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Heat Pumps for Residential Heating

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Please note

In 1976 in Canada, oil and gas heating systems were in use in 85 per cent of existing housing, whereas electric heating systems of one form or another accounted for only about 13 per cent. Because of increasing oil and gas costs in many regions, electricity is now coming into greater use as an alternate. One device that may make electric heating more attractive economically is the heat pump.

A heat pump is a system that uses refrigeration equipment to take heat from a source and discharge it to a building space requiring it. The same system can be used to remove heat from the space and discharge it to a heat "sink" when cooling is required. Heat sources and sinks for heat pumps can be the ground surrounding a building, water in lakes, rivers or wells, and outdoor air. Although still largely in the research stage, considerable interest has also been shown in the use of solar energy as a heat source for heat pumps. Of all sources, however, outdoor air has been used most extensively because it offers a universal, abundant heat source/sink for heat pump operation. It is the purpose of this Digest to outline the general features and economics of the "air-to-air" heat pump for heating in residential buildings.

Air-to-Air Heat Pump

The air-to-air heat pump was originally introduced in the southern United States where cooling and dehumidification are of prime importance and the heating seasons short and mild. The units were sized to cope with the cooling load and in most applications provided sufficient heating capacity. When heat pumps were marketed in more northerly regions, however, the heating capacity had to be supplemented with electrical resistance heaters and other special features needed for operation in colder climates.

The heat pump employs the same basic principle as the common household refrigerator, extracting heat from a space at low temperature and discharging it to another space at higher temperature. The system consists of two heat exchangers, a compressor and expansion valve, and interconnecting piping filled with a refrigerant (Figure 1). Electrical power is needed to run the compressor in the system. By reversing the direction of the refrigerant flow with a valve, the system can be used, as required, for either heating or cooling.

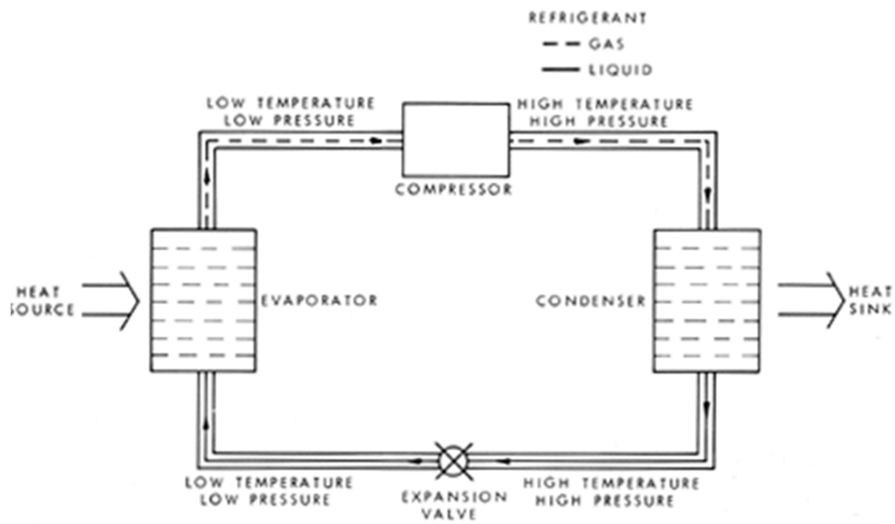

Figure 1. Basic vapour compression/refrigeration cycle.

Performance. The performance of a heat pump may be obtained by dividing the total useful heat output by the electrical energy needed to operate the system. This ratio, known as the Coefficient of Performance (COP), is always greater than one. Both the heating capacity and COP of the heat pump are reduced as the outdoor temperature drops. The outdoor temperature at which the heat pump can just satisfy the heating requirement of the space is referred to as the "balance" point, and is a function of the building heat loss as well as the capacity of the heat pump. Below the balance point the heat pump has insufficient capacity to meet demand, and the deficit must be made up by supplementary heaters (Figure 2).

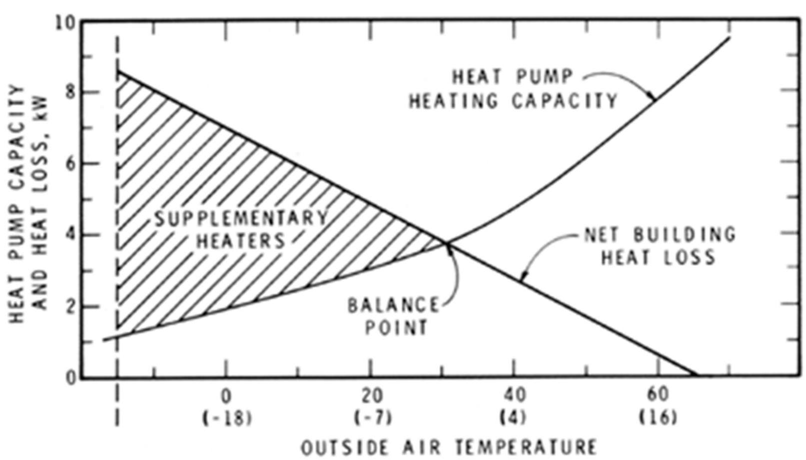

Figure 2. Heat pump capacity and building heat loss for a home in the Ottawa area.

Supplementary heaters are staged to come on in such a manner that only the portion actually required to make up the difference between the heat pump capacity and the space heating requirement is activated. Below the balance point temperature, as more stages of supplementary heaters are brought on line, the output and efficiency of the heat pump decrease. Above the balance point, the unit has surplus capacity and is made to match the building heat loss by cycling on and off.

Seasonal Performance. The performance of a heat pump and its contribution to the total heating requirement can be estimated on a seasonal basis, with the following information:

1. the manufacturer's performance data (i.e., capacity, input power and coefficient of performance versus outdoor temperature),

2. calculation of building heat loss for a specific residence,
3. a frequency analysis of outdoor air temperature at a site to determine the relative contribution of the heat pump and supplementary heaters.

A sample calculation for Ottawa illustrates the seasonal performance. For these calculations a heat pump was selected with a nominal cooling capacity of approximately 7 kW (2 tons), a residential building heat loss for an Ottawa house was assumed, and the appropriate frequency analysis of outdoor air temperature made. The calculated Seasonal Performance Factor (SPF) was 1.6, with a "balance" point of approximately 30°F (-1.1°C). The SPF is a measure of seasonal efficiency, that is, the total useful heat from the unit divided by the total electrical energy needed over an entire season, including that for supplementary heaters.

Figure 3 illustrates the results of these calculations. It shows the fraction of the annual heating energy obtained by the heat pump from the outdoor air (area A), the energy required to run the system (area B), and the supplementary heating required (area C) at lower temperatures. The total area (A + B + C) approximates the annual heating requirement of the house. For temperatures below 10°F (-12°C) in this example, supplementary heaters will have to handle essentially all the house heating requirements.

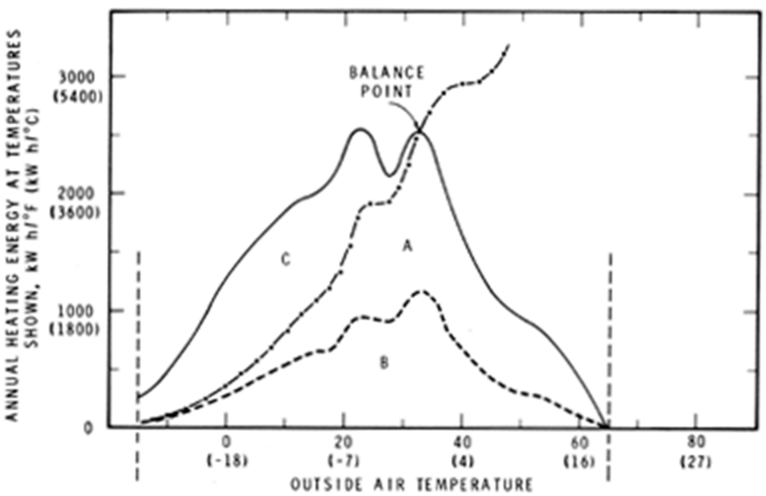

Figure 3. Heating energy distribution showing seasonal contribution by heat pump and supplementary heaters.

Cost. It has been generally accepted that a heat pump can only be justified when summer air conditioning is required for cooling purposes. In Canada, however, central air conditioning is not of primary concern, so that the decision on whether or not to use a heat pump should be based on heating energy savings alone. The following analysis and discussion therefore, consider the heat pump as a heating device.

Compare the cost of installing and operating a heat pump and supplementary heating with that of a comparable central heating electric furnace, using the heat pump calculations of the previous example for the Ottawa area. It is assumed that the cost of ductwork and electrical service would be the same in both cases. The comparative costs are shown in Table I.

Table I. Comparative Costs of Heat Pump And Electric Furnace

	Heat Pump (2-ton)	Electric Furnace (15 kW)	Cost Difference
Installation	$ 2,500.	$ 1,000.	$ 1,500.

Operation			
Maintenance	50.	20.	30.
Energy cost in first year at 2.3¢/kW·h	319. (13 870/kW·h)	515. (22 408 kW·h)	196.
Net saving in operating cost			166.

Is the heat pump a better investment than the electric furnace for this particular example? If the useful service life of a heat pump is assumed to be 15 years, a constant annual saving of $166 would justify an investment of $1,262 (interest at 10 per cent); but the extra capital investment required for a heat pump is $1,500. As the annual saving can be expected to increase at the same rate as the increased unit cost of electricity, allowance must also be made for this in the analysis.

What is the maximum investment that can be justified if the unit cost of electricity escalates at a constant rate? It can be shown that a maximum investment of $1,997 is justified if electrical unit costs increase at a rate of 8 per cent (assuming an interest rate of 10 percent and a life of 15 years, as in the previous example). If these assumptions are correct, the heat pump represents a better investment than the electric furnace.

What effect would changes in the various assumptions have on the analysis? Table II illustrates the effect on the maximum justifiable investment of changing assumptions. An interest rate of 10 per cent and a service life of 15 years is assumed in all cases.

Table II. Effect of Changing Assumptions On Maximum Investment Justified

Assumption	Maximum Investment Justified
Case I	
SPF = 1.4 (instead of 1.6)	$1,407.
Case II	
SPF = 1.4 and an electrical unit price escalation of 12 per cent	1,815.
Case III	
Same as Case I but a maintenance cost differential of $50/yr	1,165.

SPF: Seasonal Performance Factor

A comparison of Cases I and II illustrates the importance of future trends in electrical unit energy costs. The greater the increase in electrical unit rates, the higher the investment that can be justified.

Case III illustrates the importance of heat pump reliability and maintenance costs. Recent indications are that manufacturers have solved a number of the problems that plagued early air-to-air heat pumps. The average annual service cost reported in a recent study was approximately $50.00/yr.[1] Presumably future maintenance costs will tend to decrease as new and better models come on the market.

In the foregoing analysis an electrical energy cost of 2.3/kWùh in the first year, and a service life of 15 years were assumed. Both factors have important implications for the economic justification of heat pumps. In regions where much higher energy rates prevail (for example the unit price of electricity in New Brunswick in 1976 was 2.72/kWùh) heat pumps appear to be more economically viable. There is, to date, not much information on the service life of heat pumps used for heating in cold climates. If it is only 10 to 12 years the justified investment would be much less; if it is as high as 20 years, the justified investment would be much higher.

The economic justification will vary for different climatic regions. In regions milder than Ottawa, for example, southwestern Ontario, much less supplementary heating would be required and the annual performance factor would he somewhat higher. In colder regions the Seasonal Performance Factor would be less and heat pumps would not be nearly so attractive. More detailed studies of the economic potential of heat pumps are needed before it will be possible to state clearly under what conditions and in what regions they are economically justified.

Oil and Gas Furnaces Combined with Air Heat Pumps

A number of manufacturers offer air-to-air heat pump systems that can be installed on new or existing oil or gas furnaces.[2] The heat pump is designed to provide all the heating above the balance point; the furnace provides the heating below the balance point. One drawback to the heat pump-furnace combination is that with present technology the heat pump and furnace cannot be operated simultaneously. There are, however, systems designed to allow the heat pump to run below the balance point by employing special thermostatic controls that turn the heat pump off and on at predetermined supply air temperatures. If the heat pump is used only for heating, it is much easier to design a system that will allow the continuous operation of the heat pump below the balance point.

One major advantage of using an oil or gas furnace rather than electricity for supplementary heating is that it reduces the high demand load on electrical power systems. As this high electrical demand will occur during periods of extremely cold weather it could, if heat pumps were used on a large scale, put extremely high peak power demands on residential districts. Even if power is available, it could well result in higher electrical power rates.

Concluding Remarks

In the milder regions of Canada air-to-air heat pumps can, under some circumstances, compete economically with residential electrical resistance heating systems. The use of oil or gas furnaces combined with air-to-air heat pumps offers an alternative heating system that appears attractive in terms of peak load demands for electrical utility networks. As for most methods of heating, the economic validity of the heat pump depends a great deal on anticipated future electrical and fossil fuel prices.

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