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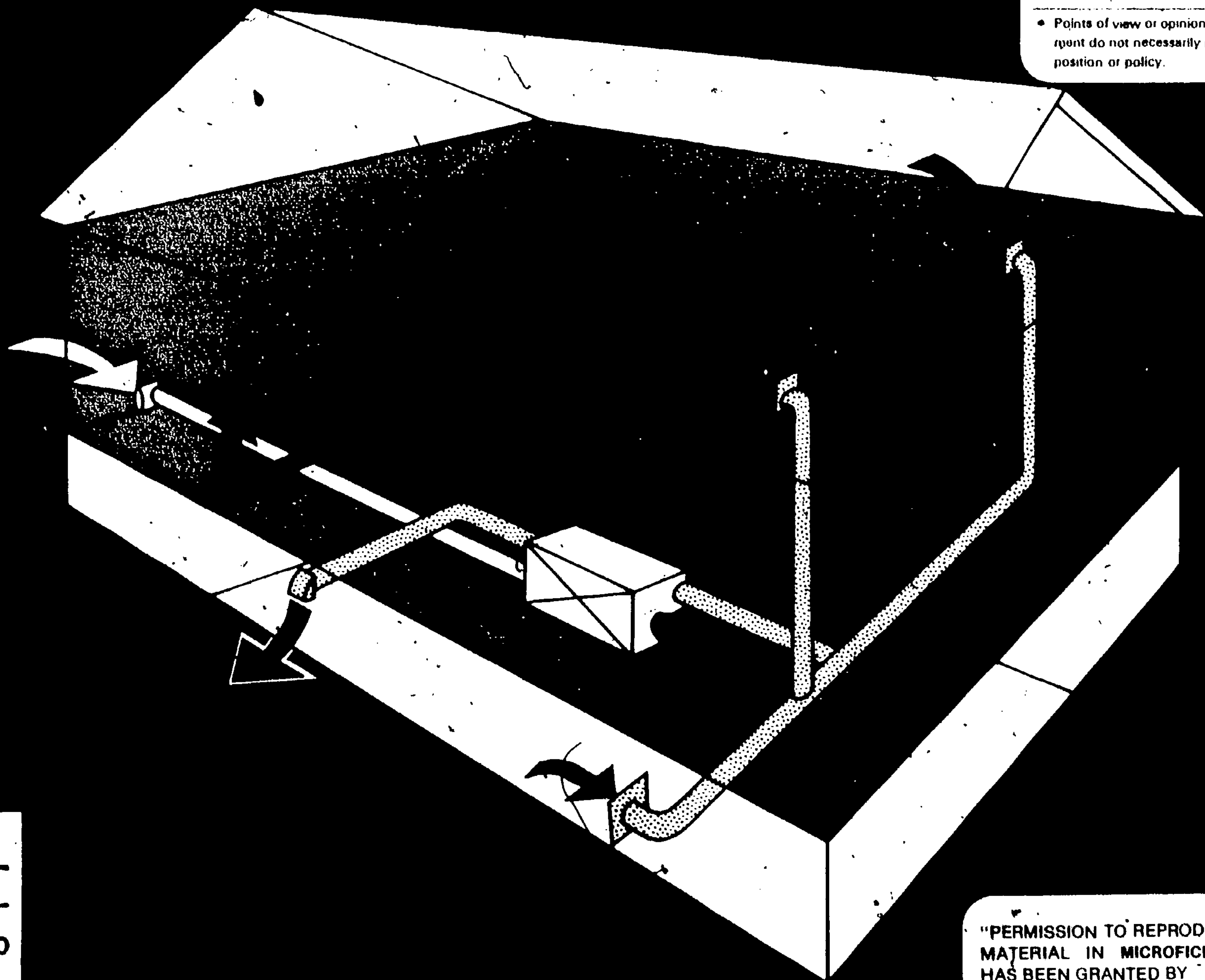
ABSTRACT

The air-to-air heat exchanger (a fan powered ventilation device that recovers heat from stale outgoing air) is explained in this six-part publication. Topic areas addressed are: (1) the nature of air-to-air heat exchangers and how they work; (2) choosing and sizing the system; (3) installation, control, and maintenance of the system; (4) heat exchange controls; (5) cost effectiveness factors; and (6) state of the art assessment of heat recovery technology. Appendices contain a discussion of current ventilation standards and lists of suppliers, suggested readings, and selected Department of Energy Appropriate Technology Small Grants Program awards under these headings: agricultural use of air-to-air heat exchangers, residential applications for air-to-air heat exchangers, residential use of heat recovery, and commerical use of heat recovery. (ML)

AIR-TO-AIR HEAT EXCHANGERS



HEAT RECOVERY VENTILATION FOR HOUSING: AIR-TO-AIR HEAT EXCHANGERS

Prepared for:
U.S. Department of Energy
Assistant Secretary,
Conservation and Renewable Energy
Small Scale Technology Branch
Appropriate Technology Program
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PREFACE

From 1978 to 1981, the U.S. Department of Energy (DOE) awarded more than 2,000 small grants to individuals, organizations and small businesses across the nation to research and demonstrate appropriate technologies. Grants were given in the general areas of conservation, solar, biomass, wind, geothermal and hydro power.

This booklet is part of a series of publications that focuses on appropriate technologies and their application in the home and the work place. These publications combine a qualitative assessment of the results of grant projects with current research for the particular technology highlighted in this document. In Appendix A, at the back of this publication, is a list of pertinent projects reviewed in preparation of this document.

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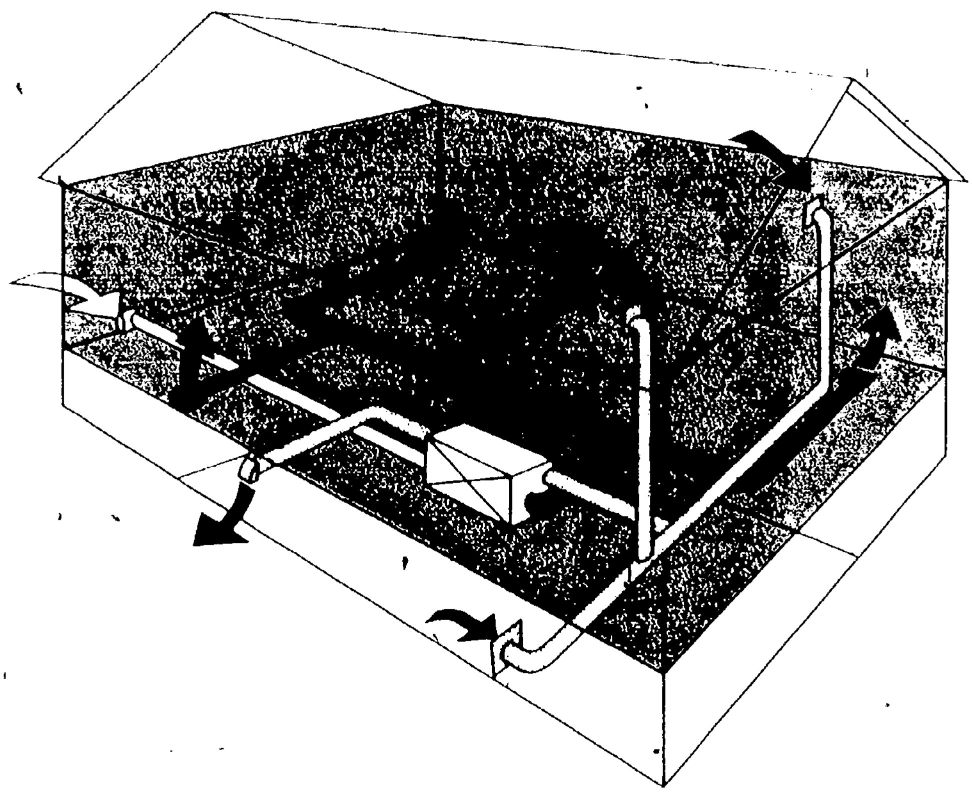

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CONTENTS

INTRODUCTION

Americans have made substantial progress in learning how to reduce residential energy consumption. In particular, well-insulated, virtually airtight houses are being built that cut heating costs to a tiny fraction of those of conventionally built houses. But, these changes in building technology have highlighted concerns about proper ventilation. A growing body of evidence is showing that specific ventilation strategies are essential in energy-efficient houses to handle a wide range of potential indoor air contaminants.

At present, one of the best available solutions to the conflict between ventilation and energy costs in this type of housing is the air-to-air heat exchanger, a fan-powered ventilation device that recovers heat from stale, outgoing air.

Air-to-air heat exchangers were researched and developed in the U.S. Department of Energy's Appropriate Technology Small Grants Program, 1978–1981. This publication will examine the results of this work as well as provide information for builders, architects and skilled owner-builders on the basics of using air-to-air heat exchangers in residential settings, including:

- how heat exchangers work;
- why they are needed and when they are appropriate;
- how to choose an adequate ventilation rate and a machine that fits the purpose;
- how to install, control and maintain the machine;
- assessing the state-of-the-art in this technology; and
- information on suppliers, ventilation standards and where to go for further information on heat exchangers.

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Overview: Heat Recovery Ventilation

In their search for ways to reduce home heating costs, several grantees turned to recapturing individual sources of "waste" heat in the home, such as clothes dryers, hot attics, refrigerators and other appliances (see Appendix A). While some of this work holds promise and may be of interest to appliance manufacturers, most residential waste heat recovery options are not yet commercialized, and some of these technologies have significant hurdles to overcome.

For example, one grantee developed a device to recover waste heat from clothes dryers and retrofitted 52 conventionally constructed houses in the community with this device. Some heat was recovered, but nearly half the participants in the project reported excess humidity. It is clear that more research is needed to develop a way to recover waste heat from clothes dryers that doesn't pollute indoor air with excess moisture, lint and the products of laundry additives.

This publication focuses primarily on the work of grantees who took another route — heat recovery ventilation. Instead of trying to recover waste heat from individual appliances with separate technologies, the concept here is to build houses that are so energy efficient and lose so little heat that much of the heat from all indoor sources is retained, through substantial thermal improvements and the use of mechanical ventilation with heat recovery (see VENTILATION FOR SUPERINSULATION). At the current state of the art, it is more cost effective to improve the overall thermal efficiency of the house than it is to attempt to increase heat supply through recapturing heat from individual appliances. In effect, most of the "waste" heat in the house is conserved at once with a single technology.

Reviewing the grant project results reveals that while heat recovery ventilation is commonplace in large-scale applications, its use in residences, on the farm and in small businesses is just beginning. In 1978, when the first projects got un[illegible]way, residential heat recovery ventilation was a new, [illegible]mostly untried technology. Yet, several grantees [illegible]its potential, and attempted to develop [illegible] devices.

For instan[illegible] a builder in Illinois set about building superinsulated houses, using early research in this field as his guide. Realizing that excess moisture might be a problem in his tightly constructed house, the builder planned to use dehumidification, not ventilation, as his answer to this potential problem. In the midst of his project, he recognized that dehumidification and ventilation could be accomplished at the same time with an air-to-air heat exchanger. But, because he couldn't find such a device on the market, he attempted to build his own. This grantee's experience is not uncommon; many builders have "discovered" superinsulation, but they often know little about one of its major components—mechanical ventilation with heat recovery.

Yet, one grantee in Vermont, who was familiar with the promise and problems of superinsulated building techniques, did extensive testing and development work that resulted in the production of a commercially available air-to-air heat recovery device that is one of the most energy efficient available today. More than 20 firms currently produce residential air-to-air heat exchangers for the market in the United States, yet consumers and professionals need more guidance before they are able to easily use this technology.

The experiences of the DOE Appropriate Technology grantees provide insights into the promise of heat-recovery ventilation for residences and agriculture. In the emerging field of residential heat-recovery ventilation, the significant work done during these projects helps illustrate how and why air-to-air heat exchangers are fast becoming an essential feature in many new and retrofitted superinsulated houses.

Ventilation for Superinsulation

Adequate ventilation is critical for all types of housing, but the advent of superinsulation has brought the need for a discrete mechanical ventilation system into the spotlight.

While houses have generally been built tighter during the last decade, one of the major features of superinsulation is virtually airtight construction. This is accomplished with the careful installation of a continuous, unbroken air-vapor barrier to stop moisture and air movement through the building shell. Also recommended in this type of construction is the use of extremely tight windows and doors, and close attention to sealing all breaks and seams in the air-vapor barrier.

These techniques, combined with much more insulation than conventional houses use (often R-60 ceilings, R-40 walls and R-10 to R-20 under floors and around foundations in cold climates), make for space heating costs that have been shown to be as low as $100 annually or less in our coldest climates using small, conventional heating systems.

This low heat requirement is possible because as much as a third of the heat needed in the house is supplied by heat from appliances, lights and even body heat of the residents. In a conventionally built house, these internal heat gains are not a major heat source (Figure 1).

Secondly, standard-sized south-facing windows can make a significant contribution to heating this type of house without additional solar storage devices. Because heat losses have been reduced to such a low level, the house can retain adequate solar energy in the mass of the structure itself.

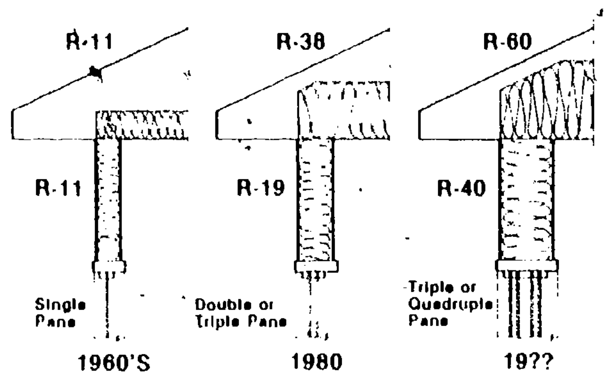
In the coldest weather, a small amount of auxiliary heat may be needed when solar gains are small or if little activity is happening in the house to produce internal heat gains. This heat load is typically so little that a minimal heating system, such as a small amount of electric heat or a small furnace (usually less than 25,000 Btuh capacity) is the natural complement to solar and internal gains. This often means that no central, forced air heating system is installed in this type of housing, because less expensive options are available.

Because the superinsulated house is so tightly built, proper ventilation must be a major focus of the design stage with this type of construction. In addition, possible indoor pollution sources should also be avoided and special attention must be given to properly isolating any combustion devices used in these houses.

Because the technology is new, and because most building professionals have rarely had to provide a special ventilation system for detached, single-family housing, ventilation and air quality concerns are frequently overlooked.

Mechanical ventilation with a properly sized and installed air-to-air heat exchanger is the major option for the ventilation system in superinsulated houses, because needed ventilation can be supplied without action on the occupants' part and at lower cost than with other strategies, such as opening windows or doors.

The evolution of insulation levels for residential buildings in cold climates.



NOTE: R value is the term used to define a material's ability to stop heat from passing through it. The higher the number, the greater the resistance to heat loss.)

A good design and careful construction are essential

Careful attention to details is crucial to the success of a superinsulated house. Its energy conserving performance depends on exact construction.

There are three key design elements that distinguish a superinsulated house:

1) High levels of insulation;
2) a continuous vapor barrier -- to ensure that the entire "envelope" is airtight, and
3) an air-to-air heat exchanger -- to keep indoor air fresh without losing heat.

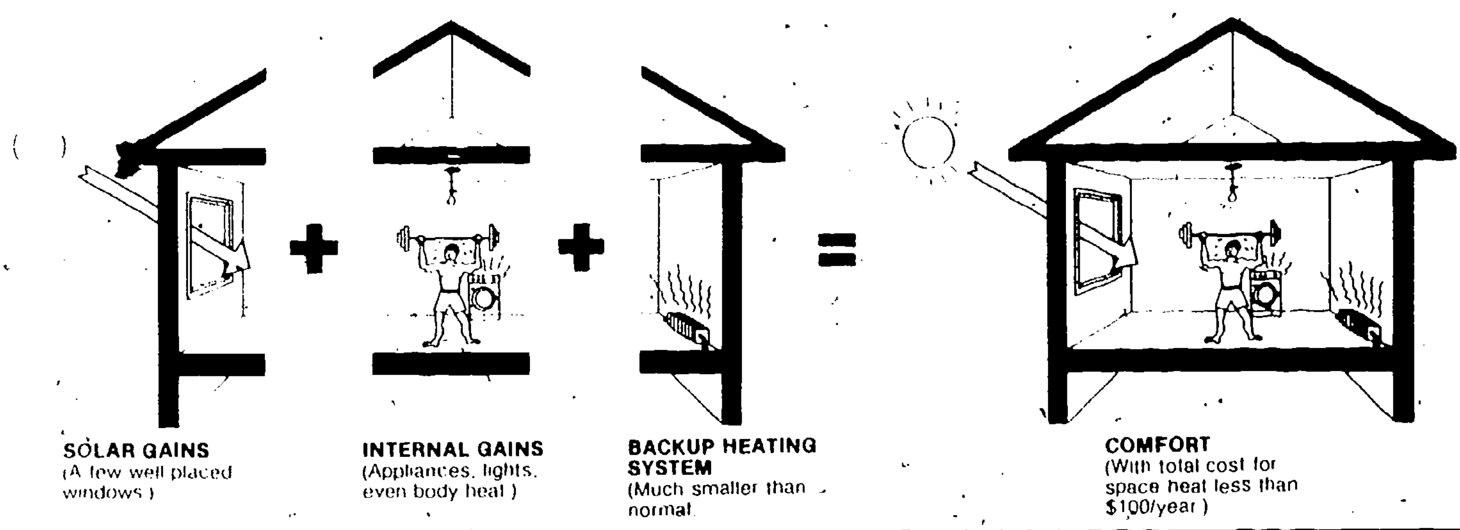


FIGURE 1: *Superinsulation is a fast-growing trend in northern climates. Solar gains, internal gains from lights, appliances and occupants, and a small back-up heating system result in comfort at greatly reduced operating costs.*

I. WHAT IS AN AIR-TO-AIR HEAT EXCHANGER AND HOW DOES IT WORK?

An air-to-air heat exchanger is a heat-recovery ventilation device that pulls stale, warm air from the house and transfers the heat in that air to the fresh, cold air being pulled into the house. Heat exchangers do not *produce* heat; they only *exchange* heat from one air stream to the other.

The heat transfers to the fresh air stream in the core of the heat exchanger, which is often made of thin sheets of plastic, treated paper or metal. In the type of machine featured in this publication, the core is designed to avoid mixing of the two air streams to ensure that most indoor pollutants are removed in the stale air stream. Moisture in the stale air condenses in the core and is drained from the machine (Figure 2).

Residential heat exchangers come in two basic types: small, through-the-wall units that are about the size of a room air conditioner and central, ducted whole-house models, many of which are about the size of a typical water heater.

Small, efficient fans power the two separated air streams, and research indicates that the most efficient residential heat exchangers on the market can recover as much as 70–80 percent of the heat in the stale air.

Although air-to-air heat exchangers are new to the residential market, they have been in use for many decades in large commercial, industrial and hospital applications. Residential air-to-air exchangers were first introduced in North America in the late 1970s, when Canadian researchers built a test house that was so tightly constructed that extra ventilation was needed. Those doing research with superinsulated houses soon focused on the air-to-air heat exchanger as one way to provide constant, reliable ventilation, thus avoiding potential indoor air quality and moisture problems.

Why are Air-to-Air Heat Exchangers Needed?

All houses need ventilation with outdoor air to provide a comfortable, healthy environment. This ventilation dilutes pollutants that are generated indoors (see SOURCES OF POLLUTION IN THE HOME).

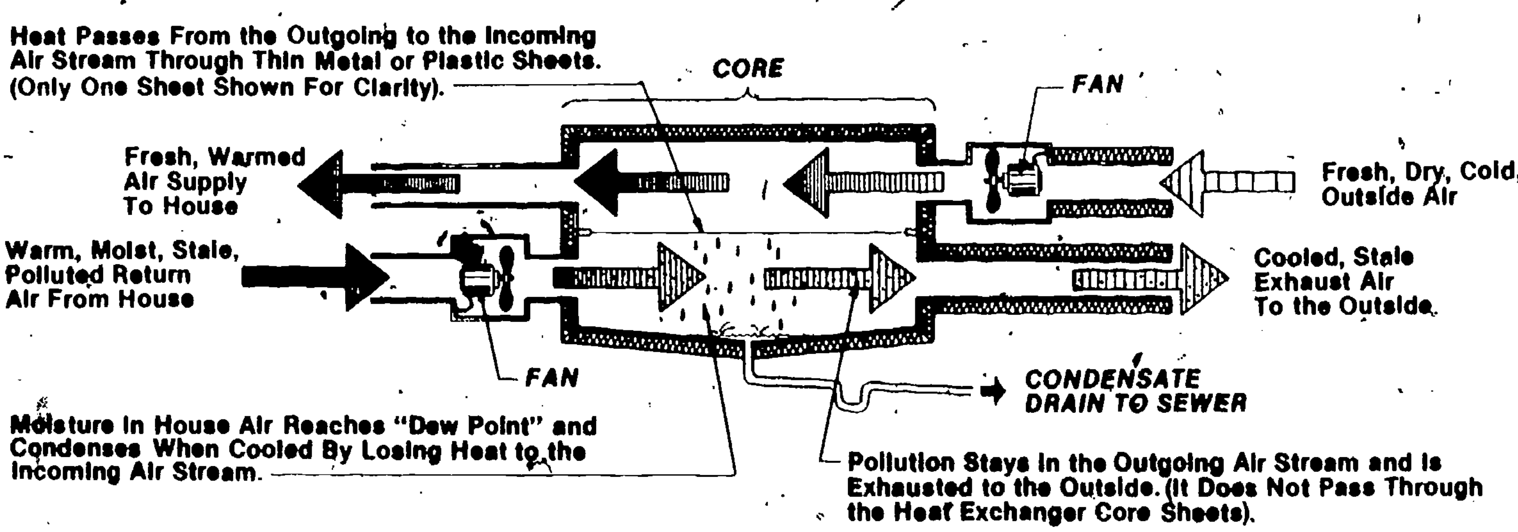
The air quality of a house depends on the number and severity of the pollution sources in the house, and how fast the pollutants are being removed, whether by exhaust fan or through air leaks. A tight house can have acceptable indoor air quality if no major pollution sources are in the house, and conversely a "leaky" house can have poor air quality if lots of sources are present.

Ventilation through air leaks, or infiltration and exfiltration, is extremely changeable. And, most experts agree that air leakage is not a reliable way to provide uniform or effective ventilation. This is because infiltration depends on many factors: the rate of air leakage depends on wind speed and direction, the type of heating plant, and on the temperature difference between the indoors and outdoors.

In addition, the location of the air leakage points around the house can affect the rate of infiltration. One cause of infiltration, the "stack effect," is driven by warm air pushing out through the upper regions of the house, thereby pulling cold air into the house from lower regions (Figure 3). Consequently, if most of the air leaks occur around the foundation, with few air leaks through the ceiling, infiltration would probably be less than if the house had air leaks both high and low.

Most conventional houses rely on ventilation from air leaks in the building's shell. Opening windows and doors is always an option, but the cost and discomfort of allowing air to rush into the house during cold weather often

FIGURE 2: *This simplified schematic diagram shows the essential components of an air-to-air heat exchanger.*



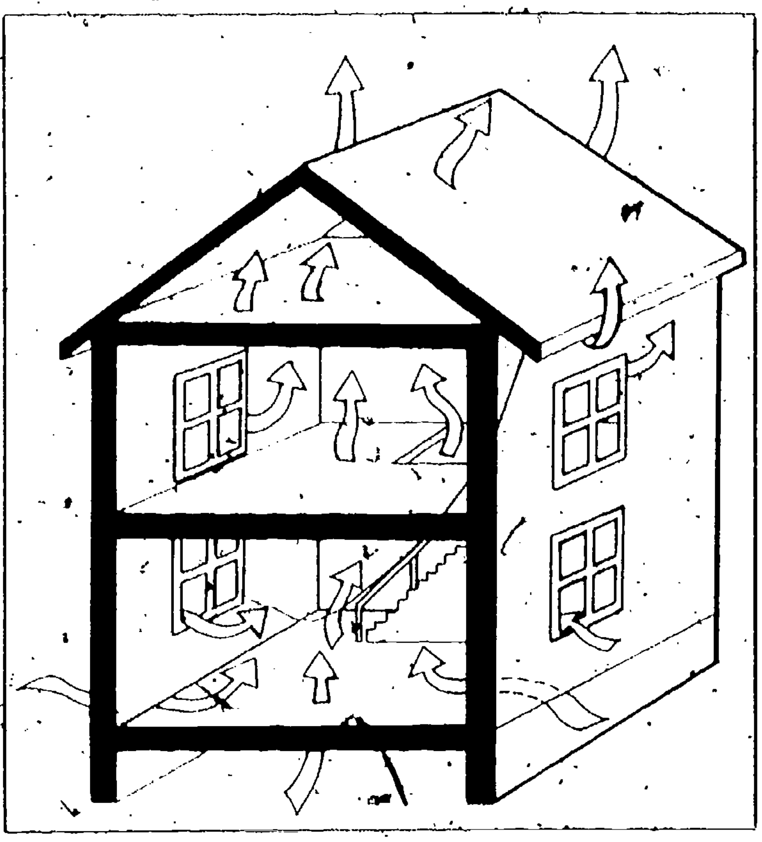


FIGURE 3: *The "stack effect" is one significant way in which conventionally built houses lose heated air through infiltration and exfiltration.*

leads most people to avoid naturally ventilating the house in this manner. Unfortunately, many people leave residential ventilation to chance; since most of us don't know the severity of pollution concentrations or the ventilation rate of our homes, we have no idea of whether ventilation is adequate when windows and doors are closed.

Air leakage is expressed in terms of "air changes per hour" (ach). One ach indicates that a volume of air equal to the whole volume of the house enters the house each hour. However, due to the uncontrolled nature of infiltration, one ach does not mean that the house will experience uniform or complete removal of contaminated air, nor that all the air in the house is completely replaced each hour.

Studies of air leakage rates indicate that most conventionally built houses have air leakage rates that span a range from a low of about .25 ach (one air change in four hours) to about 2 ach (two air changes each hour). At present, it is still difficult to easily characterize the probable air leakage rate of the "average" house, although some researchers have put it in the .5 ach to 1.5 ach range.

An important point to note here is that air leakage does not happen at a *constant* rate. It varies uncontrollably, depending on many factors. For example, a house with a measured air change rate of .5 ach during the winter may have negligible air change in the summer when temperature differences are small. Or, this house may have 1 ach during windy weather because of its location and the location of the air leaks. In other words, ventilation may be more than adequate (which carries an energy penalty) at some times, and inadequate at others. In addition, research has indicated that the rate of air leakage in various rooms in the same house can differ by as much as 10 to 1, meaning that some rooms may often have inadequate ventilation, while others are drafty and uncomfortable.

Some superinsulated houses in cold climates have been shown to have air change rates as low as .05 ach (one air change every 20 hours). These extremely tight houses need additional ventilation to make them safe for occupancy. The air-to-air heat exchanger can provide necessary ventilation at a constant, predictable rate, thus ensuring adequate ventilation with a smaller energy cost.

Can the Air-to-Air Heat Exchanger Handle Heavy Pollution Concentrations?

In low-infiltration housing, the air-to-air heat exchanger is used to replace ventilation that has traditionally come from air leakage. Manufacturers of whole-house heat exchangers have, in designing their machines, sized the machines to provide a certain amount of ventilation. This capacity relates to the size of the house. In a typical 1,200-square-foot house with no basement, a whole-house heat exchanger could provide up to about 1 ach over the house's natural air leakage rate.

Studies have shown, however, that to remove heavy pollution concentrations, significantly higher levels of ventilation could be needed. For example, to remove pollutants generated by an unvented gas cooking range, research has indicated that 7 ach (in the kitchen) would be needed to keep pollutants at a low level. A vented range hood can supply this ventilation by quickly withdrawing the polluted air before it can mix with the air in the rest of the house.

The air-to-air heat exchanger can do an excellent job of supplying ventilation often at a lower cost, and more reliably than ventilation through air leakage, but neither the exchanger or simple air leakage should be expected to handle heavy pollution sources by themselves.

When is an Air-to-Air Heat Exchanger Appropriate?

A mechanical ventilation system is an essential component in superinsulated houses. If a controlled ventilation system isn't installed in these tight houses, a number of problems can arise, including excess moisture that is often seen as water condensing on windows. In addition, occupants can find themselves suffering from burning, watery eyes, frequent headcolds and respiratory problems. These and other symptoms are sometimes reported by occupants in residences with inadequate ventilation.

The question here is one of providing needed ventilation. Heat recovery ventilation, such as that provided with an air-to-air heat exchanger, is one way to provide necessary ventilation without the energy penalty associated with simple mechanical ventilation without heat recovery.

There is little question that air-to-air heat exchangers can provide uniform, cost-effective ventilation in superinsulated houses. But, whether heat exchangers are the answer in more conventional housing is a matter of debate and a subject for further research.

Preliminary research in Sweden indicates that if the house isn't tight enough, air flows can be "short-circuited" by too many air leaks in the house. This short-circuiting can make for poor air distribution as well as lowered heat recovery efficiency. Other types of heat-recovery ventilation are being employed in these less-than-tight houses in Sweden, but these technologies are not yet available in the United States.

Until suitable heat-recovery ventilation strategies are available, known ventilation methods may be the best approach in conventional houses that need additional ventilation. Several manufacturers of forced air heating and cooling equipment have added the option of adding an outdoor air duct that is directly connected to the return air duct of the heating or cooling system. This duct has a manual damper than can be adjusted to provide more outdoor air for ventilation when it is needed. Other available ventilation options include opening windows and doors, spot ventilation with range hoods and vent fans that are ducted to the outdoors, and whole-house airing, either passively or with mechanical methods.

As one grantee in Arizona discovered, whole-house airing is an energy-efficient ventilation strategy that can reduce summer cooling costs as well as provide needed ventilation. When the house is aired at night—with a whole-house fan, night air cools the thermal mass of the house, reducing energy use for cooling during part of the day.

Some researchers note, however, that heat exchangers may be a cost effective way to solve difficult excess moisture problems in conventional housing. If the threat of moisture damage is significant, the heat exchanger may be able to quickly pay for itself in savings from avoided repair or maintenance costs.

In conventionally built houses that have been extensively tightened, known pollution sources should always be reduced, isolated or otherwise controlled at the time of the weatherization work. If moisture problems or health problems persist, the house could be tested to determine the air change rate. This can be accomplished with the use of a blower door, a device that energy conservation contractors and agencies use to pressurize the house and get an estimation of the air change rate. Remember that this rate isn't a constant and will vary with the weather and other factors. Infiltration rates are generally at their highest in the winter when temperature differences are the greatest.

7

AGRICULTURE MAKES APPROPRIATE USE OF AIR-TO-AIR HEAT EXCHANGERS

Reasons for using air-to-air heat exchangers in agriculture parallel those in the residential setting: air-to-air heat exchangers can result in better indoor air quality and reduced moisture levels in animal sheds and barns, leading to both increased livestock production and energy savings in cold climates.

But, unlike residential applications, the tightness of the agricultural building is not as critical in determining the cost-effectiveness of these devices. A more direct payback may come from improved health and longevity of the livestock because of cleaner, less humid air than from heat recovery, although heat recovery reduces the cost of this needed ventilation.

At least four grantees used air-to-air heat exchangers in agricultural settings, and agricultural applications are slowly gaining recognition and acceptance. Grantees used these devices to help dry corn and improve ventilation in animal housing.

But, like the experiences of some of those working in the residential sector, some of these grantees had difficulties using the machines, often due to a lack of information or professional advice. One grantee had problems with an incorrectly mounted machine, while another had difficulty choosing the right sized machine for his corn-drying application. A third found it difficult to find product information on appropriate machines for his project.

Despite these problems, the grantees all found promise in the technology. Heat recovery helped reduce corn drying energy costs by 20 percent, one grantee reported. A farmer using a heat exchanger in his hog farrowing house was impressed with the possibilities and plans to continue his experiments.

Another grantee in Vermont had considerable expertise with heat exchangers and built several successful prototype models for agriculture, one of which was field tested in a neighboring farmer's chicken house. The farmer was pleased with the results: the heat exchanger was credited with increasing chicken production by 10 percent and reducing heating costs.

SOURCES OF POLLUTION IN THE HOME

Recent research has shown that a surprisingly large number of pollutants can be found indoors, including:

MOISTURE: A typical family of four can produce a great deal of water vapor in the course of daily living, up to 4 gallons per day. High indoor relative humidity can cause significant building damage as well as health problems, such as respiratory troubles and diseases caused by microbial growth.

FORMALDEHYDE: Formaldehyde is most commonly used in glues used in the construction of interior particleboard, plywood and many carpets and home furnishings. Formaldehyde also is emitted from improperly installed urea-formaldehyde insulation. Formaldehyde can cause eye and respiratory irritation, and it has been implicated in other serious diseases.

INDOOR COMBUSTION POLLUTANTS: Indoor combustion, whether from a gas-fired cook stove or a fireplace, can generate a variety of pollutants, most commonly carbon monoxide and nitrogen oxides. Unvented combustion appliances are a particular problem, because all the products of combustion are directly emitted into the room air. The health dangers of high levels of carbon monoxide are well known, and low levels of carbon monoxide and nitrogen oxides may cause a number of health problems.

MISCELLANEOUS POLLUTANTS: Household products and hobby materials contain many potential indoor pollutants. Aerosols are common in most homes, and they can put an endless variety of toxic substances into the air.

HUMANS AND PETS: Humans and pets exhale a variety of bacterial and viral elements into the air. It has long been known that many diseases are transmitted through the air. Pets produce dander and fur, which can be a major problem for those with allergies.

TOBACCO SMOKE: Tobacco smoke is a well-known danger, yet one third of the adult population smokes tobacco in one form or another. Tobacco smoke contains more than 2,000 chemical compounds, and numerous studies have shown that smoke reaching non-smokers can pose a significant health hazard.

RADON: Radon is a naturally occurring radioactive gas that breaks down into compounds that may cause cancer when large quantities are inhaled over a long period of time. Unlike many indoor pollutants, radon levels can be monitored at an affordable cost. When radon levels are extremely high, simply increasing the ventilation won't greatly reduce the concentrations in many instances. Instead, the radon should be tackled at the source, a course that often requires professional assistance (Figure 4).

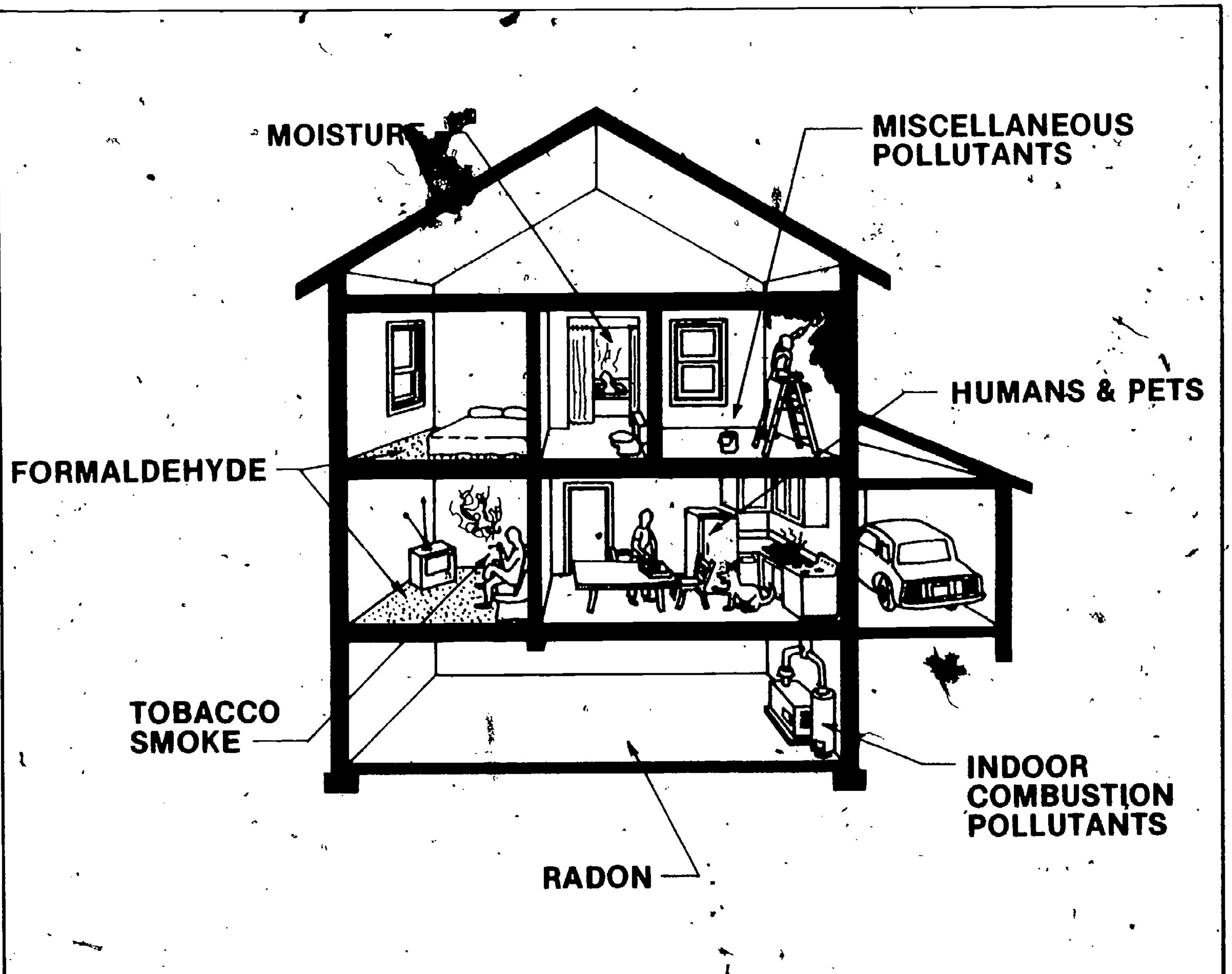


FIGURE 4: *Sources of indoor pollution exist in every home.*

II. CHOOSING AND SIZING THE SYSTEM

In this section, the features of available air-to-air heat exchangers are discussed, and information is presented on how to choose a machine and system that suits the purpose. This involves looking closely at the design and layout of the house, choosing the ventilation level, calculating the air volume of the house, and becoming familiar with available heat exchanger options.

A Central System or a Wall-mounted Unit?

The first air-to-air heat exchangers to gain popularity in the United States in the late 1970s were small, window- or wall-mounted units (Figure 5). However, as research progressed on the ventilation needs of the ultra-tight house, it became clear that small heat exchangers had several disadvantages when compared to a central, ducted whole-house model. Larger models for central use were, at this time, being developed by a number of manufacturers and by one grantee.

Research has indicated that a single wall-mounted heat exchanger won't provide adequate ventilation for a whole house. In general, small heat exchanger cores tend to be less efficient than larger cores. In addition, because the air intake and outflow are so close to one another, airflows through a small, wall-mounted heat exchanger can be easily short-circuited.

Cost is a major consideration when choosing a heat exchanger, and the cost of installing a wall- or window-mounted heat exchanger in several rooms can be greater than installing a central machine that can provide ventilation for all parts of the house.

Air mixing and flow are important to good dilution of indoor air pollution, and in this regard, a central, ducted system will provide a much better result than a wall-mounted unit (Figure 6).

However, a wall-mounted heat exchanger may be a good choice for applications where one room or a portion of a room needs better ventilation. In addition, several wall-mounted heat exchangers would be a reasonable alternative for some retrofit situations in which a central system is impossible.

A Central System Requires Planning in Advance

Costs can be substantially reduced when installing a central, ducted system in new construction or retrofit if the proper planning takes place in advance. Exchanger manufacturers should be consulted in the design phase of the project to facilitate this planning process. Ductwork layout and design must be planned for, and many problems can be avoided if the system is well-integrated into the house design (Figure 7).

Because the heat exchanger is a *ventilation device*, not a heating appliance, some designers use stud cavities in walls, joist cavities in floors and dropped ceilings as a low-cost "ready made" ductwork for the heat exchange

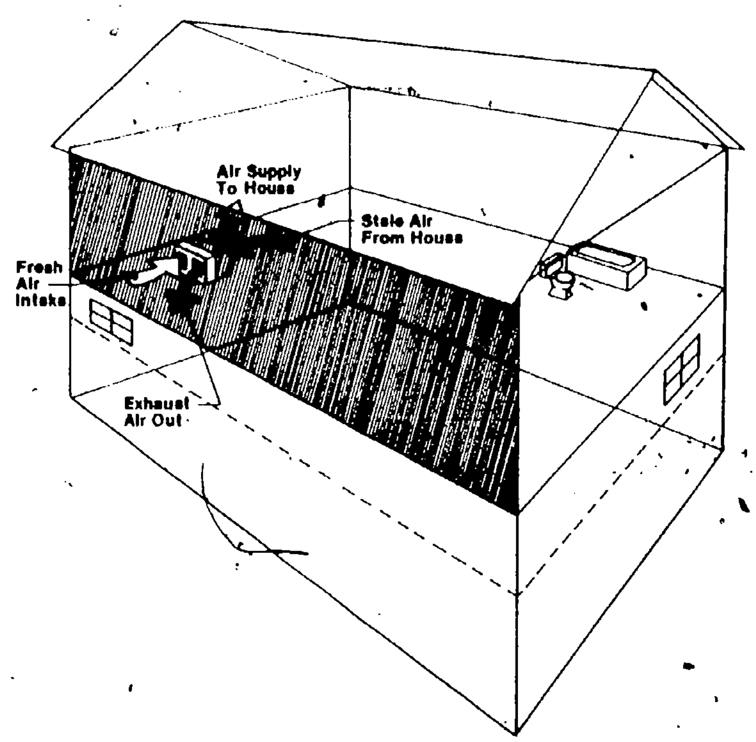


FIGURE 5: *Small, through-the-wall air-to-air heat exchangers may not adequately exchange and mix air throughout the house, but they may be adequate for one room or a portion of a room.*

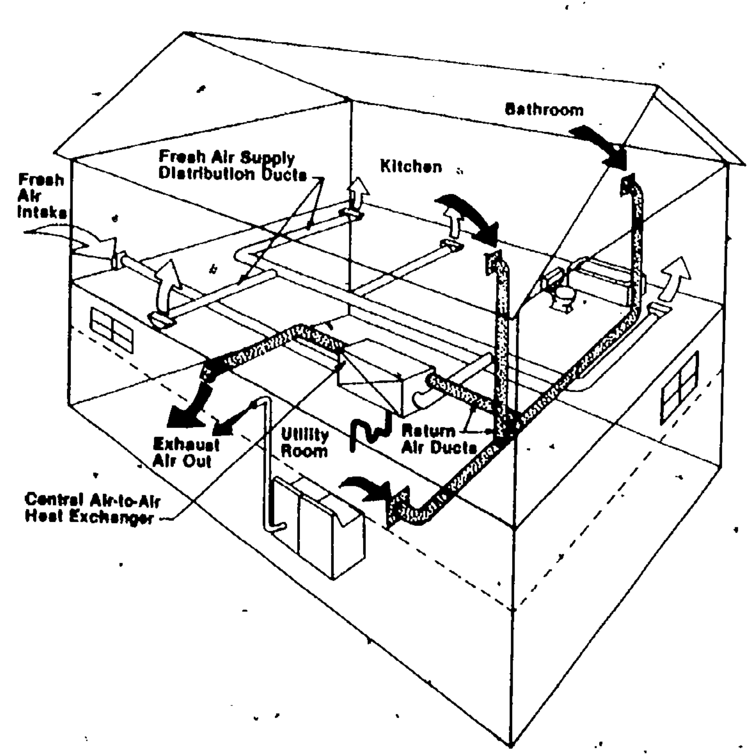


FIGURE 6: *A fully ducted central air-to-air heat exchanger has the capability of distributing fresh air to and stale air from all areas of the house.*

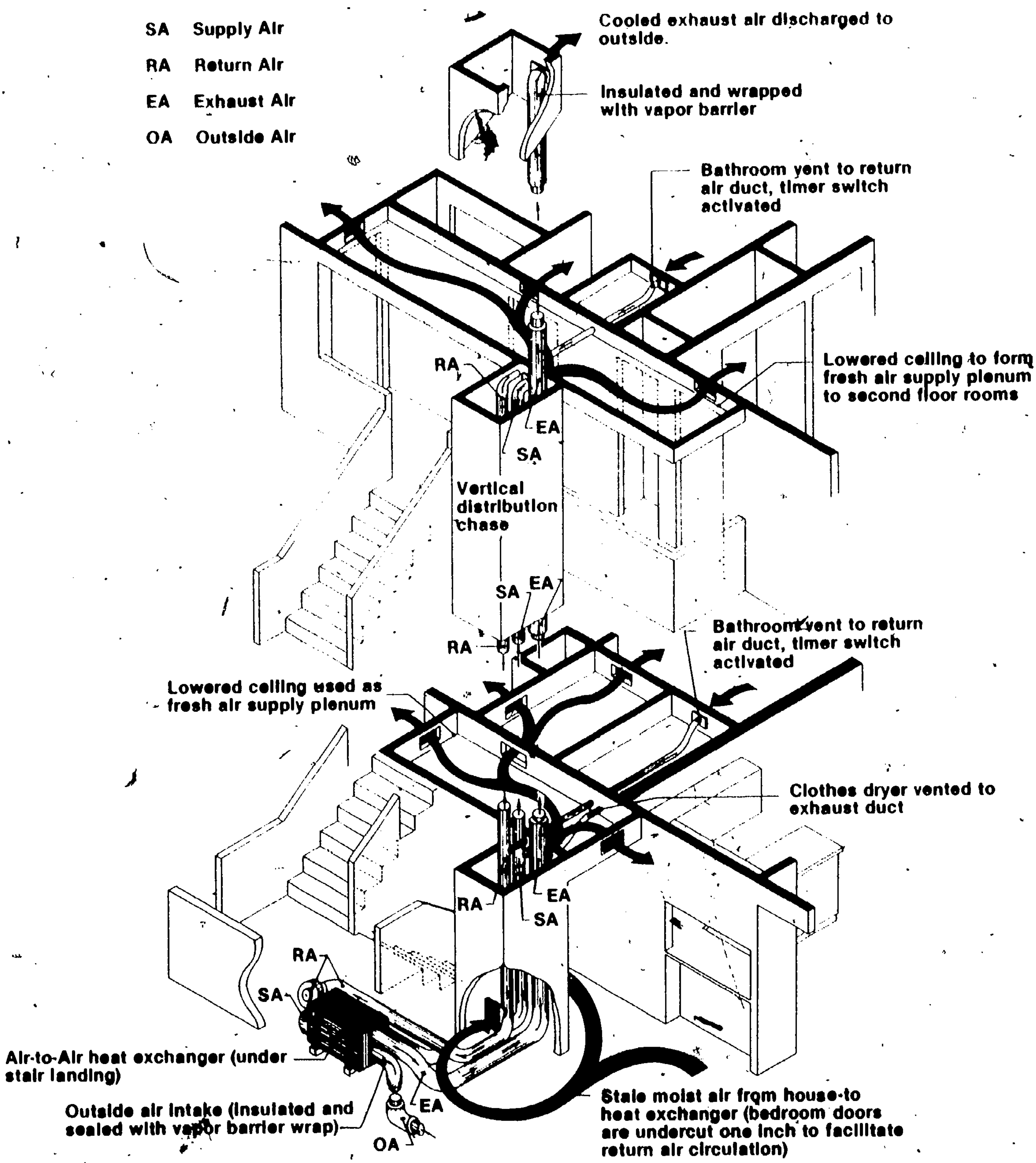


FIGURE 7: *This isometric cutaway shows how the integration of a central, ducted air-to-air heat exchanger is best accomplished during the design phase. The system shown is for a two-story house.*

system, thus saving money on the purchase of additional ductwork. In some areas, codes may forbid some of these practices, and some manufacturers who employ this type of ducting advise special treatment of these spaces.

What is the minimum air-change rate for safety and comfort?

Significant disagreement exists in the professional community about minimum ventilation levels, and until more indoor air quality research is done, it may be difficult to come to a national consensus on minimum ventilation rates. Researchers in the United States, Canada and Sweden have found that pollutant concentrations can increase substantially at air change rates under 0.5 (one-half) ach. Therefore, 0.5 ach has been considered by many to be the *minimum* recommended air change rate in houses. However, some researchers argue that lower levels may produce adequate ventilation in some instances.

Sweden has made 0.5 ach a mandatory year-round, continuous minimum (which because of its continuous nature demands a mechanical ventilation system). In the United States, California recently set a 0.7 ach minimum *at winter design conditions* for areas of the state where superinsulation is practiced. The difference between these two standards is significant in that one is year-round, while the other is a wintertime design standard.

The American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc. (ASHRAE) has recommended minimum ventilation levels pegged to a certain *continuous* amount of air entering each room (10 cubic feet per minute (cfm) per room). The ASHRAE standard also calls for 100 cfm capacity in kitchens and 50 cfm in bathrooms, which means mechanical exhaust vents must be added in these rooms.

If kitchen and bathroom vents are regularly operated, the overall air change rate will be an estimated .5 to 1 ach in most houses. However, if exhaust fan use is discounted because it depends on occupant action, the air change rate for 10 cfm per room can translate to a 0.2-0.4 ach rate in most houses (with five or six rooms). ASHRAE's standard assumes no major pollution sources in the house. (See Appendix D for more detail on the ASHRAE standards.) It should be noted that much greater air change rates than any of these minimums would be needed to remove heavy pollutant concentrations, such as tobacco smoke or combustion byproducts.

While it is true that ventilation is largely in the control of the occupant, most people have little knowledge of potential indoor pollution sources. Architects, designers, builders and energy specialists must plan to provide the necessary ventilation for new, tightly constructed houses and for comprehensive retrofit work that involves cutting infiltration levels.

In order to ensure adequate ventilation with an air-to-air heat exchanger system, it is probably best to select 0.5 ach as a minimum ventilation level *regardless of the contribution of natural air leakage*, which is uncontrollable and changes constantly.

Determining Machine Capacity

The capacity of the air-to-air heat exchanger to move air is described in terms of "cubic feet per minute" or cfm, and capacity depends on three things:

- fan performance in free air,
- the resistance of the core and exchanger case to air movement,
- the resistance of any ductwork that delivers the air.

Most reputable manufacturers will be able to describe the capacity of their machines in terms of the air flow they are capable of providing *after* subtracting expected losses due to core and ductwork resistance. For example, say a machine's fan will deliver 400 cfm in free air. After overcoming the resistance of the core, the delivery rate may be 250 cfm, and if the resistance of ductwork is considered, the final effective cfm delivered to the house could be about 200 cfm.

A second point about machine capacity is that most machines are more effective at recovering heat at lower air flow rates than at higher air flow rates. Thus, you need to choose a machine that has large enough capacity at *low speed* to meet a minimum air change rate, as well as some type of additional capacity to handle greater ventilation needs, such as occasional extra ventilation for the bathroom, kitchen and possibly for the laundry area or other special-use rooms. (Remember that extra ventilation capacity for gas cooking appliances must be provided over and above what the heat exchanger can provide.)

How to Determine the Minimum Heat Exchanger Capacity for Your Application

The following example can be used to determine how much capacity, in cubic feet per minute (cfm), is needed to provide a 0.5 air-change rate.

For an extremely tight, superinsulated 1,500-square-foot house (with no basement):

1. Determine total floor area	**= multiply length times width, 30 feet times 50 feet = 1,500 square feet**	**= 1,500 square feet**
2. Determine total house volume	**= total floor area multiplied by ceiling height = 1,500 square feet × 8 feet**	**= 12,000 cubic feet**
3. MINIMUM exchanger capacity	**= House volume multiplied by ventilation required from exchanger = 12,000 cubic feet × 0.5 ach = 6,000 cubic feet per hour, divided by 60 minutes = 100 cubic feet per minute**	**= 100 cfm minimum capacity***

*** This capacity is what should be delivered *after* losses due to core resistance and ductwork have been accounted for.**

Once you have determined the minimum ventilation capacity of the machine you will need for your house, then compare your needs to the manufacturer's information about machine capacity. Whole-house, ducted air-to-air heat exchanger models generally range in capacity from about 120 cfm to 350 cfm. Models with as much as 700 cfm capacity for residential use are also available for very large houses or those with indoor pools.

Note that different manufacturers typically will choose varying lengths of ductwork to use in calculating their maximum delivered' air flow rate. If your ductwork scheme differs substantially, the manufacturer may be able to help you determine what the actual delivered air flow might be in your situation.

While you are studying machine capacity, think about how much additional air flow you will need beyond the minimum you initially calculated. Extra capacity may be desirable to more quickly remove indoor pollutants and moisture from kitchen, baths and special-use rooms. Each machine's capacity is set by design. Through controls, air flow can be reduced, but it cannot be greater than the maximum the machine can deliver. Using the same method, you can calculate how great a capacity you would need to deliver 1 ach or greater, if desired. It may be best to choose a machine that allows for variability; if you select a machine that, at maximum speed, can just barely provide your minimum air flow needs, efficiency will be reduced, and extra ventilation with heat recovery won't be available when needed.

Note, however, that some manufacturers offer options that can allow extra ventilation without relying on extra machine capacity. For example, one manufacturer offers controls and dampers that allow air to be diverted momentarily to rooms with greater ventilation needs. Another installs "booster" fans in ductwork for kitchens and baths to temporarily increase air exhaust from these rooms.

Examine Machine Features

A variety of types of air-to-air heat exchangers are on the market, and choosing the right machine for your needs can sometimes be a confusing task. The following section explains the various components of a heat exchanger and how these features can affect performance, maintenance and other aspects of owning and operating a heat exchanger.

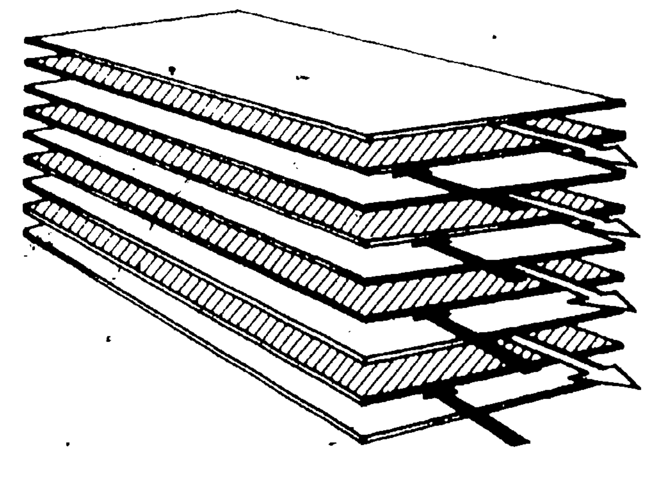


FIGURE 8: *In a flat-plate counterflow core, air streams flow in opposite directions, allowing greater heat transfer from one air stream to the other.*

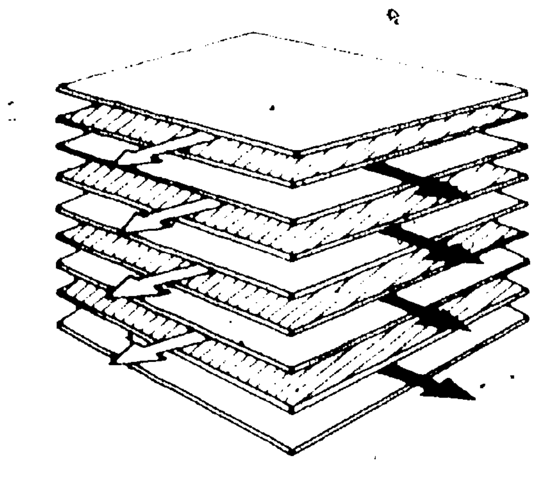


FIGURE 9: *In a flat-plate crossflow core, air streams flow at right angles to one another. A crossflow core must be larger in area than a counterflow core to equal performance.*

The essential components of the heat exchanger are the fans and the heat exchanger core. Other basic features include a condensation drain to allow moisture accumulated in the machine to drain away, a defrosting mechanism or system to avoid hindering the machine's performance during very cold weather, and the system's controls. (A discussion of ductwork installation and control strategies is presented in later sections.) Each basic component is discussed separately to allow a comparison of the available features and design options.

Exchanger Core Types

Three basic factors influence the efficiency of most types of heat exchanger cores: the size of the surface area for heat transfer, the direction of the air streams, and the speed at which air moves through the core. The greater the surface area, the more heat can transfer through the core to the fresh air stream, while the direction the two air streams are moving usually influences temperature profiles in the core.

Although there are six different types of cores available on the market, the *counterflow* core is theoretically the most efficient because the two air streams are running in opposite directions, a situation that makes for the best temperature profile for heat transfer between the two air streams (Figure 8). Conversely, a *parallel flow* core, in which the two air streams are running in the *same* direction, has an effectiveness limited to 50 percent by the laws of thermodynamics and is the least effective type of core.

Crossflow cores tend to be somewhat less efficient than counterflow cores, because the air streams are moving perpendicular to each other. A larger core can help improve the efficiency of this type of core. And, one manufacturer has designed a "double cross flow" core, which doubled the contact surface, thus making this machine similarly efficient to the counterflow core. (Figure 9).

Concentric tube counterflow cores offer similar efficiencies to the flat-plate counterflow, but they are more difficult to manufacture and can be more expensive than other types of machines (Figure 10).

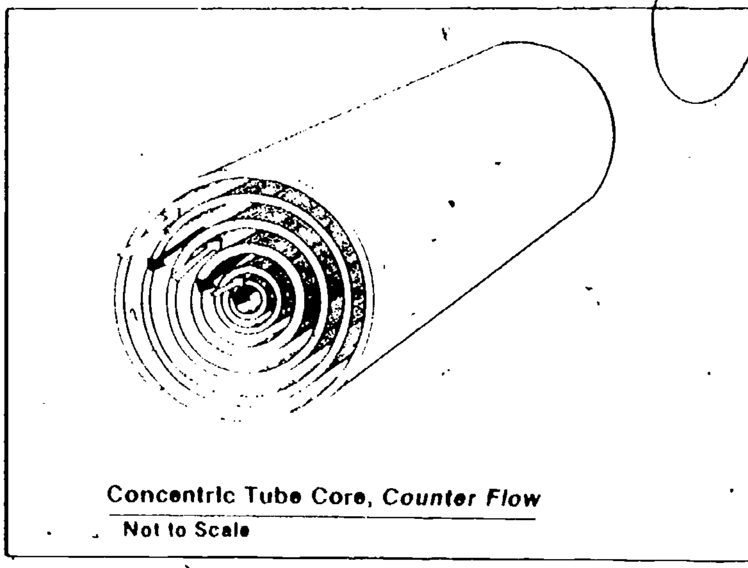


FIGURE 10: *Concentric tube counterflow cores are similar in performance to flat-plate counterflow cores, but they use a different manifolding geometry.*

Rotary cores have been used for years in commercial or industrial applications. In these types of machines, the core actually rotates between the cold and warm air streams. Rotary machines allow moisture to transfer between the two air streams (Figure 11).

Heat-Pipe cores employ permanently sealed pipes (or tubes) that contain a refrigerant. When one end of the tube is heated, the refrigerant vaporizes and travels to the other end of the tube, where cooling causes it to condense and flow back to the other end. The heat pipe operates through a condensation-evaporation cycle that is continuous as long as temperature differences are sufficient to drive the process (Figure 12). Effectiveness depends on the number of rows of heat pipe, and operation is extremely dependent on the machine being installed at the proper angle. Heat-pipe heat exchangers are well developed for industrial use and seem to hold promise for small-scale residential use. However, few manufacturers are employing this technology in the residential market.

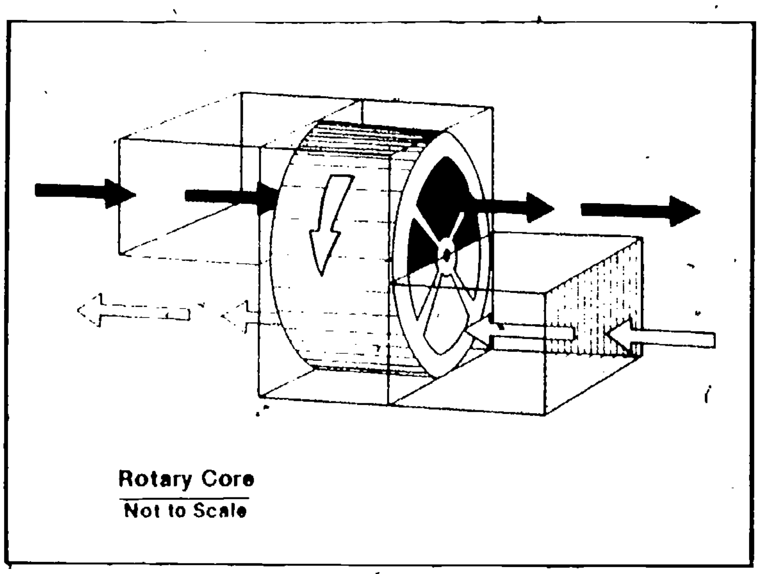


FIGURE 11: *In rotary cores, a rotating wheel of tiny air passages transfers heat from one air stream to the other. Rotary cores usually transfer moisture as well as heat.*

Moisture Transfer in the Core

A secondary feature that can influence heat transfer in the core is whether the core allows moisture to pass from the warm air stream to the cold, incoming air. Some cores are made of specially treated paper, which allows this moisture transfer to take place. Called "enthalpy" models, these heat exchangers can transfer more heat, because they recapture the energy that is given off when moisture condenses from a gas to a liquid. (This is known as latent heat transfer.) Note, however, that non-enthalpy units also recapture some of this latent heat during the months when moisture condenses in the core.

Enthalpy units may not be well suited for cold-climate applications because one of the main jobs of the heat exchanger is usually to remove excess moisture from the inside air. In addition, enthalpy cores may allow formaldehyde, which dissolves in water, to be returned to the incoming air, rather than staying in the exhaust air stream where it belongs.

On the other hand, enthalpy units may be suited to warm-weather applications where high outdoor humidity is a problem. The warm, moist outdoor air passes some of its moisture, as well as part of its heat, to the outgoing, cooler exhaust air stream, thus lowering relative humidity in the house during the summer.

However, because you must usually choose between enthalpy and non-enthalpy units when buying a machine, it is probably best to avoid the enthalpy units in cold-climate settings.

Maintenance Features

Some manufacturers feature cores that can be periodically removed and cleaned, while other manufacturers have opted to use filters rather than allow for a

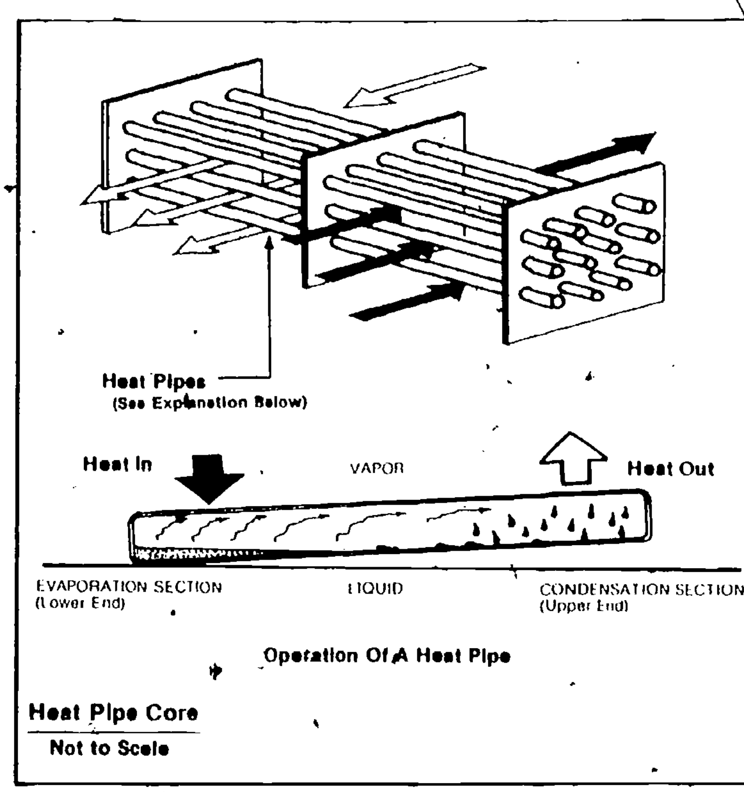


FIGURE 12: *In heat pipe cores, heat is moved from one air stream to the other by evaporation and condensation of a fluid in a heat pipe.*

removable core. In areas where outdoor air quality is poor, a filter system would probably be the best choice, because heat exchanger cores are not meant to filter small particulates from the air.

It is important to follow maintenance recommendations provided by the manufacturer in regard to filter replacement or core cleaning; the performance of the machine will likely be affected by lack of necessary maintenance. Some observers have suggested that manufacturers might want to consider an elapse run time indicator in the system control package to aid maintenance scheduling.

Defrost Capabilities

Heat exchangers designed for use in cold climates should have some provision for defrosting the core during the coldest winter days. Moisture in the warm air stream can freeze if the incoming air is cold enough, and ice buildup may eventually block the core.

An automatic defrost system is best, because it is actuated with no attention required from the occupant. Manual defrost requires monitoring the machine in cold weather and taking action when necessary.

Another option is to pre-heat the incoming cold air to avoid freezing in the first place. However, in many superinsulated houses this pre-heating element may actually use more energy than the whole house uses for back-up space heating. In addition, pre-heating the incoming air could reduce the overall efficiency of the heat recovery function of the heat exchanger.

Automatic defrost mechanisms include those that are thermostatically actuated and pressure-sensor types. Thermostatically operated defrosters sense the temperature of the incoming air stream. If the temperature is low enough, the machine will go into defrost mode, which allows warm, stale exhaust air to run through the machine to melt the ice, while the incoming air stream is cut off temporarily.

Pressure-sensor systems, such as one developed by a grantee, monitor the pressure difference between the two air streams. When one air stream's pressure increases because of ice buildup, the machine goes into defrost mode.

No matter what the defrost mechanism, air exchange stops temporarily during defrost until the machine returns to its regular operating mode. Because air is leaving but not entering the house, this creates a temporary negative pressure in the house that could cause backdrafting problems in houses with combustion appliances that draw indoor air for combustion. This is another major rationale for carefully isolating combustion devices so that they draw combustion air from the outdoors, never from the indoors.

Fan Features

Heat exchangers employ small fans to drive the two air streams. The major features of heat exchanger fans to note when shopping for a machine are energy use, noise and maintenance provisions.

If the fans' energy use is substantial, savings from heat recovery may be minimal after the cost of running the fans is considered. For this reason, most manufacturers have concentrated on the use of highly efficient, small fans. The most common type of fan used in heat exchangers is the centrifugal blower. Vane-axial fans are also used (Figure 13).

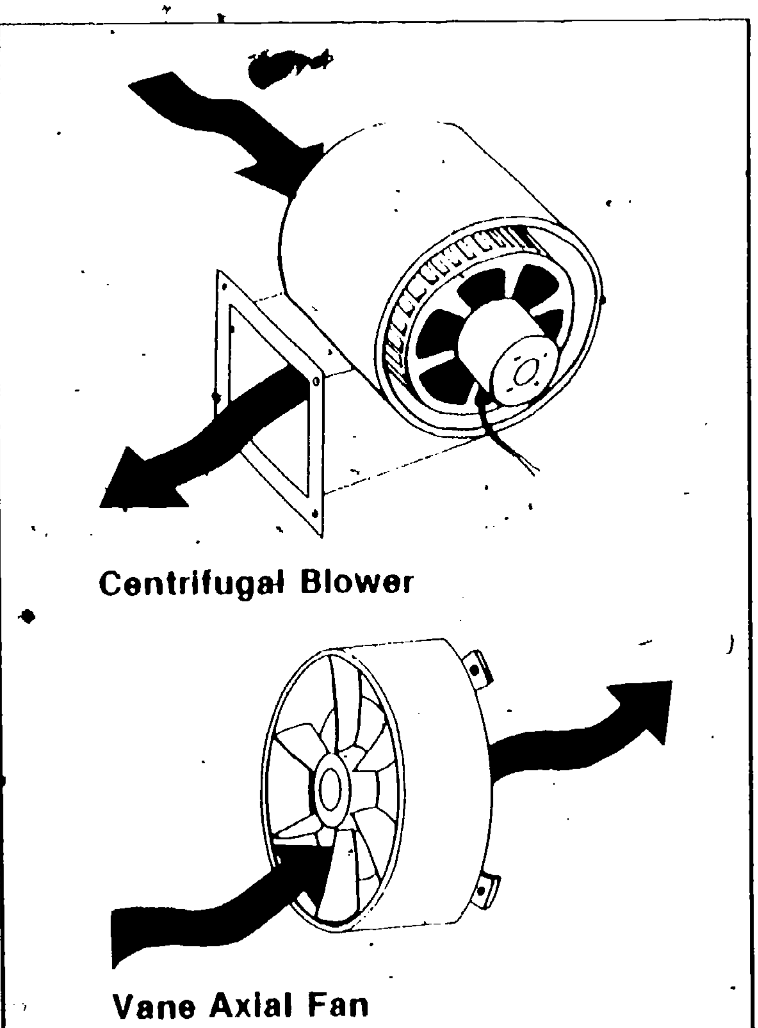


FIGURE 13: *Energy use, ease of maintenance, noise level and cost of replacement are all major considerations when comparing fans used in air-to-air heat exchangers.*

It may be wise to listen to the machine you plan to buy; some types of fan noise can be remedied when the machine is installed. If you understand the type of fan noise you are likely to get, then you can choose mounting and ductwork schemes to ensure quiet operation of the machine. Generally, however, heat exchanger fans produce less noise than most forced-air furnace fans because the small heat exchanger fans move less air.

Some fans are factory sealed and require no oiling, while others require periodic lubrication. Quality machines employ fans that are expected to last from five to seven years under continual operation. Check with the manufacturer about fan replacement schedules and fan life-expectancy. At least one manufacturer sells a heat exchanger core without fans, allowing the consumer to choose the fans best suited to the need.

The Development of a High-Efficiency Residential Heat Exchanger: The Memphremagog System

One grantee, the Memphremagog Group, a small, nonprofit energy research company in Newport, Vermont, thoroughly explored residential air-to-air heat exchanger technology in the course of its project.

The Group's work involved the production of several residential heat exchanger prototypes, and the project included thorough testing and development studies. The resulting machine, the ECHO CHANGER, is now being marketed commercially.

The story of the development of the ECHO CHANGER illustrates many practical and theoretical design considerations that are critical in heat exchanger performance. By reviewing this design process, those who plan to use heat exchangers for heat-recovery ventilation in tight, cold-climate housing can gain insights into the potential problems and promise of this technology. This work is also indicative of the type of development work that other manufacturers have done in the course of producing their heat exchangers.

Sizing the Machine's Capacity

The Memphremagog Group first planned to research and develop a small window- or wall-mounted heat exchanger. During the literature review process, however, it became clear that this type of heat exchanger wouldn't meet the Group's goal of providing ventilation for an entire house at a reasonable cost. At this early stage, the Group opted for a design that would be a central, ducted unit capable of providing adequate ventilation for a typical house.

Investigating Core Design

The Group investigated different materials to use for the core, and rejected treated paper because the goal was to develop a core that was highly impermeable to water vapor. The Group noted that "for the heating season, when *most* of the benefits of this heat exchanger will be realized, humidity reduction is one of the primary applications" for the heat exchanger. The initial choice for the core material was Coroplast^{R} copolymer polypropylene sheets, material that looks like plastic cardboard, and in fact, is used like cardboard.

Theoretical calculations indicated that the counterflow, flat plate core had the potential to provide the greatest surface area for heat exchange in the core. The first two prototypes developed were the counterflow, flat-plate type, purposely undersized to allow the group to explore construction, design and performance considerations. Testing revealed that the "short" cores (two feet in length) suffered from inefficient use of the heat transfer surface. This resulted in lower effectiveness than anticipated from initial calculations. Core effectiveness testing at this stage also indicated that air coming into the core should be baffled so that air reaches the corners of the core, instead of flowing through only the center of the core.

In addition, testing showed that pressure losses across the short cores were higher than desired for efficient operation, and this discovery led to further design work on the entrance and exit plenums.

Work with the early short cores also emphasized the level of attention that is needed to maintain a good seal between the exhaust and incoming air streams. If exhaust of indoor pollution is the goal, these two air streams must be carefully isolated. Toward this end, the Group tried a variety of sealing techniques, and discovered a satisfactory answer to the problem.

The final prototype was a four-foot long core that incorporated design modifications from this initial work to ensure good utilization of the core surface, minimize internal short-circuiting of air flows and maintain the integrity of the two air streams to avoid internal mixing of polluted air with incoming air. Efficiency and pressure drop across the core were found to be good with this prototype (Figure 14).

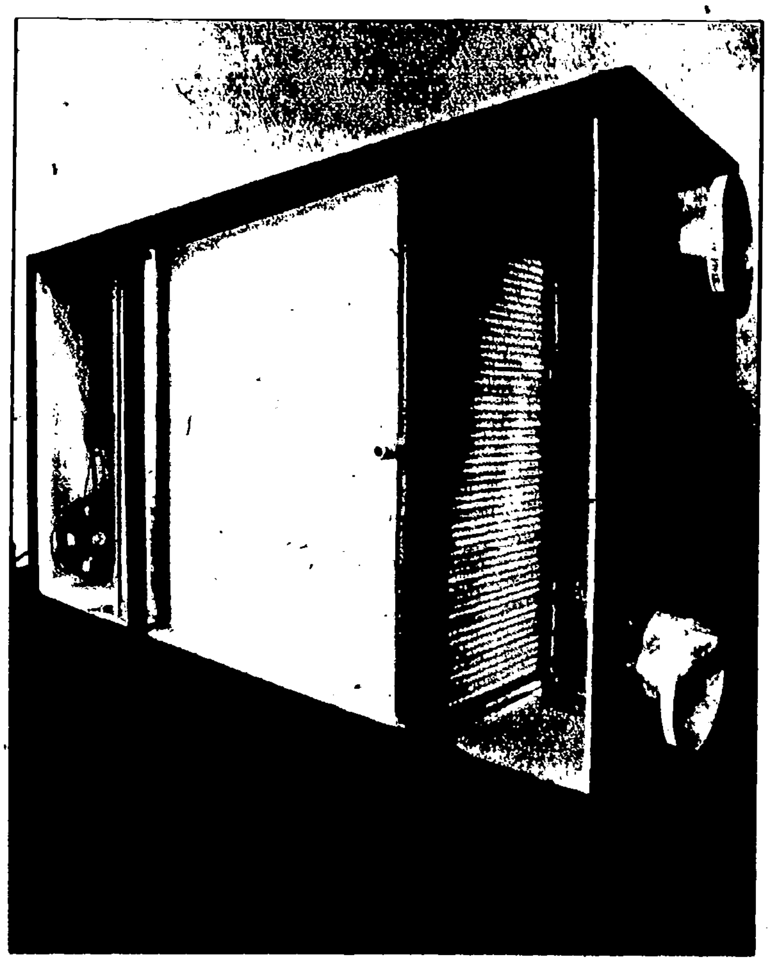


FIGURE 14: *The Memphremagog Group's heat exchanger features a core of thin sheets of fluted plastic. The front housing of the pictured exchanger has been removed to reveal the core and the layout of the machine.*

Fan Energy Studies

The Group did a thorough product search for fans that would supply the desired air flow while consuming the least amount of energy. Testing and analysis revealed that there is a potential trade-off between fan efficiency and noise: the more efficient the fan, the higher the noise level may be.

However, the grantee found that fan energy efficiency is far more important than any potential noise problems, which can be solved in a number of ways. The Group opted for a highly efficient fan, a small 32-watt vane axial fan similar to those used to cool large computers.

Low fan energy use is important when one explores annual energy use by the heat exchanger. Assuming the heat exchanger will operate continuously for 180 days per year, and that the cost of electricity is $0.07 per kilowatt-hour, the grantee's two fans (64 watts total) will consume $19.35 annually. In contrast, a similar heat exchanger with fans rated at 130 watts, operating at similar air flow rates for the same period of time would consume $39.31 annually. A fan rated at 290 watts with the same operating assumptions would consume $87.70 annually. (Note that some of the energy used to operate the fans could be returned to the house as useful heat, depending on where the fans are located in the machine, and location of the machine in the house. But heating the house with a fan will be less efficient than other heating options.)

Of course, fan power determines how much air can be handled through the heat exchanger. Larger air flow rates can be produced with higher-powered fans. Because some customers may want higher-powered fans, the Memphremagog Group opted to also produce a heat exchanger core package without fans, to allow the buyer to choose larger fans, if desired.

The 64-watt fans provide for air flows of: 240 cfm (free air), 180 cfm (includes core pressure losses) and 120 cfm after about 30-50 feet of straight ductwork is installed. This pressure drop depends on duct size, duct length, and the number of duct elbows and bends.

The Group recommends that if larger air exhaust is desired for kitchens and baths, booster fans can be installed in the ductwork at these locations, controlled by manual timer switches. Although these boosters temporarily imbalance the air flows through the machine, the loss of efficiency is small, and pollutants and moisture generated in these "wet" rooms can be exhausted more quickly without contaminating air in nearby rooms.

Core Condensation and Icing

Another significant area of research by this grantee falls in the area of defrost control. Automatic defrost is a major concern in the operation of the heat exchanger during times of extremely cold weather.

The grantee considered a percentage or programmable timer to operate the defrost mode, but later opted for a pressure-activated switch. This type of control has an advantage over the others.

Temperature-activated defrost may turn the machine on defrost when temperatures are low, whether or not icing is actually occurring. Programmable or percent timers also have little ability to actually sense when core blockage is occurring. In contrast, the pressure-activated switch turns off the incoming, cold air stream when pressure increases on the exhaust air stream, indicating that the exhaust passages are clogged. Warm, stale air continues to move through the core until the ice in the passages is melted. When this happens, pressure will drop to the point where the pressure-sensing switch will reactivate the incoming air stream fan, and normal air exchange resumes as usual until icing occurs again.

One drawback of the pressure-sensing switch is that if the core becomes blocked by other matter, such as lint or other particulates, the defrost mode will be activated improperly. However, if the system controls included a pilot light that indicated when the machine was in defrost mode, this drawback could turn into an advantage from a maintenance standpoint: if the defrost pilot light went on in warm weather, it would be a prompt to clean the core.

Tests showed that ice buildup over 24 hours of continual operation at temperatures of 0°F to −22°F outdoors, 65 to 85 percent indoor relative humidity, and indoor temperatures of 70°F to 75°F (a severe test) could be completely eliminated in less than 30 minutes of defrost mode operation. Although a thin sheet of ice also formed on the metal surfaces of the stale-air exit manifold under the severe conditions of this test, this ice never increased beyond a very thin layer. No other surfaces outside the core experienced icing.

To avoid condensation on the exterior of the metal case of the machine, the heat exchanger is insulated with 1 inch of foil-faced rigid fiberglass. In addition, both the intake and exhaust ductwork from the machine are insulated and wrapped with a carefully sealed vapor barrier during installation of each unit.

Core Cleaning

The Group investigated using filters on both the incoming and outgoing air streams to prevent dust and dirt from entering the core. Although a clean set of filters alters efficiency only slightly, as the filters become partially or totally clogged with particulate matter the two air streams could become imbalanced. Based on this, the grantee opted for making the core removable and cleanable.

In the cleaning tests, the Group set up a dust generator in a controlled chamber and intentionally blew extremely dusty and moist air into the machine. The dust generator was operated for several hours over four days until about half of the air channel space was clogged. The core was then removed from the machine and flushed with a water hose at high volume. The core was easily cleaned in this manner, and the grantee reported that tests showed that high-pressure, low-volume water would work, as well.

The grantee explained that dust buildup in the core under this test would not be representative of any actual residential setting, for dust quantities were far in excess of those found under even the "most abnormal" residential operating conditions.

Field Testing

Three units were field tested, including one that has been continually monitored in a superinsulated house in Newport since December 1981. Field tests included airflow, temperature and defrost evaluations with the machine and ductwork installed. In all instances, the heat exchanger performance closely paralleled earlier laboratory results.

One prototype model was installed on one house of a multiple-house construction project in the winter of 1981-1982. The exchanger was operated during construction to remove interior moisture during the drying of the gypsum board taping. The grantee reported that the walls of this house were dry and ready for painting in one-fourth to one-fifth the time required by the other houses.

What About Homemade Heat Exchangers?

Because of the relatively high cost or lack of availability of commercially built heat exchangers, some people have attempted to build their own. While homemade heat exchangers may have cost advantages, building one from scratch is a fairly difficult project that may produce less than satisfactory results.

For obvious reasons, few people are willing or able to build their own major home appliances, such as heating plants or dishwashers, and a homemade heat exchanger should probably be viewed in the same light.

At least two grantees built or monitored their homemade heat exchangers. One tried out the concept of using a truck radiator for a core, while the other's core was a complex design that featured an integral heater for defrosting.

In the late 1970s, Canadian researchers at the University of Saskatchewan at Saskatoon published construction plans that described how to make a rather large heat exchanger core from lengths of polyethylene plastic, housed in a plywood box. About 5,000 sets of plans have been distributed, and many of these heat exchangers have been built.

Recently, the same Canadian group revised and improved the design of their home-built unit, making it smaller and more efficient. The updated version calls for the use of fluted plastic sheets, similar to those used in the Memphremagog commercial heat exchanger.

Because of the important job the air-to-air heat exchanger must perform in the extremely tight house, do-it-yourselfers should carefully review the situation before attempting such a task. If one has the skills, a clear set of instructions, and access to the proper products, a homemade heat exchanger may be one way for a skilled homeowner to save some of the extra cost associated with a superinsulated house.

III. INSTALLING THE AIR-TO-AIR HEAT EXCHANGER

This section covers basic details of choosing the location, mounting and ductwork details for the installation of a central, whole-house heat exchanger. Again, manufacturers' recommendations should be consulted during the design and installation process to ensure proper installation of the machine.

Choosing a Location

The basement is usually an ideal location for the heat exchanger, because of ease of access for ductwork and connection to the house sewer for the condensation drain. In houses without basements, a main-floor mechanical room is a good choice. If the basement will be used for living space, a mechanical room in the basement would be the best site.

While a number of machines feature an insulated housing, some still do not. An uninsulated machine can experience condensation problems in both warm and cold locations in the house. It is best, therefore, to avoid uninsulated machines.

In addition, it is best to avoid putting heat exchangers in cold locations; the condensation drain may freeze or other problems could result. In this regard, an attic location is a poor choice because of the cold, and this location may also present problems because ductwork often must penetrate the air-vapor barrier more times than if the exchanger is located in a mechanical room or a basement. Remember, too, that the more inaccessible the machine is, the more likely needed maintenance will be postponed.

Mounting the Machine

Many machines are designed to fit between the floor joists or hang from them, mounted on straps or hangers. Manufacturers' instructions will indicate whether the machine should be mounted level or sloped to facilitate draining condensation.

If the machine vibrates when it is in operation, it should be isolated from the floor during installation. Rubber grommets or bushings can be used to further cut vibration noise. Or, manufacturers may be able to provide guidance on reducing fan or vibration noise with other strategies (Figure 15).

The condensation drain should be plumbed to a drain with a trap to avoid sewer backflow. With some exchanger models, two traps are advised. Carefully note manufacturers' recommendations in this regard.

Ductwork

Remember that heat exchangers generally have a higher efficiency when air is moving through the core at slower speeds. Care should be taken to avoid hindering air flow by choosing ductwork that is large enough, has few bends and elbows, and is as smooth as possible.

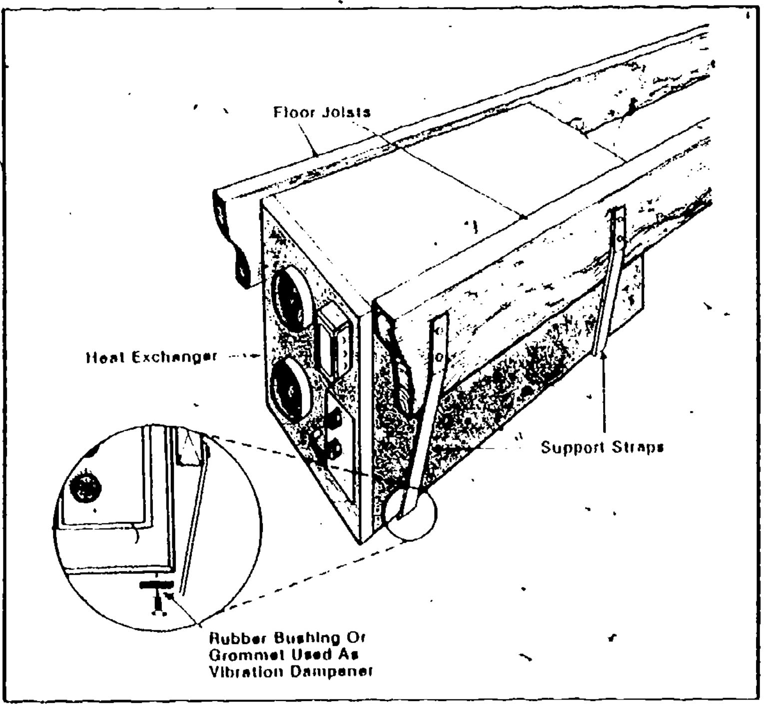


FIGURE 15: *Installing rubber bushings or grommets can help reduce vibration noise in this type of heat exchanger installation.*

Many machines are designed with fittings for 6-inch ductwork. Commonly used ductwork includes galvanized metal, sheet metal, PVC plastic pipe, inexpensive plastic sewer pipe, and flexible ducts. In some locales, codes may mandate metal ductwork, but low-cost plastic sewer pipe is probably the least expensive type of ductwork. Flexible ducts, with their ribbed surfaces, have more internal resistance to air flow, but they are easier to install and may be acceptable if ductwork resistance has been allowed for in system design.

Besides electrical and plumbing connections, four air duct connections must be made during installation. These ducts include: the outside air *intake* duct, which brings in the cold air from the outside; the stale air *exhaust* duct to the outdoors; the fresh air *supply* ducts from the machine to the living areas; and the stale air *return* ducts from the living areas to the machine. These four ducts, and special features and problems to consider, are covered separately in the following discussion.

Intake Air

The point at which the air intake duct picks up outside air should be located as far as practically possible from the stale air exhaust duct outlet, to avoid pulling stale air back into what is supposed to be the fresh air stream. Most designers recommend at least a 6-foot minimum distance from the stale air exhaust outlet, while others insist on at least 10 feet.

Note that if the south side of the house has an unobstructed southern exposure, air on this side of the house will be several degrees warmer in winter during the day than air on the other sides of the house. Therefore, it makes sense to locate the intake duct on the south wall, if possible or practical.

This duct should be located so it won't be buried under snow during the winter, and it should be well above the soil level. Never locate this duct where automobile exhaust can enter. In addition, other outside pollution sources should be considered. Avoid locating this intake port near gas exhaust vents, central vacuum cleaner exhaust ports or where outdoor cooking (barbeque) gases could be pulled into the port. Because this intake port should be checked periodically for obstructions, it should never be located where it is difficult or impossible to visually and manually inspect, such as under a closed deck or porch. The opening should be covered with a rain cap or insect screen, or whatever is recommended by the manufacturer.

If outdoor air quality does not meet federal standards, outdoor air should be filtered before it enters the house. Experts recommend use of an atmospheric dust spot filter as the best choice to trap small particulates. Gases such as carbon monoxide and sulfur dioxide can be treated to some degree by the use of activated charcoal or alumina absorbent systems.

Caution: This intake air is not in any way designed to provide air for combustion appliances, such as furnaces or water heaters that burn oil, gas, wood or any other combusion fuel. If a combustion appliance is installed in the home, special provisions should be made for supplying outside combustion air directly to these appliances, independently from the heat exchanger system. Negative pressure in the house could cause backdrafting of dangerous flue gases.

A number of builders and designers have been installing wood stoves and other combustion appliances in superinsulated houses, making the assumption that the air-to-air heat exchanger can provide enough combustion air to operate these devices. This is a potentially hazardous practice. Combustion air requirements should be calculated separately for each appliance. To ensure that the potential for backdrafting of combustion appliances will not occur, each combustion appliance should have outside combustion air directly ducted to the appliance, so that the appliance is completely and effectively isolated from indoor air.

Because this intake air duct will be moving cold air, it should be carefully sealed, insulated and then wrapped in a well-sealed airtight vapor barrier to avoid moisture condensation on the outside of the duct. Any breaks in the house's vapor barrier should be carefully sealed during the course of this installation.

Refer to the section on balancing the air flows for information on dampers that may be located in this intake duct.

Exhaust Air

The stale air exhaust outlet should be located as far away as practical from the outside air intake port; again, it is recommended that the distance from the outside air port be a minimum of 6 feet, preferably more.

To accomplish this, some designers run this exhaust duct out through the roof, although this isn't necessary in most cases. If this radical course is chosen, special attention should be given to allowing for expansion and contraction of the duct. Some people use a rubber boot or some sort of slip joint at the connection between the duct and the attic. The overriding concern here is to allow for movement with the joint, and to make sure that an air leakage point isn't created by a careless break in the airtight vapor barrier.

Because this duct is carrying the stale air away from the house, it should be tightly sealed to avoid allowing contaminants to re-enter the indoor air. In addition, this duct is usually insulated and wrapped with a well-sealed vapor barrier.

Fresh Air Supply

The key to the fresh air supply duct system is to locate the ducts so that a good supply of fresh air will reach all areas of the home and so that air mixing in the home will be adequate.

While some manufacturers say that one, single fresh air supply source will handle the needs of the house, this may not be true in practice. If the house is completely open in design, with no doors closing off rooms, this single supply duct might be adequate, but air movement and mixing may be negatively affected, even with an open-room layout. Of course, money can be saved by installing only one supply duct, but because good indoor air quality is the goal, this course should probably be avoided in favor of a ducted system.

Just as the ends of exhaust and intake air streams are located far away from each other, the fresh air supply points in the living space should be located far enough away from return air intake points to avoid short-circuiting the air flows.

The fresh air supply ducts demand the most care and ingenuity in placement, to avoid extra cost and achieve good air mixing, without creating discomforting cold-air drafts. A number of designers recommend that these air supply points be located high on the walls or in the ceilings to keep cooler air away from the occupants and to facilitate air movement and mixing. Also, the choice of registers that cover these supply air ports can influence how air will move and mix with room air.

Air can be successfully moved through plenums created by dropped ceilings. This is usually cheaper than running metal or plastic ducts through these same available cavities.

Return Air

The main focus with stale air return pick-up points should be rooms that produce the most pollutants—the kitchen, bath and special-use rooms such as hobby rooms or laundry areas.

While some designers like to duct return air from each room, the majority of duct system designs call for two or three separate ducts from the kitchen, bath and, sometimes from another central pick-up point, as well.

Codes require additional ventilation for kitchens and baths, and the heat exchanger can provide this ventilation, using the "extra" capacity of the machine, above the basic ventilation rate chosen for the house. Using simple exhaust fans in extremely tight houses makes little sense if the object is energy savings. Instead, timer switches, similar to the ones used with traditional exhaust fans, can be installed and used to operate the heat exchanger at full speed when additional ventilation is needed. (More detail on exchanger controls is covered in the next section.)

Some manufacturers employ "booster" fans in the exhaust from the kitchen and bath. Although this temporarily imbalances the system's air flows, the short-term drop in efficiency isn't a major problem. One manufacturer is using a system that diverts air flow from little-used areas of the house to the kitchen or bathroom for a short period of time.

The kitchen air pick-up point should never be located directly over the cook stove, as a traditional range hood would be. The exchanger core is not meant to handle grease, which could seriously affect the performance of the machine. Furthermore, grease will likely settle in hard-to-reach ductwork and create a potential fire hazard. Instead, the pick-up point should be in a central location across the room from the range, to allow the grease to settle without entering the return duct. A non-vented, filtering range hood should be installed to catch some of this grease close to the source.

Sometimes, this kitchen pick-up point can serve the main living rooms, as well, if the house has an open floor plan. Some designers further facilitate air movement by specifying that doors be undercut by an inch or so.

Never vent the clothes dryer to the heat exchanger return air duct. This could imbalance the system, overtax the fans, and the exchanger core will become blocked by lint accumulation. Nor should the clothes dryer be directly vented into the living space to recover waste heat. Indoor air pollution will result from the lint, moisture and laundry additives found in the dryer exhaust. The dryer may, however, be successfully vented into the *exhaust* airstream just before it is exhausted from the house. Such a vent should be outfitted with a backdraft damper (See RECOVERING HEAT FROM CLOTHES DRYERS).

Balancing the Air Flows

Once the machine and ductwork are installed, the system's airflows must be balanced to ensure that incoming and outgoing airflows are equalized. If the airflows are not balanced, the house will be subject to positive or negative pressure when the machine is running.

Positive pressure may cause air to push out through any small leakage points, and this can lead to moisture condensation inside building materials at these leakage points. On the other hand, negative indoor pressure will cause more air to be pulled into the house at leakage points rather than enter the house through the heat exchange system. (Negative pressure can also cause dangerous backdrafting of combustion flue gases if combustion appliances have not been isolated from the indoor air.) Balancing the airflows is usually accomplished with a balancing damper in the intake air duct.

Balancing the airflows is a two-person operation, which must be done on a day when the winds are calm and when temperatures indoor and outdoor are similar. All windows and doors are securely closed, and one window is opened slightly. The heat exchanger is turned on at high speed, and one person checks airflows at the window while the other stands ready to adjust the balancing damper in the intake duct. Airflow at the window can be detected with a smoke pencil, a burning cigarette or a length of thread held near the window opening. The balancing damper should be adjusted so that no air flow can be detected in or out of the window (Figure 16).

Balancing incoming and outgoing air flows also can be accomplished with an air-flow meter or with more sophisticated equipment, such as hot-wire anemometer systems. Ask for the manufacturer's assistance in securing additional professional advice or assistance on system balancing, if needed.

After inside and outside pressure balancing has been accomplished, the airflows inside the house can be further fine-tuned to compensate for differing duct lengths. This can be accomplished by installing small, inexpensive adjustable registers at air supply and return pick-up points. With the system running at high speed, the registers can be adjusted to equalize air flows. Another strategy that some manufacturers recommend is to install balancing dampers right in the ductwork, which are then adjusted in a similar manner as with the indoor-outdoor balancing operation. At least one manufacturer offers "self-balancing air controllers," which are passive balancing dampers that regulate air flow based on pressure.

Should an Air-to-Air Heat Exchanger Be Integrated Into a Forced-Air Heating System?

At first glance, the notion of using an existing forced-air heating system to distribute air from the heat exchanger might seem like a good way to save money on extra ductwork. In reality, however, this course of action can sometimes negate any energy savings from the heat exchanger and cause a variety of other problems, as well.

First, most new, superinsulated houses have such low heat requirements that a large forced-air heating system is rarely necessary. These homes are often best heated by a small amount of baseboard or radiant electric heaters or with one of the new, mini-furnaces that are directly vented to the outdoors (and draw outdoor air for combustion). Note that a single point source of heat can work well in a very well-insulated, tight house when the air and heat movement are handled indirectly by air flows caused by the heat exchanger, rather than through heating ductwork.

In superinsulated retrofit situations, the same case should hold as in new construction: heating requirements have been dramatically reduced, and the house is tight enough to effectively use an air-to-air heat exchanger. The existing forced-air heating system will be greatly oversized for the retrofitted house, and if indoor air quality is the goal, the heat exchanger will be needed much more often than the large heating plant. Yet, if the two are directly connected, and ventilation is dependent on the heating system, problems can result.

Heat exchangers have been directly connected to the cold-air return on the heating plant. Problems have arisen when the heat exchanger is not in operation but the heating plant is on. The exchanger core can ice up quickly because air is being pulled through the core by the much larger heating system fans, yet no warm, stale air is moving out to warm the core.

Then, when the exchanger is operating while the heating plant is off, the large heating system fans will still be needed to move the air through the house, if the two systems are directly connected. These fans use much more energy than those typically found on most heat exchangers, and energy savings can be dramatically reduced by powering air movement with fans much too large for the job.

Then, there is the problem of balancing airflows. The large furnace fan can pull air through the heat exchanger much faster than it can be expelled through the exhaust. To solve this imbalance, one designer dampered down the heat exchanger air intake to the point where ventilation was greatly reduced in order to balance the air flows. This type of installation makes the heat exchanger rather

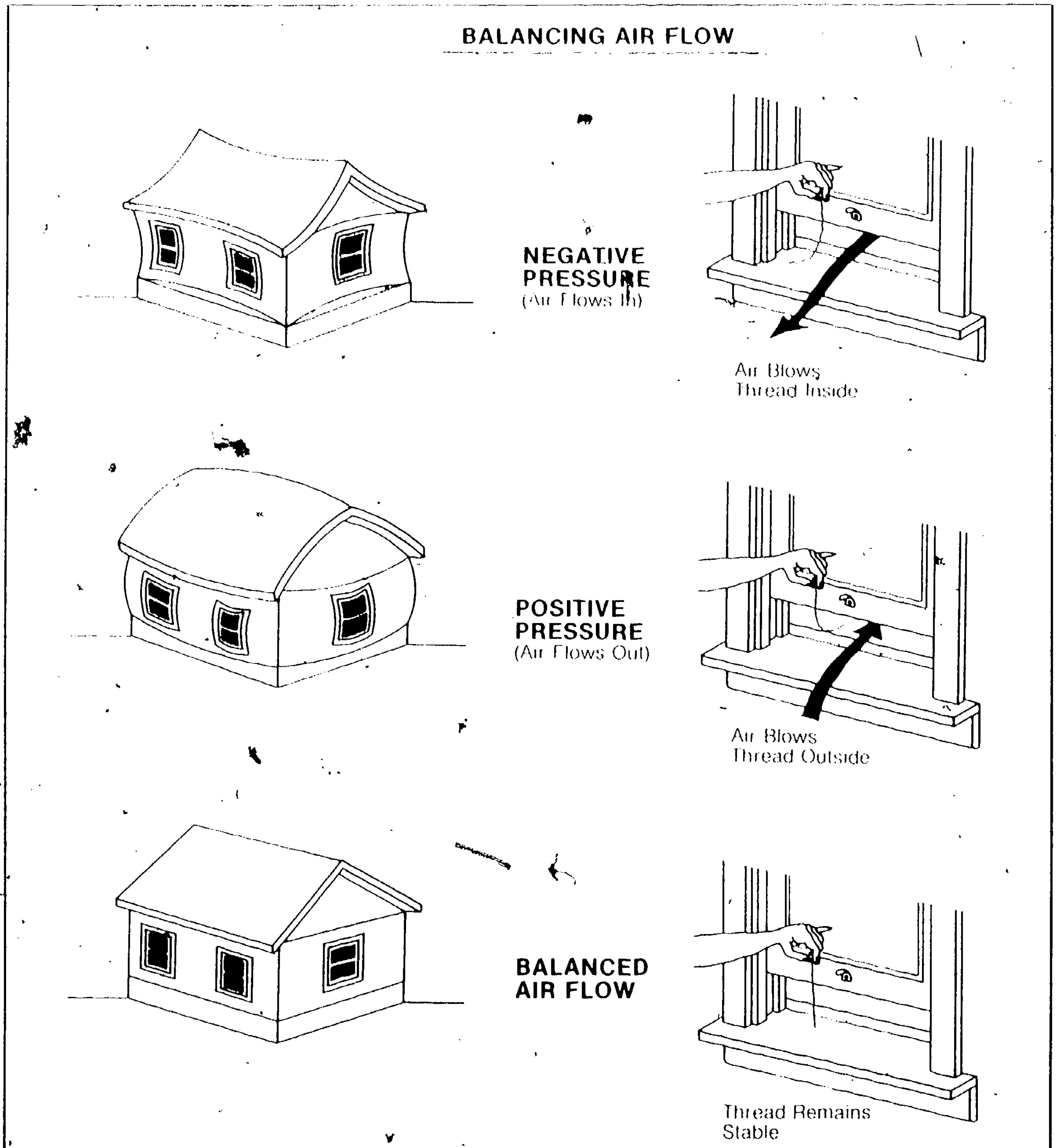


FIGURE 16: *A balanced air flow is the goal when adjusting the heat exchanger's air intake and outflow levels. This can be accomplished by dampers. On a mild day with low wind speeds, the air flow can be balanced with a two-person check. One person observes whether air is leaving or entering the house, while the other person adjusts dampers until the flow is balanced. More sophisticated techniques are also available for use in this task.*

useless; it is so dampered down that little air exchange is going to take place.

It has been suggested that the air-to-air heat exchanger could be best coupled to a forced-air system by simply dumping the fresh, warmed air near the cold-air return register in the living space. Another suggested idea has been to directly duct to the cold air return, but install an open tee that allows the furnace to bypass the heat exchanger if the two are not running simultaneously. But, neither of these methods solve the problem of proper and reliable distribution of fresh air while still saving energy.

Other experts have noted that, in many cases, the existing heating supply and return registers are not located in the places where the heat exchanger supply and return ports would be. For example, extra ductwork might still be needed to pull exhaust air from kitchens and baths, and supply air ports from the exchanger might be best located high on the walls, rather than at the floor level, which is common in most forced-air heating systems.

In general, the air-to-air heat exchangers that are on the market today are not easily compatible with a forced-air heating system, from either an operational or economic standpoint in most applications. If a forced air system is desirable or necessary for some reason (combined heating and cooling, or a very large house), engineering expertise must be obtained to ensure that all potential problems have been noted and solved.

Recovering Heat From Clothes Dryers

Several grantees explored the idea of recovering waste heat from residential clothes dryers or using waste attic heat or solar heat to preheat air for clothes dryers. In the case of one Oregon grantee, this involved the use of an air-to-air heat exchanger.

Much of this work illustrates that the clothes dryer is a problematic source of residential space heat. In many homes, the dryer is used too infrequently to make a significant contribution to space heat. Thus, investing money in recovering this heat may not be a wise energy conservation investment. And, because of the lint and other potential pollutants found in dryer exhaust, complete filtering can become an expensive proposition.

The Oregon grantee noted these problems as he attempted to apply air-to-air heat exchanger technology to the clothes dryer. But, in the course of his work, the grantee realized that air-to-air heat exchangers may be well suited to recapturing heat from commercial laundry dryers for use as space heat in adjacent rooms. Commercial dryers see near-continuous use, and in this application, automatic cleaning (to remove lint buildup from the heat exchanger core) might prove economically justifiable.

Perhaps a more promising application of heat-recovery technology for commercial laundries may be using the recaptured heat for hot water production, since this is a major energy cost for many laundries. This involves the use of an air-to-liquid heat exchanger, and a number of grantees had success with this approach because this technology is fairly well developed.

At the present state of the technology for residential applications, air-to-air heat exchangers are best used *only* for ventilation and dehumidification, not recapturing waste heat directly from clothes dryers or other internal heat producers.

IV. HEAT EXCHANGER CONTROLS

This section covers control strategies for the heat exchange system, including control by manual, automated and humidity methods. Controls that allow for greater ventilation when desired are explained, as are recommendations for achieving adequate ventilation on a continuous basis.

Continuous, Low-speed Operation

To be assured of constant ventilation, controls that allow for continuous, low-speed operation of the heat exchanger may be the best choice. In this instance, the heat exchanger runs continuously throughout the heating season. If the machine's capacity is great enough, extra ventilation for kitchens and baths can be achieved with manual over-ride timer switches that turn the exchanger on high speed for a short period of time, and then allow the machine to revert to low speed. When extra ventilation is desired in general, these same manual switches can step-up ventilation to the desired level. (This illustrates, again, the importance of choosing a machine large enough to supply the extra level of ventilation.)

If the machine in question has only one speed, a speed controller usually can be installed to allow for variable speed operation. The low-speed mode should be chosen to allow for at least 0.5 ach (or the minimum level in some parts of California of 0.7 ach) when operating continuously. (This may demand some advice from the manufacturer after considering your ductwork scheme and other factors).

Continuous operation of the machine at low speed won't consume much energy if the heat exchanger's fans are the most efficient type. Fans that consume larger amounts of energy may increase the cost of continuous operation by up to four or five times that of the low-energy fan types.

Control by Percent Timer

Percent timers activate the machine for an adjustable pre-set percentage of each hour or segment of an hour. Percent timers allow for flexibility; this type of control can offer a wide range of ventilation from minimal, but regular operation to continuous operation. Thus, there may be little difference in ventilation between control by percent timer or simple continuous operation, although peak pollution times may not coincide with the time the machine is running under this type of control. Percent timer control might be the best choice for machines that run on only one speed—energy savings can result from regular, but not constant, high-speed operation.

Control by Humidity

Most manufacturers offer controls that operate the machine whenever humidity in the house reaches an unacceptably high level. Because tight houses with inadequate ventilation can suffer from high indoor humidity (often in the 50 to 60 percent range), these types of controls can alleviate excess moisture problems.

However, this type of control does not insure continuous or regular operation of the heat exchanger. Several cases have come to light that prove that, in some households, lifestyles are such that not enough moisture will be generated to activate the machine for several days at a time. This is more likely to be the case in families where all the adults work away from the home during the day or when there are few occupants in a large house.

Humidity control involves the use of a humidistat that is operated as a "dehumidistat" to activate the device when humidity reaches a pre-set (but adjustable) level (often 35 to 40 percent relative humidity). Humidity control is best used as a back-up control, not the main control system, unless the heat exchanger is being used only for control of excess moisture.

Summer Control

Heat exchangers can recover some coolness from outgoing air when run in warm weather. But, because heat exchangers are typically used to recover heat in cold-climate conditions, some machines are not really designed to be run in the summer.

Moisture in warm, incoming air may condense in the core under summertime conditions. However, at least one manufacturer has designed a machine that features condensation drains for both air streams in the core to allow for summer condensation to be drained. Consult the manufacturer about summertime operation and recommendations.

If the machine is to be off during the warmer seasons, the occupants should be aware that ventilation will need to be accomplished entirely through operable windows.

V. ECONOMICS

How cost-effective an air-to-air heat exchanger will be in your application depends on many factors. Economic performance of heat exchangers in tight houses depends on climate, the cost of fan energy consumed, machine efficiency, fuel cost for heating, lifestyle of the occupants and what they set the thermostat at, and the cost of the machine and installation.

Obviously, the extremely tight house, like all houses, must have some sort of ventilation to maintain a healthy environment. This ventilation could be provided with windows, doors or mechanical fans. But, ventilation with heat recovery can provide this ventilation at a substantially lower cost than simple mechanical or natural ventilation, which carries an energy cost penalty.

Basically, in the house without the heat exchanger one is paying 100 percent of the cost of heating air entering the house by natural means. In the house with a heat exchanger that is 70 percent efficient, one is paying roughly one-third of this cost of heating air for ventilation, plus the cost of fan energy and machine maintenance.

In addition, there is a benefit that is more difficult to put a price tag on: predictable, controllable and uniform ventilation, something that many conventional houses lack. In reality, it would be virtually impossible for the occupants to supply a continuous 0.5 ach by closely monitoring windows, doors and exhaust vents. Part of the time, ventilation would be less than this level, and part of the time ventilation would be greater. In contrast, the heat exchange system can supply 0.5 ach continuously, with little or no action on the part of the occupant. Thus, in extremely tight houses, the question of whether to use an air-to-air heat exchanger should not be decided on a simple economic basis alone; it is an essential component of this type of construction on a *ventilation* basis.

However, the air-to-air heat exchanger is usually a cost-effective investment in a superinsulated house, whether it is considered a separate investment or as a part of the total extra cost for superinsulation. Heat exchangers are meant for use primarily in the tightest of houses. Other somewhat tight houses may also need additional ventilation, but this may be better provided with the conventional ventilation methods available in most homes (windows and simple mechanical exhaust).

Heat exchanger economics in residential settings are quite sensitive to the cost of the machine and installation, fuel cost and climate considerations. Basically, the heat exchanger has been shown to be the most cost-effective in tight houses in cold climates (above 6,000 heating degree days a year), when the exchanger cost is about $1,200 or less (machine and installation), and when fuel costs are at or above the national average. In addition, the more ventilation the machine offers (let's say 80–90 percent of the house's total ventilation is provided by the heat exchanger), the better it will look economically.

Commercially available whole-house, ducted heat exchange systems currently range in price from roughly $1,100 to $2,500, including all installation and control costs (1983 prices). The average total cost is generally about $1,300–$1,500. In the late 1970s, it was thought that heat exchangers would be available in the $200–$500 range. Lack of demand and other factors have made for much higher prices, a situation that has further impeded the use of this technology. It is likely that prices will be reduced, if mass production techniques and improved marketing efforts are adopted by manufacturers.

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VI. CONCLUSION: TECHNOLOGY ASSESSMENT

The need for some type of energy-efficient ventilation in tightly built, northern climate houses is clear; this type of housing is rapidly gaining popularity across the Northern Tier states. Yet, lack of consumer and professional information and, to some extent, the inability of the manufacturers to reach and service the market is impeding the use of the only type of residential heat-recovery ventilation currently available in the United States: the air-to-air heat exchanger.

Work done in the DOE Small Grants projects illustrates that it is possible to build a highly efficient air-to-air heat exchanger that is an economically attractive way to provide ventilation in tightly built, cold-climate houses. And, a small number of manufacturers and building-trades professionals are currently capable of providing the machine and the service expertise needed to successfully use the technology.

But, the lack of demand for these devices, largely due to lack of consumer information, has made it apparently impossible for many small businesses in this field to make their products easily accessible to consumers. Product and service development is, for the most part, in its infancy, a situation that provides considerable barriers to the potential implementation of this technology.

Specific barriers to implementation include:

- **Lack of knowledge and awareness of the indoor air quality problems that may occur in tightly built houses.**

Most building-trades professionals, homeowners and occupants have little understanding of potential indoor pollution sources and how to best remedy them. Significant potential pollution sources are currently being incorporated into some tightly built housing, and little attention is being given to the ventilation needs for these houses. Old and new energy technologies are clashing; safety and health problems may arise from this lack of understanding and knowledge.

- **Lack of agreement among professionals about proper ventilation levels in housing.**

The advent of airtight housing construction techniques has brought a new question to the professional community: How much ventilation with outdoor air is needed to provide a healthy environment? Because of the disagreement in recommendations among professionals and researchers in this field, heat exchanger manufacturers have little guidance on how to best size their machines to meet the need.

Until more indoor air quality research is completed, and until more work is done with ventilation, heat exchanger manufacturers may produce and market machines that are improperly sized to meet the ventilation requirements of the majority of houses. In addition, the method of installation of the machines may make for less-than-desirable ventilation levels in some homes.

Initial research in infiltration and ventilation is indicating that ventilation may be inadequate at times in many conventionally built houses that rely mainly on infiltration for ventilation. At present, it is extremely difficult for builders to achieve a predictable air-change rate through conventional building processes, unless mechanical ventilation is installed. And, there is no mechanism to determine when conventional houses should be tested or retrofitted with improved ventilation systems.

Some researchers argue that until a large, random-sample baseline infiltration-ventilation study is done on a national scale, agreement and recommendations on many of these points will be impossible.

- **Lack of standardized testing for residential-scale ventilation systems.**

Some nations are developing standardized testing of residential-scale heat-exchange ventilation equipment, but no such work is being done in the United States at present. This lack of standardization makes it difficult for the consumer to compare features, capacity and effectiveness of the available machines.

- **Lack of design and installation assistance and adequate consumer information.**

Most manufacturers simply make and market a machine, not a ventilation system. A thorough product search revealed that while there are more than 20 manufacturers of residential-scale air-to-air heat exchangers in the United States, only a few provide enough information, service and assistance to make this technology readily available to consumers. Professionals and builders who may wish to employ heat exchangers in housing often have little guidance on what to do after the machine arrives. The machine's installation, controls and servicing are often left solely to the buyer. Significant product research and development appears to be needed, yet few manufacturers have the resources to provide this vital link.

- **Lack of appropriate control technology.**

More research is needed to provide reliable control of air-to-air heat exchangers in the residential setting. The problem is two-fold: no national ventilation norms exist, and most manufacturers' control packages (or lack of them) are such that the buyer has little guidance on what level of ventilation is actually being accomplished by the machine. Although current technology and design tools exist to gain working control over the machines, manufacturers need to develop simple, reliable controls that are easily installed and operated. Several DOE Appropriate Technology grantees developed microprocessor and electronic controls to save energy through controlled appliance and heating operation. Exchanger manufacturers might consider exploring the possibility of adding heat exchanger controls to existing home-energy control technology similar to those currently available or those developed in the DOE projects.

Lessons from Abroad

Because of cold climate and high energy costs, some nations have done considerable research into the field of tight houses and heat-recovery ventilation. Sweden is notable in this regard: this nation adopted mandatory ventilation standards several years ago, and a significant amount of research has been directed toward controlled ventilation, as opposed to ventilation through infiltration.

Research in Sweden has indicated that the air-to-air heat exchanger provides excellent ventilation in extremely tight houses, but airflows may be short-circuited in houses that are not extremely tight. To provide heat-recovery ventilation for this second group of houses, the Swedes developed a system that is not as sensitive to air pressure changes and air leakage through the building shell.

This substitute for the air-to-air heat exchanger has been developed and marketed in Sweden for several years. This system, simply known as controlled mechanical ventilation, entails the installation of small slot vents in the top casings of the windows or through the walls in each room. The slot vents can be adjusted, but never completely closed off. Mechanical exhaust fans in bathroom and kitchen, operated by controls, negatively pressurize the house, forcing air to enter the home through the slot vents. Exhaust air is run over the coils of a heat pump that produces domestic hot water and in some cases, space heat, as well.

This system has been found to provide good ventilation, and it can provide hot water year-round, as well as meet the Swedish ventilation code which calls for a continuous 0.5 ach. It is thought to be cost-effective in more moderate climates, as well (Figure 17).

This technology is not currently available in the United States, although United States heat pump technology is easily at the level where this type of system should not be difficult to employ.

Obviously, work with heat-recovery ventilation for energy-efficient housing is just beginning in the United States, and considerable research and development and consumer education are needed to employ known or available technologies toward this end.

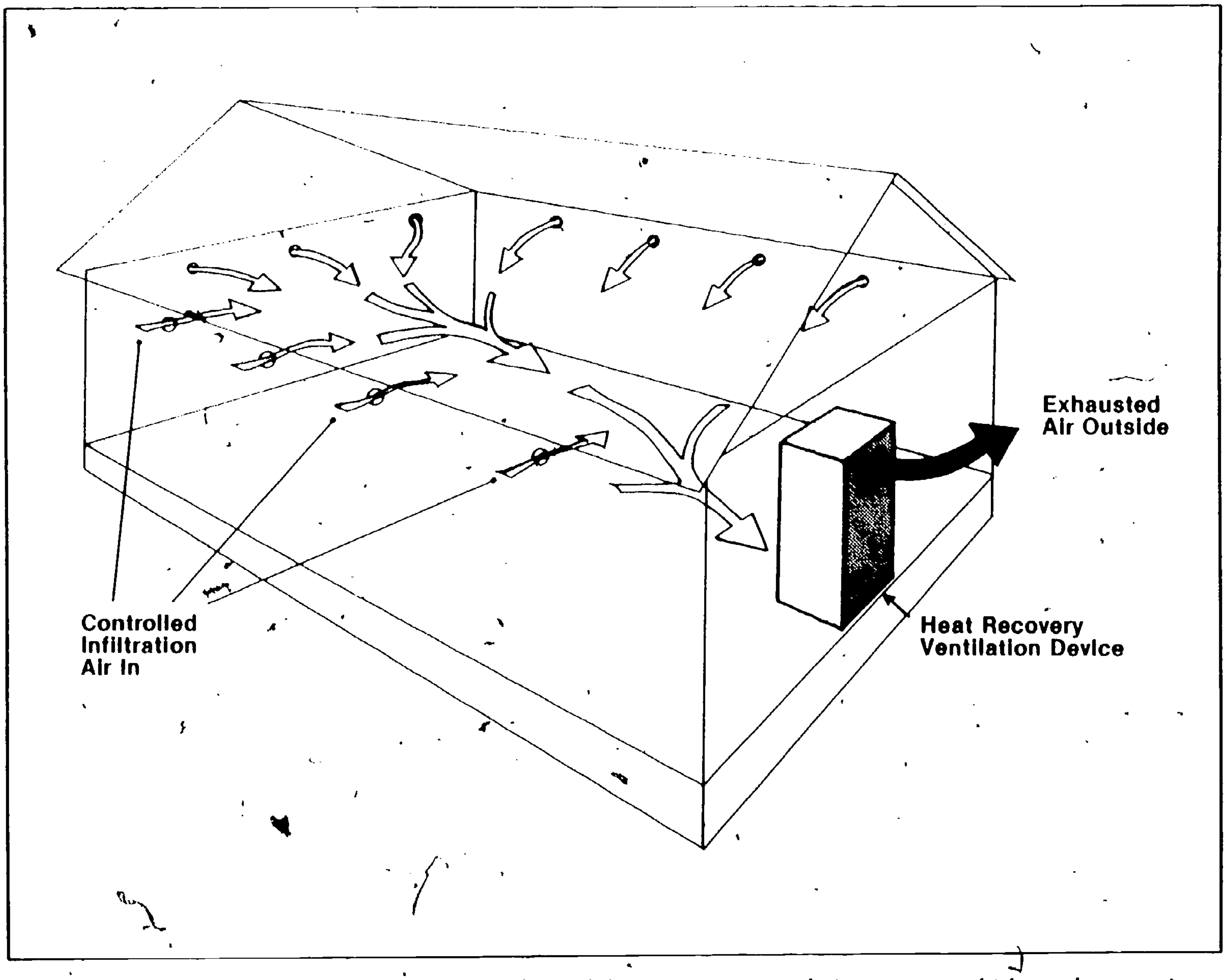

FIGURE 17: *This simplified drawing illustrates the Swedish heat-recovery ventilation system, which employs an air-to-water heat pump. Fresh air is drawn through small vent holes placed high on the walls by a fan, which pulls stale, warm air over the coils of a heat pump. The recovered heat is used to warm domestic water.*

APPENDIX A
RELATED DOE APPROPRIATE TECHNOLOGY GRANT PROJECTS

The following grant projects were among those reviewed in course of the development of this publication. Grant projects are divided into groups according to technology and end-use.

Agricultural use of air-to-air heat exchangers

Heat Exchanger Application to a Farrowing House Barn
John S. Clay
Virginia Settlers Energy Center
Blacksburg, VA
DOE Region III
DOE Grant No. DE-FG43-79R306102
ATMIS ID: VA-79-005

An air-to-air heat pipe heat exchanger was installed in a swine barn to reduce ventilation heating demands and improve air quality thus improving livestock production.

Improved Poultry House
Thomas D. Harris
Auburn, AL
DOE Region IV
DOE Grant No DE-FG44-80R410079
ATMIS ID: AL-79-002

A feasibility study is presented investigating improvements to the heating, ventilating, and air conditioning requirements of poultry production housing facilities.

A Heat Recovery System for Grain Drying
Elmer B. Oberbroeckling
New Vienna, IA
DOE Region VII
DOE Grant No. DE-FG47-80R701115
ATMIS ID: IA-80-016

A prototype air-to-air heat exchanger system was installed on a corn-drying bin to reduce purchased energy for drying corn.

Residential applications for air-to-air heat exchangers

Development of Low-Cost Air-to-Air Heat Exchangers
The Memphremagog Group
Blair Hamilton
Newport, VT
DOE Region I
DOE Grant No. DE-FG41-80R110348
ATMIS ID: VT-80-004

This project involved development of a residential-scale air-to-air heat exchanger from theoretical design work through prototype construction and field testing to the point of commercial readiness. A second (greenhouse scale) unit was developed to the final field test stage, and successfully tested in an agricultural setting.

Low Infiltration-High Insulation House Construction
Churchill Construction, Inc.
E. Joe Churchill
Macomb, IL
DOE Region V
DOE Grant No. DE-FG02-79R510111
ATMIS ID: IL-79-004

This grantee, a contractor, built a superinsulated house and employed a home-built air-to-air heat exchanger for humidity control.

Thermal Efficiency Construction Demonstration
Richard P. Bentley
Tupper Lake, NY
DOE Region II
DOE Grant No. DE-FG42-79R205035
ATMIS ID: NY-79-024

This project involved detailed monitoring of the thermal and air leakage performance of a superinsulated house. Particular attention was paid to ventilation and infiltration measurement.

Testing an Air-to-Air Heat Exchanger Attached to a Residential Clothes Dryer
Alan H. Boner
Eugene, OR
DOE Region X
DOE Grant No. DE-FG51-81R001317
ATMIS ID: OR-81-003

A prototype air-to-air heat exchanger was tested as an energy recovery device attached to a residential clothes dryer.

Residential use of heat recovery

Heat Recovered From Domestic Refrigerator for Water Heating
Hawaii Natural Energy Institute
James C.S. Chou
Honolulu, HI
DOE Region IX
DOE Grant No. DE-FG03-78R901938
ATMIS ID: HI-78-006

The concept of adding a water-cooled condenser to a household refrigerator for preheating domestic hot water was tested in a laboratory. Indications are that including this feature at point of manufacture holds promise, but design complexity and the wide variety of available refrigerators precludes easy employment of the technology by consumer modification of the appliances.

Recovery to Preheat Domestic Hot Water
Wayne W. Monroe
Windsor, CO
DOE Region VIII
DOE Grant No. DE-FG48-79R800438
ATMIS ID: CO-79-009

This project involved collecting hot attic air and circulating it through a duct system to a heat exchanger to preheat domestic hot water.

Attic Heat for Passive Preheating Domestic Hot Water
Edward T. Knudsen, Jr.
St. Petersburg, FL 33710
DOE Region IV
DOE Contract No. DE-FG44-80R410098
ATMIS ID: FL-79-012

Commercial fin-tube convectors were used as heat exchangers and installed in a garage attic. The attic heat was used to preheat the water coming into the standard water heater.

Solar Assisted Clothes Dryer
James M. Stana
Longwood, FL 32750
DOE Region IV
DOE Grant No. DE-FG44-80R410101
ATMIS ID: FL-79-003

This project investigated the possibility of inexpensively ducting attic hot air to an electric residential clothes dryer to reduce electrical energy usage.

Commercial use of heat recovery

Bakery Oven Flue Heat to Heat Domestic Hot Water
Clever Hans Bakery
Jonathan A. Bernstein
Ithaca, NY
DOE Region II
DOE Grant No. DE-FG42-80R205181
ATMIS ID: NY-80-011

A small bakery demonstrated the use of a heat exchanger to recover oven flue heat for use in heating water for bakery use.

Bakery/Restaurant Oven Waste Heat Recovery Design Software
Philip Theisen and James McCray
Madison, WI
DOE Region V
DOE Grant No. DE-FG02-80R510251
ATMIS ID WI-80-005

The grantee developed computer software (Fortran language) for analyzing air-to-air heat recovery systems for gas-fired restaurant/bakery ovens.

Waste Heat Recovery System for Commercial Cooking Appliances
Hydrocoil Mfg. Co.
R.J. Jones
Los Alamitos, CA
DOE Region IX
DOE Grant No. DE-FG03-78R901916
ATMIS ID CA-78-023

Waste heat recovery from restaurant gas-fired cooking appliances was demonstrated in this project. Flue gas waste heat was recovered and used to reduce water heater gas consumption.

Commercial Laundromat Waste Heat Recovery from Clothes Dryers
Energy Center, Sonoma State University
Roy Irving
Rohnert Park, CA
DOE Region IX
DOE Grant No. DE-FG03-78R901906
ATMIS ID: CA-78-021

The project objective was to study the feasibility of recovering waste heat from clothes dryers to preheat hot water for washing. A small-scale prototype system which included an air-to-liquid heat exchanger, 200-gallon preheat tank and interconnecting piping was designed. Specific problems addressed were economic feasibility, lint contamination and natural convection of water circulation.

Commercial Laundromat Recycles Waste Heat to Preheat Water
Saunders & Sons Enterprises
Earnest Saunders
Westerly, RI
DOE Region I
DOE Grant No. DE-FG41-80R110392
ATMIS ID: RI-80-002

A laundromat recycled waste heat from 10 commercial dryers to preheat the water used for washing. A manifold system was designed using a rubber tube mat originally developed as a solar collector material. The components have minimal problems with lint accumulation and are easy to clean—both distinct advantages over finned-tube heat exchangers. Annual energy savings of over 50 percent were noted by the grantee in the report.

Waste Heat Recovery and Solar Water Preheating in Coin Laundries
Nolan E. Cloud,
Winterville, GA
DOE Region IV
DOE Grant No. DE-FG44-80R410263
ATMIS ID: GA-80-001

Two coin laundries in Winterville, Georgia were retrofitted with dryer waste heat recovery devices and solar panels to preheat wash water. One additional laundry was equipped with the waste heat recovery device. An air-to-liquid heat exchanger is used in the dryer exhaust duct. Water is sprayed periodically on the fin tubes of the heat exchanger to remove accumulated lint.

Waste Water Energy Recovery Heat Exchanger
Crump Products, Inc
Robert F. Crump
Louisville, KY
DOE Region IV
DOE Contract No. DE-FG44-80R410171
ATMIS ID: KY-79-002

A patented water heat exchanger apparatus, suitable for actively used commercial dishwashers and/or commercial laundry equipment, was refined and evaluated for energy savings, both theoretically and with on-site testing.

Fluid Coil Heat Recovery Loop System
YWCA/YMCA
Darrell F. Huggins
LaCrosse, WI
DOE Region V
DOE Contract No. DE-FG02-79R510160
ATMIS ID: WI-79-004

The grantee demonstrated the use of a liquid-to-air heat exchanger system to recover heat from the ventilation exhaust of a YWCA/YMCA locker room and use it to preheat cold, incoming fresh air.

Residential Dryer Exhaust Energy Reclamation
Dryermate Company
Dennis M. Swing
Xenia, OH
DOE Region V
DOE Grant No. DE-FG02-79R510145
ATMIS ID: OH-79-010

A demonstration program was implemented to determine, by actual in-home testing, the advantages and disadvantages of indoor venting of ordinary residential clothes dryers. Fifty-two homes were equipped with energy devices. An opinion survey was conducted.

APPENDIX B
HEAT EXCHANGER MANUFACTURERS

The following list shows manufacturers in North America who make residential-scale air-to-air heat exchangers of various types. Inclusion in this list is in no way to be construed as an endorsement of any manufacturer or product by NCAT, DOE, or the authors.

ACS-Hoval
935 N. Lively Blvd.
Wooddale, IL 60191
(312) 860-6860

The Air Changer Co. Ltd.
334 King St., East
Suite 505
Toronto, Ontario, Canada
M5A 1K8
(416) 947-1105

Airxchange, Inc.
30 Pond Park Rd.
Hingham, MA 02043
(617) 749-8440

Aldes-Riehs
157 Glenfield Road R.D. 2
Sewickley, PA 15143
(412) 741-2659

Berner International Corp.
216 New Boston Street
Woburn, MA 01801
(617) 933-2180

Blackhawk Industries, Inc
607 Park St.
Regina, Saskatchewan
Canada, S4N 5N1
(306) 924 1551

Bossaire Inc
415 W. Broadway
Minneapolis, MN 55411
(612) 521-9033

Conservation Energy Systems Inc.
800 Spadina Crescent East
P.O. Box 8280
Saskatoon, Saskatchewan
Canada, S7K 6C6
(306) 665-6030

Des Champs Laboratories, Inc.
Box 440
17 Farinella Drive
East Hanover, NJ 07936
(201) 884-1460

Ener-Corp Management Ltd.
Two Donald St.
Winnipeg, Manitoba
Canada, R3L 0K5
(204) 477-1283

EER Products, Inc.
4501 Bruce Ave.
Minneapolis, MN 55424
(612) 926-1234

Heatex, Inc.
3530 East 28th Street
Minneapolis, MN 55406
(612) 721-2133

Memphremagog Heat
Exchangers, Inc.
P.O. Box 456
Newport, VT 05855
(802) 334-5412

Mitsubishi Electric Sales
America, Inc.
3030 East Victoria St.
Rancho Dominguez, CA 90221
(800) 421-1132

Mountain Energy & Resources, Inc.
15800 West Sixth Ave.
Golden, CO 80401
(303) 279-4971

Nutech Energy Systems, Inc.
P.O. Box 640
Exeter, Ontario
Canada, N0M 1S0
(519) 235-1440

Nutone Housing Group
Scovill Inc.
Madison and Red Bank Roads
Cincinnati, OH 45227
(513) 527-5112

P.M. Wright Ltd.
1300 Jules Poitras
Montreal, P.Q.
Canada, H4N 1X8
(514) 337-3331

Q-dot Corp.
701 North First St.
Garland, TX 75040
(214) 487-1130

RayDot Inc.
145 Jackson Ave.
Cokato, MN 55321
(612) 286-2103

Solatech Inc.
1325 East 79th Street
Minneapolis, MN 55420
(612) 854-4266

X Change Air Corp.
P.O. Box 534
Fargo, ND 58107
(701) 232-4232

Plans

Home-built exchanger plans:
U-Learn
Extension Division
University of Saskatchewan
Saskatoon, Saskatchewan
Canada S7N OWO
(306) 343-5974

APPENDIX C READING LIST

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APPENDIX D
CURRENT VENTILATION STANDARDS

Two standards apply to residential ventilation levels. The first standard, Ventilation for Acceptable Air Quality, was adopted by the American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc. (ASHRAE) in 1981. The purpose of the standard is to specify minimum ventilation rates that will provide air quality that is acceptable to the occupants and will not impair health.

The following table shows the ASHRAE Ventilation standards as they apply to residential buildings. Note that the standards are specified in cubic feet per minute (cfm) and liters per second (L/s) rather than air changes per hour (ach) and are independent of the size of the room being ventilated.

The ASHRAE standard specifies that if outdoor air quality does not meet applicable federal or state standards, air cleaning should be employed. In addition, the air delivery rates specified are assumed to be continuous, regardless of outdoor weather conditions.

The second standard that pertains to indoor air quality is the U.S. Department of Housing and Urban Development (HUD) Minimum Property Standard. HUD Minimum Property Standards apply to federally financed home construction and to homes purchased with federally insured loans. The 1979 revision of this standard set intermittent exhaust rates in kitchens and bathrooms at 15 and 8 ach respectively. The standards also call for ventilation by infiltration or other means of 0.5 ach, as well as natural ventilation through operable windows, which must have a total area of at least one-twentieth of the floor area of the room.

Some confusion may exist concerning these ventilation standards since the ASHRAE ventilation standard is specified in cfm and the HUD Minimum Property Standard in ach; however, it is easy to convert the ASHRAE standard into an air exchange rate. The procedure is as follows:

1) determine the number of rooms in your house, the total floor space area, and the height of your ceiling
2) multiply the total number of rooms in your house by 10 cfm to determine the total ventilation rate required by the ASHRAE standard
3) multiply the number obtained in 2 above by 60 to determine the hourly ventilation rate in cubic feet
4) multiply the floor space area of your house by the height of your ceilings to determine the volume of air space in your house
5) divide the hourly ventilation rate (in cubic feet) into the volume of air space in your house (also in cubic feet) to determine the air exchange rate required by the ASHRAE ventilation standard for your house.

OUTDOOR AIR REQUIREMENTS FOR VENTILATION
Residential Facilities
(Private dwelling places, single or multiple, low or high rise)

	Outdoor Air Requirements		Comments
(NOTE: Operable windows or mechanical ventilation shall be provided for use when occupancy is greater than usual conditions or when unusual contaminant levels are generated within the space.)			
	cfm/room	L/s room	
General living areas	10	5	
Bedrooms	10	5	Ventilation rate is independent of room size
All other rooms	10	5	
Kitchens	100	50	Installed capacity for intermittent use
Baths, toilets	50	25	
Garages (separate for each dwelling unit)	cfm/car space 100	L/s car space 50	
Garages (common for several units)	cfm/ft^2 floor 1.5	L/s m^2 floor 7.5	

For example, let's convert cfm to ach for a 1,200 square-foot, six-room house with 8-foot ceilings and no basement or garage.
The total ventilation rate required is 6 (rooms) × 10 cfm = 60 cfm
The hourly ventilation rate is 60 min/hr × 60 cfm = 3,600 cf/hour
The volume of air space in the house is 1200 ft^2 × 8 ft. = 9,600 cf

and the air exchange rate is

$$\frac{3600 \text{ cf/hr}}{9600 \text{ cf}} = .375 \text{ ach}$$

Additional local exhaust ventilation is, of course, required in the kitchen and bathroom. And, operable windows are required for additional ventilation throughout the house. Assuming that occupants will use this local exhaust capability, as well as contribute to ventilation by opening windows and doors, ASHRAE estimates that its standard will result in an overall air change rate of 0.5 to 1 ach. But, note that our example doesn't count these additional ventilation sources.

By setting its standard in terms of cubic feet per minute per room, ASHRAE didn't set a definite ach standard, such as HUD's 0.5 ach standard. Under the ASHRAE standard, ventilation doesn't increase by the sheer size of the house, but rather by the number of rooms in the home.

Thus, these ventilation rates would be the same—60 cubic feet per minute or 3,600 cubic feet per hour for any home with six rooms. Note that for a smaller, 1,000-square-foot, six-room home, the *ach* would calculate to be greater than in our 1,200-square-foot home. And, of course, the ach would be less in a larger, six-room 1,600-square-foot home.

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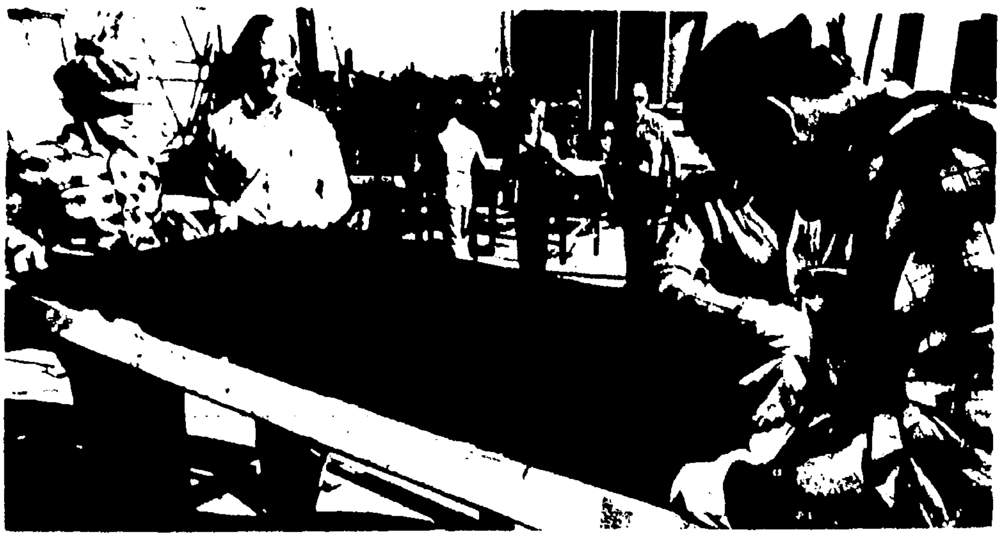

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James Madison
MARINES