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MOISTURE REMOVAL CHARACTERISTICS OF HEAT RECOVERY VENTILATION SYSTEMS UTILIZING A SENSIBLE ROTARY HEAT EXCHANGER & COMPARISON WITH STATIONARY HEAT EXCHANGER SYSTEMS

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ABSTRACT

Increased air tightness in new energy-efficient housing has led to serious problems with excessive indoor moisture in winter as well as with other "trapped" indoor air contaminants. Heat recovery ventilation systems are being used increasingly as an effective means to solve these indoor pollution problems by introducing fresh, drier outdoor air without the full penalty of the associated heating and cooling costs. Both stationary and rotary type heat exchangers are available for energy recovery. Stationary type heat exchangers with non-permeable membranes separating the exhaust air and fresh air streams typically reject all of the moisture contained in the exhaust airstream relative to the moisture content of outdoor air. Advocates of this type heat exchange system claim that its moisture rejection capability offers an important advantage over the rotary type heat exchanger which only rejects part of this moisture at low outdoor temperatures. (Condensation deposited from the exhaust stream in the rotary heat exchanger is re-evaporated into the fresh airstream.) The test and analytical results presented here for moisture rejection characteristics of rotary heat exchanger systems illustrate the following advantages for a rotary system designed to provide the recommended 1/2 air change per hour (ACH) mechanical ventilation in an average size home (1600 FT^2) which has only 0.25 ACH natural ventilation.

1. Rotary exchanger system provides 12-16 liters per day moisture removal rate (required level for average family of 4) over a broad range of outdoor temperatures (down to -20°C and below) without developing indoor relative humidity levels that are either excessively high or uncomfortably low.

2. Due to their moisture transfer characteristics, rotary exchangers do not normally freeze up and require defrosting action as do stationary type heat exchangers. The absence of defrost cycles allows rotary heat exchangers to operate at considerably higher seasonal average heat recovery efficiency than stationary type exchangers.

INTRODUCTION

The recent trend toward increasing air tightness in construction of new energy-efficient residential housing has led to excessive indoor humidity levels during cold weather, causing both visible moisture problems (condensation, mold growth, etc.) and structural damage.[1] Heat recovery ventilation systems are being used increasingly in tight houses to help improve indoor air quality including moisture rejection.[2] The two basic types of air-to-air heat exchangers used in these residential ventilation systems are rotary regenerators and stationary (fixed plate) recuperators.

Most of the stationary heat exchangers are constructed of non-permeable materials that do not allow any transfer of moisture between the exhaust airstream and the fresh airstream. Consequently, all of the moisture contained in the exhaust air is rejected from the house. Since the cold outdoor air is usually very dry compared with indoor air, the result is a substantial reduction in indoor humidity levels. When outdoor temperatures drop below about -5°C (23°F) the condensate which forms inside the heat exchanger freezes and progressively blocks the exhaust air passages.[3] Periodic defrosting action is required to maintain the heat exchanger operational. This required defrosting action complicates the system and causes reductions in both heat recovery efficiency and ventilation airflow during the time required to clear the ice.[3]

In contrast, the rotary type heat exchanger allows for some moisture transfer between exhaust air and fresh airstreams through condensation and re-evaporation within the heat exchange matrix as the heat wheel rotates between exhaust and fresh airstreams. Only part of the moisture content of the exhaust air is transferred; a substantial portion is also rejected outdoors.

Due to the continuous re-evaporation of condensate from the exhaust stream back into the dry fresh airstream, the rotary type heat exchanger does not become blocked with ice and needs no defrosting under normal operating conditions. Only at extreme low outdoor temperatures in combination with high indoor humidity levels (conditions rarely encountered) does the rotary exchanger collect moisture and frost.

Because rotary heat exchangers transfer some of the moisture between airstreams, some people have claimed that they are not as desireable for use in tight houses as the stationary type which would obviously reject more moisture from the indoor atmosphere. This paper attempts to dispell this misconception by presenting test results on moisture removal for sensible rotary heat exchangers (no desiccant on heat transfer matrix) and by showing that the combination of this moisture removal characteristic plus a small amount of natural ventilation provides a relatively ideal moisture removal characteristic for most homes.

MOISTURE REJECTION CHARACTERISTICS OF HEAT EXCHANGERS

A heat recovery ventilation system consists of two fans, a heat exchanger and a suitable ducting system. One fan exhausts stale air from the dwelling, the other fan draws in an equal amount of fresh outdoor air and the heat exchanger recovers heat from the exhaust airstream and transfers it to the fresh airstream. The two basic types of heat exchangers employed in these systems are rotary regenerators and stationary (fixed plate) recuperators. The rotary regenerator consists of a rotating disc or drum type heat transfer matrix which passes alternately through the exhaust airstream and the fresh airstream as they flow in counterflow fashion through the assembly. (Figure 1) The stationary recuperator may be one of several types such as cross-flow, counterflow, multi-pass cross-flow, etc., but most stationary exchangers* are characterized by the fact that the two airstreams are totally separated by the heat transfer surface (plates, tubes, etc.) so that there is no moisture exchange between airstreams. (c.f. cross-flow exchanger shown in Figure 2.)

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*This discussion of stationary heat exchangers does not apply to those made with porous materials (e.g. treated paper) separating the two airstreams.

Stationary Heat Exchanger Systems - In the ideal stationary heat exchanger, the two airstreams are totally separated (i.e. no cross-stream leakage of air or moisture) so that all of the moisture contained in the exhaust airstream is discharged outdoors as vapor or drained off as condensate.

This exhaust air is replaced by cold, dry outdoor air that has been preheated by the heat exchanger but no moisture is added in the heat exchanger. Thus, the moisture removal characteristic of the ideal stationary heat exchanger system is exactly the same as for simple mechanical ventilation without heat exchange. The net moisture discharge rate for a dwelling ventilated by this type of system may be expressed by

$$\dot{m}_{H_2O} = \dot{m}_{ex} (W_i - W_o) \qquad (1)$$

where

$\dot{m}_{H_2O}$ = water removal rate - Lbs/Hr

$\dot{m}_{ex}$ = mass flow rate of exhaust air - Lbs/Hr (equal to fresh airflow rate)

W_i = humidity ratio of indoor air - $\frac{\text{Lbs } H_2O}{\text{Lbs dry air}}$

W_o = humidity ratio of outdoor air - $\frac{\text{Lbs } H_2O}{\text{Lbs dry air}}$

The moisture content (W) of both indoor and outdoor air varies widely with temperature and relative humidity as illustrated on a typical psychrometric chart.

It is instructive to use Equation (1) to calculate the moisture rejection rate of this type of ventilation system for a variety of indoor and outdoor temperature and relative humidity conditions representing the range of conditions commonly encountered. To make this exercise most useful we choose a ventilation airflow rate corresponding to 1/2 air change per hour (ACH) in a typical average size house, e.g. 1600 FT^2 ($150 m^2$). The interior volume is 1600 x 7 1/2 = 12,000 FT^3 ($340 m^3$) so 1/2 ACH requires an airflow rate of 100 CFM (50 l/s). At standard air density (.075 Lb/FT^3), the corresponding air mass flow rate is 100 x .075 x 60 = 450 Lbs/Hr (205 Kg/h).

Figure 3 shows the results of applying Equation (1) to this example for a variety of temperature and humidity conditions with the aid of the ASHRAE psychrometric tables. The moisture removal rates are expressed as gallons/day or liters/day. Indoor temperature is assumed to remain constant at 21°C (70°F) and outdoor relative humidity is assumed constant at 80% (typical average value for many regions)* while indoor relative humidity and outdoor temperature are varied. Note that the moisture removal rate increases steadily as outdoor temperature is reduced.

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*The effect of outdoor humidity is quite small. To simplify this presentation, all results shown are for 80% R.H., a value believed to represent average outdoor conditions in most regions of the U.S.

ASHRAE states that the average family of four releases three gallons of water per day into the home.(4) Figure 3 illustrates that the indoor relative humidity levels resulting from a three gallon (11½ liters) per day water removal requirement are reasonable when outdoor temperatures are 0^oC (32^oF) and above (e.g. 30% to 60% R.H.) but indoor R.H. becomes excessively low when outdoor temperatures drop below about -5^oC (23^oF) (e.g. 15% to 20% R.H.). Therefore, to maintain comfortable indoor humidity levels (30% and above) at low outdoor temperatures, some type of indoor humidification would be required. This example illustrates that straight mechanical ventilation at the 1/2 ACH level without any moisture exchange between fresh air and exhaust streams produces excessively dry indoor conditions (i.e. 16% R.H.) at outdoor temperatures approaching -15^oC (5^oF).

Sensible Rotary Heat Exchange System - In the rotary heat exchanger where both exhaust air and fresh airstreams pass through the same heat transfer matrix, some of the moisture contained in the airstream being exhausted may be condensed in the matrix and re-evaporated into the fresh incoming airstream. This occurs at lower outdoor temperatures when the cold face of the heat exchanger is below the indoor dew point. Moisture transfer of this type is often desirable because cold outdoor air in winter is usually very dry and the mechanical ventilation introduced by an air-to-air heat exchanger could cause an excessive loss of interior moisture, thereby necessitating the use of a humidifier to maintain comfortable indoor humidity levels. Since a substantial amount of heat must be added to the water evaporated in a humidifier, this could impose a significant additional heating load on the home heating system.

Figure 4 illustrates the rotary air-to-air heat exchanger and a typical set of winter operating conditions where the outdoor air temperature is -7^oC (20^oF). This example assumes that the indoor air is maintained at 21^oC (70^oF), 50% relative humidity and the outdoor air is at -7^oC, 80% relative humidity. The rotary heat exchanger is designed to operate at 75% energy (enthalphy - h) effectiveness so the exhaust air is discharged outdoors at 0^oC (32^oF) and the fresh air is delivered indoors at 14.8^oC (58.7^oF) (equal airflow in both airstreams) as indicated in Figure 4.

Indoor air at 21^oC, 50% relative humidity has a moisture content (absolute humidity - W) of 0.0078 grams water per gram of dry air, a dew point of 10^oC. When this airstream enters the rotary heat exchanger matrix and comes into contact with matrix surfaces below 10^oC moisture begins condensing out on the matrix surfaces. As this airstream progresses through the heat exchange matrix, it encounters successively lower and lower matrix surface temperatures and condensation of moisture continues until the airstream emerges from the matrix cold face at a temperature of 0^oC and nearly saturated with moisture at that temperature. Extensive performance tests have shown approximately 90% relative humidity in the exiting exhaust airstream over a wide range of test conditions.

On the intake airstream side of the rotary heat exchanger, the cold, dry outdoor air enters and is warmed by the rotating matrix as it passes through. The moisture condensed on the matrix surface while in the exhaust airstream then evaporates into the dry incoming airstream thus removing all of the condensate deposited from the passage of the exhaust airstream. When the exhaust and supply airstreams have equal mass flow rates (the desired condition), the increase in absolute humidity of the fresh airstream (W_4 - W_3) must be equal to the decrease in absolute humidity of the exhaust airstream (W_1 - W_2). Thus, the fresh airsteam is supplied to the house with an absolute humidity of W_4 = .0061 gm water/gm dry air. With a temperature of 14.8^oC this corresponds to a relative humidity of 58% and a dew point of 7^oC.

Moisture Removal Rate - When removal of indoor moisture is desired (such as in extremely tight houses with heavy indoor moisture release) it is important to know the rate of moisture removal through the heat recovery ventilation system. For equal exhaust and fresh air flows, the moisture removal rate ($\dot{m}$) can be expressed by:

$$\dot{m}_{H_2O} \text{ (LB/hr removed)} = \text{CFM} \times 4.5 \ (W_1 - W_4)$$

For the example cited above, the removal rate for a 100 CFM (50 l/s) rotary system is:

$$\dot{m}_{H_2O} = 100 \text{ CFM} \times 4.5 \ (.0078 - .0061)$$

$$= 0.765 \text{ LB/hr } (0.35 \text{ Kg/hr})$$

$$= 2.2 \text{ gallons/day } = 8.3 \text{ liters/day}$$

Figure 5 provides similar results over a wide range of outdoor temperatures for various indoor relative humidity values. These curves in Figure 5 are based on 70% enthalpy efficiency for the exhaust airstream and 90% relative humidity in the cold exhaust air, conditions which are in good agreement with our test data.

Although it is desirable to operate the heat exchanger with the exhaust and fresh airflow rates equal (as in the above example), in practice it is impossible to obtain perfectly balanced flows. If the flows are not equal, it is usually preferred to have the exhaust airflow exceed the fresh airflow because this provides the warmest fresh supply air (reduced cold draft effects) and it avoids positive pressurization of the house which would cause humid inside air to flow outward carrying moisture into the wall cavities leading to concealed condensation and structural damage. In practice, the Airxchange rotary heat exchanger system in a typical installation operates with slightly greater exhaust airflow and measurements of the enthalpy effectiveness commonly show 70% on the exhaust air side and 78% on the fresh air side.

To facilitate comparison with stationary heat exchanger performance, the moisture removal curves from Figure 3 are also shown on Figure 5 as the faint dashed lines. Both types of heat exchangers have the same moisture removal performance at the higher outdoor temperatures where no condensation occurs within the heat exchanger. However, as outdoor temperature is reduced to the point where condensation begins at the heat exchanger cold face, the moisture removal curves for the rotary type exchanger begin to deviate from (fall below) those of the stationary type exchanger. At a given indoor relative humidity, the moisture removal from the rotary exchanger is nearly constant over a wide range of outdoor temperatures and exhibits a gradual decline as outdoor temperature drops from about -5°C to -30°C. It may at first appear that this declining moisture removal is undesirable, but when combined with a low level of natural infiltration, this characteristic will prove to be beneficial as will be shown later.

CONDENSATE COLLECTION AND FROST FORMATION IN HEAT EXCHANGERS

Stationary Exchangers - Moisture condensation occurs within the exhaust air passages of stationary type heat exchangers whenever the temperature of the transfer surface drops below the dew point of the exhaust air. This condensate must be drained from the exchanger through a suitable condensate drain line to some disposal means. When low outdoor temperatures cause the cold face of the heat exchanger to drop below the freezing point, frost and ice will form in the exchanger passages and progressively block the airflow. At some point during the freeze-up process, it becomes necessary to initiate a defrost cycle to clear the air passages and return the heat exchanger to normal operation.

Most fixed plate heat exchangers with a thermal efficiency in the 70% - 80% range experience frost-up problems at outdoor temperatures about -5°C and below.[3] Those that are intended for use in cold climates usually have automatic defrost systems incorporated into the heat exchanger package. This always increases the system cost and reduces its operating efficiency as shown in tests at Lawrence Berkeley Laboratories.[3]

Rotary Exchangers - Rotary heat exchangers on the other hand seldom experience this frost blockage problem. Under most operating conditions, as in the example cited above, all of the moisture condensed from the exhaust stream on the heat exchange matrix surface is re-evaporated into the fresh incoming airstream as the matrix rotates. Thus, there is no condensate accumulation in the heat exchanger to require draining away. The moisture that is rejected from the house is in the vapor state in the nearly-saturated exhaust airstream.

Under rare conditions, the fresh incoming airstream cannot hold all of the moisture that is condensed out of the exhaust airstream and condensate will accumulate on the matrix. If these conditions were to endure for an extended period, liquid water would drop to the bottom of the exhaust flow chamber, requiring a condensate drain or frost would form within the heat transfer matrix and inhibit airflow. These conditions are a combination of excessively high indoor relative humidity and very low outdoor temperatures as illustrated in Figure 6.

Line A in Figure 6 represents the theoretical upper limit to the condensate build-up or frost formation threshold. This line is the locus of conditions which would produce 100% relative humidity (saturation) in the fresh airstream leaving a 75% effective heat exchanger, thus representing the theoretical maximum indoor relative humidity that could be sustained without encountering condensate build up or frost up in the heat exchanger. This, of course, assumes that the moisture condensed from the exhaust airstream is capable of migrating within the heat exchanger matrix from the point where it is condensed to the point where it can be re-evaporated into the fresh airstream (e.g. by capillary action). The limited migration capability within any practical heat exchange matrix will produce a true frost-up line somewhat below this theoretical upper limit. However, the actual frost-up line will not necessarily be the same for all rotary heat exchangers.

A few test points shown on Figure 6 help to illustrate the Airxchange, Inc.* rotary exchanger's relative immunity to frost-up. Test data points represented by open circles show actual operating conditions where no condensate build up or frost formation was observed. Data points shown as solid circles represent conditions where heavy frost blockage occurred and the points represented as half open, half solid circles show conditions where partial frost blockage occurred which reduced airflow and thermal effectiveness moderately after which no further frost build up was observed. A test program is currently underway to complete the definition of this frost-up curve for the Airxchange sensible rotary heat exchanger.

As further evidence in support of the claim of favorable frost up characteristics for rotary exchangers, the line labeled "M" on Figure 6 shows the threshold of frost up for a hygroscopic type rotary heat exchanger tested at the University of Manitoba.[5] For comparison, the line labeled "S" shows the freezing threshold for typical stationary heat exchangers.[3]

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*This heat exchanger core consists of spirally wrapped strips of 5 mil polystyrene film spaced apart so as to provide fluid flow passages approximating closely spaced parallel planes.

To help add perspective to this discussion, a line representing the conditions for condensation (or frosting) over the entire surface of double glazed windows is also included in Figure 6. Most manufactured housing producers recommend maintaining indoor relative humidity values well below this double glazed window line because condensation around edges of windows and on window frames (especially metal frames) begins at substantially lower indoor humidities.

It is apparent from these results that a home where indoor humidity levels are kept comfortably below this double glazed window condensation line will have no difficulties with condensation collection or frost-up in a sensible rotary heat exchanger.

In practice, continuous operation of the exchanger removes moisture from the home preventing indoor humidity from reaching levels sufficient to produce condensation on double glazed windows or the accumulation of condensate in the exchanger itself. Under normal operating conditions, the rotary air-to-air heat exchanger requires neither frost protection nor condensate drain.

TOTAL MOISTURE REMOVAL-NATURAL AND MECHANICAL VENTILATION COMBINED

The foregoing paragraphs have presented the moisture removal characteristics of mechanical ventilation systems incorporating air-to-air heat exchangers of both the stationary (non-permeable) and rotary types. When these systems are installed in homes, the moisture removal which they provide is always supplemented by a certain amount of additional natural infiltration of outdoor air through cracks and leaks in the structure and by opening of doors and windows. Although modern energy-efficient home construction practice has reduced natural infiltration to relatively low levels, the amount of infiltration remaining is still capable of significant winter moisture removal and should be included in any final assessment of overall moisture removal mechanisms.

A typical value for the natural infiltration in a modern "tight" house is about 0.25 air changes per hour (ACH). Indeed, some homes have been built with as little as 0.1 ACH, but few would exhibit more than 0.5 ACH today.(6) It is worth noting that even in the very tight home (measured at 0.1 ACH) occupant activity (i.e. opening doors, exhaust fan operation, etc.) makes a significant additional contribution to natural infiltration. It is of interest then to compare an average 1600 FT^2 house with 0.25 ACH natural infiltration plus 0.5 ACH mechanical ventilation via 1) a stationary type heat exchanger system (or straight mechanical ventilation without heat exchange) vs. 2) a sensible rotary heat exchanger.

Figure 3 illustrated the moisture removal with 1/2 ACH mechanical ventilation through a stationary heat exchanger. This is equivalent to 1/2 ACH of natural infiltration; thus 0.25 ACH natural would provide exactly one half this amount of moisture removal. Combining the 1/2 ACH mechanical ventilation through a stationary heat exchanger system (Fig. 3) with 0.25 ACH natural infiltration results in the total moisture removal characteristic shown by the bold dashed lines in Figure 7.

Similarly, by adding the 0.25 ACH natural infiltration moisture figures to those of Figure 5, the solid lines of Figure 7 are obtained representing the combination of 0.25 ACH natural and 0.5 ACH mechanical ventilation via the sensible rotary heat exchanger.

Remembering that a dwelling for the average family of four must reject about three to four gallons of water daily, it is clear from the two sets of curves in Figure 7 that the rotary exchanger has the more favorable moisture rejection characteristic. For example, it shows that the moisture removal rate for a given indoor humidity level is nearly constant over a broad range of outdoor temperatures from 10°C to -30°C. Moreover, 3-4 gallons per day water removal can be achieved with indoor relative humidity in the 20-30% range below 10°C outdoor temperatures and at somewhat greater indoor R.H. at outdoor temperatures above 10°C. These indoor R.H. values are within the comfort zone and should eliminate other moisture problems such as condensation staining, mold growth, and dust mites experienced in many tight houses recently.

By contrast, the curves in Figure 7 for the stationary type heat exchanger show that a 3-4 gallons per day water removal requirement will lead to excessively low indoor relative humidity at the lower outdoor temperatures (e.g. 10% at -30°C (-20°F)) increasing to only 20% at -10°C (+14°F).

Another point is worthy of mention here. Although the above example assumed that the natural infiltration was a constant 0.25 ACH over the entire outdoor temperature range, it is well known that the magnitude of natural infiltration is a function of the indoor to outdoor temperature difference.(8) Thus, at the lowest outdoor temperatures, the natural infiltration contribution to moisture removal is likely to be greater than indicated in this example relative to its magnitude at the higher outdoor temperatures. This makes the combination of a low level of natural infiltration plus 1/2 ACH mechanical ventilation through a rotary exchanger even more favorable to the moisture removal needs of the average home.

CONCLUSION

The experimental and analytical results presented show moisture removal characteristics for a 100 CFM (50 l/s) heat recovery ventilation system with a sensible rotary heat exchanger. These results can be scaled to any desired airflow rate and are believed to apply to any other rotary exchanger having similar thermal effectiveness. From the illustrated example for a family of four in an average size home, the following conclusions may be drawn regarding the moisture removal performance of the rotary heat exchanger compared with a stationary type exchanger of equal airflow capacity. (1/2 ACH).

1. The rotary heat exchanger provides ideal moisture removal characteristics when combined with the small amount of natural infiltration (1/4 ACH) typically present in tightly constructed, energy efficient homes.

2. By comparison, the non-permeable wall stationary type heat exchanger removes an excessive amount of moisture at low outdoor temperatures and requires additional humidification to maintain comfortable indoor humidity levels.

3. Rotary heat exchangers do not require condensate drains and are not subject to frost blockage under winter operating conditions normally encountered in the Northern U.S. and Canada.

4. By contrast, stationary type heat exchangers are subject to frost blockage and require defrosting action whenever outdoor temperatures drop below about -5°C (23°F).

This frost up phenomenon ususally imposes a significant reduction in airflow and efficiency so that average heat recovery efficiency for stationary exchangers during frosting conditions is substantially lower than with a typical rotary exchanger.

Investigations to provide more complete definition of the frost up characteristics of the rotary heat exchanger are continuing. The results to date are very encouraging and future results are expected to corroberate those already obtained.

Heat recovery ventilation systems will influence indoor humidity levels in "tight" energy efficient homes, but they should not be used to "control" humidity levels. Because their prime function is ventilation, they should be operated continuously. Precise control of indoor relative humidity during the heating season can only be obtained with variable ventilation rates or use in conjunction with a humidifier or dehumidifier.

REFERENCES

(1) Zieman, M.L., and Waldman J.D., 1984, "Moisture Problems in Mobile Homes" Final Report on HUD contract No. H-10992, RADCO, Inc., Carson, CA.

(2) Offerman, F.J. et al, 1982, "Residential Air Leakage and Indoor Air Quality in Rochester, NY", Report No. LBL-13100-UC-95d, prepared for U.S. DOE, Lawrence Berkeley Laboratory, Berkeley, CA.

(3) Fisk, W.J., et al, 1983, "Freezing in Residential Air-to-Air Heat Exchangers: An Experimental Study", Report No. LBL-16783, UC-38, prepared for U.S. DOE by Lawrence Berkeley Laboratory, Berkeley, CA.

(4) ASHRAE Handbook - 1977 Fundamentals Ch. 20, Pg. 20.1, ASHRAE, NY, NY.

(5) Ruth, D.W., Fisher, D.R. & Gawley, H.N., 1975, "Investigation of Frosting in Rotary Air-to-Air Heat Exchangers", ASHRAE Transactions, 81 Part 2.

(6) Shaw, C.Y., 1981, "A Correlation Between Air Infiltration and Air Tightness for Houses in a Developed Residential Area", ASHRAE Paper No. 2655.

(7) Shurcliff, W.A., 1982, "Air-to-Air Heat Exchangers for Houses", Brick House Publishing Co., Andover, MA.

(8) ASHRAE Handbook - 1977 Fundamentals, Ch. 21 Ventilation, pp. 21.1 - 21.6, ASHRAE, NY, NY.

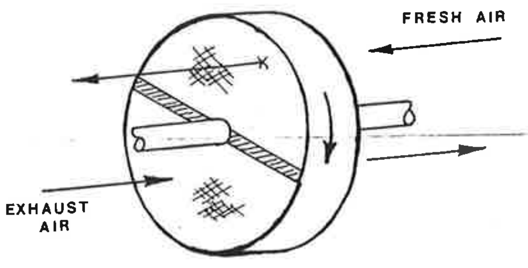

FIGURE 1 ROTARY HEAT EXCHANGER

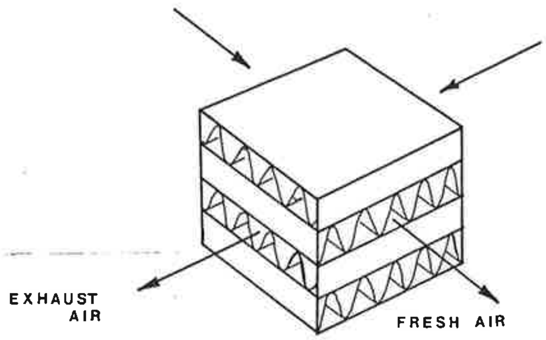

FIGURE 2 STATIONARY HEAT EXCHANGER CROSS FLOW TYPE

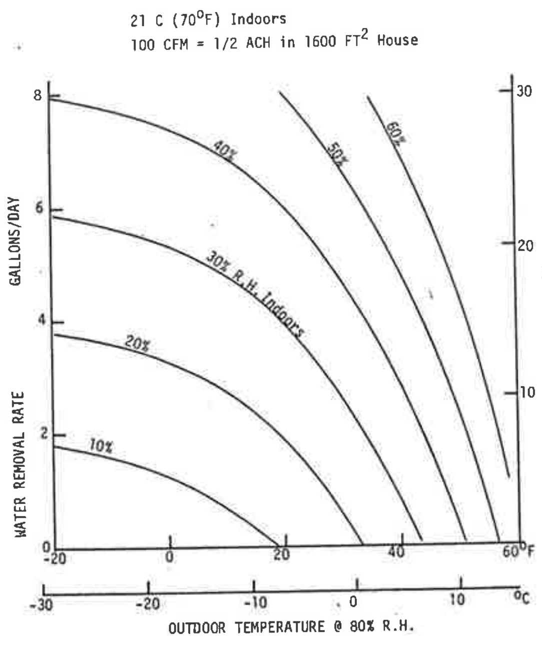

FIGURE 3 WINTER MOISTURE REMOVAL RATES FOR 100 CFM STATIONARY HEAT EXCHANGER – OR VENTILATION w/o HEAT EXCHANGE

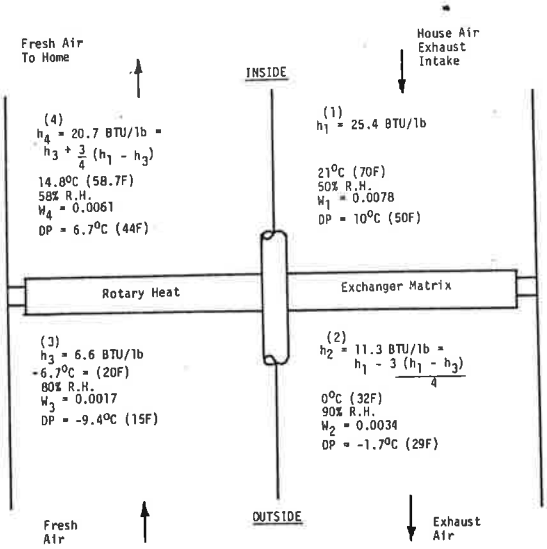

FIGURE 4 ROTARY HEAT EXCHANGER TYPICAL OPERATING PARAMETERS

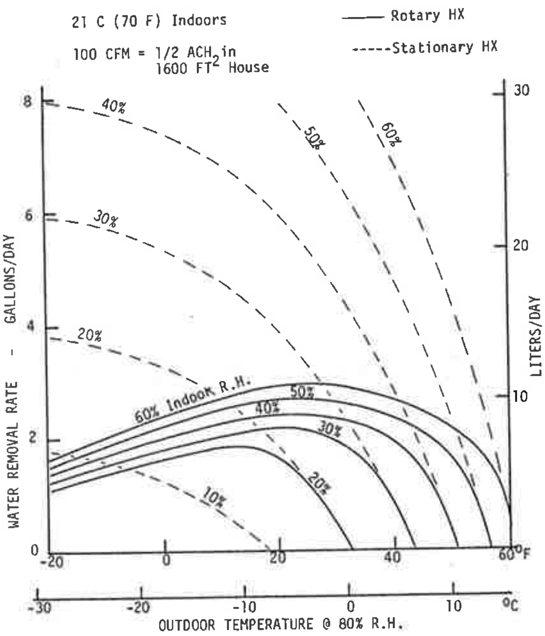

FIGURE 5 WINTER MOISTURE REMOVAL RATES FOR 100 CFM SENSIBLE ROTARY HEAT EXCHANGER

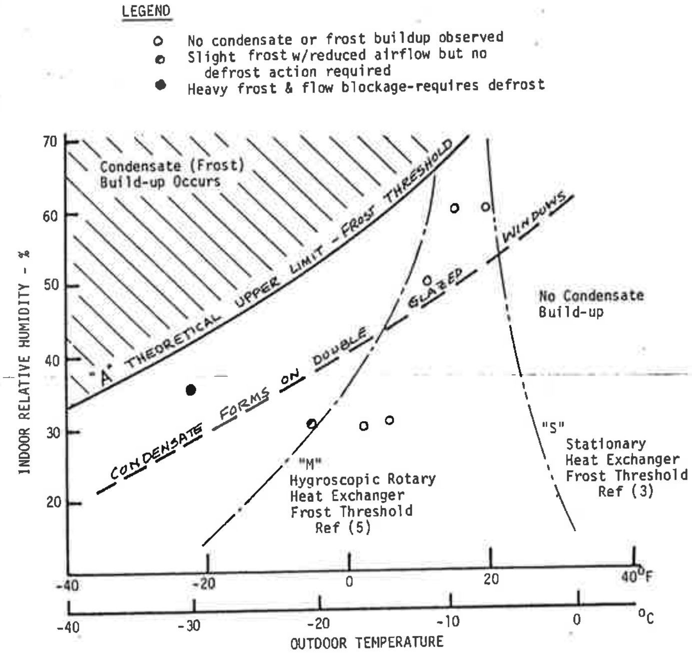

FIGURE 6 CONDITIONS REQUIRED TO AVOID CONDENSATE BUILD-UP AND FROST IN ROTARY HEAT EXCHANGERS

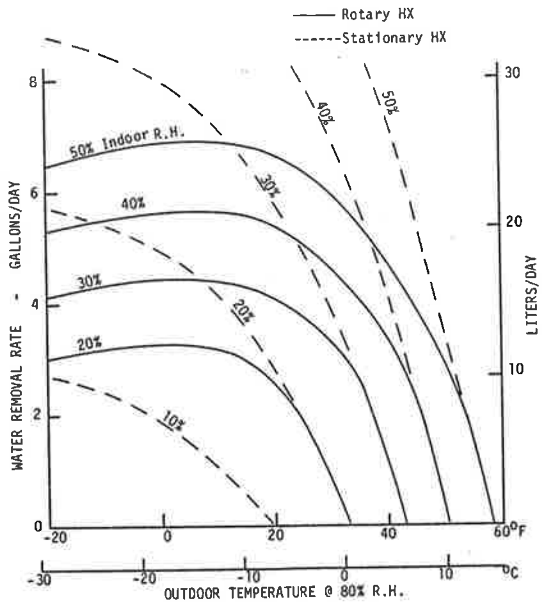

FIGURE 7 WATER REMOVAL PERFORMANCE OF A 1600 FT² HOME WITH 1/4 ACH NATURAL INFILTRATION AND 1/2 ACH MECHANICAL HEAT RECOVERY VENTILATION – ROTARY VS STATIONARY