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Air-to-Air Heat Exchangers

For Healthier Energy-efficient Homes

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To reduce heating and cooling costs, builders have used better construction techniques and materials to greatly reduce air leaks into and out of a home.

While a "tight" home will reduce the costs of heating and cooling, it also will trap water vapor and harmful particles in the home.

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Window condensation and other moisture problems are likely in a weatherized home without air exchangers. This is a problem for both people and the home structure. Bringing in outside air and exhausting indoor air (ventilation) dilutes or removes the indoor pollutants and moisture. The question is: How do you remove the moisture and pollutants while retaining the heated or cooled air? An air-to-air heat exchanger will solve that problem. Air exchangers transfer the thermal energy of the indoor air to incoming fresh air, allowing the moisture and pollutants to be vented but retaining the heat. This publication describes reasons to use air-to-air heat exchangers, technology of exchangers, the cost advantages of installing them and some tips on choosing a heat exchanger that is right for your home.

Why is ventilation a concern?

In days past, energy was cheaper than insulation and builders used less care in insulating a home. As time progressed and energy prices increased, homeowners began to reduce costs by insulating attics, walls and basements, which stopped large-scale heat transfer.

Recently, due to high energy costs and better materials, homeowners and builders are stopping the small air leaks around doors, windows, plumbing and even light switch plates. In some homes, this natural air infiltration now replaces inside air every four to 10 hours, compared with every 30 minutes 40 years ago. Unfortunately, this reduction of outside air entering the structure can lead to problems with indoor air quality. Two of the most common quality issues are excess humidity and pollutants.

Relative humidity is the ratio of the amount of water vapor in air compared with the maximum amount of water vapor the air may hold at a particular temperature. Dew point is the temperature at which the relative humidity is 100 percent and condensation forms.

Warm air has the capacity to hold more water vapor than cold air. On a warm summer day, the temperature may be 85 degrees Fahrenheit (°F), with a 50 percent relative humidity level, making the dew point 71 °F.

As the air cools, the temperature gets closer to the dew point, or the point where the water vapor begins to settle out of the air. For example, as the 85 °F air cools, the relative humidity increases, and at 70 °F, condensation forms on cool surfaces. Air at 70 °F and 40 percent relative humidity has a relative humidity of about 80 percent when cooled to 50 °F. Air at 20 °F and 90 percent relative humidity has a relative humidity of 23 percent when heated to 60 °F. Roughly, a 20 °F drop in temperature cuts the water-holding capacity in half and doubles the relative humidity.

In tight homes, human activities such as showers, drying clothes and cooking raise the relative humidity to problematic levels, leading to condensation on windows and high humidity that may lead to mold growth. The recommended relative humidity for people is around 50 percent to minimize nosebleeds, dry skin and other physical ailments. Northern climates cannot support this level of humidity during the winter. When warm, moist air comes in contact with cool surfaces, moisture condenses on the surface if it is below the dew point.

Just as water condenses on a glass of ice water, condensation will form on cold surfaces in a home. This can happen on windows, doors, floors and even inside walls. Sustained wet conditions may cause structural damage and associated problems with rot and mold. An ideal humidity for the northern Plains in the winter is 30 percent to 40 percent, a compromise between ideal conditions for human beings and the structures they inhabit.

Measuring in Home Humidity

Use a hygrometer (Figure 1), or relative humidity meter, to check a structure for relative humidity. Hygrometers can have either a dial or a digital readout. Digital hygrometers

Figure 1. Examples of relative humidity meters, also known as hygrometers.

(Photo by Carl Pedersen)

are not always more accurate. Models are commercially available that are more expensive and generally should have a higher degree of accuracy. The more expensive hygrometers generally are accurate within 5 percent of the actual relative humidity. All hygrometers require calibration to increase their level of accuracy. When purchasing a hygrometer, check the operating range because electronic hygrometers may have a minimum relative humidity level they can read, for example 20 percent.

To calibrate a hygrometer, obtain an airtight container at least three times the size of the hygrometer. Examples include a plastic bag with a zip-type seal, a food storage container with a tight-fitting lid or a coffee can with the original lid. Place a cup with water in the sealed container along with the meter for four to six hours or until water droplets are visible on the inner surface of the container. When the droplets begin to accumulate on the edge of the sealed container, this indicates a relative humidity level of 100 percent.

The reading on the hygrometer should be at least 95 percent and preferably 100 percent, Figure 2. Take note of the reading.

Now add table salt to the cup of water while stirring until the water cannot dissolve any more salt. Salt should be sitting on the bottom of the cup. Then place the cup back in the sealed container with the meter and let them sit again for two to three hours. The salt reduces the ability of the water to evaporate and, therefore, the humidity level. A salt solution should generate a humidity reading of 75 percent, but readings from 70 percent to 80 percent are acceptable, Figure 3.

Compare the two readings. If they are both different by the same amount, you can recalibrate your hygrometer by that amount. Check the owners manual for specific instructions for calibrating your unit. If your unit does not have the ability to be calibrated, then you can adjust the readings mentally.

Pollutants in Homes

Different pollutants exist in different levels in different homes. Examples include carbon dioxide and monoxide from gas-fueled appliances, radon gas from the soil surrounding foundations, formaldehyde from building materials and particulates such as mold and tobacco smoke. Table 1 (page 4) lists some major sources of indoor and outdoor pollutants. Some of the more common pollutants deserve discussion on their creation and possible human health concerns.

Carbon dioxide and carbon monoxide, resulting from combustion of fuel, can pose serious health problems. Older appliances usually generate the highest levels of carbon monoxide due to improper combustion, leaks and lack of enough fresh air for complete combustion. While carbon dioxide only causes problems at high levels, its presence usually indicates carbon monoxide is also present. High carbon dioxide levels cause drowsiness and

Figure 2. Calibration test, 100 percent humidity.

(Photo by Carl Pedersen)

Figure 3. Salt solution calibration test, 75 percent humidity.

(Photo by Carl Pedersen)

Pollutant Type

SO_2	Sulfur dioxide
N0	Nitrous oxide
NO_2	Nitrous dioxide
O_3	Ozone
CO	Carbon monoxide
CO_2	Carbon dioxide
NH_3	Ammonia
HCN	Hydrogen cyanide

Table 1. Common sources and types of pollutants.

Outdoor sources	**Pollutant Types***
Ambient air	SO_2, NO, NO_2, O_3 Hydrocarbons, CO, particulates and lead compounds
Motor vehicles	Exhaust pollutants including CO

Indoor Sources	**Pollutant Types***
Building Construction Materials	
Soil	Radon
Particle board	Formaldehyde
Insulation	Formaldehyde, fiberglass
Fire retardant	Asbestos, volatile organic compounds (VOC)
Adhesives	Organics
Paint	Mercury, organics
Building Contents	
Heating and cooking	CO, SO_2, NO, NO_2, particulates
Furnishings	Organics, odors
Water service	Radon
Human Occupants	
Metabolic activity	CO_2, NH_3, organics, odors, viruses
Human Activities	
Tobacco smoke	CO, NO_2, HCN, organics, odors
Aerosol devices	Fluorocarbons, vinyl chloride
Cleaning and cooking products	Hydrocarbons, odors, NH_3
Hobbies and crafts	Organics

indicate poor ventilation. Carbon monoxide causes headaches and fatigue at low levels and may cause unconsciousness or death at high levels. Ensuring an outside air supply for any combustion appliance and regular air exchanges alleviate the problems.

Radon enters a structure through access holes for piping, floor cracks and other openings to the soil and results from the decay of naturally occurring radioactive materials in the soil. Radon has the potential to cause lung cancer at high levels. Ventilating crawl spaces and basements with fresh air may reduce the problem, but the preferred method is to vent the gravel layer below the basement floor (Figure 4). A radon test should be conducted to determine the radon level.

Other household airborne hazards are a result of construction materials and cleaners. Formaldehyde, a common industrial chemical, is present in many building materials and household furnishings. The formaldehyde gas can leave materials and enter the environment throughout the lifetime of the material, but most of the gas leaves within the first year. Formaldehyde causes irritation in mucous membranes in the nose, throat and eyes. It needs to be vented to the outside. Formaldehyde use is restricted in construction materials today.

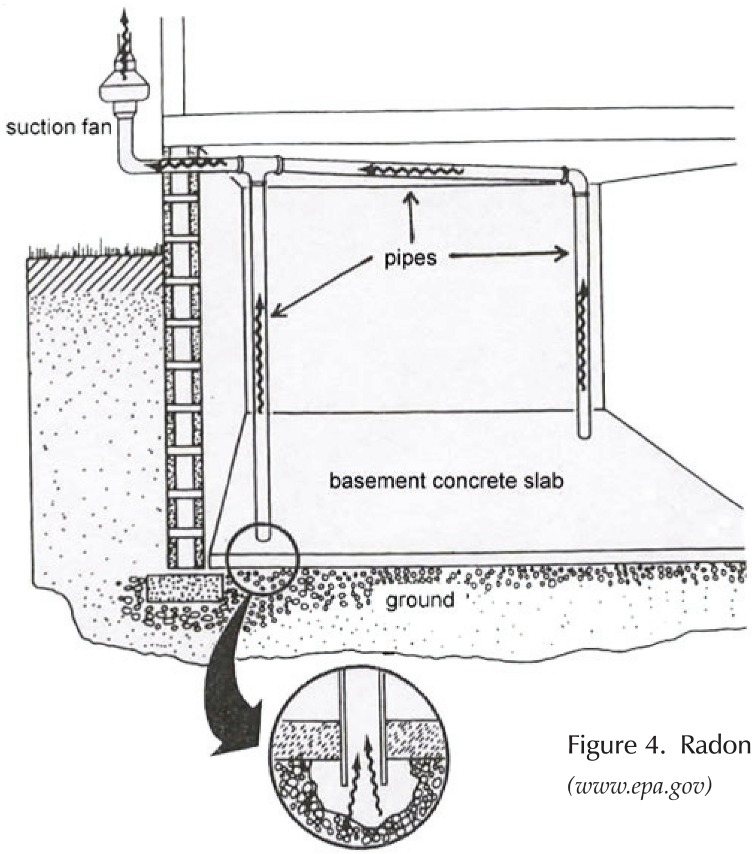


Figure 4. Radon venting.

(www.epa.gov)

Particulates include larger airborne items such as the mold spores and tobacco smoke mentioned earlier. It also includes viral and bacterial organisms, pet dander, dust and many other things. Due to a large variety of items, physical ailments vary from colds to allergies to lung disease. Some particulates may be filtered out, but others can be vented only to the outside.

Air-to-Air Exchanger Operation and Construction

One way to minimize air quality and moisture problems in a home, without opening a window, is by the installation of a mechanical ventilation system using an air-to-air heat exchanger. An air-to-air heat exchanger brings two air streams of different temperatures into thermal contact, transferring heat from the exhausting inside air to incoming outside air during the heating season. A representative heat exchanger is shown in Figure 5.

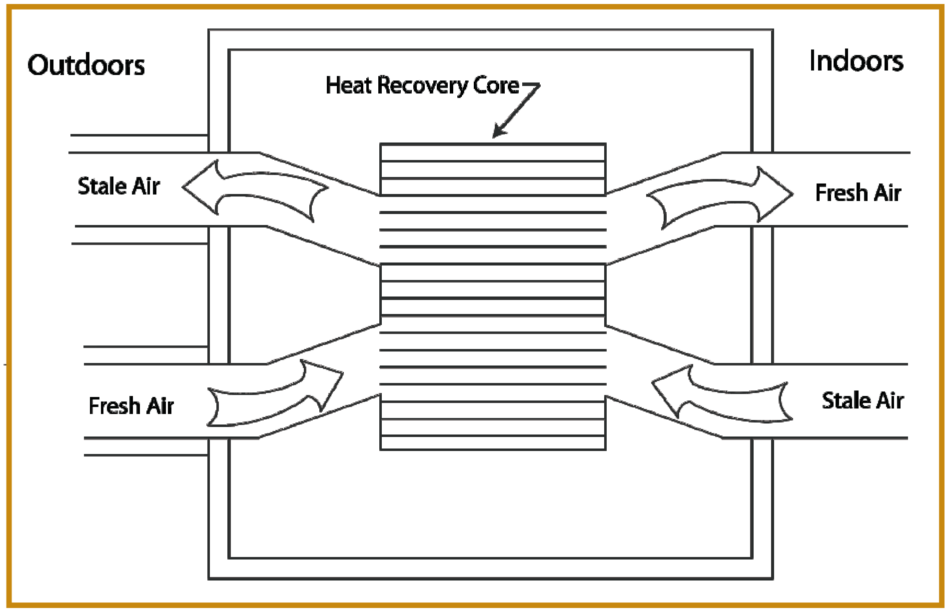


Figure 5. Typical features of an air-to-air heat exchanger.

In summer, the heat exchanger can cool and, in some cases, dehumidify the hot outside air passing through it and into the house for ventilation. The air-to-air heat exchanger removes the excess humidity and flushes out odors and pollutants generated indoors.

Heat exchangers generally are classified by the way the air moves through the unit. In a counter-flow exchanger, hot and cold air streams flow parallel in opposite directions. In a cross-flow unit, the air streams flow perpendicular to each other. An axial flow unit uses a large wheel. The air warms one side of the wheel, which transfers heat to the cold air stream as it slowly turns. A heat pipe unit uses refrigerant to transfer the heat. Other units are available for specialized applications. Small structures, such as houses, generally use counter-flow or cross-flow exchangers.

The majority of air-to-air exchangers installed in northern climates are heat recovery ventilators (HRVs). These units recover heat from exhausted air and return it to the building. Recent advances in technology have increased the use of energy recovery ventilators (ERVs) as well. In the past, ERVs mainly were used in climates with higher humidity that have a heavier cooling than heating load.

The main difference between the two is that HRVs only recover heat, while an ERV will recover heat and humidity. ERVs have had problems with lower efficiencies due to oversaturation of internal desiccant wheels during longer periods of high humidity, but with proper installation and maintenance, they can create a healthier living space and greater energy savings. In addition, the majority of ERVs being sold today are plate-type ERVs that do not contain a desiccant wheel. Consult with a heating/cooling contractor to determine if an HRV or ERV would be most beneficial in your circumstance.

The general design of an air-to-air heat exchanger uses a series of plates, called a core, stacked vertically or horizontally. An ideal plate has high thermal conductivity, high resistance to corrosion, an ability to absorb noises, low cost and low weight. Common plate materials include aluminum, different types of plastic sheets and advanced composites.

Originally, heat exchangers used aluminum plates. Problems occurred with corrosion in the damp environment, created by condensation, and poor sound characteristics. Plastics solved the corrosion and some sound problems, but the conductivity did not equal that of the aluminum and the cost was higher. Current high-technology heat exchangers use composite materials meeting all the criteria.

In addition to the core, the unit consists of an insulated container, defrost controls to prevent moisture freezing on the core and fans to move the air. All heat exchangers need insulation to increase efficiency and reduce condensation formation on the outside of the unit. Different types of defrost mechanisms with sensors within the unit are available to control the defrost process. Fans move air to provide the necessary airflow and ventilation rate.

Counter-flow heat exchangers consist of a core of flat plates. As Figure 6 shows, air enters either end of the exchanger. Heat transfers through the plates to the cooler air. The longer the air runs in the unit, the greater the heat exchange. The percentage of heat recovery is the efficiency of the unit. Efficiencies usually range around 80 percent. Generally, these units are long, shallow and rectangular, with ducts at either of the long ends.

Cross-flow heat exchangers also use flat plates, but the air flows at right angles (Figure 7). The units have a smaller footprint and may even fit in a window, but lose some of the counter-flow efficiency. Efficiencies typically do not exceed 75 percent. These units are often cube-shaped with all connections on one face of the cube. The vast majority of heat exchangers used in residential applications use the cross-flow design.

Choose the model that would best fit your particular needs. Characteristics such as space available for installation, exchange rate needed and the desired efficiency should be considered. Unfortunately, nearly every manufacturer has different ways of reporting these numbers. For example, ventilation rates depend on the resistance to airflow. A fan with an airflow rate of 150 cubic feet per minute (cfm) actually may produce this flow only at very low pressures. Likewise, a unit may have a stated efficiency of 85 percent, but may not be better than a unit with an 80 percent efficiency, depending on the test temperature.

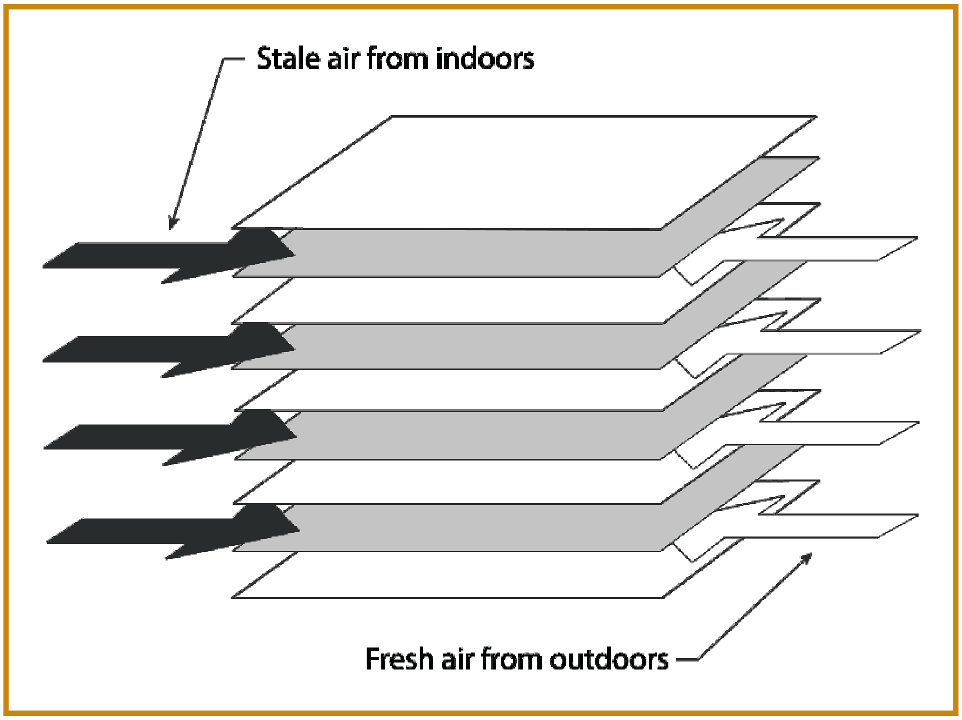


Figure 6. Counter-heat exchanger: The airstreams flow in opposite directions.

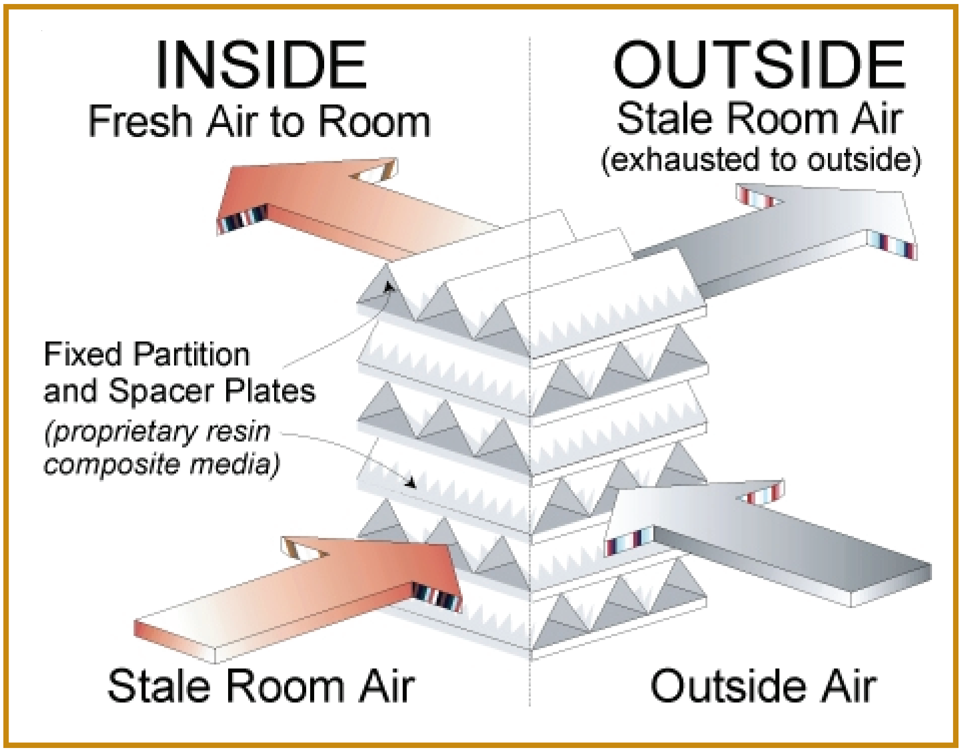


Figure 7. Cross-flow heat exchanger: The airstreams flow at right angles to each other.

(RenewAire Ventilation)

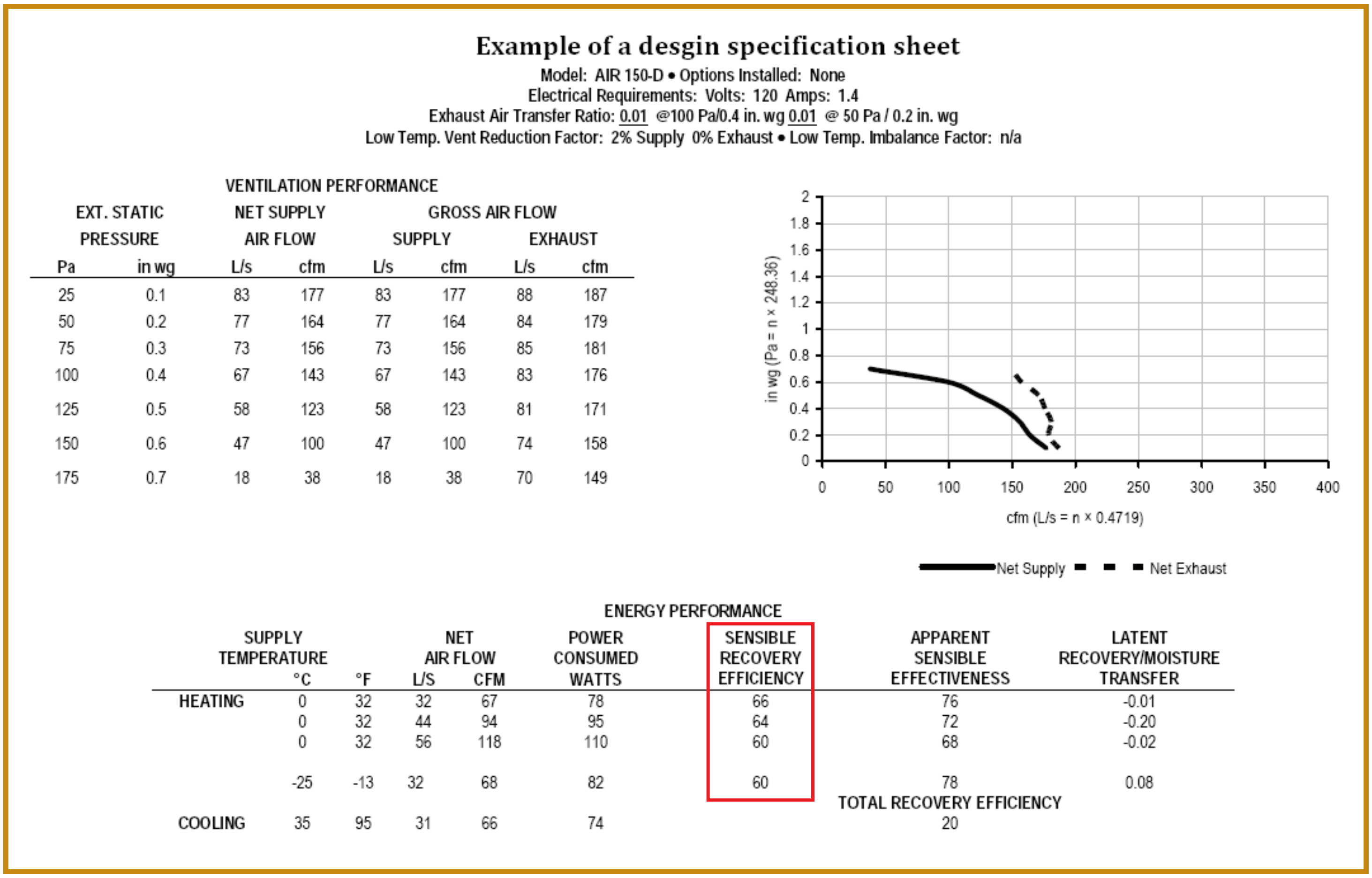
To standardize manufactures' efficiency claims, the Home Ventilating Institute (HVI) tests air-to-air heat exchangers and other ventilation equipment. The tests are used to generate an air-to-air heat exchanger specification sheet. This sheet, shown in Figure 8, normalizes exchangers to a given set of pressures and temperatures, enabling efficiencies and airflow rates to be compared across models. The ventilation performance numbers relate the airflow rates to a given pressure, while the energy performance relates a set of given outdoor temperatures to different types of efficiencies.

The most important efficiency is the sensible recovery efficiency since most heat exchange occurs during this type of process. The sensible recovery efficiency provides unit efficiencies at specific airflow rates (cfm) and temperatures. These numbers can be compared from one unit to the other to enable proper comparisons at similar airflow rates.

Cost

An inexpensive heat exchanger may cost as little as $500 to purchase. A top-of-the-line model may cost more than $2,000. While some of the more expensive heat exchangers have better efficiency, this is not always the case. Much of the increased cost occurs from consumer features such as easily cleaned cores, advanced defrost controls and sensors to turn the unit on and off. These features generally do not affect the overall efficiency, but may be beneficial for ease of operation.

Installation costs can be $500 and up, depending on the home size and the system's requirements. Installation can range from splicing into an original system to fully ducting the structure. A structure already using ducts for heating and/or cooling most likely already has the ducting to ensure all the air runs through the exchanger. Simply attaching the system to a supply end may be all that is required.



Example of a desgin specification sheet

Model: AIR 150-D • Options Installed: None
Electrical Requirements: Volts: 120 Amps: 1.4
Exhaust Air Transfer Ratio: 0.01 @100 Pa/0.4 in. wg 0.01 @ 50 Pa / 0.2 in. wg
Low Temp. Vent Reduction Factor: 2% Supply 0% Exhaust • Low Temp. Imbalance Factor: n/a

VENTILATION PERFORMANCE

EXT. STATIC PRESSURE		NET SUPPLY AIR FLOW		GROSS AIR FLOW SUPPLY		GROSS AIR FLOW EXHAUST	
Pa	in wg	L/s	cfm	L/s	cfm	L/s	cfm
25	0.1	83	177	83	177	88	187
50	0.2	77	164	77	164	84	179
75	0.3	73	156	73	156	85	181
100	0.4	67	143	67	143	83	176
125	0.5	58	123	58	123	81	171
150	0.6	47	100	47	100	74	158
175	0.7	18	38	18	38	70	149

ENERGY PERFORMANCE

	SUPPLY TEMPERATURE		NET AIR FLOW		POWER CONSUMED	SENSIBLE RECOVERY EFFICIENCY	APPARENT SENSIBLE EFFECTIVENESS	LATENT RECOVERY/MOISTURE TRANSFER
	°C	°F	L/S	CFM	WATTS			
HEATING	0	32	32	67	78	66	76	-0.01
	0	32	44	94	95	64	72	-0.20
	0	32	56	118	110	60	68	-0.02
	-25	-13	32	68	82	60	78	0.08
							TOTAL RECOVERY EFFICIENCY	
COOLING	35	95	31	66	74		20	

Figure 8. Heat recovery design specification sheet.

(Home Ventilating Institute)

Many homes have electric baseboard or hot water heating. Adding an air-to-air heat exchanger with these types of heating systems requires some thought. The most common mistake with do-it-yourself installations is failing to vent the entire home properly (Figure 9). The problem can be seen in the upper left of figure 9.

The airflow from the supply to the return duct never enters the majority of three rooms. Fresh air constantly circulates through part of the home, recycling that portion of the home without exchanging air in another portion of the home. Figure 10 shows a more complete ventilation system that serves the entire living space.

Air-to-air heat exchangers also may be installed in a number of different locations. Figure 11 shows an attic installation connecting to an extensive duct system drawing stale air from the kitchen, bathroom and utility room and distributing warmed outside air to the bedrooms and living rooms. Figure 12 shows a unit installed in the basement, again connected to a duct system.

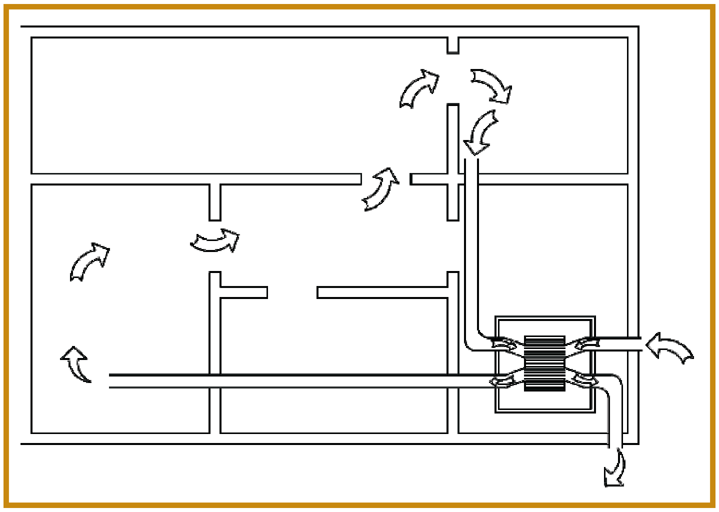


Figure 9.
A simple air-to-air heat exchange duct system will not vent the entire structure properly.

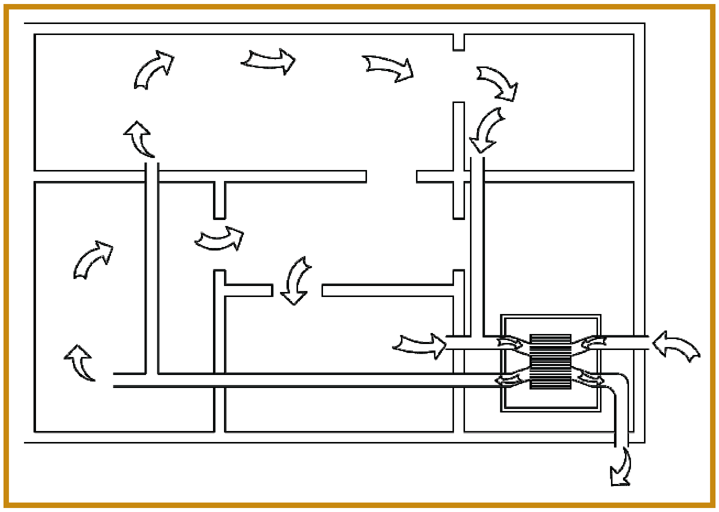


Figure 10.
Multiple supply and exhaust vents provide complete ventilation for the entire structure.

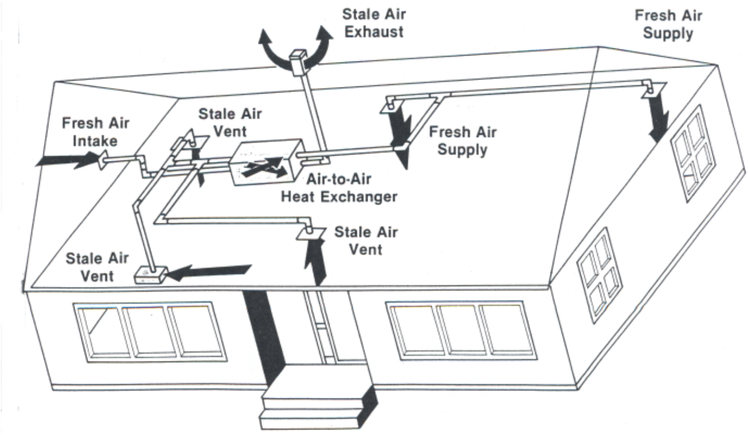


Figure 11. Attic installation of air exchanger.
(NDSU Extension Service)

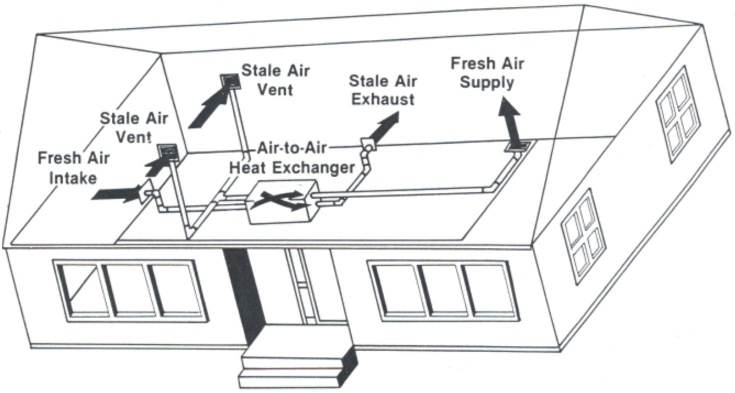


Figure 12. Basement installation of air exchanger.
(NDSU Extension Service)

Heat Exchanger Maintenance

To ensure the HRV is working properly, regular maintenance needs to be performed. The maintenance schedule will depend on the particular unit installed; refer to the owners manual for specific instructions.

Make sure the power to the unit is off before performing any maintenance. Begin with the filters. Clean or change the filters every one to three months, depending on the manufacturer's recommendations. Washable filters should be cleaned by following the manufacturer's recommendations.

When changing the filters, vacuum the area surrounding the filters. After cleaning the filters, check the outside air intakes to ensure nothing is blocking the screens and hoods.

Inspect the condensation pan and drain tubing. To be certain nothing is blocking the tubing, pour some water into the pan near the drain. If the water does not drain, the tubing will need to be cleaned.

At least once a year clean the heat exchanger core. Make sure to follow the instructions in the owners manual on the proper cleaning and maintenance of the core. Again, ensure the power is off before performing any maintenance. In addition to the core, the fans should be cleaned at least once a year. Wipe the blades clean and oil the motor only if recommended by the manufacturer.

An air-to-air heat exchanger recycles the heat from vented indoor air to heat the incoming fresh outside air needed to keep the building occupants healthy. Dangerous levels of pollutants, such as chemicals, particulates, radon and even excess water vapor that could cause structural damage and health problems, are removed. Different types of heat exchangers exist to meet the many conditions needed by homeowners, whether imposed by installation, environmental or energy considerations.

With the tighter homes built today, excess humidity leading to window condensation and other moisture problems are likely without a heat exchanger. The heat exchangers provide a direct, quick return on the investment and the peace of mind that fresh air is available to breathe at all times.

Figure 13-A. Typical installation of a heat exchanger.

(Photo courtesy of Shirley Neimayer, University of Nebraska - Lincoln).

Figure 13-B. Filters in a heat exchanger.

(Photos courtesy of Shirley Neimayer, University of Nebraska - Lincoln).

Cost Effectiveness of Heat Exchangers

A simple payback method, where the energy savings pay for the purchase and installation in a calculated time frame, shows the cost-effectiveness of adding a system.

As a guide, the following set of equations shows the cost-effectiveness of an air-to-air heat exchanger installed in a home with low infiltration levels in Fargo, N.D. For the sample calculation, the following conditions exist:

- **Floor area**: 1,500 square feet (ft^2)
- **Number of bedrooms**: 3
- **Infiltration rate**: 0.1 air exchanges per hour (ACH) or 10 hours for a complete air exchange
- **Fuel oil cost per gallon** $3.80
- **Electricity cost per kilowatt-hour (kwh)**: $0.10

Standard recommended ventilation rates have been set by the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE Standard 62.2-2007). These standards do not take into account special circumstances such as specific sensitivities or hobbies that create air quality issues. Standards vary according to the building, its use and the number of occupants (ASHRAE Standard 62.2-2007).

The benefits include moisture removal, decreasing the potential of structural damage, elimination of harmful pollutants and reduced energy costs. Any system installed also will increase the resale value of a building.

■ For a private home, the number of bedrooms determines the typical number of occupants.

In the example, a three-bedroom home has an occupant level of four, or the number of bedrooms plus one. To determine the ventilation airflow rate, the following formula is used:

Recommended ventilation rate = (0.01 x floor area, square feet) + 7.5 (number of bedrooms + 1)

Ventilation rate of example = (0.01 x 1,500 sq. ft.) + 7.5 (3 bedrooms + 1) = 45 cubic feet per minute

The ventilation airflow rate often is expressed as cubic feet per minute or cfm.

■ The recommended ventilation rate is 45 cfm for this example home.

Using a heat exchanger to warm this air to the indoor temperature recovers heating costs associated with warming the cold air to room temperature. The exact amount of energy depends, of course, on the difference in temperature between outside and inside air.

■ A measure of this is a heating degree day (HDD).

Commonly, an HDD is calculated by taking the mean difference between 65 °F and the average daily temperature. The various weather agencies around the state have tables of normal HDDs for a given area. For this example, Fargo, N.D., with an HDD of 9,000 is used.

The equations for determining the amount of energy saved (Btu) in a year use the cfm, HDD, the efficiency rating of the heat exchanger (EF) and a constant for the specific heat and specific weight of air (25.92). The formula is as follows:

Heat saved each year (Btu) = cfm x HDD x EF x 25.92

Btu – British thermal units

Cfm – ventilation airflow rate in cubic feet per minute

HDD – heating degree day

EF – heat exchanger efficiency

25.92 – constant for specific heat and weight of air

Using 45 cfm and 9,000 HDD, the heat energy saved by a 70 percent efficient heat exchanger would be:

Heat energy saved = 45 x 9,000 x 0.70 x 25.92

Heat energy saved = 7,348,320 Btu per year

As mentioned earlier, the exchanger needs a defrost control to keep ice from forming. Defrosting is generally done using an electric resistant heater. This electric cost needs to be subtracted from the energy savings cost. The cost can be determined using the following formula:

Cost of defrosting = power consumed by defrost device x hours of operation x cost of electricity

Assuming a 70-watt (W) heater, 500 hours of operation per year at temperatures below freezing and $.10 per kwh, the electric cost to operate the defroster, after converting watts to kilowatts (kW), is:

Cost = 70W x 500 hours per year x 1kW/1,000W x $0.10/kwh = $3.50 per year

To analyze the fuel savings, the energy content of the fuel and the efficiency of the appliances using the fuel need to be known.

Determining Fuel Savings and Payback Period

To determine the money saved, the total heat energy divided by the Btu content and the efficiency of the furnace gives the gallons of fuel saved.

$$\text{Gallons per year} = \frac{\text{Heat Energy Saved per year}}{\text{BTU content/gallon x efficiency of fuel}}$$

Using fuel oil as an example, it has 140,000 Btu per gallon and the typical fuel oil furnace has an efficiency of 65 percent (.65). Using these numbers, we can determine the fuel saved each year.

$$\text{Gallons per year} = \frac{\text{7,348,320 BTU per year}}{\text{140,000 BTU per gallon x .65}} = \text{81 gallons per year}$$

Multiplying this by the cost of fuel oil and subtracting the defrost heat gives the total savings.

$$\text{Cost savings} = (\text{gallons x cost per gallon}) - \text{cost to defrost}$$

Using the values calculated previously and a cost of $3.80 per gallon of fuel oil, the savings each year would be:

Cost savings = (81 gallons per year x $3.80 per gallon) –
$3.50 cost of defrosting = $304.30 per year

Given purchase, installation and miscellaneous costs of $1,000, a simple payback method shows the number of years an air-to-air heat exchanger pays for itself in saved heating costs.

$$\text{Years to payback exchanger} = \frac{\text{Total cost to purchase and install unit}}{\text{Cost savings per year}}$$

$$\text{Years to payback exchanger} = \frac{\text{\$1,000 purchase and installation cost}}{\text{\$304.30 savings per year}} = \text{3.3 years}$$

Table 2 (at right) lists the energy content, in British thermal units (Btu) of several common heating fuels.

Table 2. Energy content for common household heating fuels and accepted efficiencies.

Fuel Type	Btu	Units Sold	Standard Efficiencies (%)
Fuel oil	140,000	gallon	50% to 80%
Electric resistance	3,413	Kilowatt-hour	100%
Natural gas	100,000	CCF	75% to 96%
LP gas	95,000	gallon	75% to 97%

For more information about energy from the NDSU Extension Service:

www.ndsu.edu/energy

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