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THE HEAT PUMP APPROACH TO EXHAUST AIR HEAT RECOVERY

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ABSTRACT

Once one is committed to mechanical ventilation of houses, it is natural to think in terms of recovering heat from exhaust air. Often the first approach to heat recovery that comes to mind is the air-to-air heat exchanger; but, in many circumstances, the heat pump approach offers significant advantages.

In this approach, the exhaust air is chilled in the evaporator of a heat pump immediately prior to exiting the building. The condenser can be configured to dump the recovered heat to the interior air, to the domestic hot water or to both.

This approach -

- can be effective even if the airtightness of the house envelope is not nearly perfect
- does not require balanced intake and exhaust air flows and therefore can provide protection against interstitial condensation by depressurizing the house
- can eliminate air change heat loss completely, and
- can supply most or all of the space heating load of reasonably well-insulated houses.

Canadian research, by Scanada, NRC and others, is described and compared to efforts in other countries, primarily Sweden.

A Swedish design of air-to-water heat recovery heat pump was selected by a Canadian manufacturing company for inclusion in several demonstration low energy houses which incorporate exhaust only (negative pressure) ventilation. Performance to date has been encouraging as has market response. Some refinements to the Swedish design to adapt it to Canadian requirements have already been made and the potential for further extensions of the technology is exciting.

INTRODUCTION

There is currently a great deal of interest in the subject of mechanical ventilation of houses and much of that interest is focussed on the air-to-air heat exchanger or "heat recovery ventilator" as it is sometimes called. This paper will present an alternative approach to heat recovery ventilation, an approach based on the use of the heat pump to recover heat from exhaust air. It will be demonstrated that, in many circumstances, this approach offers several advantages over the air-to-air heat exchanger. Canadian and international research, development and demonstration efforts to advance this approach will also be reviewed.

IT IS LIKELY THAT HOUSES WILL INCREASINGLY HAVE TO INCORPORATE MECHANICAL VENTILATION

Given the current trend toward increased airtightness of house envelopes, it seems apparent that more and more of the new houses being built in North America will have to incorporate some form of mechanical ventilation. We have traditionally relied on "natural ventilation", but that will no longer suffice.

"NATURAL VENTILATION"

The term "natural ventilation" is really just a euphemistic way of referring to "leakage". The major difficulty in relying on leakage is that it is too unsure. It is a case of purest chance if it provides just the right amount of ventilation. It might provide too much ventilation, resulting in unnecessarily high heating bills, or it might not provide enough, resulting in, at the least, excessive humidity, or, at the worst, health hazards. Our current striving for tighter building envelopes make the latter scenario increasingly the more likely.

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Another difficulty in relying on "natural ventilation" is that it can lead to interstitial condensation and resulting deterioration of the building envelope. If air is leaking in, there is a good chance that at least some of it will leak out (as opposed to going up the chimney), taking with it moisture which it deposits within the fabric of the building envelope.

PASSIVE VENTILATION

One alternative to "natural ventilation" is some form of planned but passive ventilation device such as a "dummy chimney" which relies on stack effect to exhaust air. This approach can offer more control than natural ventilation, if the device incorporates a damper. It is also likely to direct more of the exhaust flow harmlessly past the envelope fabric and it is less likely to be turned off than a mechanical system, since it is silent.

On the other hand, passive systems do not offer full control. For example, closing a damper in a dummy chimney can reduce the indoor/outdoor air exchange, but there is no way of increasing it beyond some upper limit determined by the airtightness of the envelope, the indoor/outdoor temperature difference and the wind speed and direction.

MECHANICAL VENTILATION

The use of mechanical ventilation offers the greatest degree of control of the amount of ventilation and is the only method that can assure adequate ventilation in all circumstances (provided, of course, that it is properly designed).

Mechanical ventilation of houses is not entirely without disadvantages. Perhaps the most significant is that it can be and often is turned off by the occupants. This disadvantage can often be overcome by proper attention to sound concerns in the design and installation of the system; but this highlights the other major disadvantage - the design and installation practices for residential ventilation systems are not too far removed from the embryonic stage. However, progress is being made.

On the whole then, it seems that our housing industry will have to move towards widespread use of mechanical ventilation.

MECHANICAL VENTILATION NEED NOT INVOLVE HEAT RECOVERY

Many people find it difficult to think of mechanical ventilation without heat recovery. Although, in the past, air change energy costs were left to chance, it is natural to want to minimize these costs once the possibility is offered by the control that mechanical ventilation brings. But at what cost?

Consider a typical existing house that has received basic air sealing but is still loose enough that adequate air change is provided by leakage. Its air change energy cost might be $200 per year. Or consider a reasonably tight new house (say with an air change rate of 2 air changes per hour at 50 Pascals test pressure) in which all the air change is provided by a simple, non-heat-recovery mechanical exhaust system. Its air change energy cost might be $150* per year.

How much is it worth spending to provide the heat recovery capability required to recover all or part of these losses? Manufacturers of heat recovery devices quote price premiums of about $1,000 for heat recovery compared to simple exhaust systems. Thus, based on reasonable payback expectations, there is no COMPELLING economic argument for heat recovery.

However, will a ventilation system without heat recovery be
- purchased in the first place?
- used, once purchased?

One side effect of having a mechanical ventilation system is that the occupants become aware of the heat being thrown away when the ventilation system does it, whereas they were probably unaware of it when it was leaking out. Heat recovery helps them to feel better about ventilation.

Thus the case for heat recovery is <u>weak economically</u> but <u>strong psychologically and emotionally.</u>

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*Based on 500m^3 house volume, average annual air change rate of 0.5 air changes per hour, 4000 Celsius degree day climate, 80% heating efficiency, $5/GJ energy cost.

TWO APPROACHES TO EXHAUST AIR HEAT RECOVERY

The Air-to-Air Heat Exchanger. To many people, residential heat recovery means only one thing - the air-to-air heat exchanger (ATAHE). Based on the simple concept of passing hot and cold air streams on opposite sides of a thin separating membrane, the ATAHE at first seemed to offer a complete and elegantly simple solution to air change heat loss. However, that prospect proved difficult to achieve and early products, turned out by what was essentially a cottage industry, had many problems with recovery efficiency, defrosting, flow balancing and discomfort. Much progress has been made in the last couple of years, although not without corresponding sacrifices in the affordability of the product. Many of the residential heat exchangers on the market today are sophisticated, second and third generation machines, but the economic case for their use has, if anything, grown weaker, and they still have not fully addressed several fundamental disadvantages of the ATAHE concept:

- In order for effective heat exchange to take place, the intake and exhaust flows through the heat exchanger must be more or less equal. This is easy enough to achieve when the unit is standing separately but once it is connected to a ducting system, as it must be, the task is much more difficult.

- This balancing of inward and outward flows does not help prevent interstitial condensation and any error towards pressurization in the attempt to achieve balance will increase the potential for interstitial condensation.

- The ATAHE only recovers heat from that part of the house's air exchange which passes through it and, since the ATAHE is usually designed not to affect the pressure balance of the house, leakage (without heat recovery) will continue to occur if the envelope is anything less than perfectly airtight.

- This reliance on a tight envelope means that the ATAHE is not useful in most retrofit situations.

- Although the incoming air is warmed in the heat exchange process, it is still cooler than the ambient house air and distributing it without causing discomfort to the occupants remains problematic.

The Heat Recovery Heat Pump There is an alternative approach to exhaust air heat recovery which is more complex in concept but not necessarily in execution and which offers several advantages over the ATAHE in many circumstances - the heat recovery heat pump (HRHP). Figure 1 shows one possible configuration. The process is as follows:

- Just before it exits the building, the exhaust air passes through the evaporator of the heat pump, which chills it and, in the process, extracts heat.

- The heat pump transfers the recovered heat to the condenser coil which, in turn, transfers it to a recirculating flow of house air. The condenser could also be the refrigerant-to-water type and could be used to preheat domestic hot water.

The advantages offered by this approach include the following:

- The cross-envelope fan-induced flows need not be balanced.

- The HRHP can therefore be used to depressurize the house and help avoid interstitial condensation.

- The building envelope need not be especially tight. In fact, if it is tight, some means of making it less tight must be implemented since the concept relies on inward flow through the envelope or deliberate openings for the supply of fresh air. This is not a problem - making the envelope tighter is difficult; making it leakier is easy.

- Avoiding the need for a high level of airtightness allows some savings in construction cost for new houses which incorporate an HRHP and means that HRHP's can be used in existing houses.

- If the HRHP's exhaust capacity is great enough, all of the house's air exchange will flow through the HRHP; i.e. there will be no outward leakage. This means that the HRHP can recover heat from all of the house's air exchange.

- If the HRHP is designed to chill the exhaust air to below the outdoor temperature for much of the heating season, it actually recovers more heat than goes into heating the incoming air and thus also helps to make up the conductive component of the house's heat loss. In a reasonably energy efficient house, the HRHP can provide most or all of the heating; i.e. there is little or no need for a supplementary heating system.

However, the HRHP does have some disadvantages in some circumstances:

- It is difficult (although not impossible) to use a HRHP with a naturally aspirated combustion appliance since the depressurization it causes can lead to combustion venting problems.

- The depressurization can give rise to concerns regarding cold drafts, the entry of cold air into the building fabric (with resulting cooling of surfaces and increased interior condensation potential) and the entry of radon. However, by judicious use of barometric-dampered relief openings and other means, the level of depressurization can be kept fairly low; it need not be any higher than that created by the presence of an active flue in normal fuel-heated houses; i.e. neutral pressure plane at about the top storey ceiling level.

- The HRHP replaces fuel consumption with electricity consumption. There is always a net energy saving but not necessarily a net dollar saving in areas where the cost of electricity is significantly higher than the cost of heating fuel.

Let us now look at the current state of the HRHP concept and review some of the research, development and demonstration efforts that have brought it to that state.

NRC/KEEPRITE PROTOTYPE

In 1979, the Division of Building Research of the National Research Council of Canada (DBR/NRC) began to investigate the concept. The first step was the awarding of a contract for a feasibility study to KeepRite Inc., a large Ontario manufacturer of air conditioning equipment. That feasibility study[1] was positive and eventually led to a further contract[2] to KeepRite to fabricate a prototype, which was configured much the same as the configuration in Figure 1; i.e. the indoor air was the intended sink for the recovered heat.

In the winter of 1983-84 this prototype was installed in an unoccupied experimental house - one of the four Mark XI Research Houses built near Ottawa by NRC and the Canadian Home Builders' Association. An ATAHE was installed in the identical house next door and the energy consumption of the two houses was measured over several months with the heat recovery devices operating and not operating on alternate weeks[3].

The data was analyzed and extrapolated to predict the performance of the two heat recovery devices over a full heating season in different climatic areas. The results are shown in Figure 2. The HRHP is predicted to be able to save considerably more energy than the ATAHE. This is despite the fact that the HRHP unit tested was a fairly crude prototype whereas the ATAHE was a fully developed, commercially available model. (Perhaps the worst flaw in the HRHP prototype was the fact that it incorporated a time-triggered defrost cycle and thus shut down for 4.5 minutes after every 34 minutes of operation, whether defrosting was required or not.)

Figure 3 shows DBR/NRC's economic assessment of the two heat recovery devices tested. It indicates, for example that if you believe that both devices will have a service life of 10 years and you live in a climate with 4000 Celsius degree days, such as Toronto, the justified capital cost for the HRHP is about $1900 while that for the ATAHE is about $1100. These figures are based on the assumptions that electricity is the heating energy of choice and that electricity costs $0.04 (Canadian) per kilowatt-hour.

THE AQUAREX - A Swedish System Dumping Recovered Heat to the Water Heater

At about the same time as DBR/NRC was looking into the HRHP concept, we became aware of the Aquarex system developed by ElektroStandard AB in Sweden. This system, which will be described in more detail later, combines an exhaust-only ventilation system with a heat pump using the domestic water heater as a sink for the recovered heat. The fact that this existed as a commercial product and that knowledgeable Swedish building scientists believed it to be superior to the ATAHE approach encouraged further pursuit of the HRHP concept.

SCANADA/ELMERIC PROTOTYPES

You may have noted above that the DBR/NRC work on the HRHP concept began in 1979 but a prototype was not installed and tested until the winter of 1983-84. Scanada, in the meantime, remained convinced of the merits of the concept and that the HRHP could play a role in counteracting the interstitial moisture problems which seemed to be appearing in Canadian houses with increasing frequency. A subsidiary was formed to explore the HRHP concept independently of the DBR/NRC efforts (and hopefully at a more rapid rate).

Scanada prepared a performance specification for an HRHP design which would chill the exhaust air to below freezing and would dump the recovered heat to the indoor air (as per Figure 1). A mechanical consultant who specialized in refrigeration systems was commissioned to carry out the detailed design and arranged the fabrication of two prototypes by a leading Canadian furnace manufacturer. One prototype was installed in an Ottawa area house and preparations were made for long term monitoring of its performance. However, initial testing revealed that the performance was not anywhere close to the specification.

Benchtop testing and debugging of the second prototype revealed that this type of heat pump is quite different than normal outdoor evaporator air-to-air heat pumps. The concept requires a large temperature drop over the evaporator and control of both temperatures and air flows if performance targets are to be met. We found that even some of the leading experts we consulted were left guessing as to selection and arrangement of appropriate components.

After much trial and error, we were able to improve the performance of the original prototype considerably, but were never able to get it to perform up to the original specification. We therefore went back to "square one" and built our own "breadboard" prototype using components from the original prototype plus several new components, all combined in an entirely new layout. This prototype met the performance specification.

This performance can be summarized as follows:

- EXHAUST AIR FLOW	71 L/s
- EXHAUST AIR TEMPERATURE	-7°C
- RECIRCULATED AIR FLOW	255 L/s
- TEMPERATURE OF RECIRCULATED AIR LEAVING CONDENSER	40°C
- HEATING OUTPUT	6.8 kW (23,200 btuh)
- COEFFICIENT OF PERFORMANCE	2.3
- DEFROST METHOD	- maintain evaporator air flow with compressor shut off
- DEFROST CONTROL	- pressure switch triggered by pressure increase between fan and evaporator

As mentioned previously, there is an advantage to having the exhaust temperature as low as possible since, as long as the exhaust temperature is below the outdoor temperature, the unit "recovers" more heat than is put into the incoming air (i.e. the heat pump is effectively pumping heat from the outdoor air). The lower the exhaust temperature, the greater will be the portion of the heating season during which this condition is true. We found that, despite the sub-freezing temperature of the evaporator coil, the prototype was able to defrost quickly - in 2 to 4 minutes - provided the frost build-up was not permitted to become too advanced. Although we were not able to test the unit in actual usage in a house, we believe the defrost downtime with this control strategy would be much less than with the time-triggered defrost used in the KeepRite prototypes, especially considering the fact that use of the unit would result in relatively low humidity levels.

The control strategy envisioned for this design is as follows:

- A two stage thermostat is used. The high setting controls the HRHP compressor, turning it on when heat is required and off when the heating requirements are satisfied. The low setting turns the furnace on when the output of the HRHP is not sufficient to compensate for the heat loss of the house (e.g. in very cold weather).

- The compressor operation is simple on/off, rather than modulated; i.e. the HRHP output is either 6.8kW or 0kW.

- The exhaust fan runs continuously whether the compressor is on or off.

- Appendix I shows a "bin" calculation of the contribution of this HRHP to the heating of a reasonably energy efficient house in Ottawa (4657 Celsius degree days).

Unfortunately, the fabrication and testing of this successful prototype was as far as Scanada was able to progress before exhausting the resources it was able to devote to the venture. (No doubt the necessary entrepreneurial skills, seldom a strong suit of engineering consultants, were also in short supply.) Further development was therefore abandoned, even though our faith in the viability of the concept was undiminshed.

We were therefore heartened to learn that a major Canadian materials supplier to the housing industry, Fiberglas Canada Inc., in its first venture outside of a strict materials supply role, had adopted the HRHP concept.

FIBERGLAS CANADA RESEARCH AND DEMONSTRATION EFFORTS

For obvious commercial reasons, Fiberglas Canada Inc. was attracted to any building technology which made it simpler for a builder to construct a sound and healthy low energy home, featuring a highly insulated envelope.

Removing the burden of extreme airtightness was seen as a major benefit accruing from a depressurizing ventilation scheme: Shaw's work[4] shows that this approach reduces the sensitivity of the air change rate of a house to environmental factors, when compared with a balanced pressure house.

As has been explained, unbalanced ventilation strategies* lead one logically to the choice of heat pump heat recovery as the right technical approach to energy saving.

There are other factors, however. The cost-effectiveness of the equipment has to be considered; as has been indicated, this is sensitive to the cost of energy from different sources, and to the quantity of air one considers necessary for good health. Of course, when one has a heat recovery device which can recover more than 100% of the energy needed to heat ventilation air, fresh air loses the stigma of being an energy "penalty", perhaps the major philosophical contribution of the HRHP.

A significant enhancement of the cost-effectiveness of an HRHP is available in its ability to provide air conditioning with only a modest equipment cost premium.

Another major factor in the selection of equipment is the appeal to the consumer. Debates on cost-effectiveness are worthwhile, but any builder will point out that buyers are emotional and intuitive.

- Energy saving measures that can be touched are more attractive than hidden ones: a positive assurance of fresh air without running cost penalty seems to outweigh the initial premium in the mind of many buyers.

- Additional free or low cost features attract people - the more the better, even though the complexity may be a nuisance.

Why Air-to-Water HRHP? It should be remembered that the use of an HRHP was considered by Fiberglas Canada as just one component of an integrated house design strategy[5].

The choice of the Swedish ElektroStandard company's equipment was made because of its ready availability in a package that had been proven over some 8 years, mostly in a domestic hot water heating role.

FCI had opted for the air-to-water philosophy for a number of reasons:

- The constancy of domestic hot water requirement has a smoothing effect on energy demand through the year, which is good for a heat pump because it is a machine which prefers continuous operation under steady conditions.

- Domestic hot water adds to the size of heat sink into which heat recovered from ventilation air can be pumped.

- The larger heat sink should enable cost effective heat recoveries to be achieved in most areas (>100% of air change heat loss) without cooling discharge air below freezing.

  At the time, this author viewed sub-freezing operation with trepidation, because defrost problems had been rife for air-to-air heat exchangers, and because the start-up load after defrosting is probably the major determinant of the compressor's longevity. The added complexity of a defrost cycle controller also militated against the sub-freezing mode.

- It seemed philosophically correct to use the heat pump's ability to upgrade heat to the temperatures required for domestic hot water, especially since the integration of heat recovery and DHW heating equipment should reduce hardware costs compared with separate installations.

- The idea of using heat rejected by the HRHP in the air conditioning mode to provide "free" DHW was attractive, see Figures 4(a) and (b).

- The long term potential of adding extra hot water storage to a house as a means of reducing heating demand peaks is very attractive. This is especially true in areas dominated by electrical heating, where a utility company with limited capacity would recognize peak shaving strategies with financial incentives.

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*A pressurizing system would be more logical in a cooling dominated climate.

Predictive Work

- The HOTCAN program was used to predict average power required for space heat and domestic hot water (see Appendix I and Figure 5). (Figure 6 illustrates the demand curves for two widely different climate zones).
- When this amount is greater than the heat pump output, 100% of heat pump output is credited.
- When it is less than the heat pump output, the heat pump is only credited with this proportion of its output capability.
- An assumed COP factor is then applied to the gross output credit to give the nett output credit.

This simple predictive technique indicates the following: (see Figures 7, 8, and 9)

- A saving of between 7500 kWh and 10500 kWh can be achieved for a house ventilated at 170 cfm (80 L/S), without the need for defrost.
- As a percentage of air change heat loss, this translates to:

132% in Victoria, B.C.	3076 K degree days
99% in Winnipeg, Man.	5889 K degree days

- Energy credit is most sensitive to COP in milder climates, and to capacity in colder climates.

Preliminary Findings in the Field

- A low energy house featuring an air-water HRHP installation with a heat pumping capacity of 1300W has been monitored for total house energy consumption for two years with the following results[5] (see Figure 10).

Predicted total energy consumption with ATAHE at 70% efficiency = 19933 kWh

Actual total energy consumption using air-water HRHP (averaged over two years) = 15605 kWh

Predicted total energy consumption using a credit of 7620 kWh (by the technique described earlier) = 17651 kWh

CONCLUSIONS

- Reasonable confidence that the predictive technique is not too optimistic. (Note that the time constant/buffering effect of high levels of insulation may play a significant role in achieving full utilization of heatpump output.)

FUTURE WORK

- Much more extensive monitoring is now underway on ten houses in Canada.
- Matching heatpump output to house demand offers the potential for greater cost effectiveness, especially in milder climates.
- The retrofit housing market is probably attractive, especially in houses which are presently all electric. Testwork on houses with standard rather than super insulation should help determine how crucial the insulation buffer is.
- The effect of repeated defrost cycles on compressor life needs to be determined to make a trade-off between higher heat output and equipment reliability.

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APPENDIX I

HEAT RECOVERY HEAT PUMP (HRHP) PERFORMANCE EVALUATION USING THE "BIN" METHOD

LOCATION: OTTAWA

HOUSE DESCRIPTION:

CONDUCTIVE HEAT LOSS COEFFICIENT - 115 W/C
AIR CHANGE HEAT LOSS COEFFICIENT - 85 W/C (71 L/s EXHAUST FLOW, ALL AIR CHANGE THROUGH HRHP)
INDOOR TEMPERATURE - 20 C
FURNACE OUTPUT - 10 KW

OUTDOOR TEMP.RANGE MID-POINT (C)	NUMBER OF HOURS	HOUSE HEAT LOSS (KW)	AVAILABLE FREE HEAT (KW)	HEATING REQUIRED (KW)	HRHP OUTPUT (KW)	HRHP INPUT (KW)	REQUIRED FURNACE OUTPUT (KW)	HRHP ENERGY CONSUMP'N (KWH)*	FURNACE ENERGY CONSUMP'N (KWH)*	FURNACE ENERGY CONS. W/O HRHP (KWH)*
16.7	711	0.660	1.6	0.000	6.8	2.9	0.000	0	0	0
13.9	692	1.220	1.6	0.000	6.8	2.9	0.000	0	0	0
11.1	633	1.780	1.6	0.180	6.8	2.9	0.000	48	0	114
8.3	540	2.340	1.6	0.740	6.8	2.9	0.000	168	0	400
5.6	565	2.880	1.6	1.280	6.8	2.9	0.000	304	0	723
2.8	670	3.440	1.6	1.840	6.8	2.9	0.000	519	0	1233
0.0	728	4.000	1.6	2.400	6.8	2.9	0.000	735	0	1747
-2.8	536	4.560	1.6	2.960	6.8	2.9	0.000	667	0	1587
-5.6	467	5.120	1.6	3.520	6.8	2.9	0.000	691	0	1644
-8.3	383	5.660	1.6	4.060	6.8	2.9	0.000	654	0	1555
-11.1	348	6.220	1.6	4.620	6.8	2.9	0.000	676	0	1608
-13.9	275	6.780	1.6	5.180	6.8	2.9	0.000	599	0	1425
-16.7	211	7.340	1.6	5.740	6.8	2.9	0.000	509	0	1211
-19.4	145	7.880	1.6	6.280	6.8	2.9	0.000	383	0	911
-22.2	83	8.440	1.6	6.840	6.8	2.9	0.040	237	3	568
-25.0	41	9.000	1.6	7.400	6.8	2.9	0.600	117	25	303
-27.8	15	9.560	1.6	7.960	6.8	2.9	1.160	43	17	119
-30.6	3	10.120	1.6	8.520	6.8	2.9	1.720	9	5	26
-33.3	1	10.660	1.6	9.060	6.8	2.9	2.260	3	2	9
							TOTALS	6363	53	15181

6416

ENERGY SAVING DUE TO USE OF HRHP = 15181 6416 = 8766 KWH

* Where "HEATING REQUIRED" is less than "HRHP OUTPUT", HRHP is assumed to operate for a fraction of each hour equal to the ratio HEATING REQUIRED/HRHP OUTPUT. A similar approach is used for the furnace.

APPENDIX II

SAMPLE CALCULATION OF ENERGY CREDIT FOR AIR-TO-WATER HEAT PUMP

- Low energy house
- Winnipeg 5889 K degree days
- 0.5 air changes per hour (170 cfm)
- Heat extracted from exhaust air 2500W
- COP = 2
- Gross output of unit = 5000W (5 kW)

MONTH	POWER REQUIRED FOR*				USEFUL OUTPUT (kWh)
	SPACE HEAT (kW)	DHW (kW)	TOTAL (kW)		
				dys. hrs.	
JAN.	5.98	0.58	6.56	31 x 24 x 5.0	3720
FEB.	5.13	0.58	5.71	28 x 24 x 5.0	3360
MAR.	3.85	0.58	4.43	31 x 24 x 4.43	3296
APR.	2.10	0.58	2.68	30 x 24 x 2.68	1930
MAY	0.82	0.58	1.40	31 x 24 x 1.40	1042
JUNE	0.05	0.58	0.64	30 x 24 x 0.64	461
JULY	-	0.58	0.58	31 x 24 x 0.58	432
AUG.	-	0.58	0.58	31 x 24 x 0.58	432
SEPT.	0.46	0.58	1.04	30 x 24 x 1.04	749
OCT.	1.51	0.58	2.09	31 x 24 x 2.09	1555
NOV.	3.51	0.58	4.09	30 x 24 x 4.09	2945
DEC.	5.16	0.58	5.74	31 x 24 x 5.00	3720
					23642

* from HOTCAN

$$\text{Credit} = \text{useful output} \times \frac{\text{COP} - 1}{\text{COP}}$$

$$= 23642 \times \frac{1}{2} = 11821 \text{ kWh/year}$$

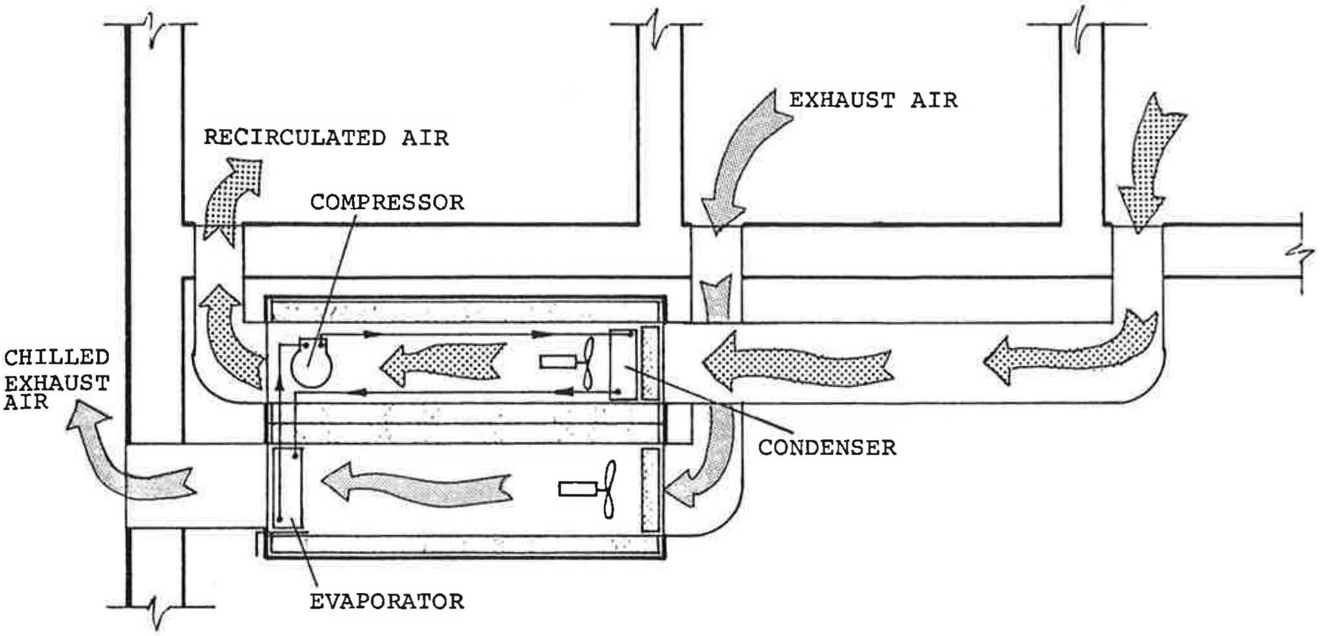


Figure 1. A possible heat recovery heat pump configuration.

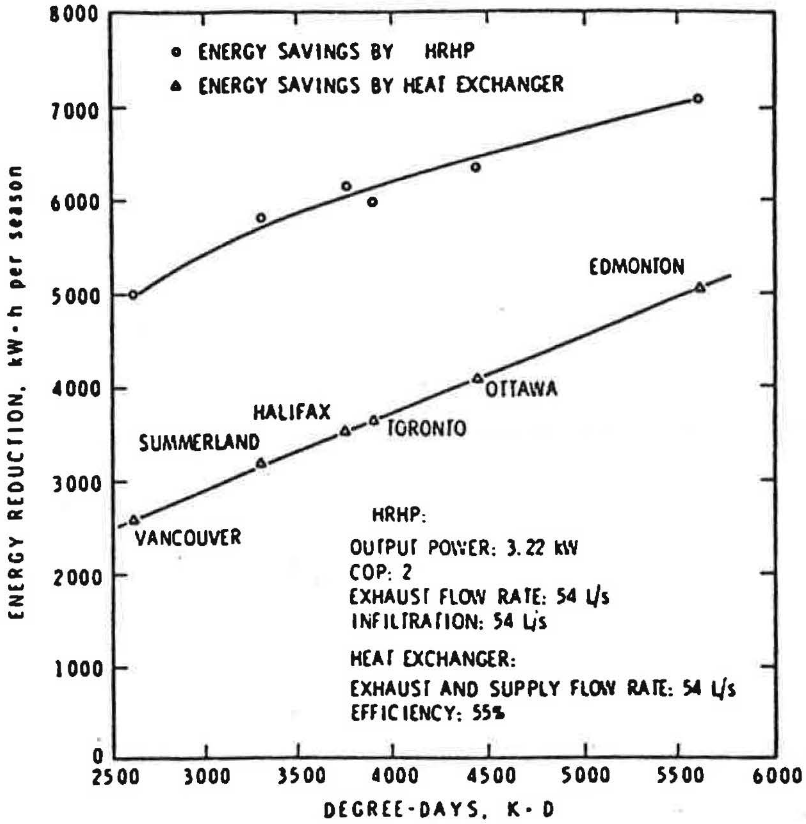


Figure 2. Predicted space heating energy savings due to use of air-to-air heat exchanger and heat recovery heat pump.

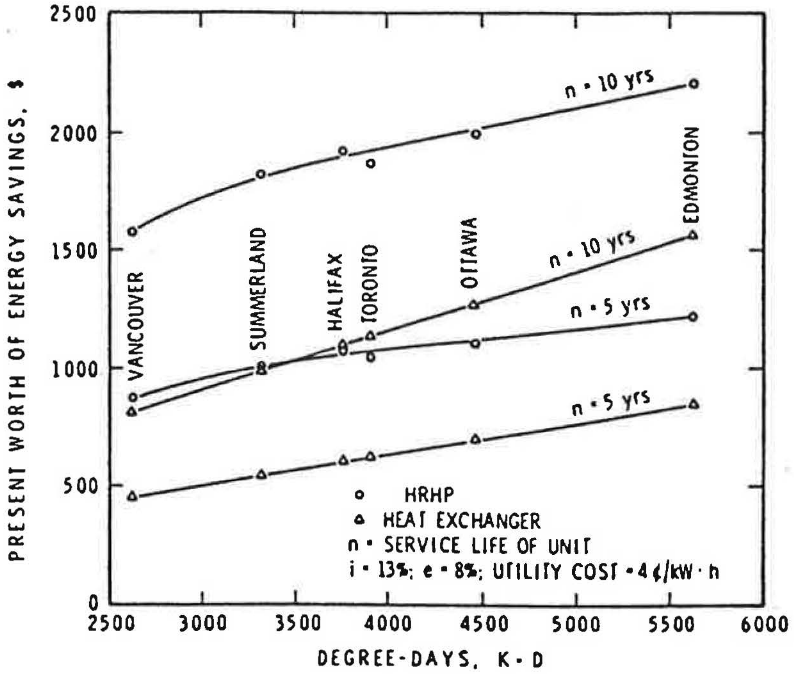


Figure 3. Present worth of annual energy savings achieved by air-to-air heat exchanger and heat recovery heat pump.

Flow Switching

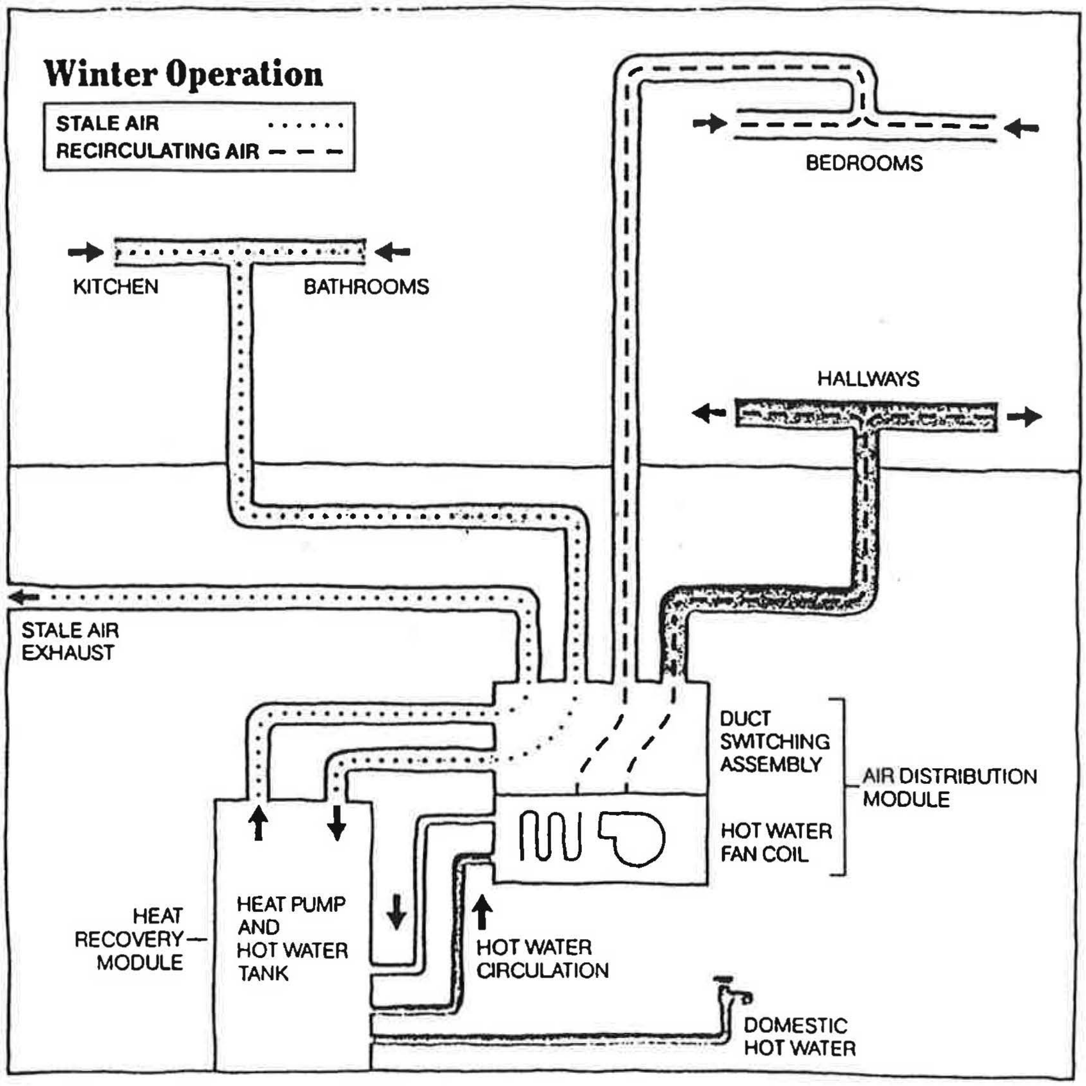


FIGURE 4(a)

Flow Switching

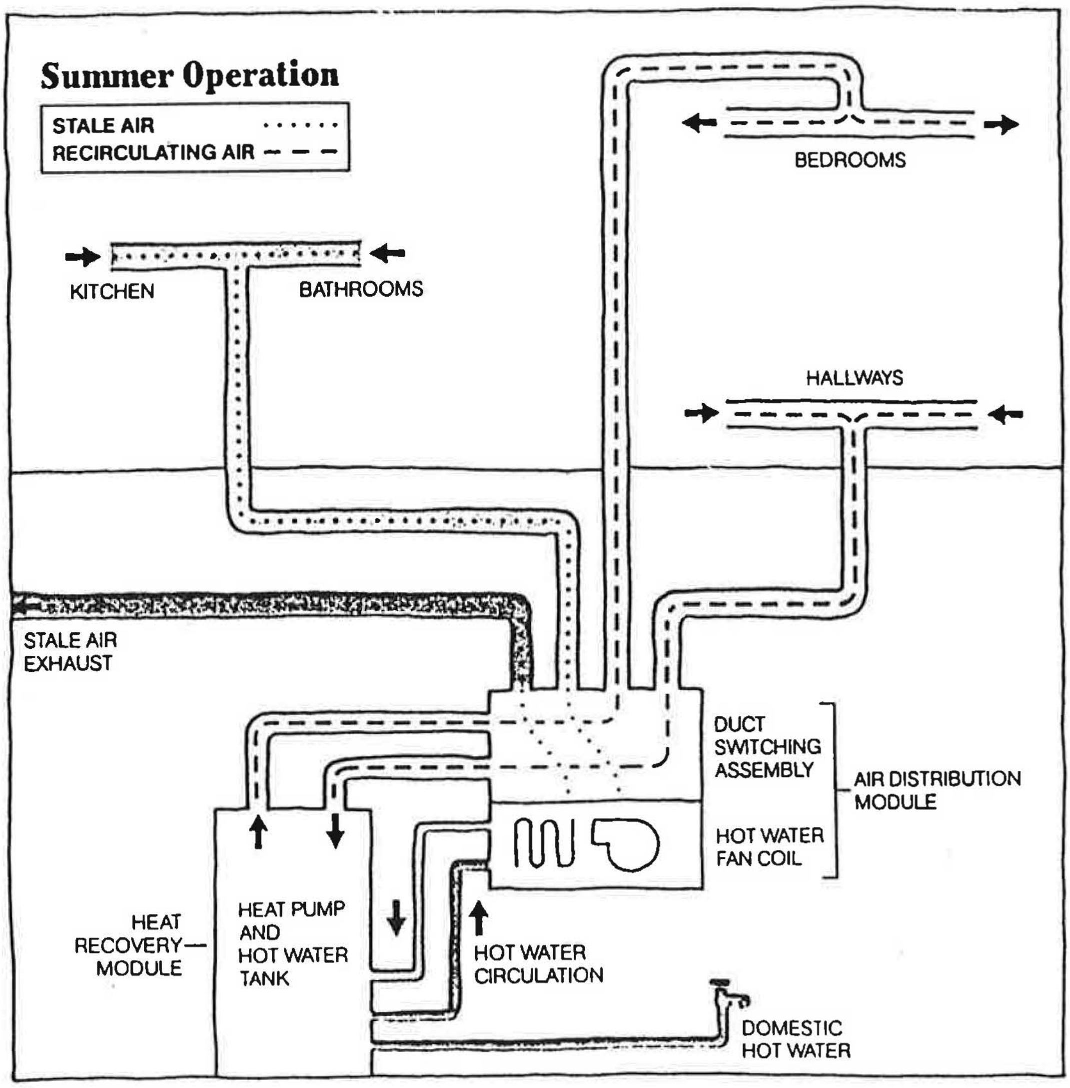
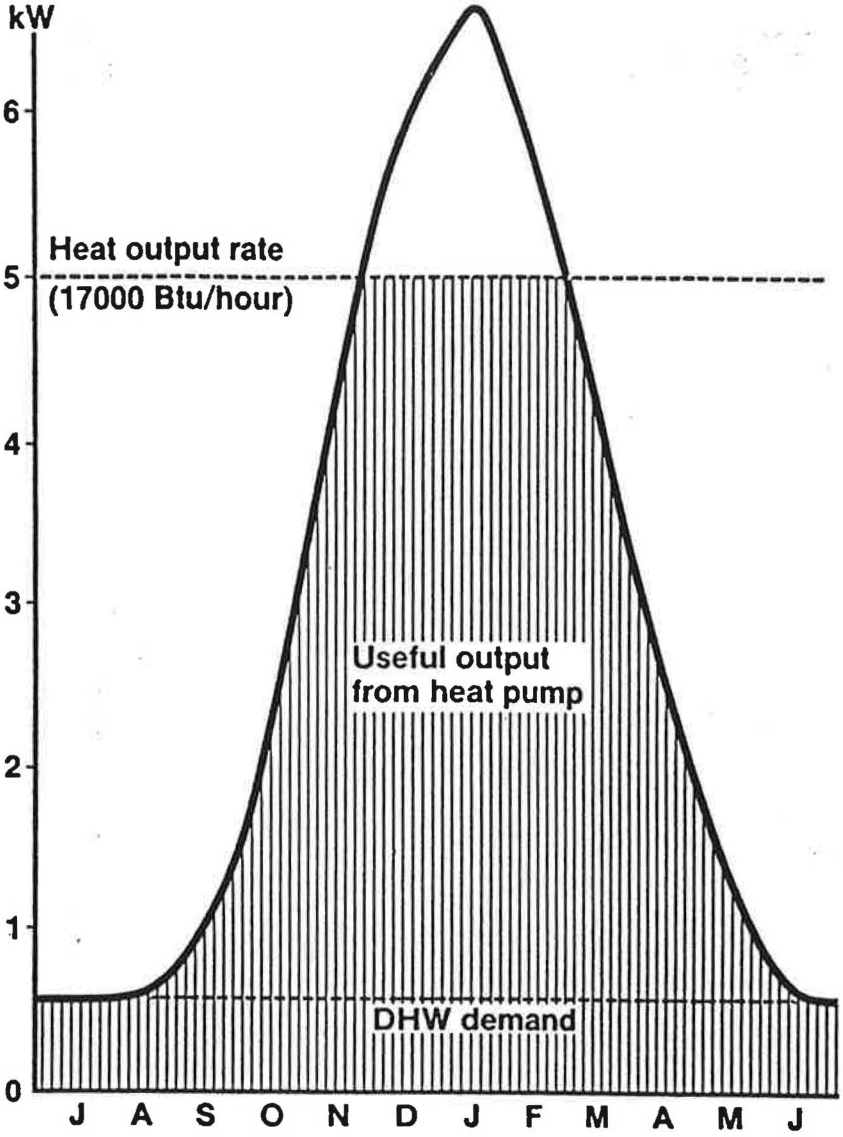


FIGURE 4(b)

Combined Space Heating and DHW Demand



Useful output = 23642 kWh ($\approx 80 \times 10^6$ Btu)

$$\text{Credit ("free heat")} = 23642 \times \frac{\text{COP} - 1}{\text{COP}}$$

$$= 23642 \times \frac{1}{2}$$

$$= 11821 \text{ kWh } (\approx 40 \times 10^6 \text{ Btu})$$

(COP = 2 is conservative)

FIGURE 5

Combined Space Heating and DHW Loads for 2000 Ft² Two Storey House (Well Insulated)

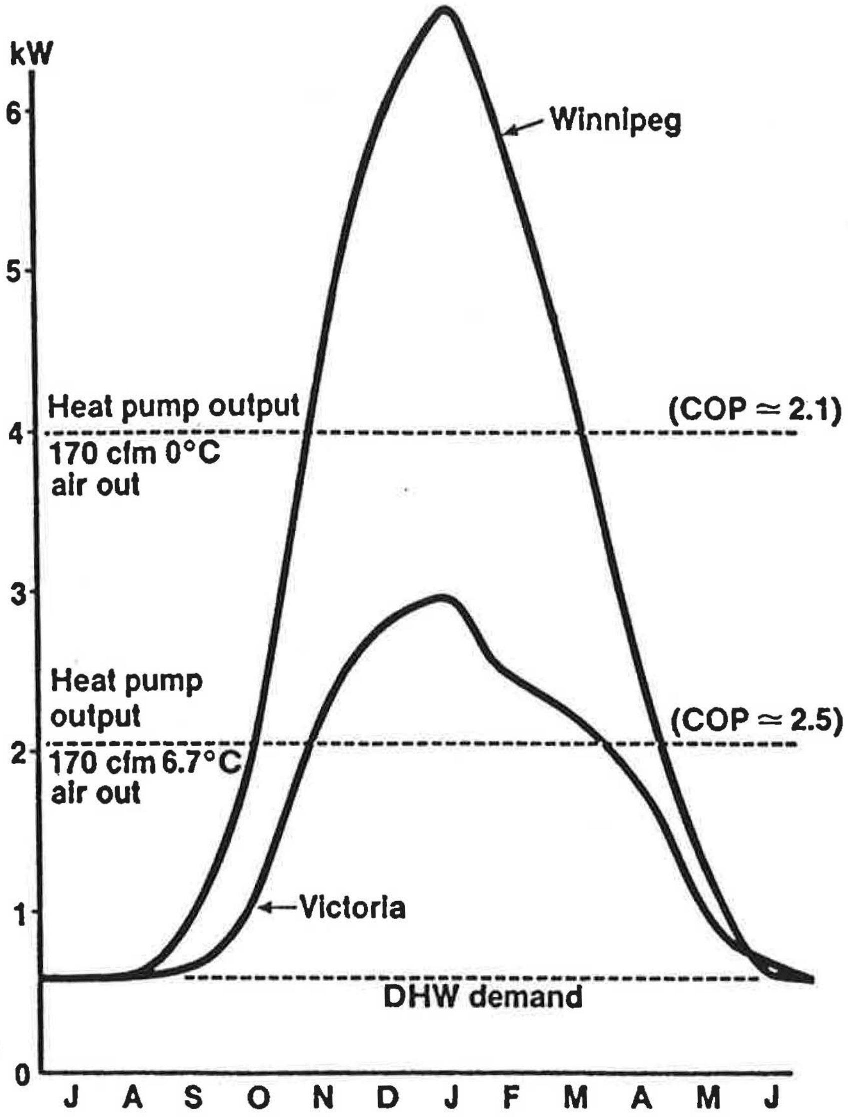
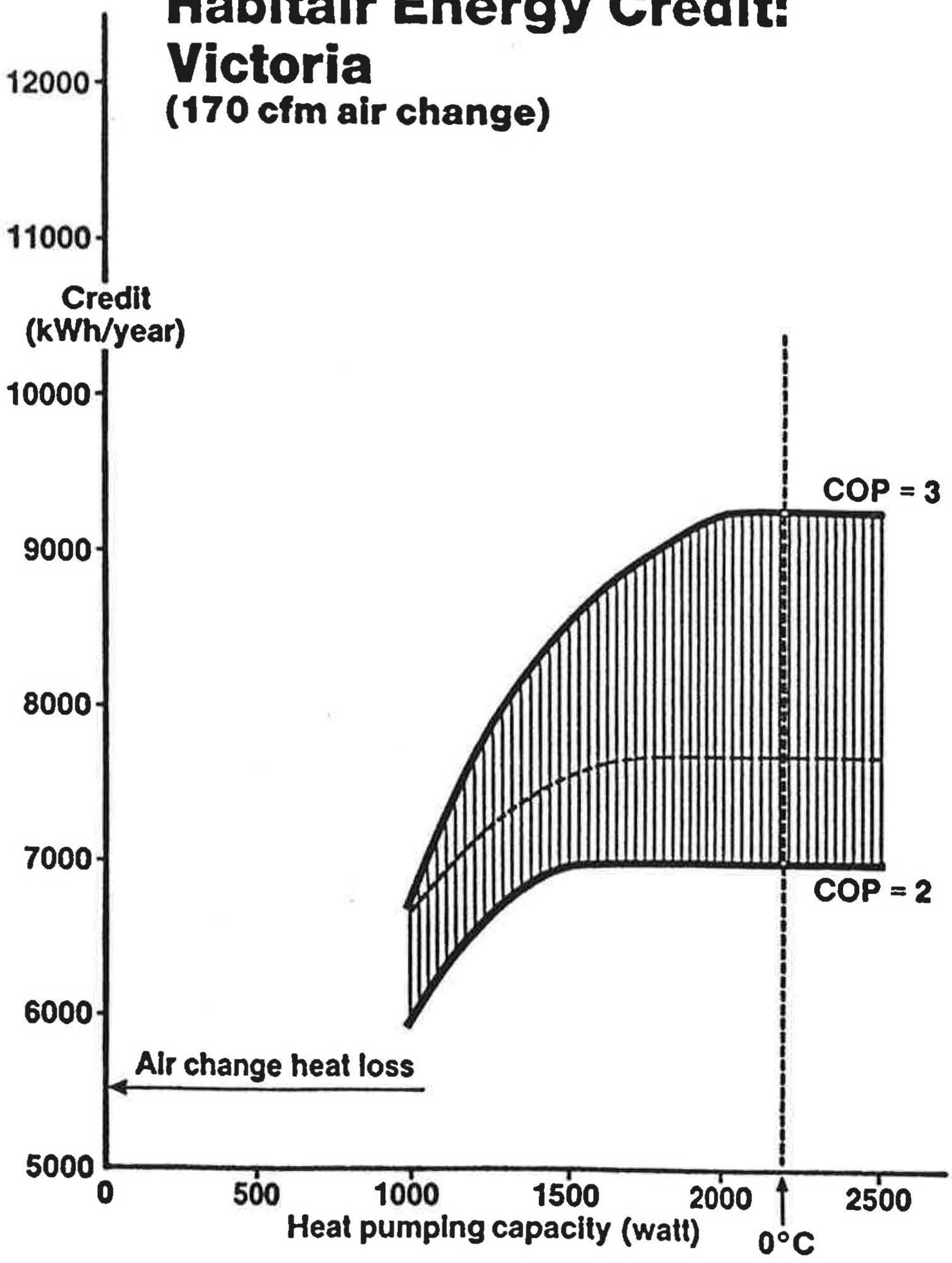


FIGURE 6



Habitair Energy Credit: Victoria (170 cfm air change)

FIGURE 7

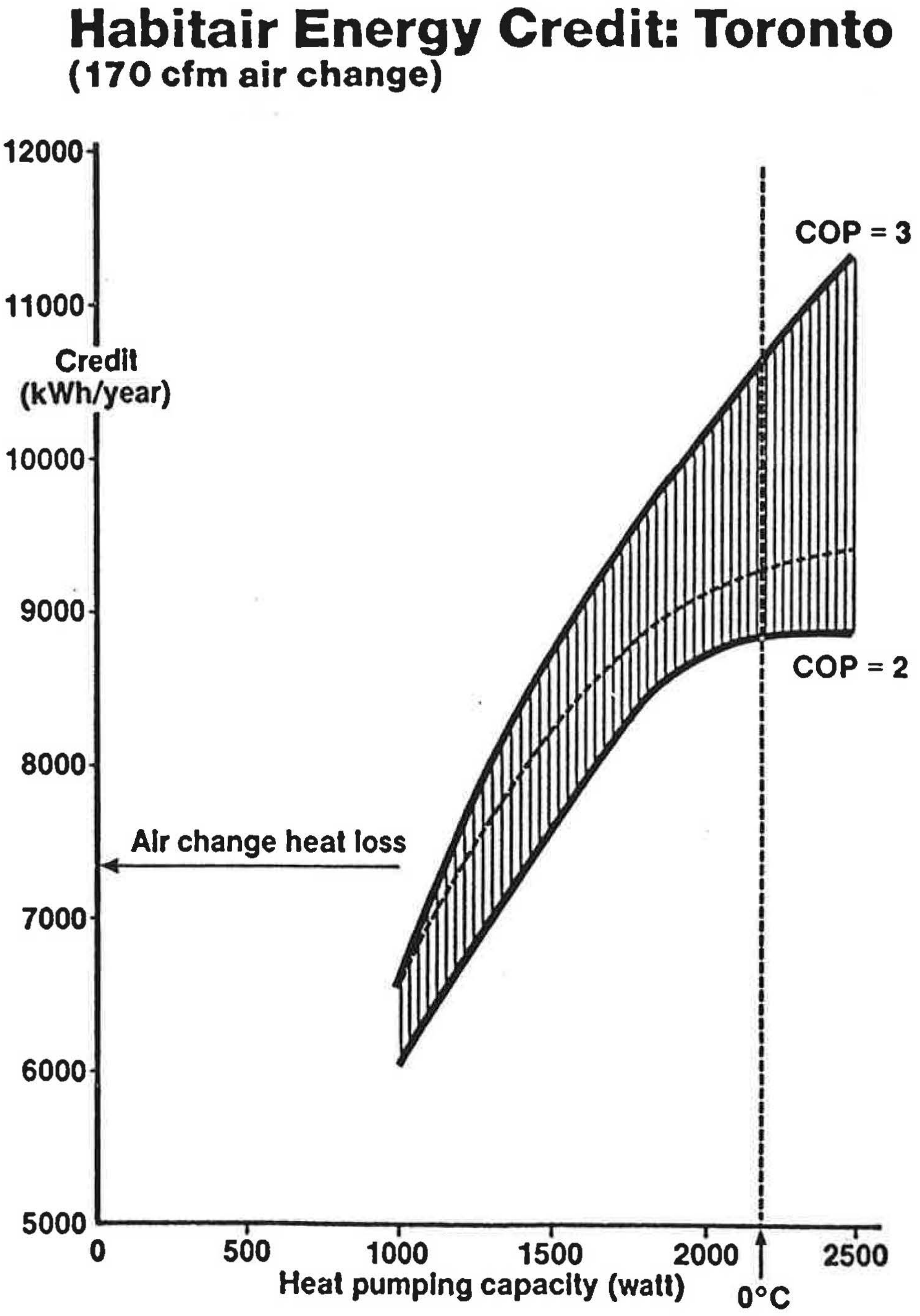

Habitair Energy Credit: Toronto
(170 cfm air change)
12000
11000
Credit
(kWh/year)
10000
9000
8000
7000
6000
5000
0
500
1000
1500
2000
2500
Heat pumping capacity (watt)
0°C
COP = 3
COP = 2
Air change heat loss

FIGURE 8

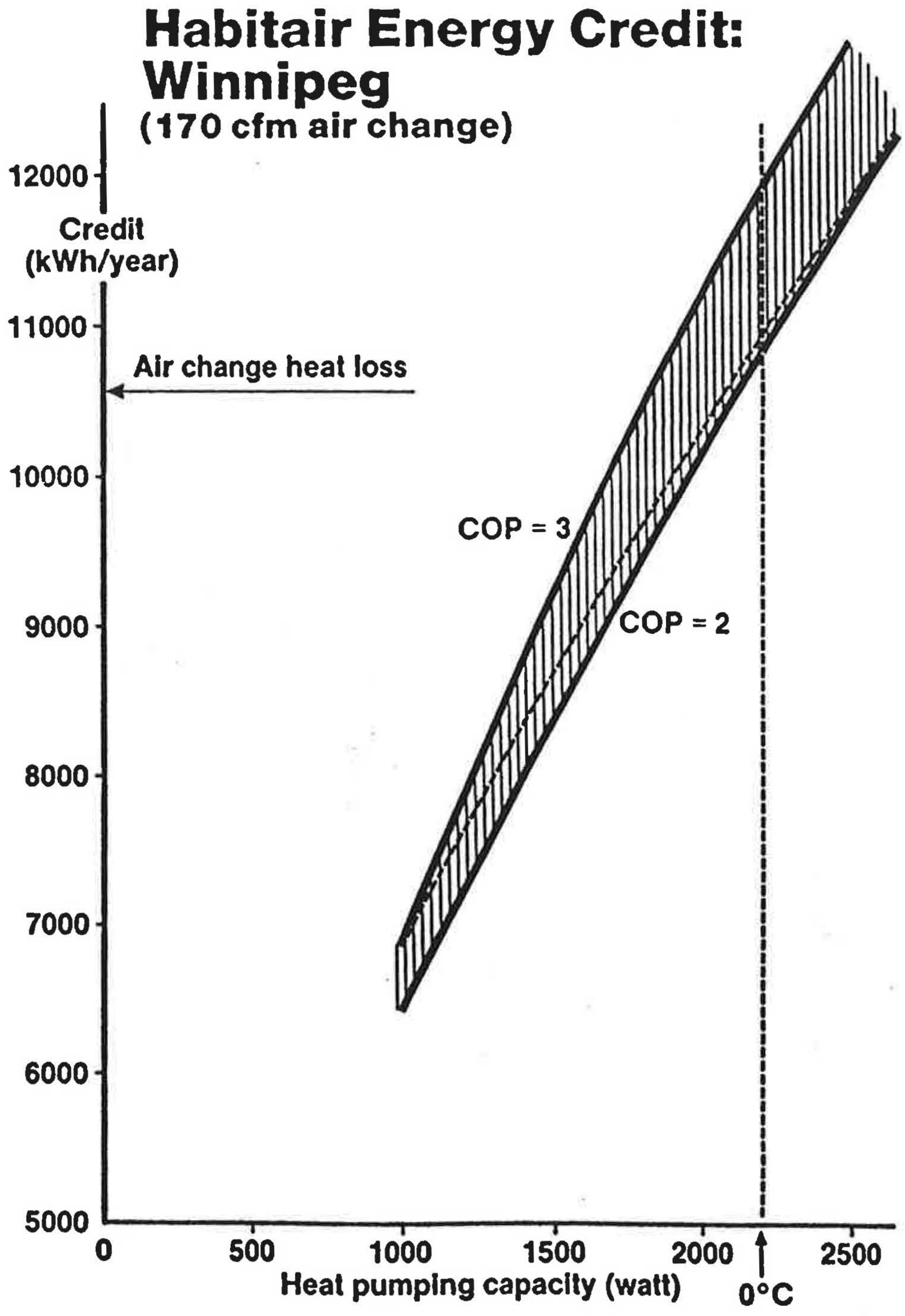
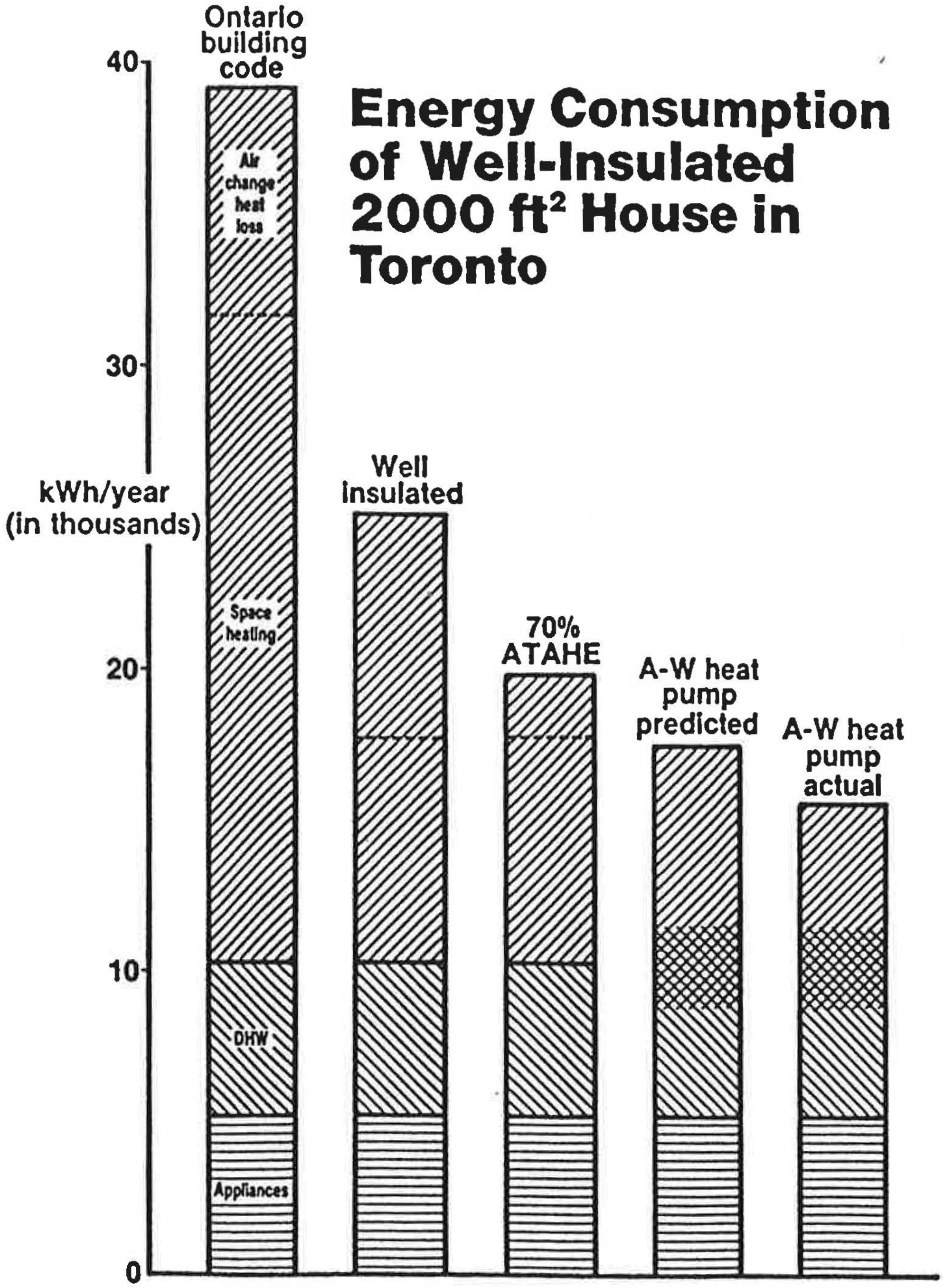

Habitair Energy Credit:
Winnipeg
(170 cfm air change)
12000
Credit
(kWh/year)
11000
Air change heat loss
10000
COP = 3
9000
COP = 2
8000
7000
6000
5000
0
500
1000
1500
2000
2500
Heat pumping capacity (watt)
0°C

FIGURE 9



Energy Consumption of Well-Insulated 2000 ft^2 House in Toronto

FIGURE 10