Washington Energy Extension Service

AIR-TO-AIR HEAT EXCHANGERS

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Some degree of natural ventilation occurs in every home, regardless of how tightly it is built. This results in cold drafts that could account for as much as half (50%) of the home's heat loss. Fortunately, many leaks in the home can be easily plugged with basic weatherization materials such as caulking, weatherstripping, switchplate gaskets, and fireplace covers. Being very low cost, these materials usually pay for themselves in one year or less, making them a very wise investment.

After weatherization some homes may exhibit noticeable increases of indoor air pollutants, including odors and moisture. Usually such homes have large sources of indoor contaminants, or are already very tight before weatherization. In addition, new construction techniques now make it possible to build a house so tight that it takes ten hours or more for the household air to be replaced by fresh outside air. This is much longer than the air replacement time of one-half to one and one-half hours for a conventional home. Without some form of forced ventilation the air in many newer, better built conventional homes--possibly unhealthy. This is even more true in extremely tight superinsulated homes.

Increased ventilation could be achieved by opening windows or turning on exhaust fans (which suck in cold air through cracks in the home). However, this would conflict with the original goal of making the home tight to save energy. Recently, energy efficient ventilation devices for homes, called air-to-air heat exchangers, have appeared on the market. They exhaust pollutants and provide fresh air while recovering 60 - 90% of the exhaust air's heat.

This pamphlet will discuss types of air-to-air heat exchangers, their advantages and disadvantages, installation details, and how to select an air-to-air heat exchanger that is appropriate.

HOW AN AIR-TO-AIR HEAT EXCHANGER WORKS

An air-to-air heat exchanger system (hereafter called heat exchanger) consists of 1)two fans or blowers, 2) controls, 3) a heat exchanger chamber, and 4) duct work for air distribution (some units do not require duct work). One fan or blower exhausts the stale indoor air, while the other brings fresh air into the home. Inside the heat exchanger chamber the stale and fresh air streams are divided into tens or hundreds of individual channels. The channels are arranged so that fresh and stale passageways are in close contact with each other without the air streams actually mixing. Because heat always flows from areas of high temperature to areas of low temperature, heat is transferred from the warm stale air to the cooler fresh air through the thin partitions. (Some heat exchangers use heat pipes or heat wheels to conduct heat. These will be discussed later.)

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OFFERED IN COOPERATION WITH PUGET POWER

Figure 1 illustrates the flow of air and heat through a heat exchanger that is 75% efficient at recouping heat from the stale air.

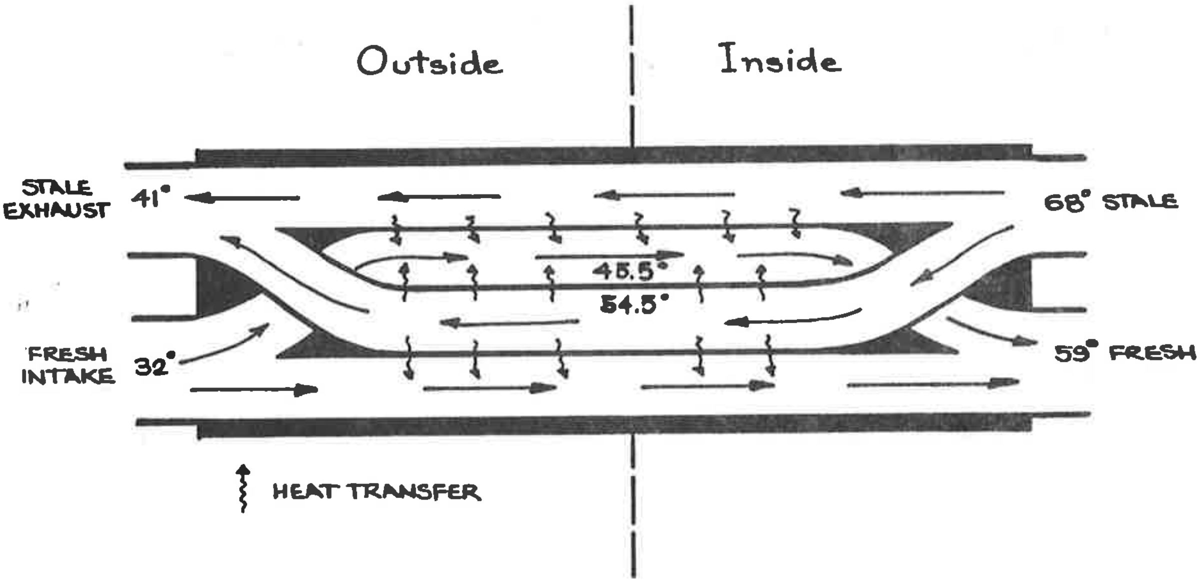

Figure 1. Example of heat flow in a counterflow heat exchanger

Although, in this example, the fresh air entering the home (59°F) is cooler than the indoor air (68°F), it is considerably warmer than the outside air (32°F). The steady state efficiency of a heat exchanger (i.e. when it is in operation, not a seasonal average) can be calculated by:

$$\frac{\text{Temperature of incoming fresh air - Outside temperature}}{\text{Indoor temperature - Outside temperature}} \times 100\%$$

In the above example:

$$\frac{59^{\circ} - 32^{\circ}}{68^{\circ} - 32^{\circ}} \times 100\% = \frac{27^{\circ}}{36^{\circ}} \times 100\% = .75 \times 100\% = 75\%$$

Most residential heat exchangers have efficiencies between 60 - 90%. For any given heat exchanger, the efficiency decreases as the airflow rate through the unit increases.

DESIGN CONFIGURATIONS

There are four main types of residential heat exchangers: counterflow, crossflow, rotary, and heat pipe.

- Counterflow

Counterflow heat exchangers are the most common types available. As in Figure 1, stale and fresh air streams are separated by thin partitions and travel in opposite directions. The maximum efficiency of this configuration is theoretically 100%. Actual claimed efficiencies range from 65 - 92%. Partitions are typically made from plastic or metal, thus these units do not recover water vapor. Counterflow heat exchangers tend to be large, from three to six feet in length and from one to two feet in diameter. Because of their size, they are usually installed in basements, storage areas, crawlspaces, or attics. Air is distributed throughout the home by way of ducts. A counterflow heat exchanger can easily ventilate an entire house, providing 70 - 350 cubic feet per minute (cfm) of fresh air. Power requirements for the fans or blowers range from 64 - 500 watts. Counterflow heat exchangers cost from $700 - $2500 (1985 prices), and the price does not always include fans, controls, or duct work.

You can also build your own counterflow whole-house heat exchanger out of plywood and polyethylene plastic. Plans are available through the University of Saskatchewan (see Suggested Reading). Materials necessary for constructing one usually cost between $350 and $400.

- Crossflow

To avoid the difficulty of manifolding opposing air streams to the core, some manufacturers have used a crossflow design. Crossflow heat exchangers are similar to counterflow systems except that the fresh and stale air streams cross each other at right angles instead of flowing in opposite directions (Figure 2). With this configuration it is possible to make the heat exchanger compact, yet have a large surface area to facilitate heat transfer. Although the maximum theoretical efficiency for recovering sensible heat is more than 90%, efficiencies are claimed to range from 60 - 83%. Most of the whole house crossflow units use a plastic or metal core, while wall mount units favor treated paper. At least one wall mount model, designed for basthroom use, has partitions made of plastics.

Crossflow heat exchangers are typically smaller than counterflow heat exchanger. The blowers can provide 23 - 350 cfm, depending on type of ventilation. Power requirements range from 30 - 290 watts. Prices for crossflow heat exchangers are between $130 and $1400 (1984 prices).

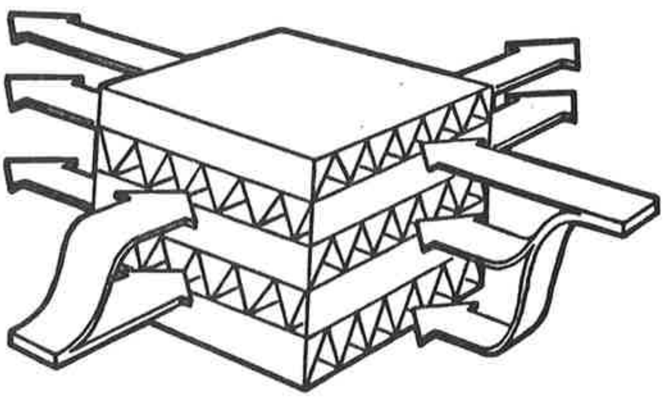

Figure 2 Crossflow heat exchanger

- Rotary

Rotary heat exhangers are very different from counterflow or crossflow heat exchangers. The heat exchanger consists of a drum that is packed with hundreds of small parallel tubes that absorb and release heat (see Figure 3).

A partition separates fresh and stale air streams as the drum, or heat wheel, slowly, rotates. Stale air warms the walls of the tubes as it passes through the drum. When the tubes rotate past the partition, cool fresh air is blown in a reverse direction through the warm tubes where the fresh air absorbs heat. The maximum efficiency is theoretically near 100%, but in

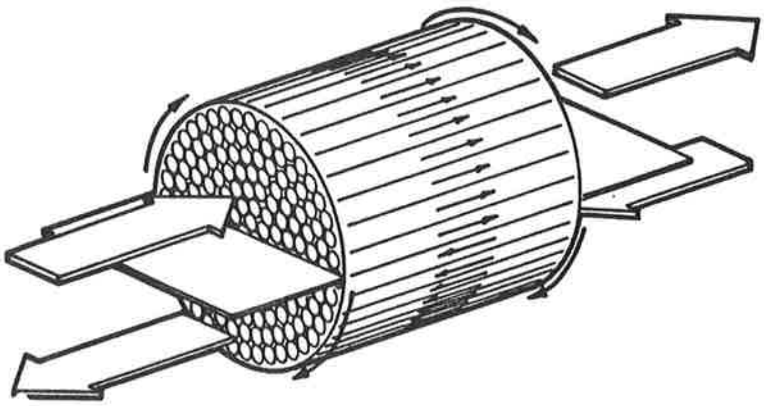

Figure 3 Rotary heat exchanger

practice the units are from 70 - 82% efficient (including latent heat recovery). Tubes for household units are usually made of treated paper that has the ability to absorb moisture from the stale air and release it into the fresh air. Another rotary design uses a plastic ribbon about one inch wide wound around itself into a flat disc. This disc turns like a record on a turntable. The plastic ribbon has small but distinct bumps on one side to separate the layers and create the air passage. As with crossflow configurations, rotary heat exchangers are compact and can be wall or window mounted, or connected to duct work. Airflow rates range from 31 - 295 cfm, and power requirements are 25 - 270 watts. Prices (1984) range from $350 (window/wallmount) to $1200 (wholehouse).

- Heat Pipe

Heat pipe heat exchangers are yet another very different type of exchanger. This design uses about two dozen sealed tubes or pipes, each containing a refrigerant. The pipes are arranged perpendicular to the air streams so that one end is exposed to incoming cold air and the other end is exposed to outgoing warm air (see Figure 4).

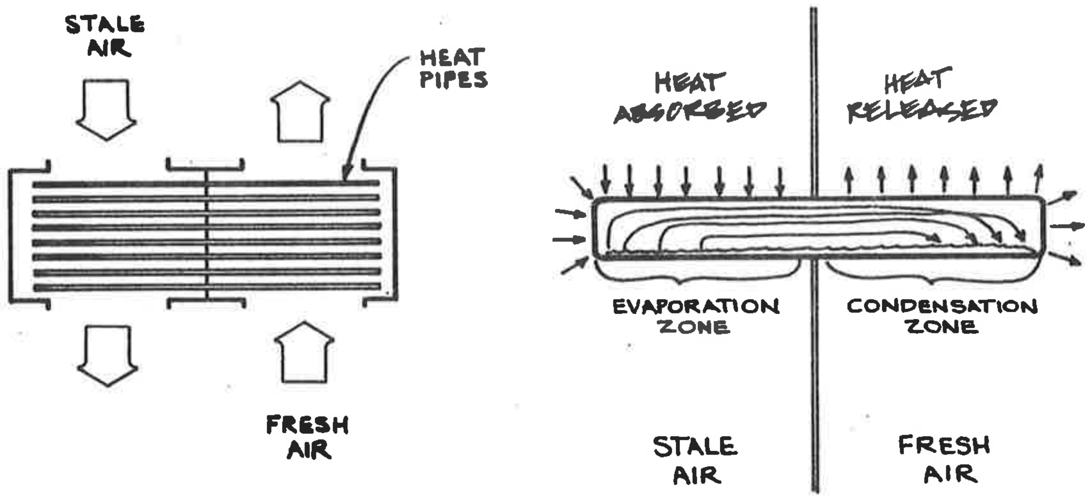

Figure 4. Heat pipe heat exchanger; figure on right shows details of a single heat pipe

When the liquid refrigerant is warmed by stale air in the evaporation zone, some of it becomes a vapor or gas. This phase change captures heat, which is then stored in the vapor. The vapor disperses to the other end of the pipe (condensation zone) where it encounters the cold, fresh air. Exposed to cooler temperatures, some of the vapor condenses into a liquid, releasing the heat it absorbed earlier. The liquid then flows to the evaporation zone where the cycle repeats itself. Although their maximum efficiency is theoretically 100%, in practice heat pipe heat exchangers only achieve approximately 65% efficiency (at 230 cfm). No recovery of moisture is possible with this design. This type of heat exchanger measures about two feet by nine inches by nine inches. The manufacturer will supply the core alone for about $250 - $400 (1984), so the airflow (9cfm) and power requirements will be determined by the owner-supplied fans and controls. Premanufactured units complete with fans and some controls range from about $500 to $1200, depending on the airflow required. Because of the way the airstreams are separated, there is virtually no cross-leakage.

Characteristics of these four types of heat exchangers are summarized in Table 1.

MATERIALS USED FOR PARTITIONS

The most common materials used for partitions are plastic (polybutylene, PVC, etc.), metal, and coated paper. Plastic and metal partitions do not allow water vapor to pass through them, but paper partitions or rotary style exchanger cores allow some water vapor to move from the stale air to the fresh air. If the air of your home tends to be too dry, then this is an advantage. However, if excessive moisture is a problem in your home, heat exchangers with plastic or metal partitions will be more effective at lowering the indoor humidity.

Heat exchangers that recover water vapor as well as heat are called enthalpy heat exchangers. This refers to the fact that they recover not only sensible heat (that is, heat that you sense as temperature), but also latent heat, which is the heat contained in water vapor. Latent heat is liberated when water vapor condenses into liquid water or becomes ice. But, unless condensation or frosting occurs, latent heat contributes very little warmth to the home. Thus, the value of retaining water vapor in the home for its heat content alone is questionable.

INSTALLATION

The installation procedure depends on whether the heat exchanger is a window/wall mounted unit or a whole-house system with duct work.

Table 1. Characteristics of Heat Exchangers

Characteristics	Counterflow	Crossflow	Rotary	Heat Pipe
Whole-house	Yes	Yes	Yes	Yes
Wall/window mount	No	Yes	Yes	No
Claimed efficiency (%)	65-92	60-83	70-82	65±
Ventilating capacity (cfm)	70-350	23-350	31-295	*
Moisture transfer	No	Yes/No	Yes	NO
Power (watts)	64-500	30-290	25-270	*
Cost (1984)	$700-2700	$170-1400	$350-1200	$250-1200

* Depends on fans selected by consumer
** Not including fans, controls, or ducts.

- Window/wall mounted units

Window/wall mounted units are usually simpler to install, particularly in double-hung or sliding windows. A window mounted heat exchanger usually requires some panels to seal the gaps between the heat exchanger and the window frame. Consult with your dealer for the appropriate materials. Installing a heat exchanger through a wall or ceiling may require the help of a professional, depending on your carpentry skills. Window, wall, or ceiling mounted units can adequately ventilate one to three rooms if they are properly sized and there is excellent air flow between the rooms. These units have been criticized for "short circuiting," however. That is, since the fresh and exhaust air ports are so close together, the fresh air can be exhausted before it mixes adequately with room air. Likewise, exhaust air can be brought back in through the fresh air intake. Room size heat exchangers are usually plugged into standard 110-volt electric outlets.

• Whole-house units

Whole-house units are typically mounted in basements, crawlspaces, attics, or utility rooms. The mounts should incorporate a vibration absorbing material to prevent noise from being transmitted to the house. Many whole-house heat exchangers must be directly wired to a junction box, which may require the help of an electrician.

Vents for removing stale air (exhaust ducts) should be located in rooms with the greatest air problems -- usually kitchens, baths, utility rooms, and hobby rooms. Avoid having exhaust vents located near cookstoves or connected directly to clothes dryers, otherwise the heat exchanger may become clogged with grease or lint.

Fresh air supply vents are preferably located as far as possible from the exhaust vents, and in areas where the cool fresh air will not constantly blow on anyone. Hallways and bedrooms are a good location. One option, if you have a forced air heating system, is to have the fresh air enter the return air supply of the furnace where it will be warmed and distributed throughout the house. Most manufacturers do not recommend that you have a direct connection between the heat exchanger and the furnace duct. Such a design will cause an imbalanced airflow inside the heat exchanger due to the suction of the furnace (see Figure 5), and this will reduce the efficiency of the system. A better arrangement is to have the fresh air enter the living space next to the return air vent of the furnace (see Figure 5). Although some of the cool fresh air will mix with the air of the living space, much of it will be sucked into the return air duct of the furnace when the furnace is running. There is one situation where it may be acceptable to link a heat exchanger directly to a furnace air return duct. This is advisable only if your furnace fan runs continuously, and if you can restore the balance of the flow of air through the heat exchanger.

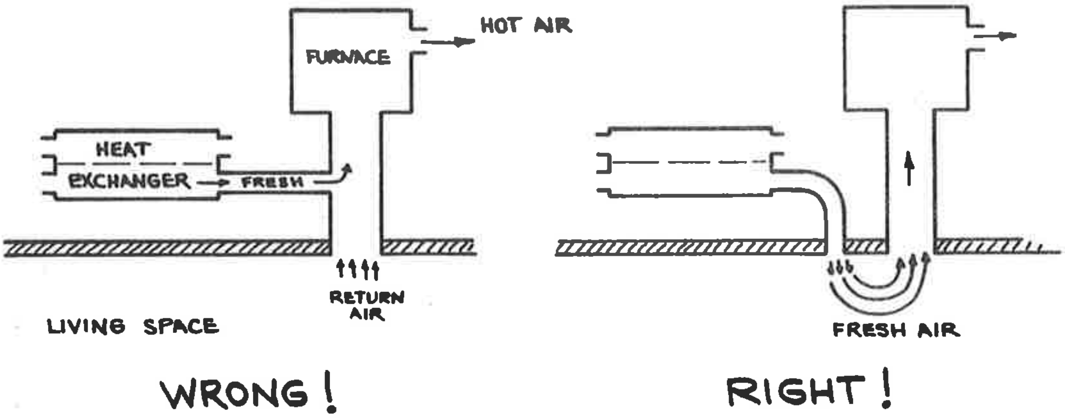

Figure 5. Relationship of heat exchanger and furnace

Outside vents should be spaced at least five feet apart and preferably placed on the same side of the house. Avoid placing the fresh air intake where it will suck in smoke from a neighbor's chimney or automobile exhaust from a busy street or highway.

All ducts leading to and from the heat exchanger should be insulated to prevent heat loss or condensation of water. (a) For this reason it is wise to locate the unit and run as much of the ductwork as possible within the heated space. A central closet or beneath stairs will often provide enough clearance for maintenance purposes. Remember that units with plastic or metal cores will also need a line for the condensate drain(s). (b) Increased resistance is also the reason manufacturers say to avoid "flex" duct or at least to keep it at a minimum (e.g. first two feet out of the heat exchanger.

In most installations the duct work for the stale air is longer than the duct work for the fresh air, thus, some manufacturers install more powerful fans for the stale air pathway. A few manufacturers include dampers in the ducts so the air streams can be balanced.

CONDENSATION AND FROST REMOVAL

Frost forming inside the heat exchanger can partially or totally obstruct the passageways of the stale air stream. The conditions that promote frosting are cold outside air and cool, dry air inside the home. In Western Washington frosting will rarely occur in heat exchangers and no precautions are necessary. However, in mountainous areas or in colder parts of Eastern Washington, frosting may be common during the winter. The consumer living in these frost prone areas should select a heat exchanger that has built-in frost protection. Two common ways of defrosting an exchanger are 1) warming the incoming air with a built-in heating element before it enters the exchanger, and 2) reducing or stopping the flow of incoming air so the heat of the stale air will melt the frost. Continuing to exhaust air while intake is completely stopped can create a negative pressure in the home. This, in turn, has been known to cause backdrafting down chimneys of fireplaces, heating systems and fireplaces. Two solutions to this problem are: 1) continuing to bring in fresh air, but by passing the heat exchanger core, and 2) recirculating stale air from the heat exchanger to a secondary heated space like a basement instead of exhausting it from the home.

Condensation of water is heat exchangers with metal or plastic partitions is common in all climates, and most are designed to let the condensation flow to a drainpipe. If the core is designed so the condensate drains toward the warm end, freezing will be less of a problem. Heat exchangers with paper partitions recover much of the water vapor from the stale air before it has a chance to condense freeze, so provisions for removing condensation or frost are not necessary for these types.

CONTROLS

Ideally, a heat exchanger would include a sensor that would detect air pollutants, and turn on the heat exchanger only when necessary. Unfortunately, no such controls are available for residences at this time. The general recommendations is to run the heat exchanger continuously at a low fan speed that will supply adequate ventilation. Then, when conditions warrant increased ventilation, a switch kicks the fan motors up to a higher speed. Descriptions of several types of controls follow. For a proper control, a combination of these is most likely.

- Manual controls

Even if the unit is designed to run continuously, there will be some periods when it should or can be turned off (e.g. for safety during maintenance, or in the summer when all the windows are open.) This may be done with a switch wired in by an electrician, one supplied by the manufacturer, or a simple plug in a socket.

- Multiple speeds/variable speeds

Many units come with predetermined multiple speeds (e.g. off-low-med-high). Others have one speed fan motors. Often a variable speed control is wired in on these latter types. Like a light dimmer switch, this device will allow continuous adjustment from zero to the maximum fan speed of the motor. Usually the variable speed control is used to set the low, continuous operation fan speed. When some other device signals a need for greater ventilation, this speed control in bypassed and the fan automatically goes up to a maximum.

• Timers

Usually one of three types of timers is used. A 24-hour timer can be used to turn the heat exchanger "on" and "off" or boost fan speed on a routine basis. Similarly a percentage timer will perform the same function for whatever percent of its cycle the dial indicates (i.e. if it is set at 20% and has a one hour cycle, it will run for 12 minutes every hour). The problem with both of these devices is that the fan "on" time may not correlate with pollutant levels. The most common timer employed is a simple "crank" timer. In this case. a knob is turned to indicate a set number of minutes the timer will run (usually between 10 - 60 minutes). This way the timer will continue to ventilate the room even after the activity has ceased. This is especially useful for bathrooms, kitchens, hobby rooms, or laundry rooms. Some devices will have a "hold" switch at the end of the dial, which allows operation without a timed shut off. If timing is desired, the knob is nudged off hold onto the minute markings.

• Dehumidistat

This device will boost or turn on the fan when the relative humidity goes higher than the predetermined level. As yet they are one of the better control devices because high humidity often correlates with high pollutant levels. While the dehumidistat dial will read from 10% - 60% or 20% - 80%, the set point should be whatever is needed to keep condensation off the windows. Initially, the device should be set around 40%, then adjusted accordingly. Some conditions, like single-glazed windows, cold outside temperatures and/or high indoor relative humidity may make it difficult to avoid condensation. Two good locations for the dehumidistat sensor are a neutral room or the exhaust duct work just before the heat exchanger--rather than a persistantly damp room such as a bathroom.

• Booster fans

Some manufacturers prefer to run the heat exchanger fans at one speed only. If boosted ventilation is needed, bathroom or kitchen vent fans which feeds through the heat exchanger is turned on. This only temporarily overpowers the exhaust.

Timers and dehumidistats are standard equipment on some heat exchangers, but for most systems you will have to purchase them separately.

MAINTENANCE

Compared with many other household "appliances," heat exchangers, require very little maintenance and can be expected to give many years of trouble-free performance. Most units have filters that trap dirt and lint before they have a chance to enter the exchanger. These must be cleaned or replaced periodically. Screens over the outside vents must be kept clean of debris. This is extremely important to prevent clogging of the exchanger core. While some units can be vacuumed or hosed down, and others have cores that can be removed for washing, there are some which provide no access for any sort of maintenance to the core. Paper elements in crossflow exchangers can usually be replaced. Always follow the manufacturer's recommendations for all maintenance procedures.

SELECTING A HEAT EXCHANGER

First, determine whether you really need a heat exchanger. Forced ventilation is virtually mandatory in homes that have very slow air change rates, such as superinsulated houses. But conventional homes usually have air change rates sufficient to keep air pollutant levels low. Yet, if a home has excessive moisture, lingering odors, or high levels of other indoor contaminants, a heat exchanger is one option for reducing the problem. If your goal is just getting rid of moisture, a portable dehumidifier will cost less, will probably be more effective, and will be more energy efficient than a heat exchanger. Keep in mind that reducing the source of the pollutant is usually the least expensive and most effective strategy for maintaining air quality.

Another consideration is the quality of air surrounding your home. If the outside air is heavily contaminated with automobile emissions, wood smoke, or other pollutants, then a heat exchanger may actually increase the concentration of these pollutants inside your home.

If, at this point, you believe that a heat exchanger is desirable, decide whether you will need a whole-house heat exchanger or only a window/wall mounted unit. Next, determine the airflow requirements to ventilate the space. It is often suggested that the heat exchanger be sized to replace the air in the space once every two hours, or in other words, one-half air change per hour (ACH). The airflow rate of ventilation equipment is usually given in cubic feet per minute (cfm). To calculate the capacity of the heat exchanger needed for your home use the following equation:

$$\text{cfm} = \frac{\text{volume of space} \times \text{ACH}}{60}$$

Example: What is the rate of airflow necessary to provide an additional 0.5 air change per hour (ACH) for a 1250 square foot home with eight foot ceilings?

$$\text{cfm} = \frac{(1250 \times 8) \times 0.5}{60} = 83.3 \text{ cfm}$$

Remember, any duct work will reduce the flow of air through the system. In order to make sure the intended air flow is achieved, the static pressure of the ducting system must be calculated. Then check the static pressure curve of the heat exchanger fans to insure they can produce the desired air flow at the system's static pressure. The installer or a good ventilation expert should make the correction for these losses.

Before shopping for a heat exchanger you should decide where you want to install it and where you need to run new ducts (if any). Measure the space to determine any limits in the dimensions of the unit.

When comparing brands of heat exchangers find out the airflow rate (cfm) and the efficiency of the unit. Remember, efficiency varies with airflow rate, so compare heat exchanger efficiencies at one specific ventilation rate. Determine the dimensions of the unit and the power requirements. Get a figure for annual cost of fan power consumption at the ventilation rate you need. Different units can vary widely. Ask what the partitions are made of, and if they can be cleaned or replaced. How is condensation or frost removed? Are the installation instructions complete and clearly written? How difficult is the installation? What accessories (fans, controls, duct work etc.) come with the unit? What are the terms of the warranty? How much will the total installation cost?

HOW MUCH ENERGY WILL YOU SAVE

How much energy (or money) will a heat exchanger save you as opposed to opening a window or running an exhaust fan to achieve the same amount of ventilation? It depends on your climate, the size of your house, and the cost of energy to heat your home. Table 2 can help you compute what the savings would be if a heat exchanger were run 24 hours a day from October through April.

To calculate the overall "net" savings of the heat exchanger, the savings given in Table 2 must be adjusted by subtracting the cost of the electricity to run the unit (Table 3). That is:

Net savings = Unadjusted savings (Table 2) - energy cost (Table 3)

If energy prices increase in the future, the amount of money saved by having a heat exchanger will become greater every year.

Aside from the economic benefits of having a heat exchanger, keep in mind that a heat exchanger allows a finer, more automatic control of ventilation than windows or most exhaust fans. Certainly, the health benefits from providing a constant flow of fresh air into a home are difficult to measure and impossible to express in dollars and cents.

Table 2. Savings from operating an air-to-air heat exchanger to provide 0.5 ACH, October through April for a 1500 square foot home with eight foot ceilings and kept at 68°F. Select the city which has the climate most similar to your own. To obtain values for homes of other sizes multiply savings by correction factor (CF): 1000 sq. ft., CF=0.67; 2000 sq. ft., CF=1.33; 2500 sq. ft., CF=1.67.

	HEATING FUEL COST					
	.57	.86	1.15	1.43	1.71	- Oil ($/gallon)*
	.41	.62	.82	1.03	1.23	- N. Gas ($/therm)*
Location	2	3	4	5	6	- Electricity (¢/KWH)**
Ellensburg	$67	$101	$124	$168	$202	
Olympia	50	75	100	125	150	
Port Angeles	49	74	99	124	149	
Seattle	44	65	87	109	131	
Spokane	69	103	137	172	206	
Walla Walla	51	77	102	128	153	

* Assumes a furnace efficiency of 70%
** Electric resistance heating only; heat pumps excluded

Table 3. Annual cost of operating heat exchanger for September-March period (24 hours a day; 213 days)

	COST OF ELECTRICITY (¢/KWH)				
Power (Watts)	2	3	4	5	6
25	$ 2.56	$ 3.83	$ 5.11	$ 6.39	$ 7.67
50	5.11	7.67	10.22	12.78	15.34
100	10.22	15.34	20.45	25.56	30.67
200	20.45	30.67	40.90	51.12	61.34

SUGGESTED READING

- Shurcliffe, William A. Air to Air Heat Exchangers. Brick House Publishing. 1982.

  The most complete work to date on how various styles of equipment work, though one of the earliest. Goes into the physics.

- Corbett, Robert J. and Miller, Barbara. Heat Recovery Ventilation for Housing. NCAT. 1984.

  Shorter than Shurcliffe's work, not as technical, but still very good.

MAGAZINES

- "Air-to-Air Heat Exchangers for Houses", Solar Age. March, 1982.

  Good basics by Shurcliff - includes chart - may be a little dated.

- "Fresh Air Without Frostbite", Rodale's New Shelter. January, 1983.

  Interesting findings on actual air flow rates and efficiencies of the few units they tested.

- "Economics of Air to Air Heat Exchangers", Solar Age. March, 1984.

- "Tips and Cautions About Air Exchangers", Solar Age. October, 1984.

  Richard Karg also has written an entire installation manual. This article covers some of the more important lessons learned.

This factsheet was written by David Schaub and Chuck Eberdt. Illustrations provided by Steve Tracy.