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NT-87-07-3

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AIRFLOW REDUCTION DURING COLD WEATHER OPERATION OF RESIDENTIAL HEAT RECOVERY VENTILATORS

C.A. McGugan, P.E. **P.F. Edwards** **M.A. Riley**
ASHRAE Associate Member

ABSTRACT

Laboratory measurements of the performance of residential heat recovery ventilators have been carried out for the R-2000 Energy Efficient Home Program. This work was based on a preliminary test procedure developed by the Canadian Standards Association, part of which calls for testing the HRV under cold weather conditions. An environmental chamber was used to simulate outdoor conditions. Initial tests were carried out with an outdoor temperature of -20°C; subsequent tests were carried out at a temperature of -25°C. During the tests, airflows, temperatures, and relative humidities of airstreams entering and leaving the HRV, along with electric power inputs, were monitored. Frost buildup in the heat exchangers and defrost mechanisms, such as fan shutoff or recirculation, led to reductions in airflows. The magnitude of the reductions is dependent on the design of the heat exchanger and the defrost mechanism used. This paper presents the results of tests performed on a number of HRVs commercially available in Canada at the time of the testing. The flow reductions for the various defrost mechanisms are discussed.

INTRODUCTION

The construction of low-energy housing in Canada has encouraged the development of a number of residential heat recovery ventilators (HRVs) for use in these homes. This, in turn, has created a demand for a standardized testing procedure to be used in rating the performance of these heat recovery ventilators.

The existing standard, ASHRAE Standard 84-78, "*Method of Testing Air-to-Air Heat Exchangers*" was intended for the testing of commercial heat exchangers without integral fans. Since the majority of heat recovery ventilators designed for residential use include fans, additional testing procedures were required. These procedures were developed for the Canadian Standards Association and are contained in CSA Standard C439M, "*Standard Methods of Test for Rating the Performance of Heat Recovery Ventilators*", which was published as a preliminary standard in May 1985.

An Ontario research organization has established a laboratory facility for measuring the performance of heat recovery ventilators in accordance with CSA Standard C439M. Figure 1 shows a layout of this facility. Under the sponsorship of the R-2000 Super Energy Efficient Housing Program, tests have been carried out by ORF on a number of HRVs available in Canada. Figure 2 shows a schematic of the test loop and instrumentation.

P.F. Edwards, Supervisor, HRV Laboratory, Ontario Research Foundation; C.A. McGugan, P.Eng., Head, Process Energy Systems, Ontario Research Foundation and M. Riley, Chief, Residential Technology & Industry Development, R-2000 Home Program, New Housing Division, Energy, Mines and Resources Canada

TESTING PROCEDURES

Testing of heat recovery ventilators is required to determine how they will operate when installed in a building. The information obtained from the testing can be used by designers when specifying a unit for a particular application and by purchasers when deciding which HRV to buy. The test results are also useful to manufacturers for identifying whether the units perform as designed.

In order to provide comparable information for the various devices and from different testing facilities, standards have been developed. A description of the types of tests contained in CSA Standard C439M, "*Standard Methods of Test for Rating the Performance of Heat Recovery Ventilators* ", is given here. There are five basic tests in the CSA Standard. These are:

1. Airflow Test
2. Cross-Leakage Measurement
3. Heat Transfer Performance in Cooling Conditions
4. Heat Transfer Performance in Nonfrosting Heating Conditions
5. Performance in Cold Weather Conditions

The last test determines how the heat recovery ventilator will perform under simulated cold weather conditions. A description of the tests follows.

Airflow Tests

The airflow test measures the quantity of air that the ventilator will deliver under various external static pressures. These static pressures represent the resistance to airflow produced by ductwork, filters, grilles, and other components of the air distribution system connected to the ventilator.

For this test, the ventilator is installed in the test loop. The ventilation fans and test loop fans are operated, and dampers are adjusted to provide a variety of static pressures at the ventilator. The airflow rate is measured and plotted against the differences between the static pressures at the inlet and outlet of the ventilator for each airstream.

Cross-Leakage Measurement

"Cross-leakage" is the term applied to the transfer of a portion of one airstream over to the other in an air-to-air heat exchanger. In the case of heat recovery ventilators, only the leakage of exhaust air into the fresh airstream is considered. The major effects of cross-leakage are to reduce the amount of fresh air entering the building and to increase the apparent heat exchanger effectiveness.

The term used for cross-leakage in CSA Standard C439M is the "*exhaust air transfer ratio* ". To measure this ratio, the heat recovery ventilator is installed in the test loop. The fresh air side of the loop is opened so that outdoor air is brought into the loop, and fresh air leaving the test ventilator is vented through an exhaust system that discharges the air well away from the fresh air intake.

The exhaust section of the loop is left closed to contain the tracer gas injected into that section. Since cross-leakage is dependent upon pressure differences between the fresh air and exhaust airstreams in the HRV, a set of pressures to simulate potential conditions in an actual installation were recommended for the CSA standard. For locations at the HRV connections as described, these static pressures are:

	Test Conditon 1	Test Condition 2
Location 1 - Fresh air entering ventilator	-25 pascals	-12.5 pascals
Location 2 - Fresh air leaving ventilator	+75 pascals	+37.5 pascals
Location 3 - Exhaust air entering ventilator	-75 pascals	-37.5 pascals
Location 4 - Exhaust air leaving ventilator	+25 pascals	+12.5 pascals

Locations 1 and 4 are the connections from the ventilator to the outdoors. These ducts are usually short, with low pressure drops. Locations 2 and 3 are the connections to the house distribution and exhaust systems, which frequently have much greater lengths of ductwork.

The loop dampers are adjusted to provide pressures as near as possible to the ones specified. Once these conditions are achieved, tracer gas is injected into the exhaust air loop. The level of tracer gas in the exhaust loop is monitored using an infrared analyzer. The injection rate is regulated until a steady concentration is obtained in the exhaust air. When this occurs, alternative measurements of tracer gas concentrations are taken from the fresh air leaving the ventilator and the exhaust air entering the ventilator. The fresh air entering the ventilator is also monitored to ensure that no tracer gas has contaminated the supply air.

A series of five readings is taken and the concentration averaged. The exhaust air transfer ratio is calculated as: $R = C_2/C_3$ where:

R = exhaust air transfer ratio
C_2 = measured concentration of tracer gas at Location 2
C_3 = measured concentration of tracer gas at Location 3

The actual fresh airflow can be calculated using the exhaust air transfer ratio. If the ratio is measured to be 0.2, then 20% of the air entering the building at Location 2 is exhaust air. Thus, if the total flow rate is 100 L/s , only 80 L/s is actually fresh air.

Heat Transfer Performance in Cooling Conditions

This test determines the performance of the HRV under cooling conditions. The unit is installed in the test loop with static pressures set as described in the cross-leakage test. The fresh air entering the HRV is conditioned to a minimum of 14°C above the temperature of the exhaust air entering the HRV, with a minimum humidity ratio difference of 0.007 Kg/Kg of dry air between the two streams. The test is carried out with the mass flow of the two airstreams equal.

The temperatures, humidities, mass flows, and static pressures of the airstreams entering and leaving the HRV are measured during this test, along with electrical power input to the unit. These values are used in the calculation of the apparent effectiveness and total heat recovery efficiency of the HRV.

Heat Transfer Performance in Nonfrosting Heating Conditions

The performance of the HRV under heating conditions where frosting or condensation will not occur in the exhaust stream is determined in this test. The CSA Standard C439M calls for a minimum supply-exhaust air temperature difference of 30°C and a minimum humidity ratio difference of 0.003 Kg/Kg dry air. The actual tests are undertaken with "outdoor air temperature" of 0°C and "indoor air temperature" of 22°C in an effort to obtain test data in a more representative nonfrosting heating condition.

The unit is installed in the test loop and operated with balanced mass flows at the test points described in the cross-leakage tests. Temperatures, humidities, and mass flows of the airstreams entering and leaving the HRV are measured during this test, along with electrical power input to the unit. These values are used in calculation of the apparent effectiveness and heat recovery efficiency of the HRV.

Low Temperature Operation

One of the most important factors for a heat recovery ventilator intended for use in Canada is its performance at low ambient temperatures. The initial cold weather test proposed for the CSA Standard called for the HRV to be operated with a -20°C incoming air temperature for a period of 24 hours after stability had been reached. A number of units were tested in this way during an initial round of tests. The results of these tests indicated that it was difficult to determine when stability had been reached, and that -20°C might not be a low enough temperature for units to be used in most areas of Canada.

The revised test for CSA Standard C439M requires the ventilator to be operated with a fresh air supply temperature of -25°C over a 72-hour period. The exhaust air conditions for the test are 22°C dry-bulb temperature and 40% relative humidity. Airflow rates, heat recovery, and electrical energy requirements are monitored over the test period.

The intent of this test is to determine whether the heat recovery ventilator will operate satisfactorily at the test conditions. The time required for defrost on units with fan shutdown and the power requirements for units with electric preheaters is also important. The total fresh air and exhaust airflow rates are calculated over the last 12 hours of the test period, along with the total energy recovered and electrical consumption. These values are used to calculate sensible and total heat recovery efficiencies as defined in the CSA Standard. The reduction in ventilation rate and imbalance in supply air exhaust flow rates are also calculated in this test.

DEFROST METHODS

Most HRVs will experience frost buildup on heat transfer surfaces with -20°C air entering the heat exchanger. This frosting occurs in exhaust air passages when the surfaces are below the frost point of the exhaust air. This frost buildup will act as an insulator and reduce heat transfer; however, its greatest effect is to reduce the flow of air through the unit. This can lead to almost total blockage of the exhaust air passages. Air is prevented from passing through the core, and, therefore, no heat is recovered, and the building becomes pressurized. To avoid these problems most HRVs employ some defrost mechanisms. The most commonly used methods are:

- shutdown of fresh air fan to allow defrost by exhaust air;
- recirculation of exhaust or house air through the fresh air side via automatic dampers;
- use of a preheated coil to heat the incoming air above the temperature at which frosting becomes a problem.

These are discussed in more detail in the following sections.

Other, less common defrost methods include:

- bypassing a portion of the outdoor airflow around the core;
- stopping the outdoor airflow and dumping the exhaust air back into the building after it passes through the heat exchanger;
- electric defrost elements in core;
- use of mechanical dampers to divert outdoor airflow from sections of the core to allow defrost;
- derating heat exchanger effectiveness (by tilting of heat pipes or changing speed of rotary units).

Defrost by Outdoor Air Shutoff

In this method, a sensor is used to shut off the fresh air supply. The most simple method is to shut off the outdoor air fan. The exhaust air fan continues to run, warming the core and melting accumulated frost. The penalty associated with this type of defrost is the fact that no energy is recovered from the exhaust stream during the defrosting period. Outdoor air must be brought in through the building shell and fully heated. In the efficiency calculation contained in CSA Standard C439, the energy used for heating makeup air is subtracted from the energy recovered by the HRV. There is also potential for depressurization of the building, since the unit is exhausting only. If the building shell is tight, airflow may be induced through the outdoor air side of the HRV. This will provide some heat recovery, but may slow down or stop melting of frost. Some manufacturers recirculate the exhaust airstream via an automatic damper to avoid depressurization. Frosting of the exhaust side will reduce flow through the unit to a certain extent between periods of defrost.

In a variation of this method, the HRV operates in such a way as to cut off the airflow to and from the outdoors during the defrost period. House air is then circulated through the fresh air side of the HRV, or exhaust air is dumped into the room where the HRV is located. This may be accomplished using one or more dampers and sometimes shutting off one fan. This method will result in reduced ventilation flows but should not have the same reduction in efficiency as the exhaust-only method, since makeup air is not required during the defrost period. The house air circulated through the HRV will be cooled, producing a heating load in the house. This energy is subtracted from the recovered energy in the efficiency calculation in the CSA Standard.

Prevention of Frosting by Use of Preheat Coil

It is possible to avoid formation of frost in an HRV by preheating the incoming air before it reaches the heat exchange core. The air must be heated to a temperature where frosting will not occur on the exhaust side of the HRV. Otherwise, if frosting takes place, reductions in airflow and efficiency will occur. Preheating the incoming air limits the amount of energy that the HRV can recover and will reduce the efficiency of the unit. In cold climates, substantial amounts of energy can be used by the preheat coil.

RESULTS OF TESTS

Tests at -20°C

Initial tests were carried out on 12 residential HRVs in 1984 (Edwards and McGugan 1986). The cold weather test was set up as shown in Figure 3. Six of the units tested used a conventional fan shutoff defrost method described above (with no recirculation dampers). Of the remaining six, four used electric preheat coils, and two did not have any defrost mechanisms. Ventilation reduction was calculated as the percentage reduction in average flow rate of the supply and exhaust airstreams over the 24-hour cold weather test as compared with operation under nonfrosting conditions. Table 1 shows the airflow reductions for the 12 units tested.

The large flow reductions for Unit A result from improper operation of the defrost control mechanism. The defrost period for the unit was not long enough to clear the core, and, therefore, frost and ice accumulated in the core during the test. The defrost mechanism for Unit C failed to initiate a defrost during the test. Frost built up in the exhaust side of the core until an equilibrium was attained. Units B, D, E, and F show results that are more typical of properly operating supply fan shutoff defrost mechanisms. The reduction in supply flow is due to the shutdown of the supply fan and is a fairly good indication of the length of time that the unit is in defrost. The reductions in exhaust flow result from increased pressure drops produced by frost and ice buildup in the cores during defrost. Figure 4 shows an example of the airflow variations in Unit D during 24 hours of testing. The defrost cycles are marked by the drop in flow of the warm supply flow. The drop in exhaust airflow between cycles is a result of the buildup of frost and ice in the HRV core. A similar reduction in flows was noted by other researchers (Fisk et al. 1985).

The results for the units using preheat show that there was some frosting in the cores, which caused a reduction in exhaust airflows. Figure 5 shows the flow rate for Unit I during the 24-hour test. The initial drop in exhaust flow rate can be seen during the first three hours of the test. Figure 6 shows the airflow rates for Unit G. The exhaust flow shows a small but steady decline over the 24-hour test period indicating that frost was continuing to accumulate in the core. From examination of the heat exchanger cores immediately after the test it was apparent that unequal distribution of cold supply airflow through the cores contributed to the frosting. Frost accumulation was usually in exhaust air passages directly in front of the cold air inlet to the unit.

Test at -25°C

After the initial series of tests, the test procedure was revised so that units would be tested for 72 hours with an inlet air temperature of -25°C. The data on airflow reduction for eight units tested under this new procedure are listed in Table 2. In addition to the lower temperature test condition, there was concern about depressurization of houses by HRVs in defrost. To address this concern, manufacturers attempted to design their defrost mechanisms so that supply and exhaust air flow would on average be within 10% of each other. The results show that in almost all cases this could be achieved.

As expected, the lower test temperature meant that, in most cases, flow reductions were larger due to increased defrosting requirements. Unit Q, which recirculated cooled exhaust air back through the supply air side, had the greatest flow reduction. Unit T employs a defrost mechanism that has evolved from the recirculation development. In this unit, a damper is located at the supply air inlet to the HRV. In normal operation, this damper covers a port in the casing of the HRV. During defrost, the damper moves to block the duct connection to outdoors, opening the casing port, so that the supply air fan draws warm space air through the core. The exhaust fan continues to run, and frost in the core is quickly melted.

The low airflow reductions for Unit T are due to the fast defrost, and the fact that baseline airflows are taken at conditions of 22°C. During the -25°C test, the air entering the fans is usually below 22°C, and so has a greater density. Since reported airflows are corrected to standard conditions, the higher densities produce higher flow rates. This helps to offset the reductions in flow resulting from shutoff of supply air and frosting of exhaust air passages.

IMPACT OF AIRFLOW REDUCTIONS

There are two major effects of airflow reductions due to frosting and defrosting. The first of these is the reduced ventilation rate provided by the HRV. If ventilation requirements for a house are constant and independent of outdoor temperature, then an HRV with significant flow reductions will need to be oversized to compensate for the lower flows in locations where frosting will occur. If the HRV's main function is humidity control, then the reduced airflow in cold weather may not be a problem due to increased dehumidification capacity of the outdoor air at colder temperatures.

The reduction in ventilation may not be significant on a seasonal basis if the HRV operates in the frosting region for only a short period of time. Work done by others (Fisk et al, 1983) indicated freezing in HRV cores began with entering air temperatures in the range of -3°C to -12°C . The rate of decrease in exhaust airflow was monitored, and was found to increase as entering air temperatures decreased. Therefore, in climates where there are few hours of operation below -3°C , ventilation flow reduction should not be a problem.

The second effect of frosting and defrosting is the potential for flow imbalances and resulting pressurization or depressurization of the building in which the HRV is operating. For units with supply fan shutoff, or shutoff of supply airflow, if the exhaust fan is running, it will tend to depressurize the building. For buildings with very tight shells, significant depressurization could occur. If shutoff of the supply fan is used without dampers to stop the outdoor airflow, cold air could be drawn through the HRV. This will help to limit the extent of depressurization, but could slow down or stop the melting of frost in the HRV, possibly leading to blockage of the exhaust air side. If a damper is used for positive blockage of the outdoor air supply, other problems could occur. If the building shell is relatively tight, air could be drawn in through openings used for other exhaust systems. Flow through chimneys and vents for combustion appliances such as fireplaces and gas furnaces could be reversed, forcing combustion products into the living space. This problem can be avoided if both exhaust and outdoor air ducts are blocked during the defrost period. For units that run with an excess of supply flow over exhaust, pressurization of the building can result. In cold climates, this can produce exfiltration, which results in condensation in the building shell, and potential damage. These factors need to be considered when selecting an HRV for use in a cold climate.

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ACKNOWLEDGMENTS

The authors gratefully acknowledge the support of the R-2000 Energy Efficient Home Program of Energy Mines and Resources, which funded the testing work described in this paper.

TABLE 1

Effect of Cold Weather Operation (-20°C) on Ventilation Rate of 12 HRVS

HRV DESIGNATION	TYPE OF DEFROST	PERCENT REDUCTION IN AIRFLOW	
		SUPPLY	EXHAUST
A	Supply Fan Shutoff	58	38
B	Supply Fan Shutoff	15	4
C	Supply Fan Shutoff*	0	21
D	Supply Fan Shutoff	10	6
E	Supply Fan Shutoff	23	4
F	Supply & Exhaust Fan Shutoff	28	1
G	1000 Watt Preheat	0	7
H	1500 Watt Preheat	4	3
I	1500 Watt Preheat	0	15
J	1000 Watt Preheat	1	4
K	No Defrost	34	45
L	No Defrost	0	0

* Defrost Method did not operate

TABLE 2

Flow Reductions for HRV'S AT -25°C

UNIT DESIGNATION	TYPE OF DEFROST	PERCENT REDUCTION IN AIRFLOW	
		SUPPLY	EXHAUST
M	Exhaust Fan Shutdown and Circulation of Space Air through Supply Side by Means of Damper	20	29
N	Supply Fan Shutdown	18	12
O	Supply Fan Shutdown Augmented by 140 W Electric Heater in Core	7	11
P	Supply Fan Shutdown Augmented by 325 W Electric Heater in Core	11	12
Q	Recirculation of Exhaust Air through Supply Side	50	45
R	Supply Fan Shutdown	25	34
S	Exhaust Fan Shutdown and Circulation of Space Air through Supply Side by Means of Damper. Exhaust Fan Runs for Last Two Minutes of Defrost Cycle	25	19
T	Circulation of Space Air through Supply Air Side by Means of Damper	1	2

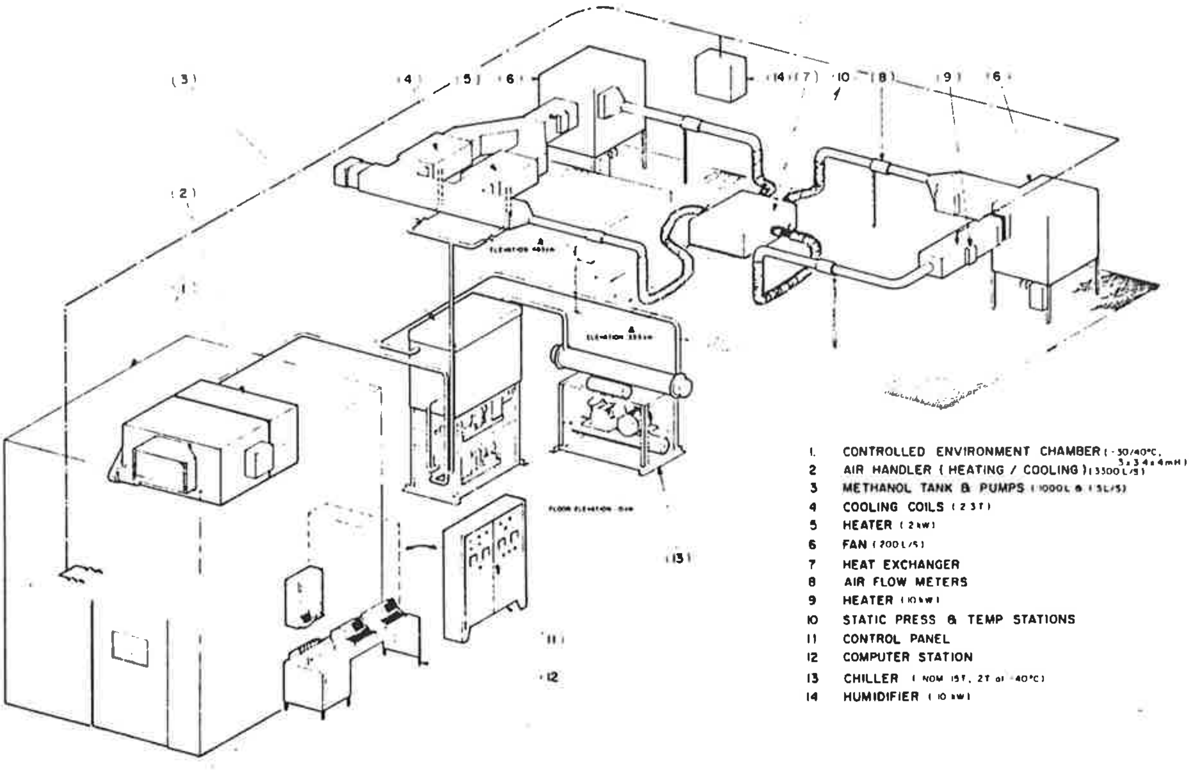

Figure 1. Energy and combustion systems center controlled environment research and development facility

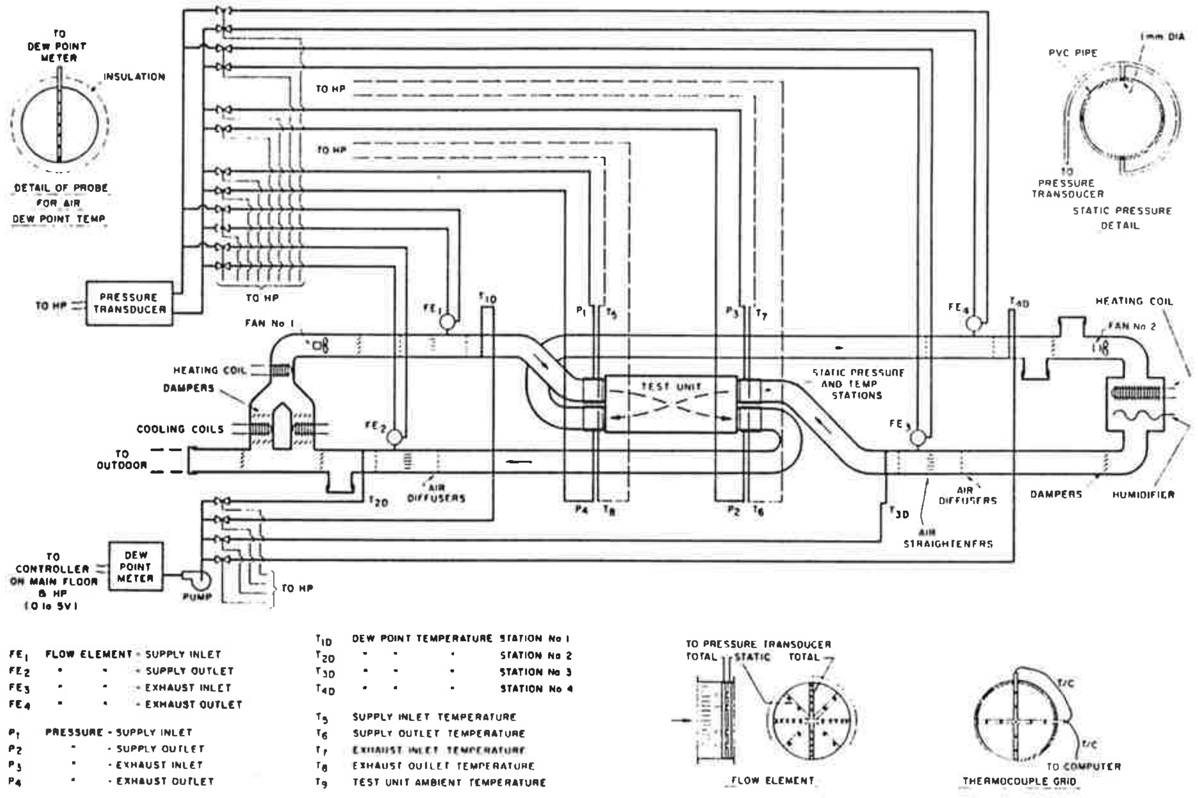

Figure 2. Schematic of test facility for air to air heat exchangers

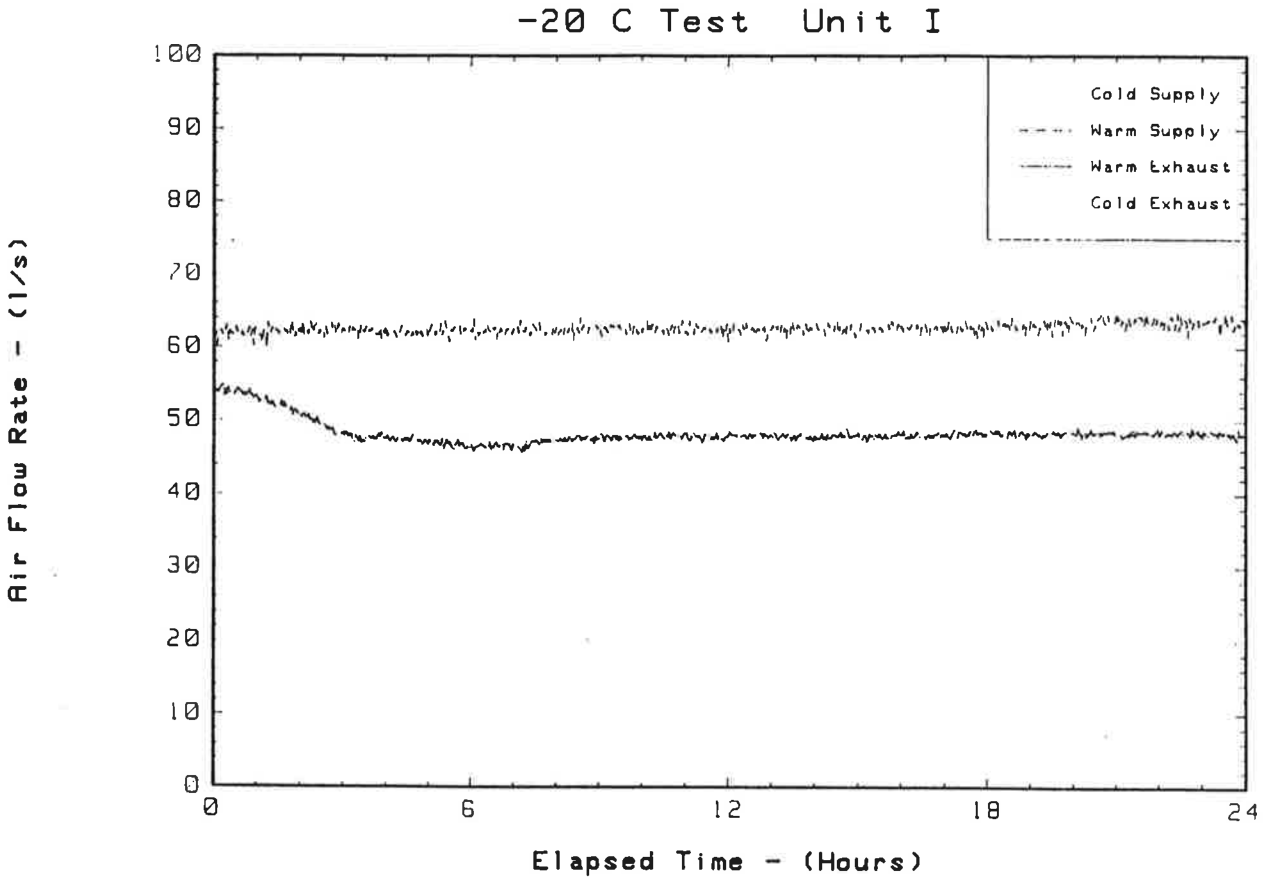

Figure 5. HRV test results, airflow rate vs. time

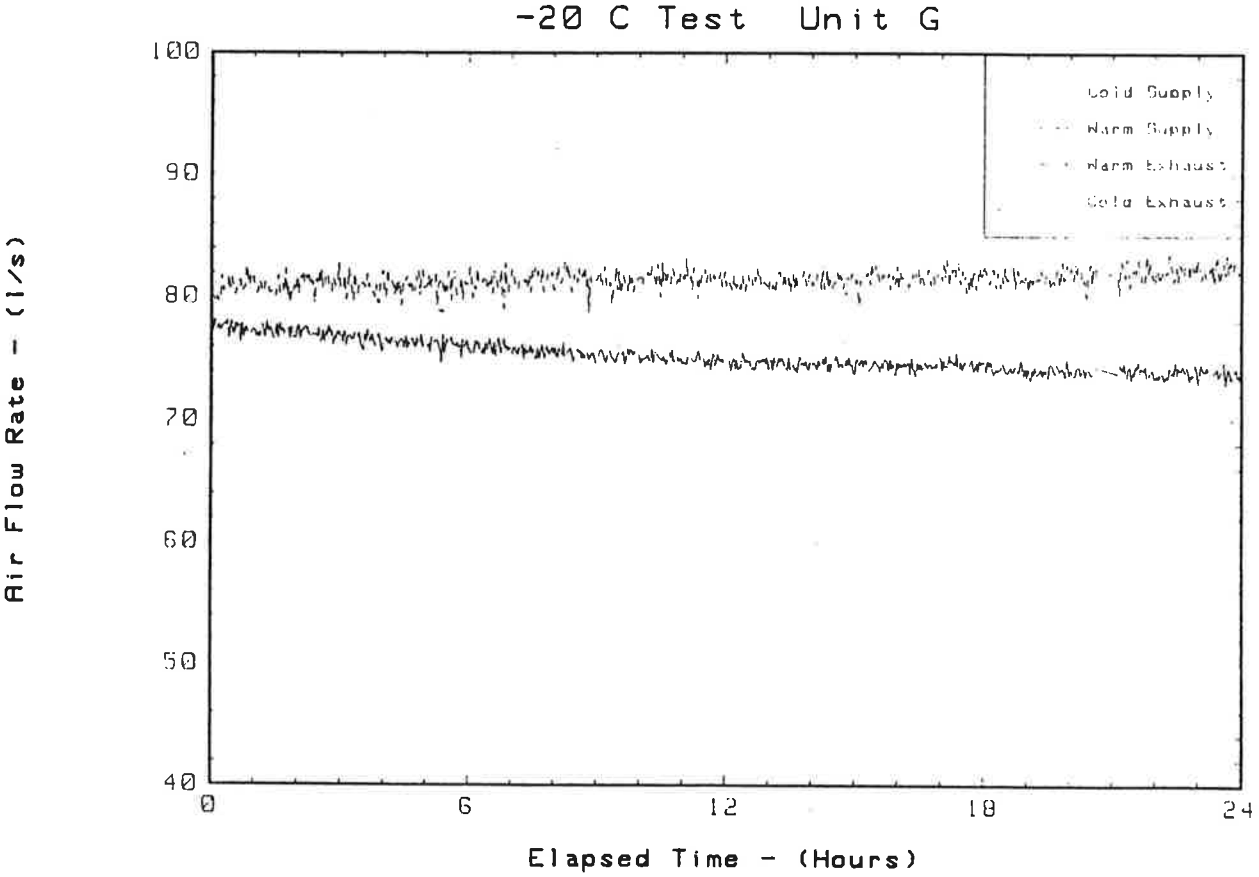

Figure 6. HRV test results, airflow rate vs. time

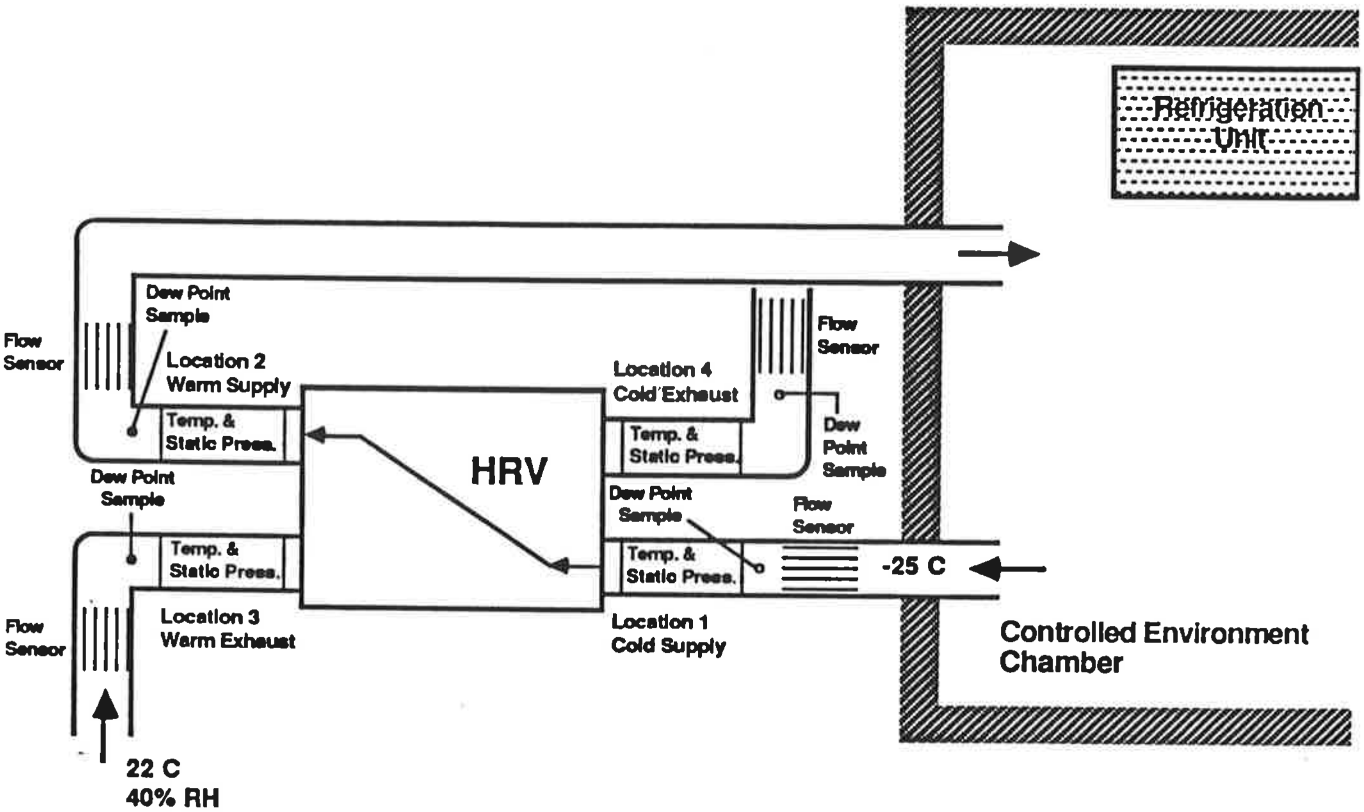

Figure 3. Setup for cold weather test of HRV

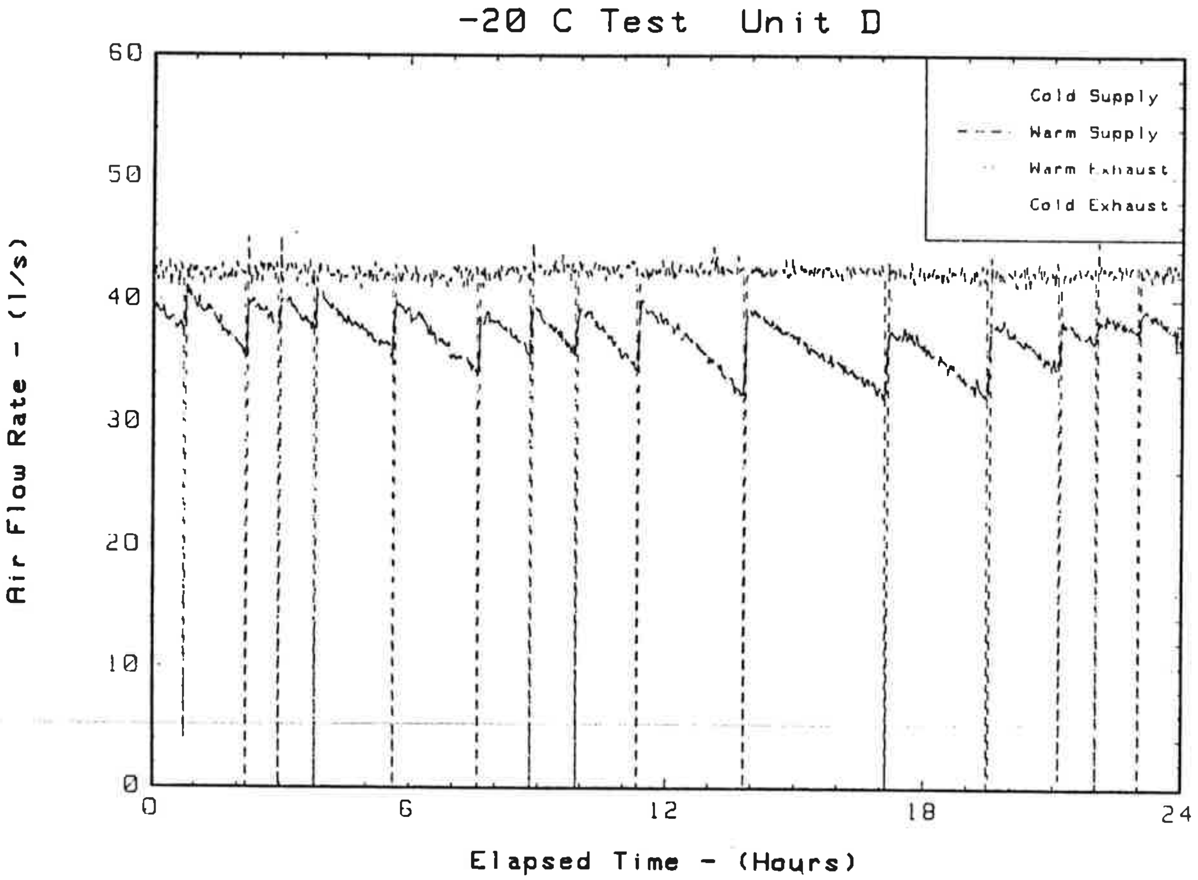

Figure 4. HRV test results, airflow rate vs. time