AIR-TO-AIR HEAT RECOVERY DEVICES FOR SMALL BUILDINGS

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ABSTRACT

With the escalation of fuel costs, many people are turning to tighter, better insulated buildings as a means of achieving energy conservation. This is especially true in northern climates, where heating seasons are long and severe. Installing efficient well sealed vapor barriers and weather stripping and caulking around doors and windows reduces cold air infiltration but can lead to damaging moisture buildup, as well as unpleasant and even unhealthy accumulations of odors and gases. To provide the necessary ventilation air to maintain air quality in homes while holding down energy costs, air-to-air heat exchangers have been proposed for residential and other simple structures normally not served by an active or forced ventilation system.

Four basic types of air-to-air heat exchangers are suited for small scale use: rotary, coil-loop, heat pipe, and plate. The operating principles of each of these units are presented and their individual advantages and disadvantages are discussed. A test program has been initiated to evaluate the performance of a few commercial units as well as several units designed and/or built at the University of Alaska. Preliminary results from several of these tests are presented along with a critique on their design.

INTRODUCTION

Increased concern for energy conservation due to rapidly rising energy costs has focused attention on building design and operation. In years gone by, architectural features and construction cost considerations dominated building design. Consequently, buildings were designed without much concern over their annual energy budget. Energy conservation in design has become a more important factor now and as a result buildings are being built with more insulation to reduce transmission heat losses and tighter construction to reduce infiltration heat losses. A need to mechanically ventilate homes and small buildings has arisen due to these improvements in insulation and building construction standards which have produced tighter structures. As heating costs have risen, it has become economic to seal a structure to the point where building air leakage may only permit 0.1 air change per hour or less. These low values of air exchange are far below the 0.5 to 1.0 air exchange rates typical of older buildings. The use of mechanical ventilation in these newer structures is a must to ensure that humidity, odor, and other contaminants do not build up to harmful levels.

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Indoor pollutants which have been found in structures [1] includes:

1. Formaldehyde - a bonding agent used in plywood and particle board as well as in foam insulation and foam padding in furniture.
2. Nitrogen dioxide and carbon monoxide - fumes from gas cook stoves and portable unvented heaters.
3. Soot particles and benzopyrene - cigarette, pipe and cigar smoke.
4. Radon - a radioactive gas produced from soil and rock based building materials as well as water taken directly from underground wells. This noble gas is a daughter product of radium-226 and appears as part of the uranium-238 decay chain.

In addition to these pollutants, high humidity levels often occur in tightly sealed buildings. The sources of this moisture are breathing, bathing, cooking, and washing. High humidities can lead to degradation of building materials due to condensation and/or frost formation in cold climate regions. Water and ice formation on windows and window sills or frost accumulation in insulation due to a faculty vapor barrier are more common in the well sealed structures.

Several solutions to the indoor pollution problem are possible which include:

1. Installation of a mechanical ventilation system incorporating an air-to-air heat exhanger to increase outdoor ventilation air in order to dilute contaminants and also transfer thermal energy form the exhaust air stream to the fresh outdoor air stream.
2. Selection of building materials in new construction which do not produce potentially harmful gases.
3. Installation of a filtering system to remove specific pollutants.
4. Installation of sealing or venting devices at the time of construction to eliminate the harmful contaminates at their source.

The focus of this paper is on the first measure mentioned. It appears on the surface that the mechanical ventilation system incorporating an air-to-air heat exchanger is also the most attractive economically.

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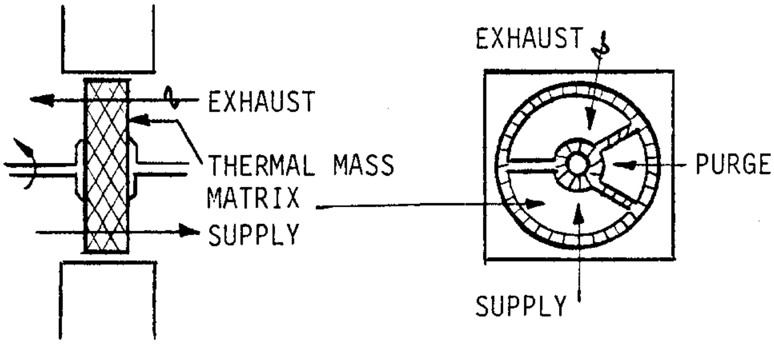
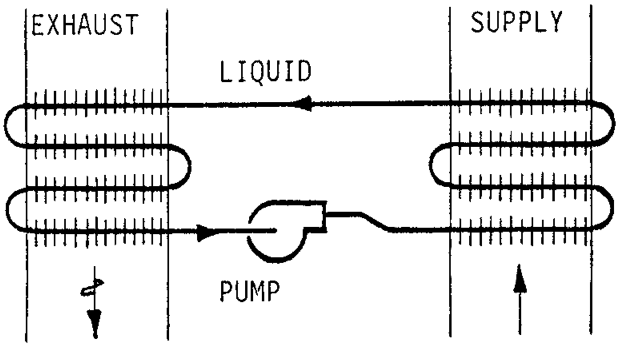
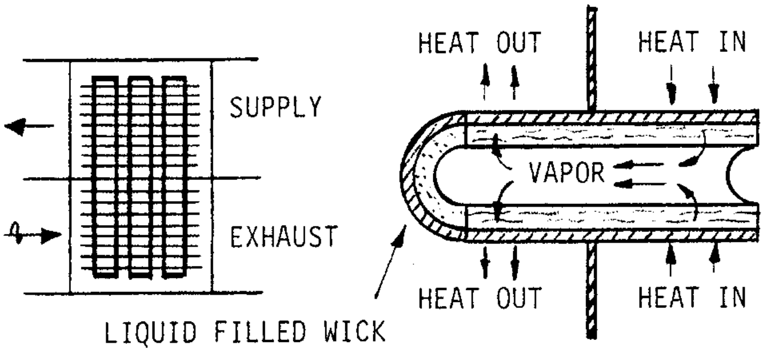
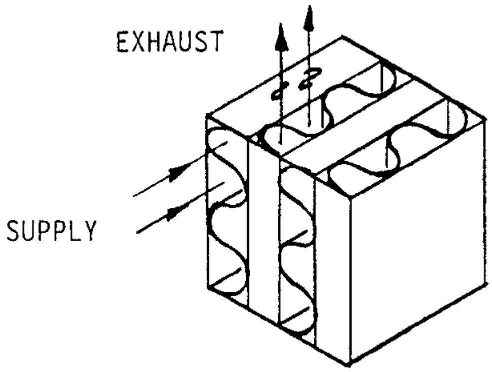
at exchangers are shown in
Fig. 1, with a description of their dual features. The following
paragraphs provide a more in-depth description of each type.

a. Rotary Heat Exchanger This is a porous wheel through which the exhaust and supply air streams flow. As the cylinder rotates it is alternately heated and cooled by the air streams. If latent heat transfer is also desired the wheel material is treated with a hygroscopic substance. Some cross contamination can occur between the two air streams which can be almost entirely eliminated by including a purge section. Defrosting of the wheel can be accomplished by rotational speed control. Supply and exhaust air ducting must be brought together at the wheel.

b. Coil-Loop Run-Around Heat Exchanger This system uses a standard liquid-to-air finned-tube coil with a pump to circulate a water-glycol mixture. Sensible heat only is transferred between the air streams by the circulated liquid. Frost buildup in the coil can be controlled by intermittent operation or a three way control valve using recirculation. No cross contamination between air streams occur✓and the supply and exhaust air streams can be widely separated. Ease of installation, simplicity, and low maintenance have made this system attractive.

c. Heat Pipe Heat Exchanger This system is composed of a set of finned tubes. The supply and exhaust air streams are seperated by a baffle and the flow is normal to the heat pipes in a counterflow fashion. The tubes, heat pipes, contain a working fluid such as freon, carbon dioxide, or ammonia which boils or vaporizes on the hot side and condenses on the cold side of the exchanger. The vapor travels from the warm to the cold end of the tube through its core because of the pressure difference created between the evaporating and condensing ends of the pipe. The liquid returns to the evaporation end by capillary flow in a wick material placed inside of the tube. The heat transfer rate through the tube can be controlled by the tilt

SCHEMATIC	FEATURES
	ROTARY SENSIBLE AND LATENT HEAT RECOVERY. MINIMAL CROSS CONTAMINATION PURGE SECTION REQUIRED MECHANICAL DRIVER REQUIRED FROSTING LIMITATIONS CLOSE PROXIMITY OF SUPPLY AND EXHAUST.
	COIL LOOP RUNAROUND SENSIBLE HEAT RECOVERY NO CROSS CONTAMINATION PUMP REQUIRED FROST CONTROL AVAILABLE FLEXIBILITY OF SUPPLY AND EXHAUST.
	HEAT PIPE SENSIBLE HEAT RECOVERY NO CROSS CONTAMINATION NO PUMP OR DRIVES REQUIRED FROST CONTROL AVAILABLE CLOSE PROXIMITY OF SUPPLY AND EXHAUST.
	PLATE SENSIBLE HEAT RECOVERY NO CROSS CONTAMINATION NO PUMP OR DRIVES REQUIRED FROST CONTROL AVAILABLE CLOSE PROXIMITY OF SUPPLY AND EXHAUST.

of the tube. Placing the warm end down provides a gravity assist to returning the condensate thereby increasing the heat transfer rate. The heat pipe unit only recovers sensible heat. Frost and temperature control can be performed by tilting the tubes or using by-pass air. These techniques, however, are usually used in large commercial units. In a small structure, intermittent operation would be the most economical approach.

d. Plate Type Heat Exchanger This system contains multiple plates separating the supply and exhaust air streams which pass through the exchanger in either a cross-flow or counterflow arrangement. Metal, plastic, or paper have been used as the transfer surface. Sensible and however, short circuiting can occur between supply and exhaust air inlets and outlets with improper design.

HEAT RECOVERY DEVICE PERFORMANCE

Air-to-air heat exchangers used in heat recovery applications have historically been rated based on a term called efficiency. However, when the mass flow rates in the exhaust and supply air sides are not equal, the efficiency measure can lead to erroneous results. This efficiency is defined as:

$$\eta = \frac{(X_1 - X_2)}{(X_1 - X_3)} \tag{1}$$

where X represents the dry-bulb temperature, enthalpy or humidity ratio of the entering and leaving air streams as shown in Fig. 2. The term η is then the sensible, total, or latent efficiency, respectively.

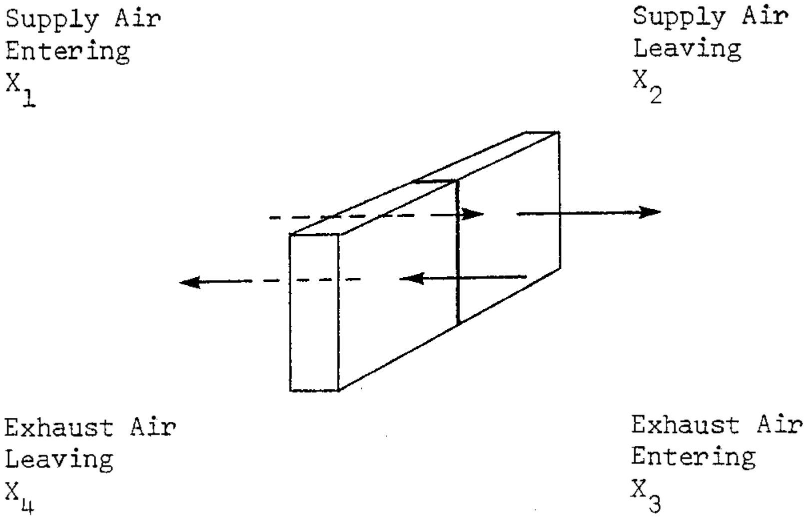


Fig. 2 Schematic diagram of air-to-air heat exchanger.

A more accurate description of the heat exchangers performance is the effectiveness which is defined as:

$$\varepsilon = \frac{m_s (X_1 - X_2)}{m_{min} (X_1 - X_3)} \qquad (2)$$

where ε is the sensible, latent, or total effectiveness, m_s and m_e the supply and exhaust air mass flow-rates, and m_{min} the minimum of m_s or m_e.

The effectiveness definition reduces to equation (1) when the mass flow-rates are equal on both sides of the heat exchanger such that the effectiveness and efficiency are identical.

POTENTIAL ENERGY SAVINGS

The potential energy savings produced by an air-to-air heat recovery device depends on numerous factors. The most obvious are the duration and severity of the heating season, length of time of operation, quantity of outdoor ventilation air required, local weather conditions, frosting within the heat exchanger, etc. It must be remembered that the use of an air-to-air heat exchanger will result in an increase in the heating/energy requirements in a well sealed structure. In small buildings that have sufficient natural ventilation due to infiltration-exfiltration, an air-to-air heat exchanger is not recommended at all.

The potential energy savings for a 2,000 sq. ft., single story structure, assuming that 0.5 air changes per hour (ACPH) are required, can be estimated. This air exchange rate is equivalent to a volumetric flow rate of 133 cfm. Further, it is assumed that 33 cfm is provided by natural infiltration. Then the required flow through the heat recovery device is 100 cfm. The energy saved can easily be calculated as:

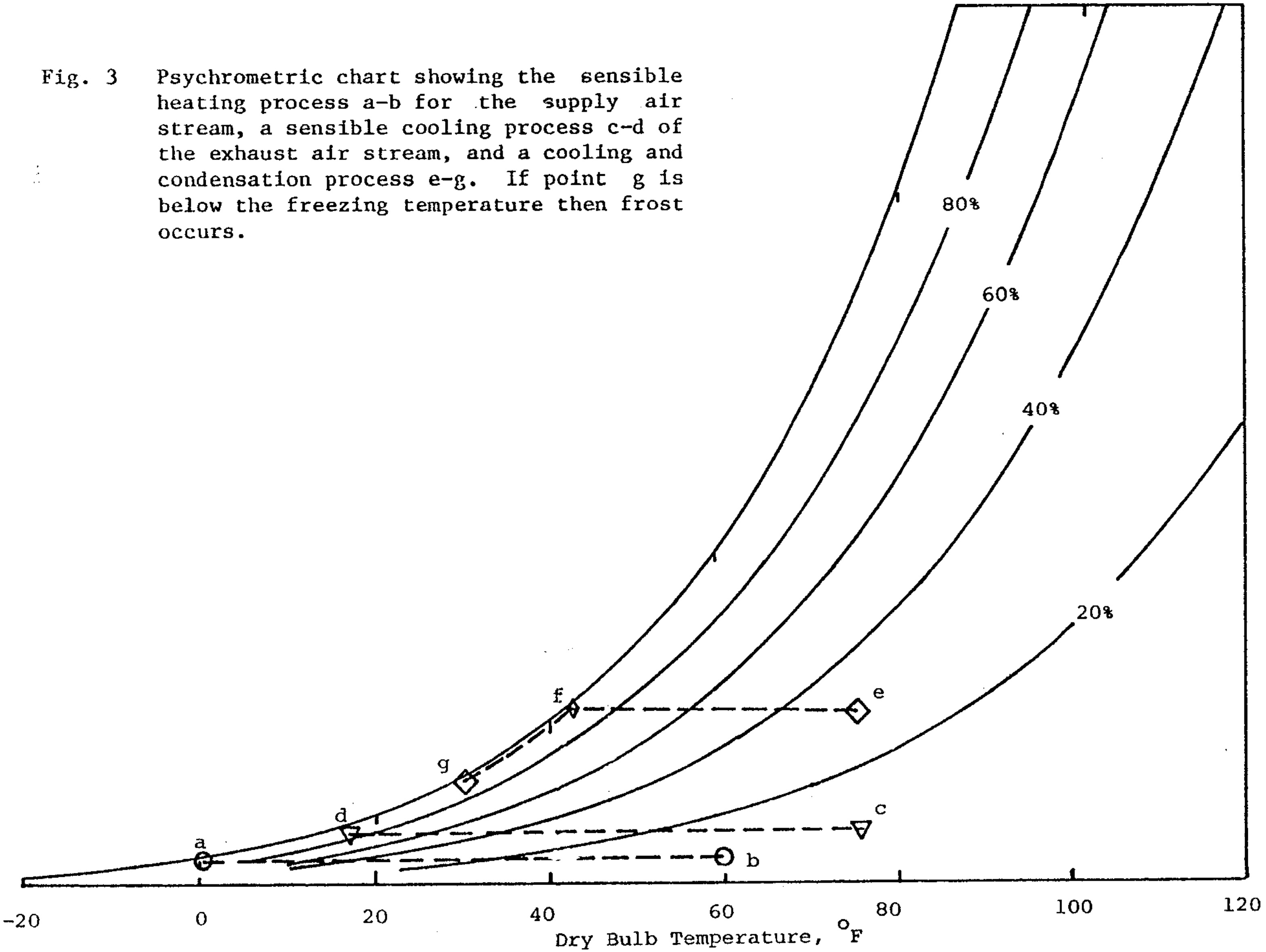
$$E = .26\eta\, V(H.I.) \qquad (3)$$

where E is Btu/year; η is thermal efficiency, %; V is volumetric flow rate, cfm; and H.I. is the total degree-days accumulated during the heating season, °F-day. For central interior Alaska with a 12,000 °F-day heating season (September - April) a savings of 20×10^6 Btu is possible assuming 24 hour per day operation, unit efficiency of 65% and at flow rate of 100 cfm. This energy savings is equivalent to 200 gallons of fuel oil assuming a heating system efficiency of 70%.

FROSTING PROBLEMS

Frosting is a problem in all four types of units described in a previous section. Whether or not frosting or condensation occurs depends upon the indoor and outdoor temperatures as well as the indoor relative humidity. Shown in Fig. 3 is a psychrometric chart with the heating process for the cold air stream shown as curve a-b. Warming the cold air in the heat exchanger results in a decrease in the relative humidity although the absolute humidity remains constant. Curve c-d shows the cooling of the warm air stream without condensation or frosting. Increasing the indoor relative humidity results in condensation as shown by curve e-g at point f. If the temperature between f and g is below the freezing temperature, then frosting occurs.

Fig. 3 Psychrometric chart showing the sensible heating process a-b for the supply air stream, a sensible cooling process c-d of the exhaust air stream, and a cooling and condensation process e-g. If point g is below the freezing temperature then frost occurs.



Condensation in the heat exchanger is not a serious problem as long as a water drip pan and drain have been included in the design and the heat exchange element is not damaged by water. Frosting, however, results in a decrease in the flow rate through the unit as the flow area is reduced. In addition, the performance of the unit decreases as a result of the insulating effect of the frost layer.

SMALL SCALE HEAT EXCHANGERS

The Besant [4] exchanger is shown in Fig. 4. This is a build-it-yourself unit constructed of 1/2 inch plywood using 6 mil polyethlene sheets for the plate type heat transfer surfaces. The drawer, partly open at the bottom of the picture, serves as a condensate reservoir. It could easily be modified to accept a drain line. The view of the bottom of the unit in Fig. 5 shows the 1/2 inch plywood serving as frames and spacers for the polyethlene sheets. The unit is 90 inches high, 24 inches deep and 18 inches wide. It was found during testing that it was necessary to insulate the unit to avoid condensation/frost buildup on the outside surfaces. Construction time for the Besant unit was 30 hours if all necessary wood working equipment are available. The materials for the heat exchanger and the supply and exhaust air fans totaled $250.

A Canadian manufactured commercially available air-to-air heat exchanger [5] is shown in Fig. 6. This unit is similar to the Besant design except the outer housing is a fiberglass shell. A drain has been included at the bottom of the unit. The supply and exhaust fans with controls are a part of the package. The total price F.O.B. Fairbanks was approximately $800.

A second Canadian manufactured air-to-air heat exchanger [6] is shown in Fig. 7. This unit again is a spin-off from the Besant design except in this case the housing is galvanized sheet metal. A drain is included at the bottom of the unit and the supply and exhaust fans have been premounted. Thermostat and humidistat controllers have also been premounted on the unit to provide for automatic defrosting. The F.O.B. Fairbanks price was about $750.

A small heat pipe coil manufactured by the Q-Dot Corporation [9] is shown partially out of the duct housing in Fig. 8. The galvanized sheet metal housing was designed and fabricated in Fairbanks. In contrast to the three previous described units, this exchanger is much smaller in size. Also, the coil being made of aluminum, lends itself to cleaning, should the surfaces become fouled with dust, lint, dirt, grease, etc. It is estimated that the coil, housing and fans would cost $350 as a package purchase.

Fig. 9 shows the Lossnay [7] heat exchanger manufactured by Mitsubishi Electric Company in Japan. The cross-flow plate type heat transfer element is also shown in this picture. This element is made of paper and allows both sensible and latent transfers of energy. The unit is designed for through the wall mounting and is totally self-contained having multi-speed supply and exhaust fans installed in the unit. No drain provisions have been included and the paper element experienced shrinkage when it dried out after being saturated with moisture due to

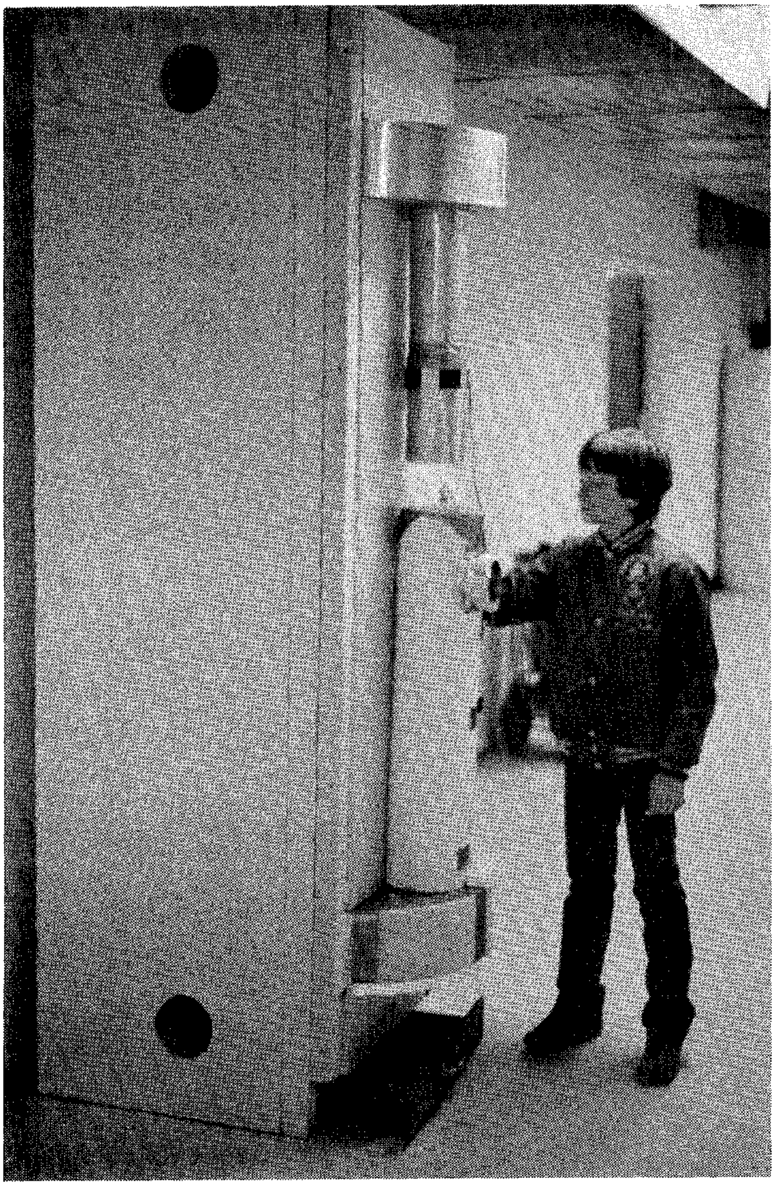


Fig. 4 Air-to-air heat exchanger built from plans developed by Besant [4] at the University of Saskatchewan.

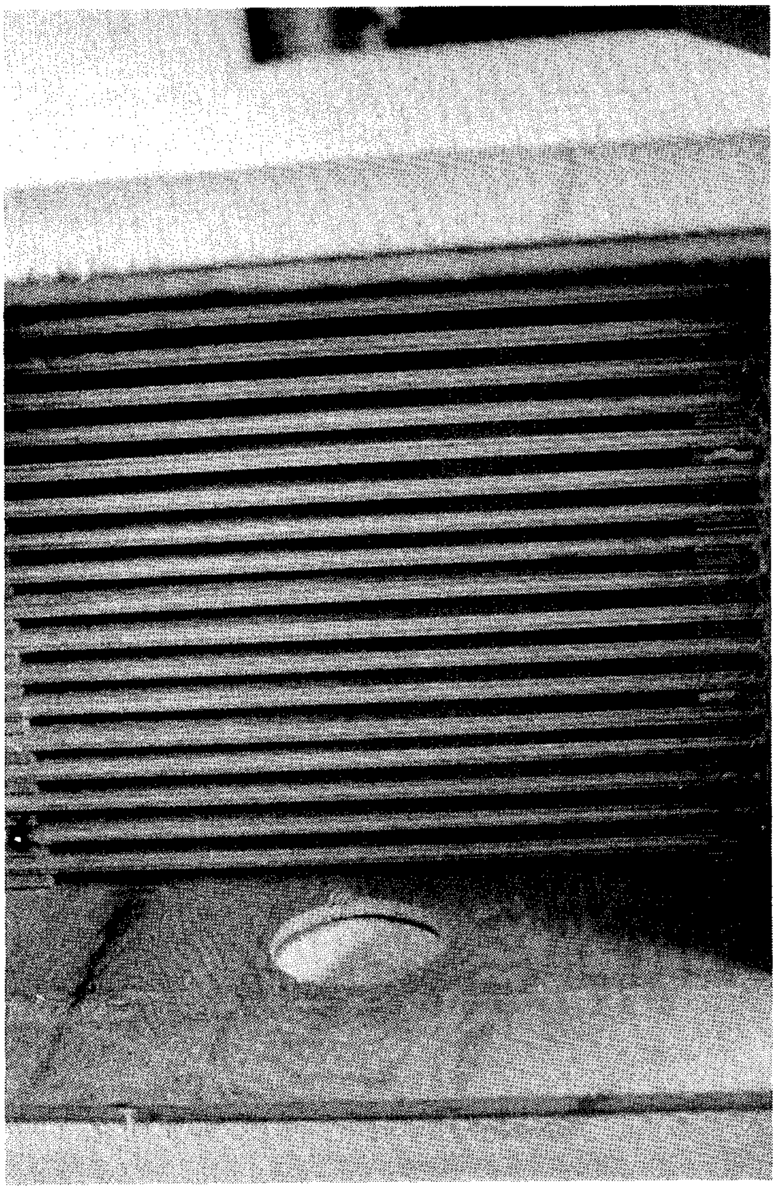


Fig. 5 Internal view of heat exchanger shown in Fig. 4. The 1/2 inch plywood spacers separating the 6 mil polyethylene sheets which serve as the heat transfer surface are shown.

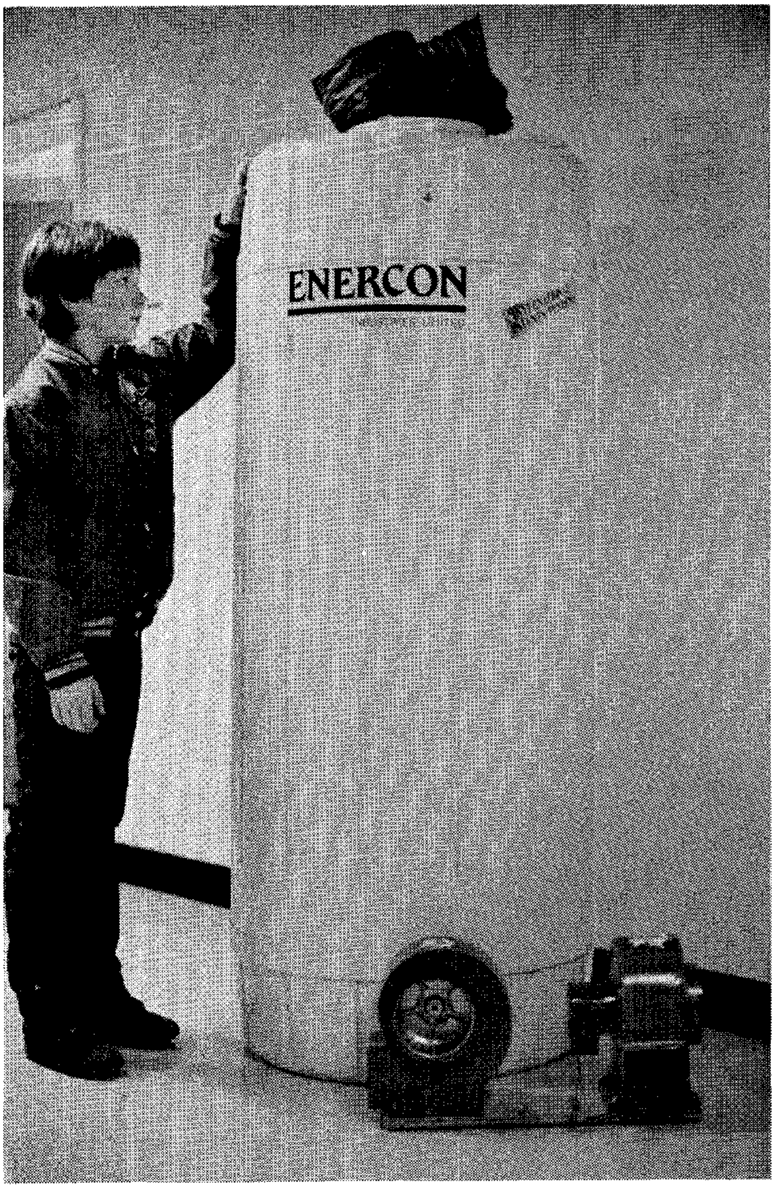


Fig. 6 A Canadian manufactured residential heat exchanger [5] similar in design to the Besant unit. The supply and exhaust fans included with the unit are also shown.

condensation and frost buildup in the paper element. Short circuiting of the supply and exhaust air occurs since the cool supply air is delivered to the room at the top of the unit. A smaller Lossnay heat exchanger rated at 24 cfm has a plastic cross-flow heat exchanger which should solve the shrinkage problem. The cost of the unit shown F.O.B. Fairbanks was about $250.

Two other heat exchangers are presently being constructed. The first of these is a thermal wheel similar to the unit built and tested by Shoukri [10]. The material chosen for fabrication of the porous wheel is an aluminum hexcell slab 6 inches thick having 3/32 inch "diameter" cells. A second unit is of the coil-run-around design using two automotive heater cores as the heat transfer elements. Because of the availability of these used cores, this system may prove to be quite attractive economically in addition to being a relatively easy system to build.

TEST PROGRAM

A test program to evaluate the heat exchange effectiveness and efficiency of the various types of heat recovery devices has been initiated at the University of Alaska. The cold room facilities, capable of temperatures down to -25°F, were used as a source of cold air. Shown in Fig. 7 is a picture of the Humid-Fire No. 11 under test. Insulated air conditioning flex duct of five inch diameter is used to connect the supply and return air to the cold room. A Digetec Model 2000 Datalogger recorded supply and exhaust air temperatures before and after the heat exchange process as well as the room temperature. The air speed was measured with an Alnor hot wire annemometer.

Each exchanger system is tested at two flow rates for a 24 hour duration. The reason for the long term test is to determine the influence of frost formation on the performance of the unit. The relative humidity of the room air during the test programs was maintained at 20% and the cold room temperature averaged -15°F. Long term test results are shown in Fig. 10 for the Basant unit at volumetric flow rates of 32 cfm and 64 cfm. As seen, the efficiency of the unit decreases as a frost layer builds up on the surfaces of the polyethlene sheets. At the completion of the 24 hour test, 2.2 pounds of condensate was drained from the unit. The efficiency of the heat exchanger tested was less than the results reported by Besant. A possible explanation might be lack of adequate sealing between adjacent flow passages. Efficiency results are shown in Fig. 11 for the Humid-Fire model also.

After completion of performance testing on the units, they are being placed in small buildings for testing throughout the 1980-81 winter season. This program will assist in determining long term reliability under field conditions.

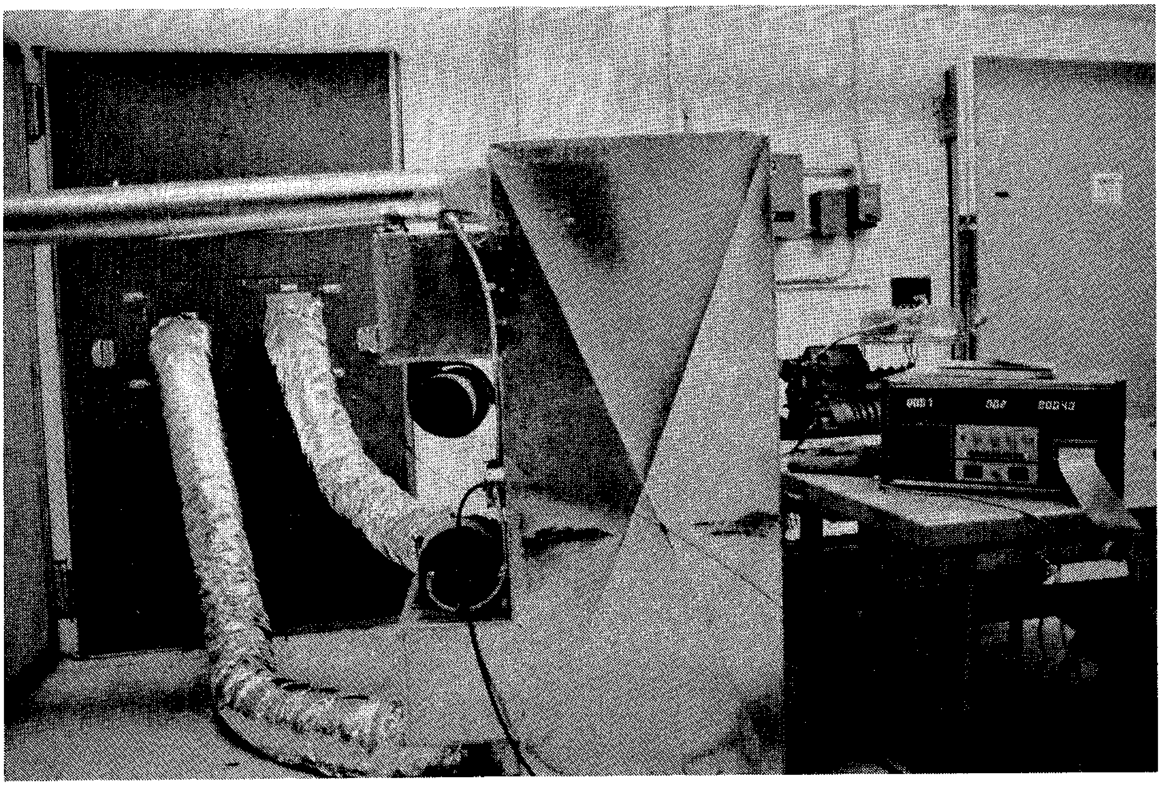


Fig. 7 A Canadian manufactured residential heat exchanger [6] with galvanized sheet metal housing also similar in design to Besant unit. The device is set-up for performance testing using the cold room to simulate outdoors. Also shown is the data logger which samples temperatures every hour.

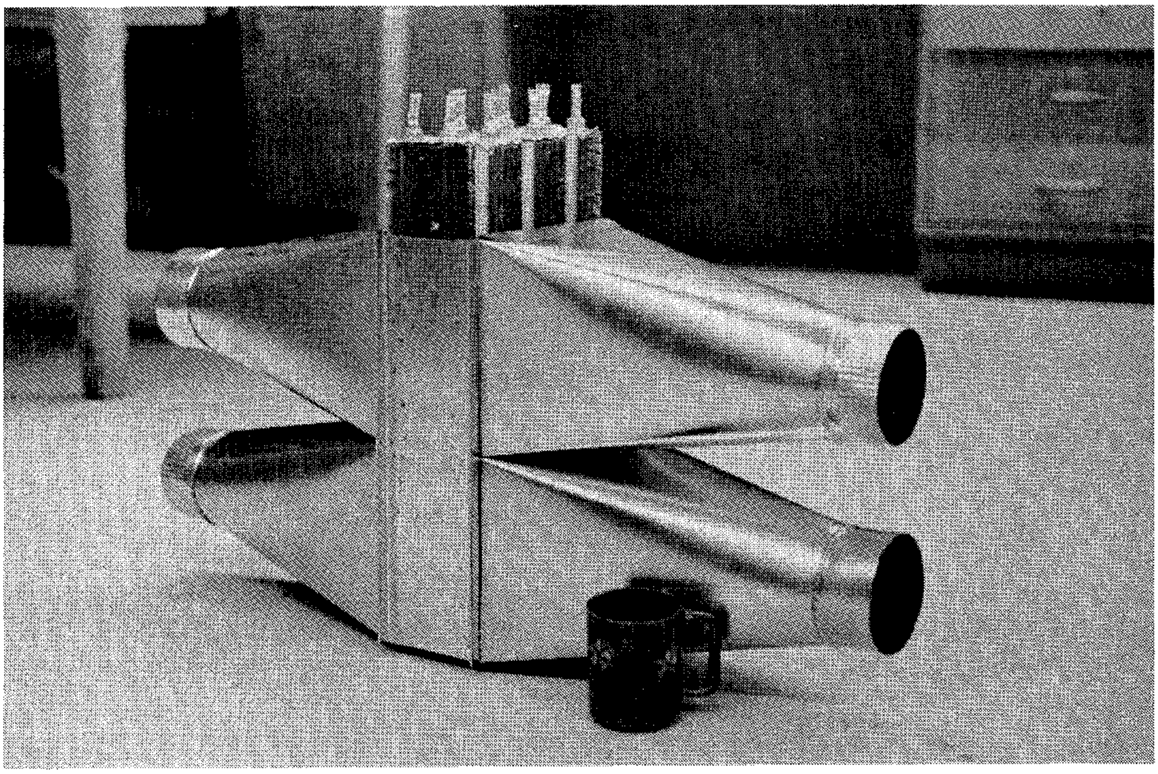


Fig. 8 A Q-Dot heat pipe coil [9] for air-to-air heat recovery partially inserted into sheet metal housing. The heat transfer rate in the unit can be controlled by tilting the entire assembly.

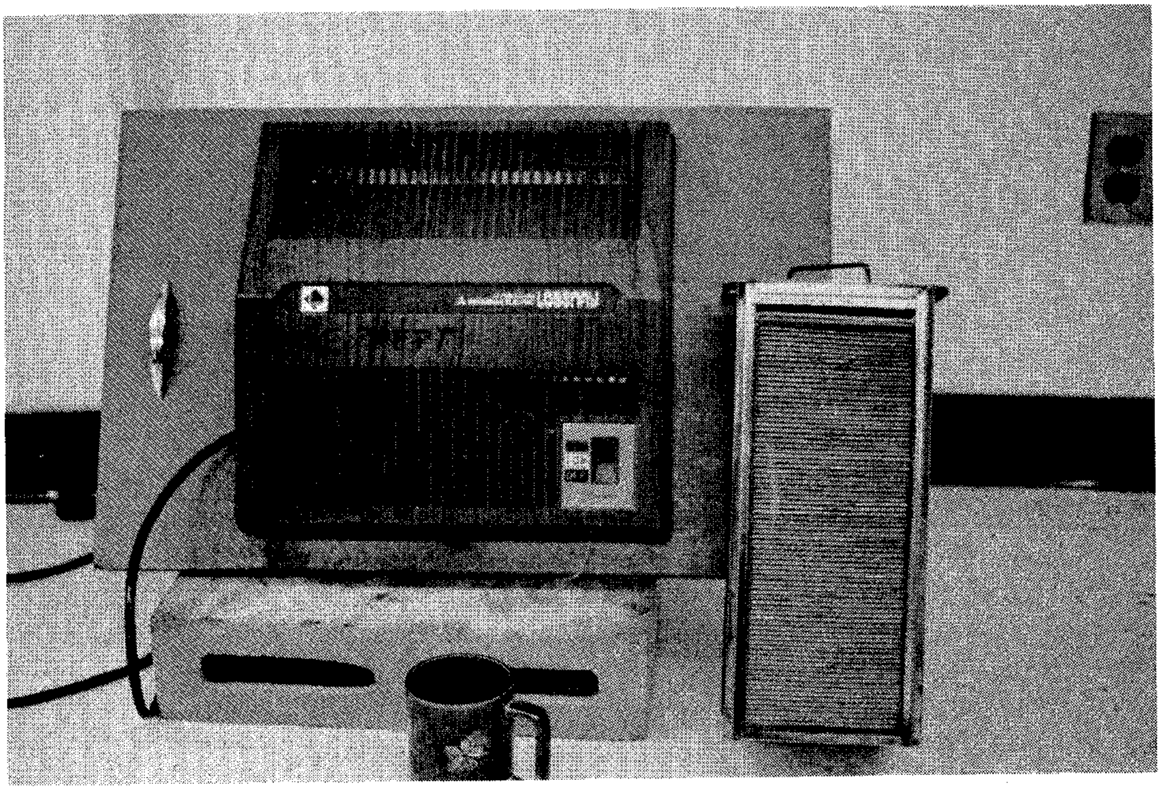
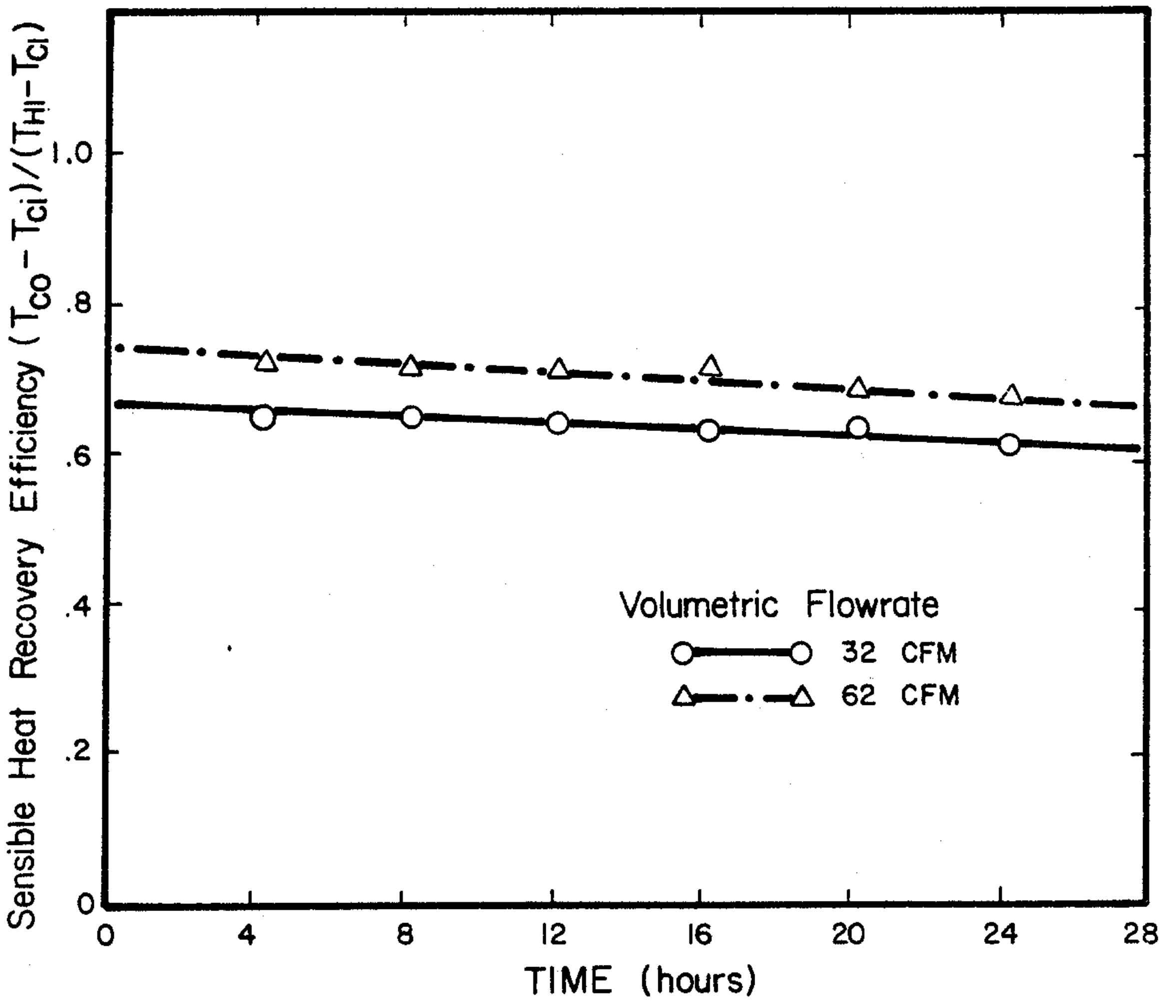
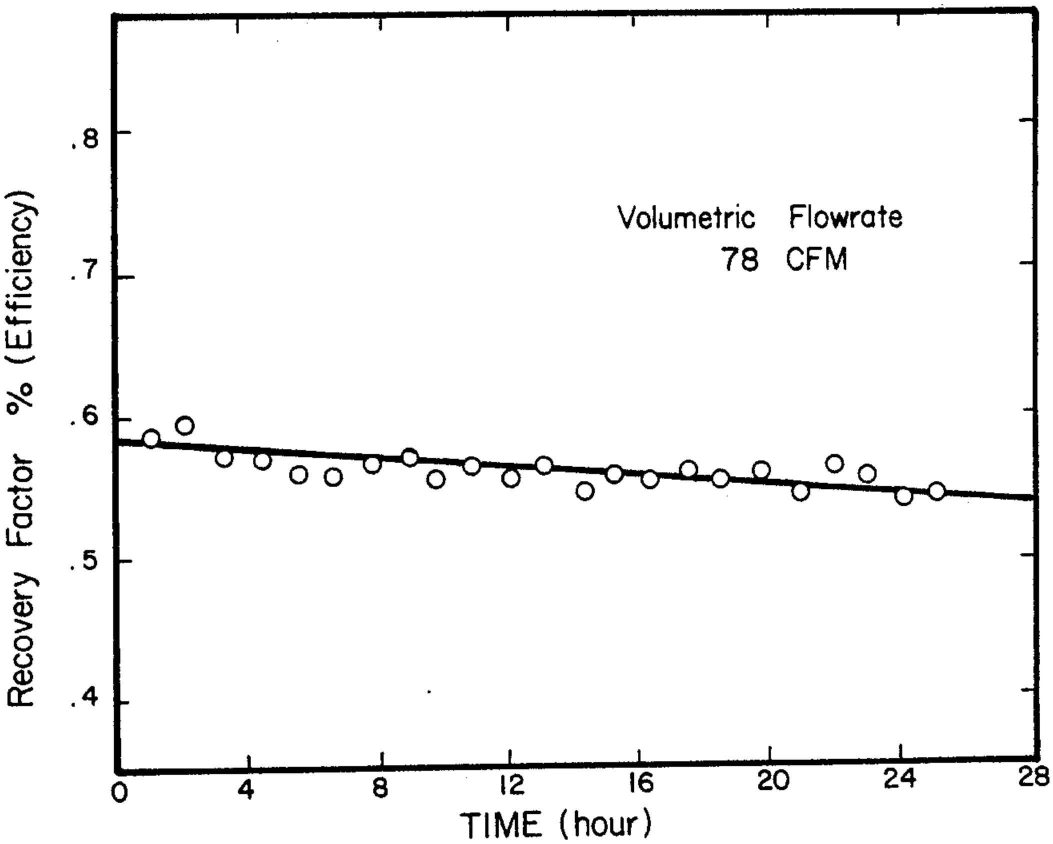


Fig. 9 The Lossnay [7] air-to-air residential heat exchanger manufactured by Mitsubishi Electric Co. in Japan. The unit is self contained including supply and exhaust fans. The cross-flow heat transfer element is made of paper which is also shown. Some shrinkage occurred when the paper element dried out after becoming plugged with frost.



Time varying performance of Besant type air-to-air heat exchanger

Figure 10



Time varying performance of Humid Air No. 11 air-to-air heat exchanger

Figure 11

ECONOMICS

In addition to the purchase cost of the unit, installation costs would also become part of the initial capital cost. With the exception of the Lossnay unit, ducting from the kitchen, baths, and laundry room, filters, back draft dampers, and supply and exhaust ducting, inlets, and outlets would also have to be purchased and installed. The annual operating cost for the unit would be the cost of electricity to power the supply and exhaust fans plus any required maintenance.

Assuming one needed to recover one's costs over a period of three to eight years at a market discount rate of 10%, then the capital recovery factors are 40% at three years and 20% at eight years. If fuel oil costs $1.00 per gallon and electricity costs $.08 per KWH, then from the previous example the annual saving in fuel costs would be $200 and the annual cost of operation during the heating season, assuming two 30w fans, would be $28. This yields an annual savings of $172 which allows a maximum initial investment of $430 for a three year payback period or $860 for an eight year pay back period. Of course, higher efficiencies or rapidly inflating energy costs would make the investment more attractive.

CONCLUSIONS

Making structures "air-tight" for energy conservation and to prevent moisture migration into building materials will become an even more common practice in the north. As building becomes tighter, it will be necessary to provide mechanical ventilation to maintain air quality. Four different types of heat exchangers have been described which have a good potential for air-to-air heat recovery. Several units are already on the market and have been described along with several do-it-yourself types. Both the first cost and operating and maintenance of these air-to-air heat exchangers must be evaluated before the economic decision can be made as to their need in air tight structures in comparison to letting the structure breathe. In northern climates the potential savings due to the "air tight" structures is greater and as a result makes the air-to-air heat exchanger more economically attractive.

ACKNOWLEDGEMENT

The Department of Transportation/Public Facilities, State of Alaska, has provided the funding for this engineering research project. Scott Bell, a mechanical engineering student at the University of Alaska, did the fabrication of the locally built units as well as some of the initial testing. Marilynn Griffin and Roxy Benoit did the typing on this paper under, as usual, the last minute pressure of the author.

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