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TEST RESULTS AND METHODS: RESIDENTIAL AIR-TO-AIR HEAT EXCHANGERS FOR MAINTAINING INDOOR AIR QUALITY AND SAVING ENERGY

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ABSTRACT

The Lawrence Berkeley Laboratory has constructed a facility for testing various performance aspects of residential air-to-air heat exchangers. When used in conjunction with a mechanical ventilation system, a residential heat exchanger permits the adequate ventilation of a residence while recovering most of the energy normally lost during ventilation. By constructing or retrofitting a home so that it has low natural infiltration rates and by using a heat exchanger-ventilation system, a homeowner can save energy, reduce heating and cooling costs, and prevent the buildup of indoor-generated air contaminants. In this paper we present the test results obtained on five different residential heat exchangers and describe the performance criteria and the test facility. The performance parameters measured were heat exchanger effectiveness (a measure of heat transfer ability), airstream static pressure drop, and fan system performance. The performance of the five heat exchangers differed greatly. The ability to transfer heat ranged from 43 percent to 75 percent of the theoretical maximum. The resistance to air flow varied by a factor of two. One of the heat exchangers was highly susceptible to leakage between airstreams and one had an unstable performance. In the future, additional heat exchangers will be tested, a new test system will be used to measure cross-stream leakage, and the possibility and consequences of freeze-up within the heat exchangers will be investigated.

INTRODUCTION

Recently, because of high energy costs and recognition that the infiltration of outside air constitutes a large fraction of the heat load of a house, some builders are developing and implementing procedures to reduce the influx of outside air.[1,2] Unfortunately, this reduction of outside air entering the structure can lead to problems with the quality of the indoor air. In tightly sealed homes, humidity can rise to uncomfortable levels and high levels of indoor-generated pollutants have been found, such as NO_2 from gas appliances, radon gas from the soil surrounding building basements and foundations, and formaldehyde from building materials, furnishings and some types of insulation.[3]

One means of alleviating these air-quality problems, without sacrificing all of the gains of energy-conserving measures, is to install a mechanical ventilation system that incorporates an air-to-air heat exchanger. An air-to-air heat exchanger is a device that brings two airstreams of differing temperature into thermal contact for the purpose of transferring heat between them. In winter, cold outside air is brought into the exchanger where it is warmed by the heat transferred to it from the warm air exhausted from the house. In summer, the heat exchanger can cool and, in some cases, dehumidify the hot outside air that is passed through it and into the house for the purpose of ventilation.

The heat exchanger program at Lawrence Berkeley Laboratory (LBL) focuses on three main aspects: their cost-effectiveness as an energy-conservation measure,[4] field studies of performance in residences located throughout the United States, and laboratory testing of commercially available units. The laboratory studies focus on measuring the thermal performance and fan performance of commercially available air-to-air heat exchangers as reported here.

The essential aim of this report is to describe the results obtained on performance tests of five commercially available air-to-air heat exchangers used in residential mechanical ventilation systems. The description of our findings is preceded by general background information on the design and installation of heat exchangers, our test facility, and the criteria and methods used for these performance tests. The information in this report is presented in a more complete form in reference 5.

GENERAL DESCRIPTION OF AIR-TO-AIR HEAT EXCHANGERS

In a residential air-to-air heat exchanger, the incoming airstreams are broken in to many smaller streams and the heat exchanger is constructed so that on either side of each cold airstream there is a hot stream and vice versa. Heat exchangers are generally classified by their flow configuration. In a counterflow exchanger, the hot and cold airstreams flow parallel to one another but in opposite directions. In a crossflow exchanger, the flow paths are perpendicular to one another. Many other types of heat exchangers are available, predominantly in large sizes for commercial and industrial use.

The part of the heat exchanger where the heat is actually transferred is called the core of the exchanger. Heat exchanger cores are made from a number of different materials, such as metals, plastics, and treated paper. Some manufacturers supply small ventilation/heat exchanger systems containing a core, fans, and filters all mounted in an insulated sheet-metal case. Other manufacturers supply just a core.

Installation of Residential Heat Exchanger

Mechanical ventilation systems using air-to-air heat exchangers can be installed in a number of different ways. Window- or wall-mounted units are installed much like a window air conditioner. In some installations, the heat exchanger is connected to an extensive duct work system that draws stale air from the kitchen, bathroom, and utility room of the house and distributes the warmed outside air to the bedrooms and the living room. In other installations a less extensive duct system is used.

Other factors related to the installation of heat exchangers, such as insulating the heat exchanger and ducting, providing drains for condensate, and balancing the airstream flow rates, are discussed in reference 5.

HEAT EXCHANGER PERFORMANCE

Theoretical Performance Criteria

In a residential heat exchanger, leakage of air, condensation and freezing of water vapor, internal heat sources (such as fan motors), and heat transfer to and from the surroundings, all affect performance. For the classical (textbook) heat exchanger, none of these complications is considered and performance is characterized in terms of "heat exchanger effectiveness."

Heat exchanger effectiveness is defined as the ratio of actual heat transfer to that which is theoretically possible--i.e., the heat transfer that would occur in an infinitely large counterflow heat exchanger.

The heat transfer that occurs between the two airstreams in a heat exchanger causes each airstream to change temperature. The airstream with the smallest capacitance undergoes the greatest temperature change. (Airstream capacitance is defined as the product of the airstream mass flow rate and airstream specific heat and can be considered the thermal inertia of the airstream.) In an infinitely large counterflow heat exchanger, the minimum capacitance airstream changes from its initial temperature to the inlet temperature of the other airstream, and the heat exchanger effectiveness is 100 percent. In a real (finite size) heat exchanger, the effectiveness equals the ratio of the temperature change of the airstream with the smallest capacitance to the temperature difference between the two entering airstreams. The equation for effectiveness is:

$$\epsilon = \frac{\Delta T'}{(T_{hs} - T_{cs})} \tag{1}$$

where:

$\Delta T'$ = the temperature change of the minimum capacitance airstream

T_{hs} = the temperature of the hot airstream supplied to the heat exchanger

T_{cs} = the temperature of the cold airstream supplied to the heat exchanger

The effectiveness of a heat exchanger decreases with increasing flow rates due to the smaller airstream temperature changes that occur at high flow rates. As long as no condensation or freezing occurs within the heat exchanger, airstream temperatures and humidity have only a minor effect on heat exchanger effectiveness.

Factors Affecting Actual Performance

Condensation/Freeze-up. The performance of a heat exchanger will be affected whenever water vapor from the hot airstream condenses as the hot air is cooled in the heat exchanger core. The temperature of the airstreams entering the heat exchanger, the humidity of the hot entering airstream, and the performance of the heat exchanger, determine whether condensation will occur. Condensation first occurs on the heat exchanger wall (the surface separating the two airstreams) if the wall is below the hot airstream dewpoint temperature. The condensed water will either drain out of the heat exchanger or re-evaporate at some location where the wall temperature is higher than the dewpoint temperature.

If condensation occurs during the winter season, it will occur in the air being exhausted from the house, and the temperature change of the cold airstream entering the house will be increased. An examination of weather data for the United States indicates that condensation will occur only rarely during summertime use of a heat exchanger. (All results reported here involve tests where no condensation occurred.)

If the outside air temperature is sufficiently below $0^{o}C$ ($32^{o}F$), condensed water may freeze inside the heat exchanger core and obstruct all or some portion of the airflow. Some manufacturers include freeze-protection systems with their heat exchangers. The consequences of freeze-up and conditions under which it occurs are different for each type of heat exchanger. The freeze-up problem will be investigated in the laboratory and in field trials at a future date.

Ratio of Mass Flow Rates. The ratio of airstream mass flow rates through the heat exchanger affects both the temperature change of the airstream supplied to the residence and the amount of air leakage through the house envelope. To minimize the energy requirements for heating or cooling a residence, the airstream mass flow rates should be equal.

Unfortunately, in actual use of a residential heat exchanger, it is very difficult to maintain balanced (equal) mass flow rates. Changes in air density and viscosity (due to temperature changes), unequal clogging of airstream filters, and freezing within the heat exchanger core, will cause imbalances in the mass flow rates. Imbalances in flow rate will cause the energy saved during actual use of heat exchanger systems to be less than that indicated by the heat exchanger effectiveness. (Other factors, such as increased performance due to condensation, may counteract this effect.) Further study is needed to investigate the magnitude and consequences of flow-rate imbalances and to determine whether periodic balancing of flow rates is required.

Additional Factors that Affect Heat Exchanger Thermal Performance. Other factors that affect heat exchanger performance are the leakage of air between a heat exchanger and its surroundings, fouling and corrosion of the heat-transfer surfaces, and the release of heat by the heat-exchanger fan motors. In addition, some heat exchangers are designed to transfer moisture as well as heat.

Fan System Performance

The total energy performance of a heat-exchanger system depends on both the rate of heat transfer within the heat-exchanger core and the rate of energy consumption by the fan system. The fan power consumption, for a given air flow rate, depends on the efficiency of the fan and fan motor and the resistance to air flow in the heat exchanger and attached ducting. If the resistance to air flow is high, it will take more fan energy and larger fans to provide a given ventilation rate than when the resistance to air flow is low.

HEAT EXCHANGER TEST FACILITY

The Heat Exchanger Test Facility currently contains two major systems for testing commercially available heat exchangers: the Thermal Performance Test System and the Fan Performance Test System.

The Thermal Performance Test System (Figure 1) is designed to control and measure the pressure, temperature, humidity, and flow rate of the airstreams entering and leaving a heat exchanger. The measurements are used to evaluate heat exchanger performance.

The Fan Performance Test System measures the power consumption of the fans, the airstream flow rates, and the static pressure drop in the piping system attached to the heat exchangers. The static pressure drop is a measure of the flow resistance in the duct system attached to the heat exchanger. The test results can be used to predict the power consumption and airstream flow rates for a heat exchanger system during actual residential operation, as well as to size the ducting for a particular air flow rate.

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HEAT EXCHANGER DESCRIPTIONS AND TEST RESULTS*

VMC Genvex Heat Exchanger - Description and Test Results

The Genvex Heat Exchanger has a crossflow core (made from parallel plates of aluminum sheet metal), two fans, and two filters all mounted in an insulated sheet metal case. One side of the case is removable for access to the core, fans, and filters. The core can be easily removed and replaced. The 220-volt, single-phase fan motors are designed for use with 50-cycle power typical of European countries but will operate with the 60-cycle power supplied in the United States. The total heat transfer area in the core is 8.622 m^2 (92.8 ft^2). The heat exchanger weighs approximately 68 kg (150 lb.).

Figure 2 shows the effectiveness-versus-flow rate curve for the Genvex Heat Exchanger. The effectiveness was 64% at 102 m^3/hr (60 ft^3/min) and 45.5% at 391 m^3/hr (230 ft^3/min). The test results should be considered preliminary because this model exhibited considerable leakage between airstreams.

A plot of airstream static pressure drop versus flow rate is not available for this heat exchanger. The tests were run with the fans removed from the heat exchanger case; therefore, the data does not accurately represent the true pressure drop characteristics of the heat exchanger.

The results of the fan performance tests on the Genvex Heat Exchanger are presented in Figure 4. In the tests, the air flow rate was varied from 116 to 192 m^3/hr (68 to 159 ft^3/min) and the total fan power consumption ranged between 132 and 148 watts.

This heat exchanger is manufactured in Denmark and there is no known distributor for this unit in the United States.

*All test results reported are for the case of balanced volumetric flow rates through the heat exchanger.

Flakt RDAA Heat Exchanger - Description and Test Results

The Flakt Heat Exchanger is a crossflow unit similar in basic design to the Genvex Heat Exchanger. Only the major differences between the two units will be described here.

The air passages in the Flakt Heat Exchanger contain "fins" to increase the heat transfer and maintain the plate spacing. The fins are thin sheets of aluminum that criss-cross the flow passages and divide the space between the parallel plates into small triangular passages. The total area for heat transfer between airstreams is 7.80 m^2 (84 ft^2). The unit weighs approximately 36.3 kg (80 lbs).

This heat exchanger contains an electric resistance heating element to preheat the outside air before it enters the core. The heating element is used to prevent freezing and to ensure that the temperature of the air supplied to the residence does not fall below 11°C (52°F). The preheating of the outside air should prevent freeze-up in the core; however, it will also reduce the amount of heat recovered from the exhausted airstream.

The effectiveness-versus-flow rate curve for the Flakt Heat Exchanger is presented in Figure 2. The effectiveness was 67.5 % at 102 m^3/hr (60 ft^3/min) and 56 % at 39/m^3/hr (230 ft^3/hr). Figure 3 contains a plot of airstream static pressure drop versus flow rate for this heat exchanger. The pressure drop was 2.5 mm of water at 102 m^3/hr and 25.7 mm of water at 391 m^3/hr (0.1 in of water at 60 ft^3/min and 1.0 in of water at 230 ft^3/min).

The results of the fan performance tests are presented in Figure 4. The total fan power consumption ranged from 139 to 160 watts as the flow was varied from 105 to 292 m^3/hr (61 to 172 ft^3/min).

This heat exchanger is manufactured in Sweden and is available in the United States through Flakt Products, Inc., P.O. Box 21500, Fort Lauderdale, Fla. 33335.

Plastic-Sheet Heat Exchanger - Description and Test Results

The Plastic-Sheet Heat Exchanger was fabricated at Lawrence Berkeley Laboratory. It is similar to a Canadian model specifically designed so that it could be constructed inexpensively and easily by a homeowner.

In this heat exchanger, the air flows in a counterflow arrangement throughout most of the core. The core is constructed from parallel sheets of 0.015 cm (0.006 in) thick polyethylene plastic. The plastic sheets are separated by 1.90 cm (0.75 in) thick wood strips that form the exterior frame of the heat exchanger. The outside of the heat exchanger is covered with 0.318 cm (1/8 in) thick finished plywood. The heat exchanger was tested without fans. This heat exchanger has much larger outer dimensions than the other units tested (approximately 200 by 50 by 36 cm (78 by 20 by 14 in)). The unit weighs approximately 63.5 kg (140 lbs). The total heat transfer area is 19.3 m^2 (208 ft^2).

The Plastic-Sheet Heat Exchanger had the lowest effectiveness of all the units tested. In addition, it was impossible to maintain steady pressures and flow rates during testing. The flexible plastic sheets that form the air passages deform with even a slight imbalance in airstream pressure. (The air channels for the high-pressure airstream expand and those for the low-pressure airstream contract.)

Figure 2 contains a plot of effectiveness versus flow rate for this heat exchanger. The effectiveness was 56% at 102 m^3/hr (60 ft^3/min) and 44% at 391 m^3/hr (230 ft^3/min). The pressure drop versus flow rate curve for the Plastic Sheet Heat Exchanger is presented in Figure 3. The static pressure drop of the airstreams was 0.5 mm of water at 102 m^3/hr and 15.3 mm of water at 391 m^3/hr (0.02 in of water at 60 ft^3/min and 0.6 in of water at 230 ft^3/min).

This unit is not available commercially, but a similar Canadian unit is available with fans from D.C. Heat Exchangers, Rural Route 3, Saskatoon, Saskatchewan, Canada. In the Canadian heat exchanger, the air passages are 1.27 cm (0.5 in) thick; therefore, the heat-transfer area is greater and the effectiveness is expected to be higher.

Aldes VMPI Heat Exchanger - Description and Test Results

The Aldes VMPI Heat Exchanger has a complicated plastic core. The air flow arrangement is mostly counterflow; however, near the heat exchanger ends, the air flows are perpendicular (crossflow). The plastic air channels are rigid enough to hold their shape even when the airstream pressures are imbalanced. The plastic core is contained in an insulated sheet-metal case. The total area for heat transfer within the heat exchanger is 19.3 m^2 (208 ft^2). This unit weighs approximately 22.7 kg (50 lb).

The heat exchanger was tested without fans. It is normally sold as part of a complete system containing the heat exchanger, two fans mounted in small fan boxes, flexible ducting, diffusers, and other components.

The Aldes Heat Exchanger has a high effectiveness compared to the first three units described. It also has a low airstream pressure drop. The effectiveness of the Aldes Heat Exchanger, presented in Figure 2, was 74% at 102 m^3/hr (60 ft^3/min) and 63% at 391 m^3/hr (230 ft^3/min).

The airstream static pressure drop versus flow rate curve is presented in Figure 3. The static pressure drop was 1.3 mm of water at 102 m^3/hr and 10.7 mm of water at 391 m^3/hr (0.05 in of water at 60 ft^3/min and 0.42 in of water at 230 ft^3/min).

At the present time, there is no known distributor for this unit in the United States.

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Des Champs Model 74 Heat Exchanger - Description and Test Results

The final heat exchanger described in this report is predominately a counterflow unit. A continuous piece of sheet metal folded back and forth forms the air passages; this configuration eliminates many paths for potential air leakage. The air-channel spacing is maintained by rows of indentations and protrusions stamped in the sheet metal at regular intervals. The sheet metal core is mounted in an uninsulated sheet metal case with provisions for attachment to rectangular ducting. The heat exchanger has 10.7 m^2 (115 ft^2) of heat-transfer area. It weighs approximately 31.8 kg (70 lb) with the fans installed.

The heat exchanger is supplied with externally mounted fans but the fans were removed before testing. The fans are forward-curved centrifugal units with shaded-pole motors.

The Des Champs Model 74 Heat Exchanger has the highest overall effectiveness of all the units described in this report. Its effectiveness is higher than that of the Aldes Heat Exchanger for most of the flow rate range; however, its static-pressure-drop is greater than that of the Aldes. The effectiveness-versus-flow rate curve for this heat exchanger is presented in Figure 2. The effectiveness was 73% at 102 m^3/hr (60 ft^3/min) and 68% at 391 m^3/hr (230 ft^3/min). The pressure drop-versus-flow rate curve for this heat exchanger is presented in Figure 3. The airstream static pressure drop was 2.2 mm of water at 102 m^3/hr and 24.7 mm of water at 391 m^3/hr (0.09 in of water at 60 ft^3/min and 0.97 in of water at 230 ft^3/min).

This heat exchanger is manufactured in the United States by Des Champs Laboratories, Inc., P. O. Box 348, East Hanover, NJ, 07936.

CONCLUSIONS

Based on the performance criteria of effectiveness and airstream static pressure drop, several acceptable heat exchangers have been identified. We believe that heat exchangers with performance characteristics superior to those found here can be manufactured for a reasonable cost.

The fan power consumption for a residential heat exchanger can be quite low. For instance, the two heat exchangers tested for fan performance required approximately 150 watts to produce a ventilation rate of 255 m^3/hr (150 ft^3/min); however, these heat exchangers were equipped with more efficient fan motors than those typically used in the United States.

In the future, the performance of additional heat exchangers will be evaluated. In addition, low-temperature thermal performance tests will be run in order to measure the increased performance when condensation occurs and to identify the conditions under which freezing occurs within the heat exchangers. Finally, leakage tests will be performed using a new leakage test system, employing a tracer gas to distinguish between airstreams and to accurately indicate the rate of total cross-stream leakage.

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REFERENCES

1. Besant, R.W., Dumont, R.S., and Schoenau, G., "Saskatchewan House: 100 Percent Solar in a Severe Climate," Solar Age, 4 (5):18-21, May 1979.

2. Grimsrud, D.T., and Diamond, R.C., Building Energy Performance Standards: Infiltration Issues, University of California, Lawrence Berkeley Laboratory report, LBL-9623, January 1979.

3. Hollowell, C.D., Berk, J.V., and Traynor, G.W., Impact of Reduced Infiltration and Ventilation on Indoor Air Quality in Residential Buildings, University of California, Lawrence Berkeley Laboratory report, LBL-8470, November 1979.

4. Roseme, G.D., Berk, J.V., Boegel, M.L., Halsey, H.I., Hollowell, C.D., Rosenfeld, A.H., and Turiel, I., Residential Ventilation with Heat Recovery: Improving Indoor Air Quality and Saving Energy, University of California, Lawrence Berkeley Laboratory report, LBL 9749, May 1980.

5. Fisk, W.J., Roseme, G.D., and Hollowell, C.D., Performance of Residential Heat Exchangers: Test Results and Methods, University of California, Lawrence Berkeley Laboratory report, LBL 11792, September 1980.

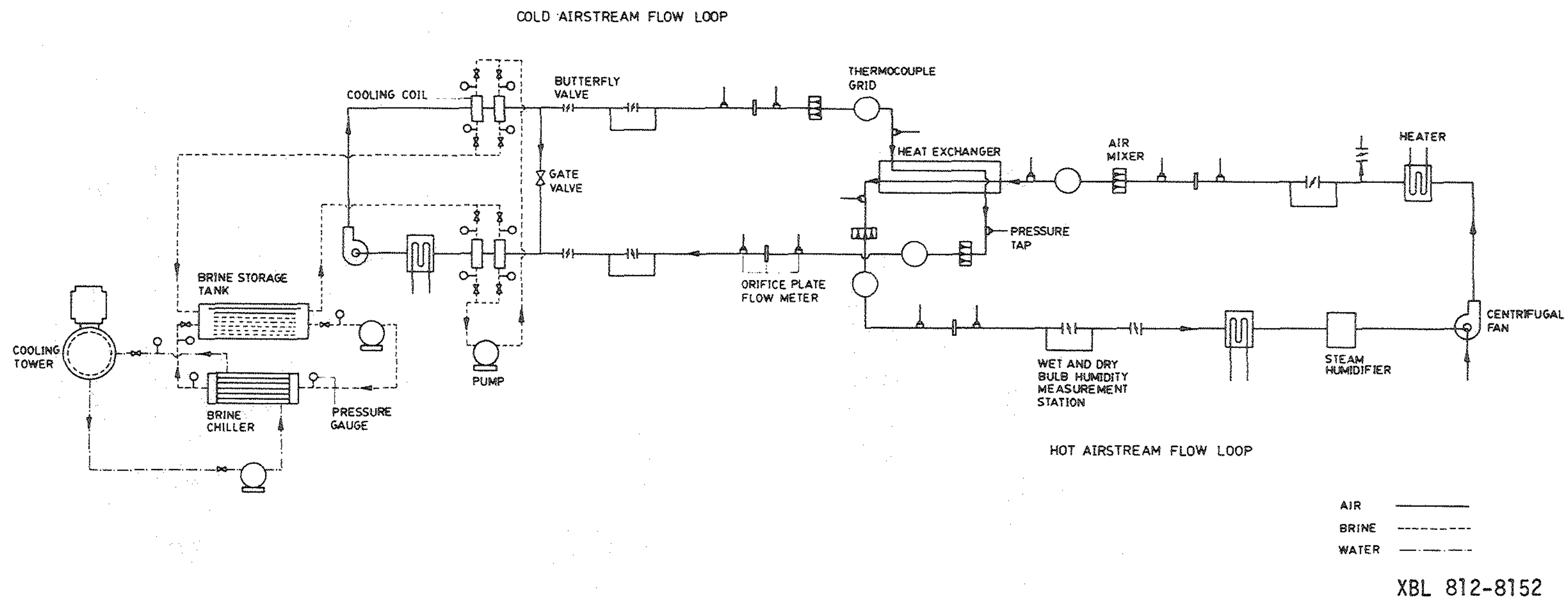

FIGURE 1. THERMAL PERFORMANCE TEST SYSTEM,HEAT EXCHANGER TEST FACILITY

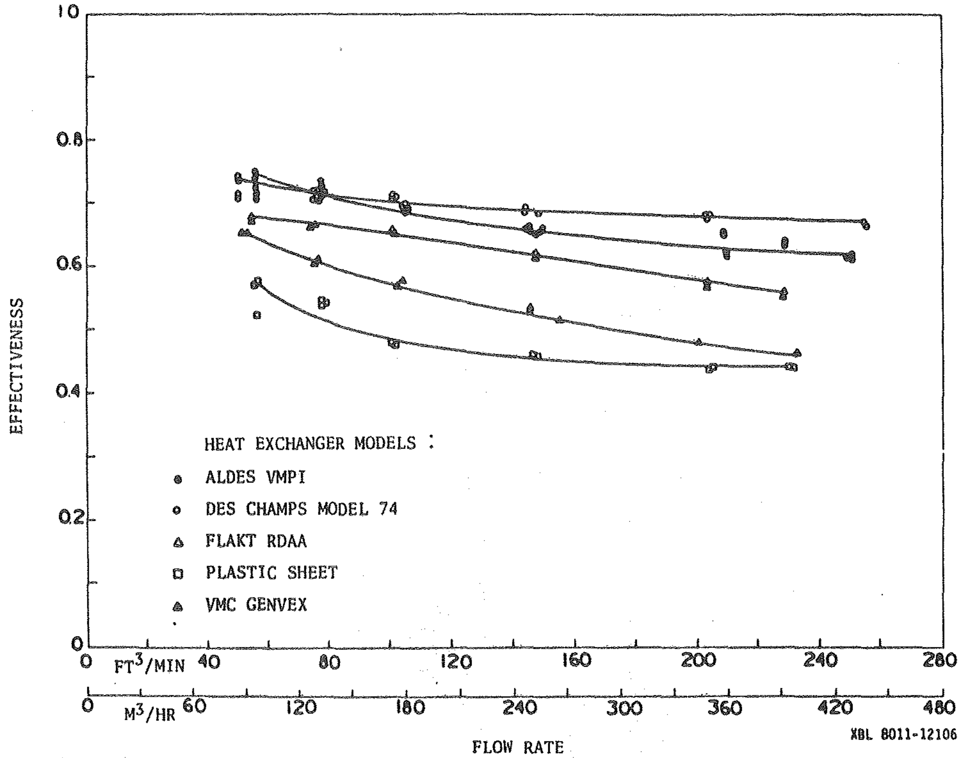

FIGURE 2. EFFECTIVENESS VERSUS FLOW RATE FOR FIVE MODELS OF RESIDENTIAL HEAT EXCHANGERS

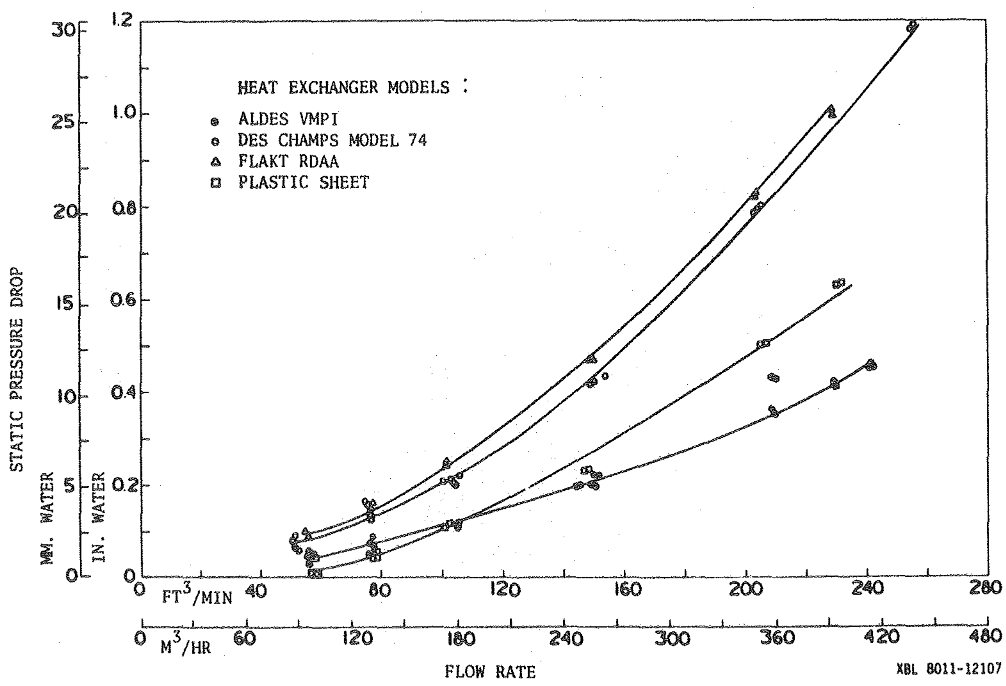

FIGURE 3. AIRSTREAM STATIC PRESSURE DROP VERSUS FLOW RATE FOR FOUR MODELS OF RESIDENTIAL HEAT EXCHANGERS

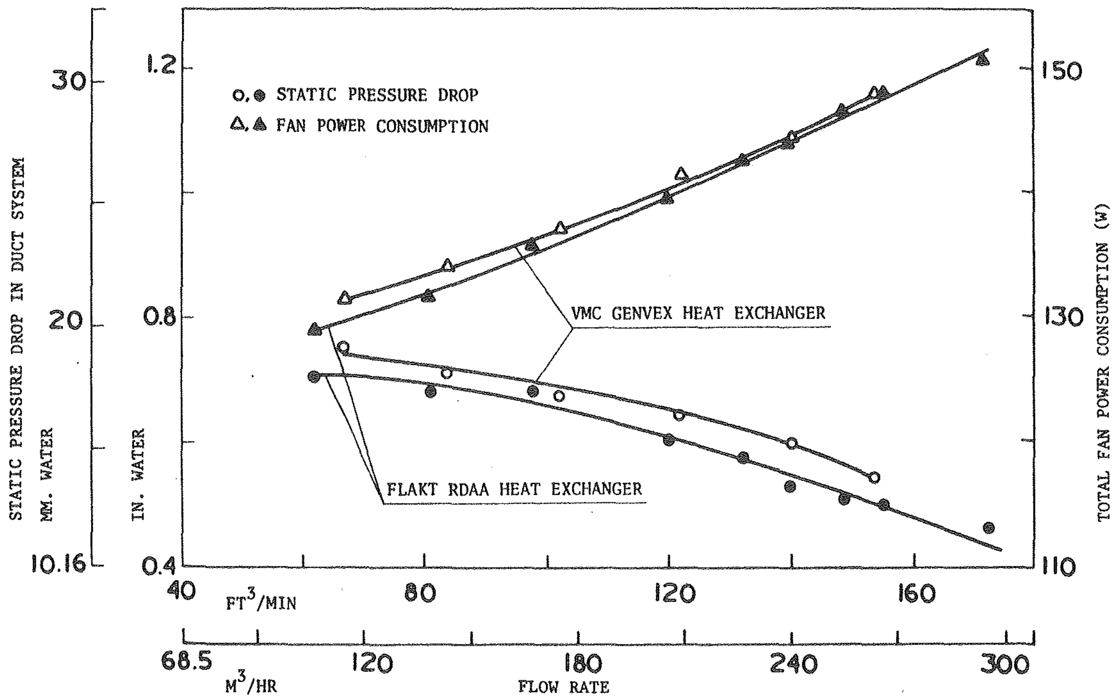

FIGURE 4. FAN SYSTEM PERFORMANCE FOR TWO MODELS OF RESIDENTIAL HEAT EXCHANGERS