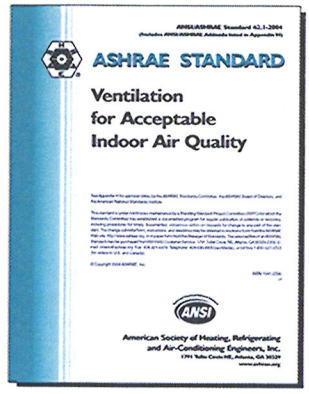


Figure 75

ASHRAE Standard 62.1

Energy Recovery

As of this writing, ASHRAE 62.1 states that the use of energy recovery for the ventilation air should be considered for the purposes of energy conservation. But unlike ASHRAE 90.1, there are no requirements by ASHRAE 62.1 to incorporate energy recovery into the design of the ventilation system.

The ASHRAE ventilation air rates have generally increased over time. This increase in outside air has resulted in an increase in size and operating cost of a conventional HVAC unit. That is where the use of an energy recovery system can be advantageous. The base HVAC unit can be reduced in size and the energy savings of the recovery can generate an attractive payback as we will see in our example selection at the end of this TDP.

UL and NFPA

This section will discuss the role of UL (Underwriters' Laboratories) and NFPA (National Fire Protection Association) in the manufacture and application of recovery products. We will use typical energy wheel construction when citing examples.

First we should understand the role of UL. The goal of the UL organization is to ensure that products that pass UL testing are completely safe with respect to electrical and fire safety. When a product passes the tests, it becomes listed by UL. Underwriters' Laboratories not only tests products in their laboratories, but they visit and audit production of products already listed to ensure that the product is in continuous conformance with the listing. The UL seal is shown in Figure 76.



Figure 76

Underwriter's Laboratories Seal

When the first recovery wheels were designed and manufactured in 1982, Underwriters' Laboratories was involved in testing and qualifying the materials used. As a result of that early involvement, UL Standards 1812 and 1815 exist today as a guide for engineers involved in certification and evaluation of these products.

With respect to fire safety, using a wheel as an example, the area of concern would be the material used for the heat exchange matrix. Certain heat exchanger materials (example: a polymer base matrix) must undergo thorough evaluation since they are applied in the airstream. Any material used in the airstream is of concern. Fixed-plate exchangers also use a variety of synthetic materials that must be evaluated.

Several options are used to qualify a product for listing. Wheels, for instance, are subjected to the UL 900 fire test used for air filters. This test evaluates both flammability and smoke density under operating conditions simulating actual use in an airstream. Typically, the wheels surpass the criteria established for filters.

NFPA

Energy recovery materials used in the airstream should also comply with NFPA standards. Specifically, heat recovery materials used for heat transfer or air movement in the airstream must be constructed to specific requirements limiting their flammability and smoke generation density. The NFPA is the basis for all the major building codes in the U.S. and Standard 90A states that listing of a product by a testing laboratory like UL shall be sufficient evidence of compliance.

Application of Heat and Energy Recovery

Heat Recovery in Rooftop Units

Rooftop units are often used in applications such as movie theaters and auditoriums where there are involve a large number of occupants. See Figure 77. The ventilation air required to satisfy ASHRAE 62.1 is one of the primary loads on the equipment chosen to serve these spaces. The amount of ventilation air can easily climb above what a standard rooftop unit can handle. As a rule of thumb, a packaged rooftop unit can handle no greater than approximately 25 percent ventilation air. Above that, space relative humidity may not be able to be maintained at or below 60 percent, which is the upper limit defined by ASHRAE. This is because a rooftop unit is a pre-engineered package with a limited envelope of operation.

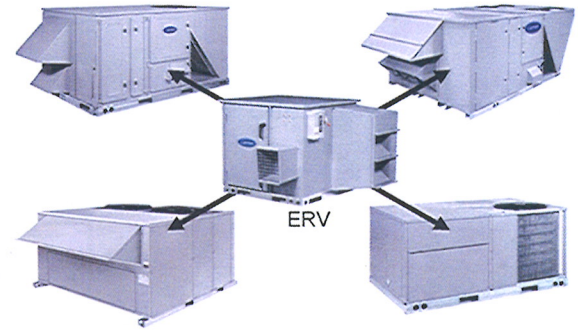


Figure 77

Rooftop Units with an ERV

Several manufacturers offer factory-installed recovery products. The benefits of factory-installed energy

recovery as compared to field-installed energy recovery area lower first cost and the use of factory-installed controls. Factory controls allow the unit to function efficiently during heating and cooling seasons.

Economizer Operation

One of the concerns in northern climates when applying recovery is possible interference with the rooftop unit economizer function.

One of the concerns in northern climates is to not interfere with the rooftop unit economizer function when adding recovery. In doing so, the designer should check to see if a factory-supplied recovery module limits the operation of free cooling.

Energy Recovery Wheel

The addition of an energy recovery wheel is probably the number one method used with rooftop units for ventilation air energy recovery. The energy recovery wheel is popular with a rooftop especially if the exhaust air is easily ducted in close proximity to the incoming ventilation air. See the Selection Example with Economic Analysis section in this TDP, which uses a rooftop unit with a rotary wheel.

Rooftop manufacturers that offer a factory-installed wheel may also offer an ERV unit for mounting next to the packaged rooftop. Energy recovery units are available from 200 cfm up to 10,000 cfm of ventilation air. Whether the wheel is factory installed or inside an ERV as shown in Figure 78, both methods accomplish the goal of preconditioning the outdoor air prior to introduction to the rooftop unit.

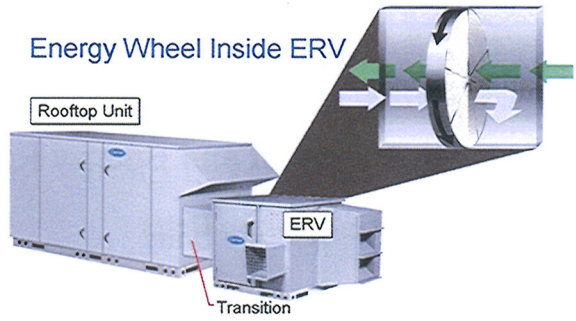


Figure 78

Rooftop Unit with Energy Recovery Ventilator

Outdoor Air Heat Pump

Another solution for rooftop units is to use an outdoor air heat pump to precondition the ventilation air. As with the wheel, the building's exhaust air and ventilation air must be brought together at the rooftop unit. The OAHP preconditions the ventilation air (both summer and winter) and rejects this heat to the exhaust air. In summer, this allows the standard rooftop coil to better meet the sensible and latent capacity of the unit.

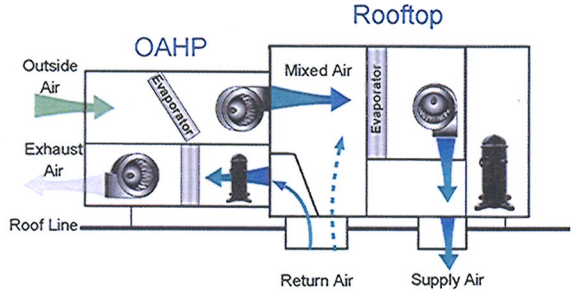


Figure 79

Outdoor Air Heat Pump Cross Section

As shown in Figure 79, the energy recovery device installs next to the ventilation air intake and exhaust air exit. Clean return air mixes with the pretreated ventilation air before entering the evaporator coil. A separate exhaust duct connection to the unit (separate from the normal return air duct) can allow the building's bathroom or other undesirable exhaust airstream to exit through the energy recovery device also, if desired.

OAHP

The 2 or 3-row cooling coil of the OAHP is combined in series with the rooftop unit's 3-row evaporator coil, resulting in a 6-row cooling coil that can handle the large latent loads.

In this manner, exhaust air can be isolated from the ventilation airstream to prevent cross-contamination. This is an improvement over the wheel, which, unless provided with a purge section, allows a small amount of cross-contamination as the wheel passes between the two airstreams.

When the outside air conditions are suitable for "free" cooling, the energy recovery device compression system is deactivated, and the rooftop unit operates in the economizer mode as if there were no preheat unit in the ventilation airstream.

Essentially, the energy recovery device handles the ventilation air loads while the rooftop unit handles the building's interior loads.

Dehumidification Coil Combined with OAHP

There is often a need for an energy recovery device to treat the large amounts of ventilation air during the warm, humid days of summer. However, the spring or fall seasons present a different situation. The skin loads on the building can become practically zero, and the ventilation air load becomes small and predominantly sensible in nature. In some installations, the predominant load comes from the people inside.

Part Load Operation

Rooftop units in the 2 to 6-ton ranges are typically equipped with a single compressor that cycles on and off at part loads. These are ideal applications for hot gas reheat coils.

Under these conditions, the OAHP would not be needed to pre-treat the ventilation air, and the rooftop unit would have more than enough capacity to satisfy the temperature needs. When the thermostat is satisfied, the rooftop unit's compressor will cycle "off," allowing the indoor relative humidity to rise. However, with a reheat coil option installed as shown in Figure 80, the rooftop unit's compressor could remain on, handling the internal latent load while the reheat coil tempers the supply air to a temperature that does not over-cool the occupants. Thus, the temperature and relative humidity would remain under control even when it is not a warm and humid day. Since the reheat energy comes from "on-site" hot gas from the compressor and is not new energy, this system complies with ASHRAE 90.1.

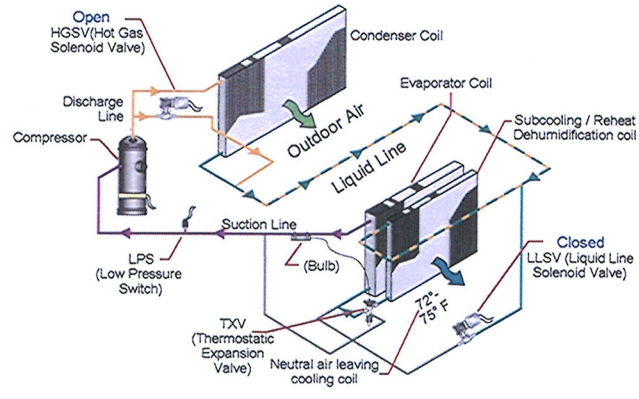


Figure 80

Hot Gas Reheat Mode

Heat Pipes

Heat pipes can be used in rooftops units because they have a relatively low airside pressure drop. See Figure 81. The nature of a rooftop unit is to provide air conditioning simplicity and ease of maintenance. Heat pipes fit that description, also, because of their simplicity, lack of moving parts, and low maintenance.

To fit within some rooftop configurations, the supply and exhaust sections of the heat pipe assembly may need to be separated. This is accomplished by splitting the sections and connecting them with piping in a split system arrangement.

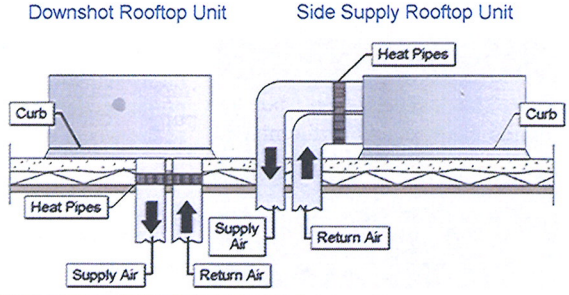


Figure 81

Heat Pipes Installed with Rooftops

Heat Recovery in Air Handlers

The same types of heat and energy recovery options used for rooftop units are available to integrate with central station air-handling units. The exception would be the exhaust-air heat pump. This device is typically available in smaller sizes (3500 cfm and under) primarily for direct-coupled use with a rooftop unit. To accommodate typical energy recovery products, the air handler may need to be stacked as shown in Figure 82.



Figure 82

Stacked Air Handler Energy Recovery Sections

Most U.S. air handler manufacturers offer the option of an energy recovery wheel integral to their standard air-handling unit package. In addition to preconditioning the ventilation air, the use of recovery allows winter operation without exposing other coils in the unit to below-freezing outdoor air temperatures. See Figures 83 and 84. Air handlers are flexible and can accommodate a variety of rotary wheel freeze protection methods such as: ventilation air preheat, exhaust air preheat, bypass damper, and variable speed capacity control.

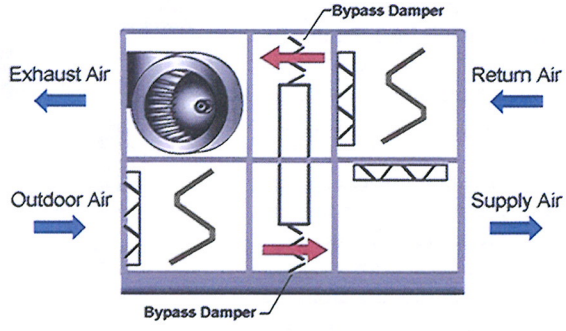


Figure 83

Cross Section of Stacked Unit

Custom air-handling unit manufacturers also can incorporate energy wheels (passive and active type) within their product offering. These units can be individually tailored for a specific application and made to fit a designated footprint. The wheels can be supplied from several different manufacturers based on project specifications.

Air handler manufacturers also have the ability to factory install heat pipes within the unit casing. Typically, they are mounted downstream of the filter section. See Figure 85.

Runaround loops are also used in air-handling units. The ventilation coil can be positioned to precondition the air prior to the main heating and cooling coil in the air-handling unit. The exhaust coil can reside in a variety of locations such as the exhaust fan cabinet or separate exhaust ducts depending on the system configuration.

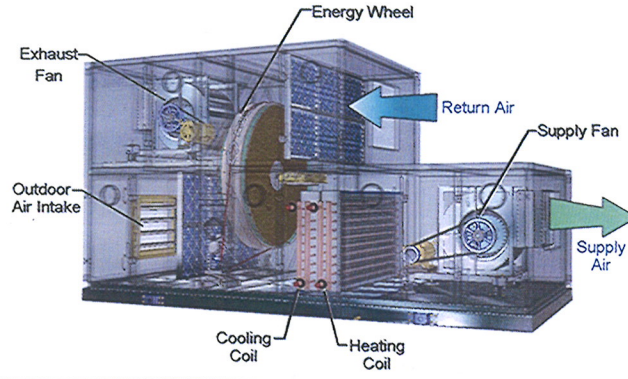


Figure 84

Wheel in Custom Air-Handling Unit
(Photo courtesy of AnnexAir)

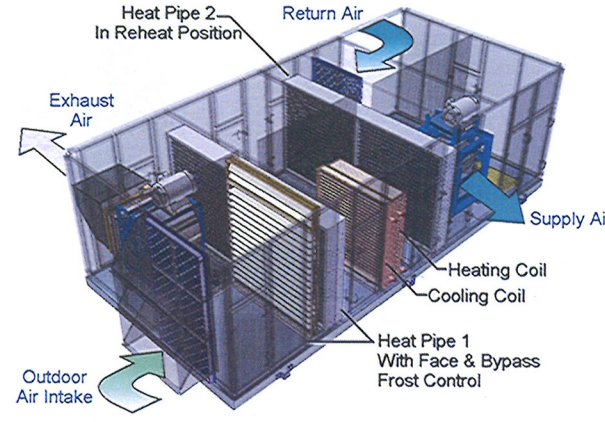


Figure 85

Heat Pipe in Custom Air-Handling Unit
(Photo courtesy of AnnexAir)

Heat Recovery in Dedicated Outdoor Air Systems

A dedicated outdoor air system is a system that brings in 100 percent ventilation air to meet ASHRAE 62.1 ventilation levels or to meet other make-up air amounts as required by the building. Because of the highly variable nature of the ambient conditions, dedicated outdoor air systems must be responsive and well designed. Energy recovery is often used to save energy, help reduce the installed cost of the main heating and cooling equipment, and maintain comfort for the occupants within the spaces that are receiving the outdoor air.

There are quite a few possible distribution methods for dedicated outdoor air systems.

Ceiling Plenum

This arrangement is not encouraged per ASHRAE 62.1 but was very popular for many years. The preconditioned ventilation air is distributed into the common return plenum by the individual plenum-mounted units (such as water source heat pumps). If the ventilation air is not delivered at a neutral temperature, the ventilation air load has to be picked up by the plenum-mounted unit. This method can result in a disproportionate amount of ventilation air to individual units based on where and how the air is introduced into the plenum.

Direct Connected to Individual Units

In this configuration, the ventilation air is ducted into the back end of the local units. If the local units contain a cooling coil, it must be sized to handle any remaining ventilation air load if the ventilation air has not been conditioned. This method allows for a more accurate balance of ventilation air to each unit. See Figure 86.

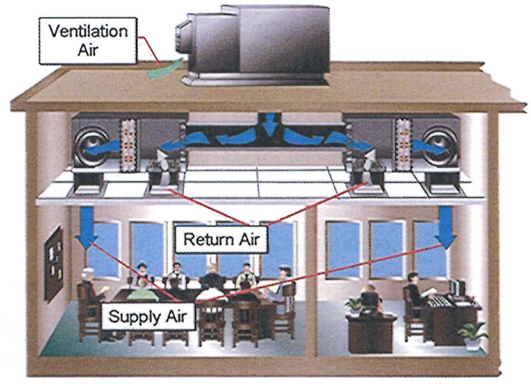


Figure 86

Ventilation Air Direct Connection to Units

Supplied Directly to the Conditioned Space

This arrangement distributes the ventilation air directly into the conditioned space. This arrangement is discussed also in the Coupled and Uncoupled Systems section of this TDP. See Figure 87. A benefit to this method is that the ventilation air amounts can be individually balanced and distributed into each room in the amounts required by ASHRAE 62.1 based on the room's loads.

In all cases, the outdoor air must be heated in winter and cooled in summer by the dedicated outdoor air system. If the ventilation air is conditioned to the same leaving air db and wb as the main HVAC unit, the entire

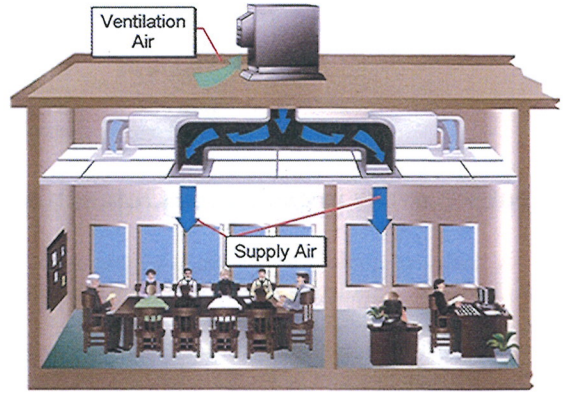


Figure 87

Ventilation Air Direct Connection to Conditioned Space

ventilation air load will be met by the dedicated air system and will not have to be covered by the individual cooling units.

Shown in Figure 88 is a dedicated outdoor air system configuration for delivering air at the same conditions as the main cooling units. The system is composed of an outdoor air intake, total energy recovery wheel, heating coil downstream of the wheel, and cooling coil. On the exhaust side, the system has the wheel with capacity control damper, and a separate exhaust air fan.

The system could also be designed with the heating coil in the reheat position.

Filtration would be required upstream of the unit in the outdoor air intake and upstream of the unit in the exhaust airstream.

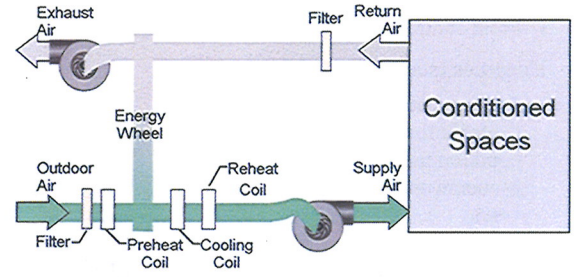


Figure 88

Flow Schematic of Dedicated Outdoor Air System

Application Considerations by Building Type

Shown below are 9 categories of buildings with specific application tips for each type. In all cases, local codes and design procedures specific to the project should be followed.

Industrial Process Areas (see Figure 89)

- Cross-transfer of pollutants from exhaust to ventilation air can occur.
- Operational temperature range is normally required.
- The ability to clean the pollutants from the exhaust airstream that deposit on the wheel is desirable.
- Do not use energy recovery from fume hood exhaust.



Figure 89

Industrial Process

Print Shops

- Do not use energy recovery on the air from the printer exhaust.
- A recovery unit may require supplementary heating and dehumidification to control the space humidity to tolerances required for paper-based products.
- Regular cleaning to keep latent performance at factory original levels is suggested.

Ice Rinks

- Ventilation air must be dried and pretreated to keep indoor relative humidity below the dew points at ice levels on the rink.
- Ventilation can be staged for occupancy, but allowance must be made for the operation of gas-fired ice surface maintenance machines during low occupancy.
- Frost control is rarely required due to the dry nature of exhaust air.

Hospitals (see Figure 90)

- Energy recovery wheels are acceptable for ventilation in common use areas such as patient rooms, waiting areas, and hallways.
- Operating rooms and labs may need to avoid the possibility of even the slightest cross-transfer of exhaust to ventilation. Most hospital ventilation codes require final filters and separation of intake and exhaust.
- Recovery units must be regularly cleaned and maintained to ensure the highest ventilation air quality.
- Ventilation is a year-round, 24-hour-per-day requirement, so provision for low temperature operation (frost control) must be considered in cold climates.



Figure 90

Hospitals

Nursing Homes

- Odor generation mandates ventilation rates at or above the minimums listed in ASHRAE Standard 62.
- Energy recovery with humidity control is important for occupant comfort and health.
- Frost control is required in many cold climates.
- Special laboratory or infectious disease areas should have dedicated exhausts.

Correctional Facilities

- Odor generation mandates ventilation rates at or above the minimums listed in ASHRAE Standard 62.
- Year-round, 24-hour-per-day operation requires low temperature (frost) operational controls in many cold climates.
- The possible need to control infectious disease may require final filters in areas such as clinics.

Toilet Exhaust

- Odor control is rarely an issue when toilet exhaust is provided at ASHRAE Standard 62 minimums. Consider additional exhaust to balance air flows when using energy recovery.
- Make-up air for toilet exhaust is generally provided by transfer air from surrounding spaces.
- The mixing of toilet exhaust with space ventilation exhaust is acceptable for systems where cross-transfer is limited to 10 percent or less of the exhaust airstream.

Hospitality/Smoking (see Figure 91)

- Control and separation of smoking and non-smoking areas presents design challenges as does kitchen ventilation from grills, fryers, and ovens.
- Where smoking is allowed and exhausted through an energy recovery wheel, thorough cleaning every 90 days is highly recommended to avoid build-up of tars and nicotine on the surface of the wheel.
- Ventilation air coming through a wheel that has smoking room exhaust must always be supplied back to the smoking space. It should not be supplied to non-smoking areas due to concerns for odor transfer. Space conditioning should be provided separately, as well.



Figure 91

Hospitality

Retail (see Figure 92)

- Retail ventilation is important to minimize the concentration of chemicals in the space due to clothing dyes, paint, and formaldehyde from products and furnishings.
- Significant savings in ventilation costs are available due to long hours of operation.
- Frost control should be considered in colder climates.



Figure 92

Retail Applications

Selection Example With Economic Analysis

As we have seen in this TDP, there are several types of air-to-air heat and energy recovery choices that may be used in comfort air-conditioning applications. For our selection example, we will choose to use an energy wheel.

The energy wheel was chosen over the other recovery types we examined in this TDP for several reasons. The example HVAC unit is a standard rooftop unit with electric heat. The location of the ventilation and exhaust airstreams are easily positioned next to each other. This is a comfort air-conditioning application and complete isolation of the two airstreams is not required. The energy wheel can transfer both sensible and latent heat thus maximizing system payback. Fixed plates, runaround loops, and heat pipes were not considered to be good solutions in this situation.

We will utilize the manufacturer's selection software for our example. See Figure 93.

Determine the reduction in unit size, yearly operating cost savings, and payback by adding energy recovery.

Job Conditions:

Dental Office Building, New York City Area

Summer Conditions:

- Indoor air: 75° F, 50 percent rh
- Outdoor air: 95° F db, 76° F wb

Ventilation airflow:

- 1250 cfm
- Occupied cycle 8 a.m. to 8 p.m.
- Monday through Friday

Winter Conditions:

- Indoor air: 70° F, 40 percent rh
- Outdoor air: 15° F db, 10° F wb

Selected unit: (no recovery):

15-ton electric heat rooftop



Figure 93

Selection Software

Step 1 - Input Outdoor and Exhaust Airflows

We will select the unit based on airflow.

Using our psychrometric example from earlier in the TDP, the total unit airflow is 5000 cfm with 1250 cfm of outdoor air. Therefore, we will enter 1250 cfm for the ventilation and exhaust airflows. See Figure 94.

Notice there are other selection criteria available. If we had selected from a list of available units, we would have arrived at the same answer for wheel size since each size is made to handle a certain range of airflow.

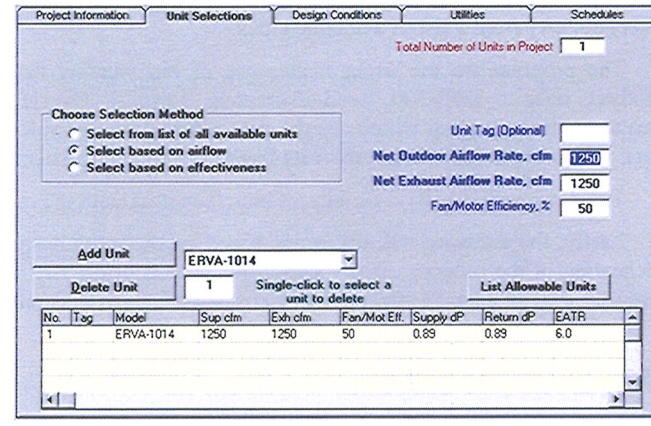


Figure 94

Input Outdoor and Exhaust Airflows
(Screen capture courtesy of MicroMetl and AirXchange)

If effectiveness is the only criterion, the user can enter a desired effectiveness. Only units that meet this performance at the desired flow rates would be chosen.

Since the program will calculate dollars saved per year, we must also take into account the energy consumed by the recovery unit fans. We will use a value of 50 percent that reflects a combination of the motor efficiency, fan efficiency, and drive losses.

Step 2 - Input Design Conditions and Location

Next we will define the weather conditions that will apply to the entire project. There are two aspects to the weather: the design conditions and the city where the project is located.

Design Conditions

The design conditions are the indoor and outdoor conditions that the engineer uses for sizing heating and cooling equipment. Conditions for both summer and winter, for both indoors and outdoors, and for both dry bulb temperature and wet bulb temperature are required. We will use 95° F db and 76° F wb, which are values the engineer selected for this application. See Figure 95.

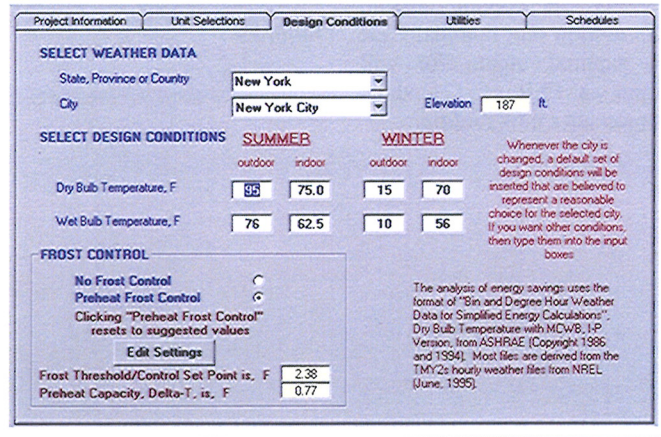


Figure 95

Input Design Conditions
(Screen capture courtesy of MicroMetl and AirXchange)

Yearly Weather Data

The calculation of energy and cost savings over the entire year requires weather data. We will select our city from a list of available cities.

The program we are using makes use of bin weather data. For a discussion on the Bin Method, refer to TDP-300, Load Estimating, Level 1: Overview. The data itself comes from various sources, among which are the data referred to as Typical Meteorological Year or TMY data, which is available in hourly form from the U.S. government.

The data produces dry bulb bins of hours together with the mean coincident wet bulb.

Lastly, the software will determine based on the room design and the outdoor conditions, if preheating of the outdoor air is required for frost control. The preheat energy, if frost control is required, will be added to the operating cost for the recovery unit.

Step 3 - Input Utilities

In order to evaluate the energy consumption and economics associated with the use of a recovery application, we must input information about the proposed rooftop. The required information consists of the efficiency of the rooftop unit and the type and cost of the energy that is being used.

For our example, we will input electric as our heating method. See Figure 96.

For the cooling season, the rooftop unit nominal EER is required input. We will input an EER of 12, which represents a new rooftop.

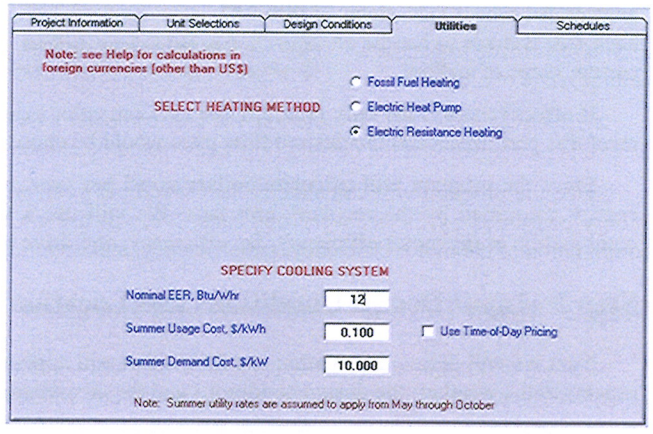


Figure 96

Input Utilities
(Screen capture courtesy of MicroMetl and AirXchange)

Step 4 - Input Operating Schedules

Many buildings do not require ventilation 24 hours per day, 7 days per week, for the entire year. A hospital or nursing home would be an exception. In order to do a fair evaluation, we must take credit for recovery only during those periods of time when ventilation would be required. The ventilation air presents an added load to the HVAC system in addition to the space loads. This input screen shown in Figure 97 allows us to limit the analysis of annual energy consumption to those periods when ventilation is actually used.

For our office building application, we will choose to operate from 8 a.m. to 8 p.m. Daytime operation would result in higher outdoor temperatures on the average than a nighttime operation.

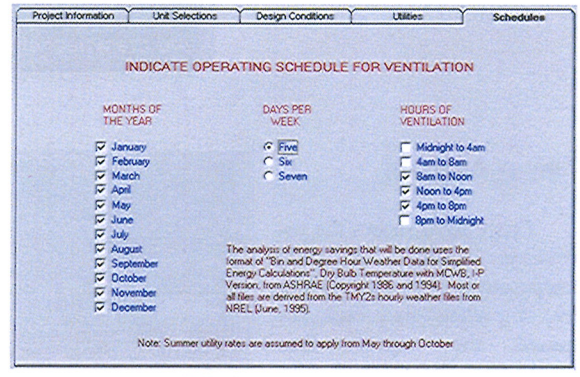


Figure 97

Input Operating Schedules
(Screen capture courtesy of MicoMetl and AirXchange)

Our example building will be occupied Monday through Friday, and is unoccupied on the weekends so no ventilation air is introduced during these times.

At this point we can generate output information.

Step 5 - Generate Output Data

Design Data and Wheel Performance

The software will display the design conditions entering and leaving the recovery wheel. See Figure 98. Some interesting parameters to note:

- Entering air to wheel is 95° F db/ 76° F wb
- Leaving air off wheel is 81.37° F db 67.81° F wb
- Net effectiveness during summer is 61.7 percent
- Net effectiveness during winter is 62.9 percent
- Installed HVAC reduction is 3.15 tons cooling

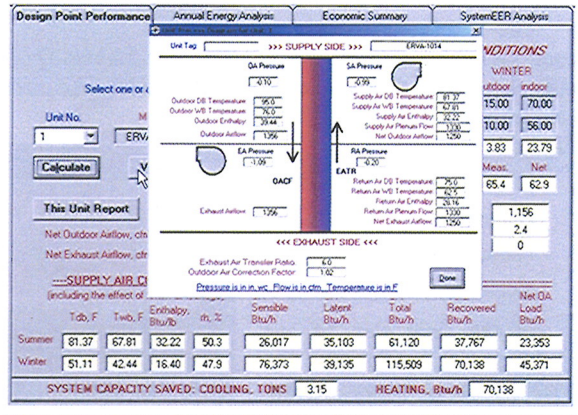


Figure 98

Design Data and Wheel Performance
(Screen capture courtesy of MicoMetl and AirXchange)

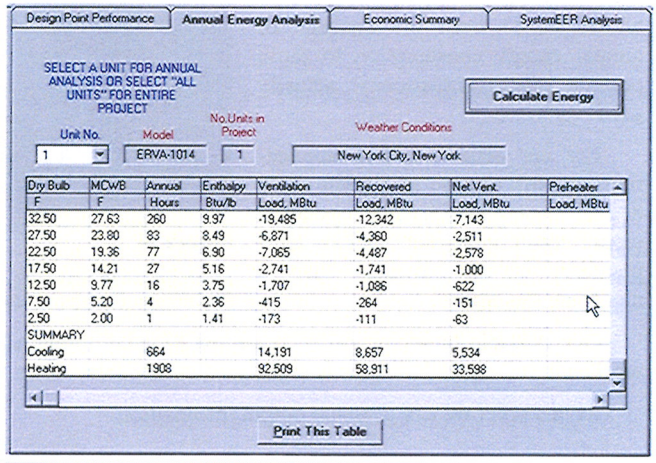
The fan arrangement shown is that of typical air-handling applications. The user may toggle fan positions if a different fan arrangement is desired.

Software Application

The computer generated answers differ slightly from the values used in our examples in the Psychrometric Section. This is because the software application includes the effect of return air leakage, and the wheel effectiveness value is not identical.

Energy Analysis

This output shows the recovered energy in each temperature bin. See Figure 99. If preheat had been required, the required Btu would have been listed. The ventilation load goes from positive to negative numbers based on bin temperature.



Dry Bulb F	MCWB F	Annual Hours	Enthalpy Btu/lb	Ventilation Load, MBtu	Recovered Load, MBtu	Net Vent. Load, MBtu	Preheater Load, MBtu
32.50	27.63	260	9.97	-19,485	-12,342	-7,143	
27.50	23.80	83	8.49	-6,871	-4,360	-2,511	
22.50	19.36	77	6.90	-7,065	-4,487	-2,578	
17.50	14.21	27	5.16	-2,741	-1,741	-1,000	
12.50	9.77	16	3.75	-1,707	-1,086	-622	
7.50	5.20	4	2.36	-415	-264	-151	
2.50	2.00	1	1.41	-173	-111	-63	
SUMMARY							
Cooling		664		14,191	8,657	5,534	
Heating		1908		92,509	58,911	33,598	

Figure 99

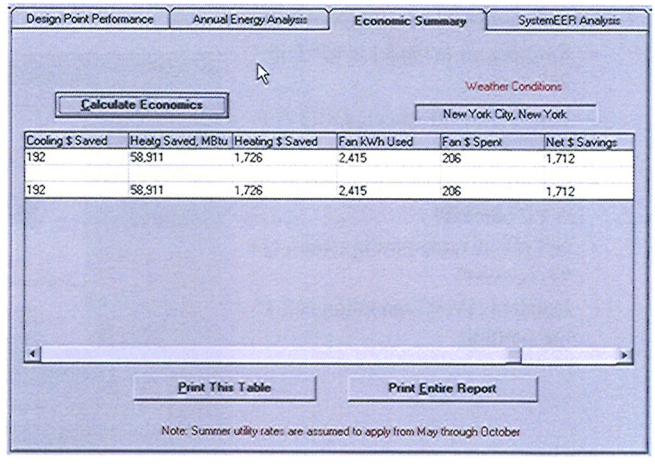
Energy Analysis
(Screen capture courtesy of MicoMetl and AirXchange)

Economic Summary

The yearly net operating cost savings on this system after subtracting the fan energy can now be calculated. See Figure 100.

Cooling saved + $192
Heating saved + $1,726
Fan energy - $206
Net Total Savings= $1,712

In the final step of our analysis, we will use this $1,712 annual energy savings to calculate a simple payback for using energy recovery.



Cooling $ Saved	Heatg Saved, MBtu	Heating $ Saved	Fan kWh Used	Fan $ Spent	Net $ Savings
192	58,911	1,726	2,415	206	1,712
192	58,911	1,726	2,415	206	1,712

Figure 100

Economic Summary
(Screen capture courtesy of MicoMetl and AirXchange)

System EER

System EER is also called combined efficiency (CEF). The impact of the use of a recovery device on the efficiency of a package unit can be calculated. The recovery unit will have an inherently very high EER (formally termed RER by ARI). In this example, the software has calculated it to be 57.98. This analysis is done for thecooling mode only. See Figure 101.

The EER of our 12 ½-ton rooftop was retrieved from catalog data. The output table shows the capacity and EER of the cooling equipment, the percentage of the total cooling capacity that is provided by the recovery wheel, and the improved system EER for the combined system.

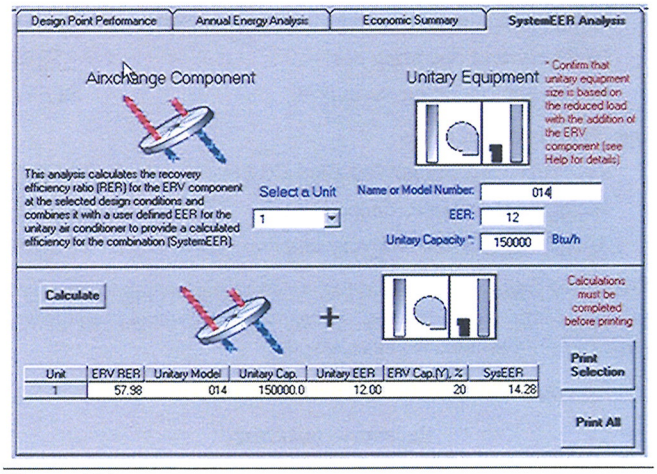


Figure 101

System EER
(Screen capture courtesy of MicoMetl and AirXchange)

System EER is derived from the ratio of the cooling capacity of the ERV to the total system capacity.

- Recovery unit RER is 57.98
- Rooftop EER is 12.0
- Recovery unit capacity is 20 percent of the total combined capacity
- Total System EER CEF is 14.28

Software such as we have been using solves for the load transferred from the HVAC unit to the energy recovery device. This load transfer has value. The value may be measurable in terms of a reduction in installed tons of rooftop due to the downsizing.

Together, the first cost savings and the operating cost savings can be compared to the added cost of the energy recovery device in the downsized system.

Life Cycle Costing

For a detailed discussion about life cycle analysis, see TDP-903, Life Cycle Costing.

Detailed life cycle costs typically ideally involve scheduled maintenance of the energy recovery device. All units become dirty over time and must be cleaned. The cycle of cleaning is dependent on the dirtiness of the exhaust air and the hours of operation. In this example, we will simplify and exclude maintenance.

Step 6 - Determine Payback

Let's sum up our economic model on this example (Figure 102):

Yearly Operating Costs

Energy consumption savings utilizing recovery =	$ 1,918
Recovery unit operating cost =	– $206
Net system operating savings =	$1,712

One Time Installed Costs

Recovery Unit Budget Installed Cost =	$4,500
Packaged Rooftop Reduced Cost =	– $3,750 *
Actual Cost for the recovery unit =	$750

*A rule of thumb we can use for our example is approximately $1,050 per ton installed cost for a packaged unit. Since the use of the recovery wheel has allowed us to utilize a 12½ ton unit instead of a 15 ton unit, we have saved:

2.5 tons * 1,050 $/ton = $3,750

$$\text{Payback} = \frac{\text{Recovery Unit Cost}}{\text{Yearly Operating Savings}}$$

$$= \frac{\$750}{\$1,712}$$

$$= 0.44 \text{ years}$$

This is a very attractive payback. Had the operating hours been longer and/or the percent of ventilation air been greater, an even quicker payback would have been possible. For instance, if we run a quick calculation for a hospital operating 7 days a week, 24 hours per day, then the payback would be only 2 months.

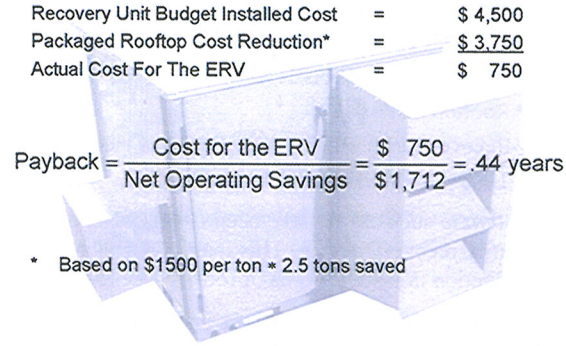


Figure 102

Payback

Commissioning

When commissioning air-to-air heat or energy recovery systems, it is most important that the two airflows are balanced per the requirements of the specifications. See Figure 103.

If, for example, the supply airflow is 1330 cfm, and the heat recovery selection was based on 1250 cfm of net exhaust air, both fans must be balanced and the airflow confirmed within normal tolerances.

It is possible that a contractor may not appreciate the impact of unbalanced airflow on the recovery process. As we have seen in this TDP, the effect of unbalanced airflows can be substantial.



Figure 103

Balanced Airflows are Important

Unbalanced airflows not only affect performance, but if the unit is installed in a geography where below-freezing temperatures occur, frost or ice build-up could be accelerated and require more frequent defrost cycles. This reduces overall unit performance.

Professional balancing using accurate flow measurement is suggested. Flow stations have been used successfully in this process, either as an integral part of the equipment or field-added for the balance process.

Summary

The use of air-to-air recovery devices has increased in response to the requirement for increased levels of ventilation air. The basis for good IAQ starts with supplying proper amounts of ventilation air per ASHRAE 62.1 requirements. Ventilation air requirements constitute a substantial portion of the cooling and heating loads of the building. Increasing the ventilation air loads increases both operating cost and system equipment costs. Energy recovery is used to apply energy conserving practices to save money.

There are several types of heat and energy recovery products in the market. The more widely used products are runaround loops, fixed-plate heat exchangers, heat pipes, energy wheels, and outdoor air heat pumps.

The best recovery type for the application often depends on two simple factors: the quality of the exhaust air and the physical layout of the exhaust and ventilation airstreams.

The psychrometric chart is important to illustrate the sensible and the latent recovery process and also to show how the major types of heat recovery products differ. Since recovery may be a *heat* exchange only (change in dry bulb temperature) or an *energy* exchange (change in sensible and latent levels), a basic knowledge of psychrometrics is required for an understanding of recovery.

Codes and standards that influence the energy recovery industry are involved in the goal of reducing building energy usage. Air-to-air energy recovery equipment can be used to achieve that goal. ARI Standard 1060 has become the standard of testing and evaluation of air-to-air recovery devices. The ASHRAE Standard 84 defines a uniform method of testing for obtaining performance data.

The application of heat or energy recovery in specific system types such as rooftops and dedicated air systems is important. In this TDP module we learned that an HVAC system lends itself to certain recovery types simply because of the configuration. As an example, a rooftop unit project often positions the exhaust airstream and the ventilation airstream close together, so an energy wheel, heat pipe, or exhaust air heat pump can be used. Either way, life cycle costs play a prominent role in making a final decision of which system to utilize.

Lastly, computerized selection software is typically available from the manufacturer for life cycle recovery calculations and final selections.

Work Session

1. Name the three application types used for both new and retrofit applications of energy recovery.

   _____

   _____

   _____

2. Define air-to-air recovery.

   _____

   _____

3. What is the relationship between ventilation and energy recovery?

   _____

   _____

4. Describe sensible and total recovery and what the differences are between them.

   _____

   _____

5. Explain what coupled and uncoupled systems are and how they differ in their application.

   _____

   _____

6. Which recovery device often uses a tilt mechanism for capacity control? _____
   a) Runaround loop
   b) Heat pipe recovery unit
   c) Energy wheel
   d) Fixed-plate heat exchanger

7. True or False? Capacity control for a runaround loop is usually accomplished by use of a 2-way mixing valve. _____

8. What is an attraction of a runaround loop?

_____

_____

9. What is the general criteria where energy recovery is a good choice?

_____

_____

10. What is the difference between passive and active recovery?

_____

_____

11. What type of energy recovery design uses a desiccant and what does a desiccant do?

_____

_____

12. Why is a packaged rooftop unit application a good candidate for energy recovery? Explain the issue as a function of ventilation air amounts.

_____

_____

13. What is the formula for sensible effectiveness?

_____

14. Give 1 example of leakage and carryover.

_____

_____

15. True or False? Both energy wheels and heat pipes may use a purge. _____

16. Match the device with the definition.

_____	Runaround loops	A. These systems circulate a fluid (usually a glycol mixture) between two airstreams.
_____	Energy wheel	B. This is a sensible-only exchanger made from alternate layers of plates.
_____	Heat pipes	C. Sensible-only recovery products that look like ordinary finned tube coils, except each successive tube is independent and not connected to other tubes.
_____	Fixed-plate	D. These products can transfer sensible and latent heat by using a desiccant coating.

17. Explain how the use of energy recovery can result in the downsizing of the base HVAC unit.

_____

_____

18. Match the code or standard with its intention

_____	ARI 1060	A. Impact of recovery on system efficiency
_____	ASHRAE 62,1	B. Methods and calculations for testing
_____	UL and NFPA	C. Electrical and fire safety
_____	ASHRAE 90.1	D. Testing and evaluation of recovery products for ratings
_____	ASHRAE 84	E. Operating efficiency
_____	ARI Guideline V	F. Ventilation air and IAQ

Notes:

Notes:

Notes:

Work Session Answers

1. Process
   Combination process and comfort
   Comfort

2. Air-to-air recovery is the process of capturing and transferring energy between the building exhaust air and the incoming building ventilation airstreams.

3. The greater the amount of ventilation air introduction into a building, the greater the first and operating costs will be for the HVAC equipment. This creates the need for energy recovery systems that allow "used" energy to be recycled rather than requiring the constant availability and creation of new energy.

4. Sensible recovery is the transfer of heat between the exhaust and ventilation airstreams. It is strictly a dry bulb temperature change. "Total" energy recovery describes the change in temperature and moisture level of the ventilation airstream as it passes through the recovery device.

5. In a coupled system, power to the recovery device and the base unit can be conveniently supplied from a single power source. The recovery unit preconditions the ventilation n air and introduces it into the main HVAC unit to be mixed with return air. The recovery unit is part of the base unit assembly.

   An uncoupled system is a combination of a traditional HVAC unit with a renotely located energy recovery unit. The recovery unit will be placed where a convenient combination of exhaust air and ventilation air can be located. Uncoupled systems can be used to deliver the ventilation air to the building by several different methods.

6. b) heat pipe recovery unit

7. False, runaround loops use 3-way mixing valves to prevent ventilation airstream overheating and overcooling.

8. Runaround loops are attractive for applications that have the exhaust and the supply airstreams at different locations since they can work while keeping the two airstreams separate. For that reason, cross leakage is usually non-existent and no contamination is possible.

9. Any building with comfort conditioning requiring relatively high levels of ventilation air is a likely candidate. A clean exhaust airstream is also required.

10. Passive recovery devices utilize the heat or cool energy in the ambient and the building exhaust air to accomplish transfer of heat or energy.

    Active energy recovery uses a new energy source located in the exhaust airstream. Total energy consumption is higher than passive energy recovery but the resultant supply air has a lower dew point than passive.

11. When an energy wheel is to be used for both sensible and latent heat transfer, a coating, called a desiccant, is permanently bonded to the energy transfer matrix. The desiccant allows the moisture to cling to the wheel, thus allowing the transfer of latent heat.

12. As a rule of thumb, a rooftop unit with DX coil can handle no greater than about 25 percent ventilation air without loosing control of space humidity. New ASHRAE ventilation rates may result in greater percentages. Above these conditions, the typical rooftop unit's evaporator coil will be inadequate to handle the larger latent load of the ventilation air.

13. Sensible effectiveness can be reasonably predicted using the following formula:

$$\text{Sensible Effectiveness} = \frac{\Delta T \text{ of one airstream}}{\Delta \text{EAT of the two airstreams}}$$

14. Leakage can result from pressure differences between opposing airstreams. This can happen in a plate heat exchanger if the partition is not airtight.

    Carry-over is a characteristic of wheels and refers to air that is carried from one air airstream to another as a result of the wheel rotation cutting across each airstream.

15. False, only energy wheels utilize a purge to remove any dirty air that is trapped in the media.

16. A Runaround loops
    D Energy wheel
    C Heat pipes
    B Fixed-plate

17. Utilizing a recovery device results in an air mixture temperature entering the evaporator coil that is lower. This in turn will reduce the amount of work that the rooftop unit has to do. The result will be a down size in base unit capacity and an associated first cost and operating cost savings from the original HVAC unit without energy recovery.

18. D ARI 1060
    F ASHRAE 62.1
    C UL and NFPA
    E ASHRAE 90.1
    B ASHRAE 84
    A ASHRAE Guideline V

References

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Annexair, Drummondville, Quebec, Canada. www.annexair.com

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Heat Pipe Technologies, Gainesville, FL. www.heatpipe.com

MicroMetl, Indianapolis, IN. www.micrometl.com

Appendix A – Heat and Energy Recovery Comparison

ASHRAE Comparison of Air-to-Air Energy Recovery Devices

	Fixed Plate	Membrane Plate	Energy Wheel	Heat Wheel	Heat Pipe	Runaround Coil Loop	Thermosiphon
Airflow arrangements	Counterflow Cross-flow	Counterflow Cross-flow	Counterflow Parallel-flow	Counterflow	Counterflow Parallel-flow	-	Counterflow Parallel-flow
Equipment size range, cfm	50 and up	50 and up	50 to 74,000 and up	50 to 74,000 and up	100 and up	100 and up	100 and up
Typical sensible effectiveness	50 to 80	50 to 75	50 to 85	50 to 85	45 to 65	55 to 65	40 to 60
Typical latent effectiveness	-	50 to 72	50 to 85	0	-	-	-
Total effectiveness	-	50 to 73	50 to 85	-	-	-	-
Face velocity	200 to 1000	200 to 600	500 to 1000	400 to 1000	400 to 800	300 to 600	400 to 800
Pressure drop, in. wg	0.4 to 4	0.4 to 2	0.4 to 1.2	0.4 to 1.2	0.6 to 2	0.6 to 2	0.6 to 2
EATR, %	0 to 5	0 to 5	0.5 to 10	0.5 to 10	0 to 1	0	0
OACF	0.97 to 1.06	0.97 to 1.06	0.99 to 1.1	1 to 1.2	0.99 to 1.01	1.0	1.0
Temperature range, °F	-75 to 1470	12 to 120	-65 to 1470	-65 to 1470	-40 to 105	-50 to 930	-40 to 105
Typical mode of purchase	Exchanger only Exchanger in case Exchanger and blowers Complete system	Exchanger only Exchanger in case Exchanger and external blowers Complete system	Exchanger only Exchanger in case Exchanger and blowers Complete system	Exchanger only Exchanger in case Exchanger and blowers Complete system	Exchanger only Exchanger in case Exchanger and blowers Complete system	Coil only Complete system	Exchanger only Exchanger in case
Advantages	No moving parts Low pressure drop Easily cleaned	No moving parts Low pressure drop Low air leakage	Moisture or mass transfer Compact large sizes Low pressure drop Available on all ventilation system platforms	Compact large sizes Low pressure drop Easily cleaned	No moving parts except tilt Fan location not critical Allowable pressure differential up to 2 psi	Exhaust airstream can be separated from supply air Fan location not critical	No moving parts Exhaust airstream can be separated from supply air Fan location not critical
Limitations	Large size at higher flow rates	Few suppliers Long-term maintenance and perform-ance unknown	Supply air may require some further cooling or heating Some EATR without purge	Some EATR without purge	Effectiveness limited by pressure drop and cost Few suppliers	Predicting performance requires accurate simulation model	Effectiveness may be limited by pressure drop and cost Few suppliers
Heat rate control (HRC) methods	Bypass dampers and ducting	Bypass dampers and ducting	Bypass dampers and wheel speed control	Bypass dampers and wheel speed control	Title angle down to 10% of maximum heat rate	Bypass valve or pump speed control	Control valve over full range

**Rated effectiveness values are for balanced flow conditions. Effectiveness values increase slightly if flow rates of either or both airstreams are higher than flow rates at which testing is done.*

EATR = Exhaust Air Transfer Ratio
OACF = Outside Air Correction Factor

Prerequisites:

To obtain the highest benefit from this module, it is suggested that participants have prerequisite knowledge from the TDPs listed below, or equivalent.

TDP No.	Book Cat. No.	Instructor CD Cat. No.	Title
TDP-102	796-026	797-026	ABCs of Comfort
TDP-103	796-027	797-027	Concepts of Air Conditioning
TDP-201	796-030	797-030	Psychrometrics, Level 1: Introduction

Learning Objectives:

After reading this module, participants will be able to:

- Describe the relationship between ventilation air and energy recovery.
- Explain the differences between sensible heat recovery and total heat recovery
- Use the psychrometric chart to demonstrate how energy recovery results in downsizing of HVAC equipment.
- Explain coupled and uncoupled systems.
- Explain how effectiveness is calculated.
- List the codes and standards that apply to the air-to-air recovery industry.
- Describe the types of heat recovery devices and the principles of operation.
- Explain frost control, cross-contamination and purge.
- List applications where each heat recovery option is a good choice and also when the application is not appropriate for heat recovery.
- Select a recovery unit with software, find the reduction in central unit capacity, and calculate operating cost and payback.

Supplemental Material:

TDP No.	Book Cat. No.	Instructor CD Cat. No.	Title
TDP-902	06-796-077	06-797-077	Indoor Air Quality
TDP-300	06-796-085	06-797-085	Load Estimating, Level 1: Overview
TDP-400	796-037	797-037	Principles of Mechanical Refrigeration, Level 1: Fundamentals
TDP-611	796-049	797-049	Central Station Air Handlers
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Instructor Information

Each TDP topic is supported with a number of different items to meet the specific needs of the user. Instructor materials consist of a CD-ROM disk that includes a PowerPoint™ presentation with convenient links to all required support materials required for the topic. This always includes: slides, presenter notes, text file including work sessions and work session solutions, quiz and quiz answers. Depending upon the topic, the instructor CD may also include sound, video, spreadsheets, forms, or other material required to present a complete class. Self-study or student material consists of a text including work sessions and work session answers, and may also include forms, worksheets, calculators, etc.



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