INTEGRATED HEAT PUMPS FOR RESIDENTIAL SPACE CONDITIONING AND WATER HEATING

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ABSTRACT

This paper reviews the utilization of heat pump systems with integrated water heating capabilities in the United States (U.S.) residential market. Current product offerings from two U.S. manufacturers are briefly presented. The advantages of such systems are summarized and a discussion on the associated economics presented.

INTRODUCTION

The large and diverse climate patterns within the U.S. impose great and differing heating and cooling requirements on residences in various geographical areas. In fact, costs associated with comfort conditioning are generally a household's single largest utility expense. Yet, regardless of location, utility bills for generating hot water year round are also large. Referring to Figure 1, it can be seen that for various representative U.S. cities the annual cost for water heating is the second highest (and sometimes even the highest in southern cities) utility expense.[1] To assist in reducing overall utility costs, energy associated with water heating also needs to be reduced. One method of reducing the energy to heat potable water is to utilize the waste (or inexpensive) heat obtained during space conditioning.

The notion of integrating water heating functions with space conditioning is not new. Several companies have investigated the concept and developed products to take advantage of this cost-saving opportunity. However, the early products are no longer on the market;

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[1] Representative water heating costs are derived using the following assumptions: daily hot water usage of 243 liters (64.3 gallons), average U.S. electricity rate of $.0841, average water temperature rise of 28° C (82° F), electric water heater efficiency of 85%.

those pioneer systems had a higher level of complexity and a larger installed cost than the market was willing to accept.[2] Today's products offer innovations that reduce product complexities and offer excellent payback periods, making them an attractive addition to the market.

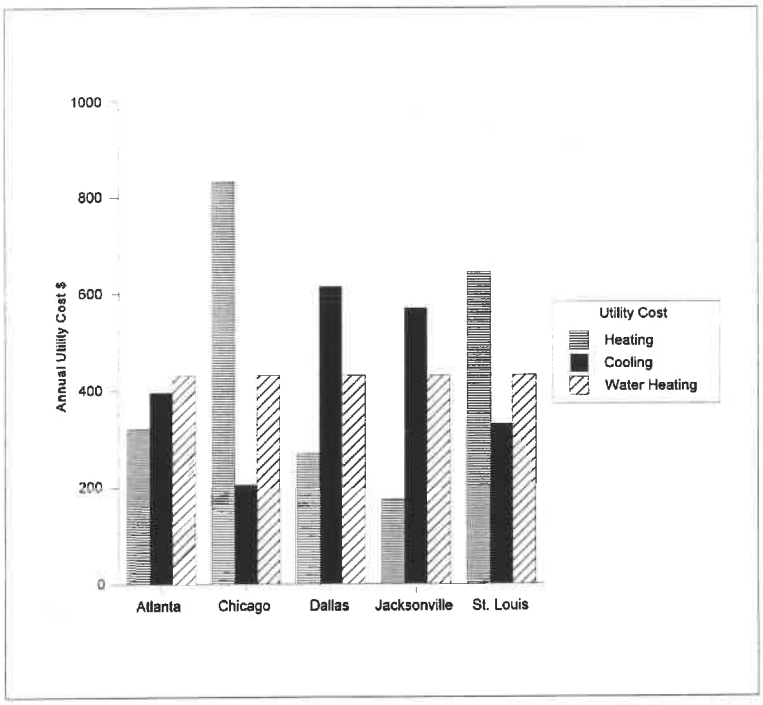

Figure 1: Annual Utility Cost vs. Location (10.5 kW, 10 SEER/7 HSPF Heat Pump and Electric Water Heater, $.0841 kWh)

CURRENT PRODUCT OFFERINGS

Currently, there are two U.S. manufacturers with fully-integrated heat pump systems [3] on the market. Although similar in concept and offering somewhat similar benefits, they function slightly differently. Figure 2 illustrates a schematic of a system marketed by NORDYNE Incorporated.[4] It is a fully-integrated heat pump system with heat exchangers matched to the compressor capacity. The integral refrigerant-to-water coil is a full

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2 Some of the complexities arose because integrated systems need to overcome compressor/heat exchanger mismatches and compensate for refrigerant and oil in the heat exchangers.

3 Fully-integrated heat pump systems are those that offer water heating capabilities in concert with heating/cooling space conditioning and dedicated hot water capabilities. This differs from those applications that use desuperheaters to heat water during operation of the underlying space conditioning system, or applications that have stand-alone dedicated heat pump water heaters that are not integrated with the space conditioning system.

4 NORDYNE markets under the Intertherm and Miller brand names, and its integrated system is trademarked *Powermiser*.

condensing heat exchanger.[5] In generating hot water, the system can utilize either the indoor (during the cooling mode) or outdoor (during the heating mode) heat exchanger as the ehat source, depending on respective temperatures and thermostat setting.

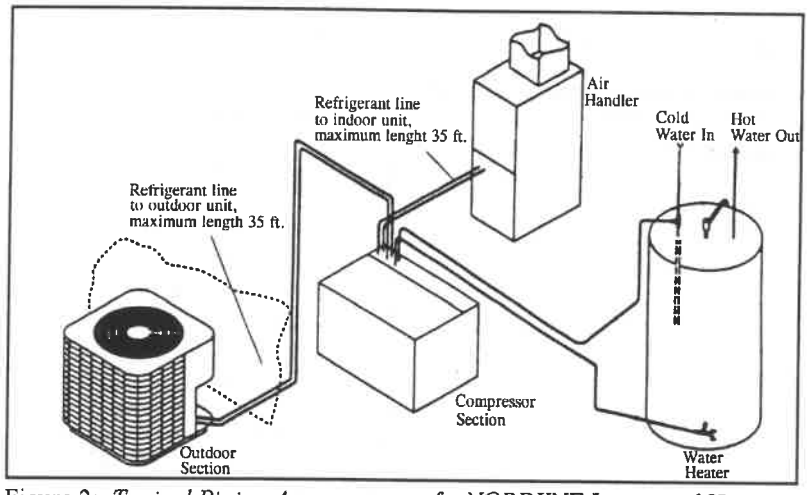

Figure 2: *Typical Piping Arrangement of a NORDYNE Integrated Heat Pump System*

Figure 3 illustrates a system available from Lennox International.[6] This system has a small, dedicated domestic heat pump water heater (typically 3 kW heating capacity), fully integrated with a separate space conditioning heat pump system. The heat source (evaporator) for the small, dedicated domestic heat pump water heater is an air-to-refrigerant coil located in the return air stream of a ducted system.[7] Due to component redundancy, this configuration offers additional flexibility in system matching.

These integrated heat pump systems provide a number of benefits to electric utilities and to residential consumers.

Utility Benefits

Integrated heat pumps are excellent tools to support utility demand-side management (DSM) program objectives. Since comfort conditioning and water heating are the two largest energy loads in a residence, reductions in either of these two produce significant energy savings. For a given residence, the power requirement more than doubles when an

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5 When hot water is produced during the space cooling mode, the water heat exchanger may appear to operate as a desuperheater. However, since a full condenser is utilized, the entire heat of rejection can be used to produce hot water.

6 The Lennox system is marketed under the trade name *RWH21*.

7 With this concept, the domestic heat pump water heater heats the potable water and simultaneously pre-cools the circulating air before it is ducted to the indoor unit of the space conditioning system.

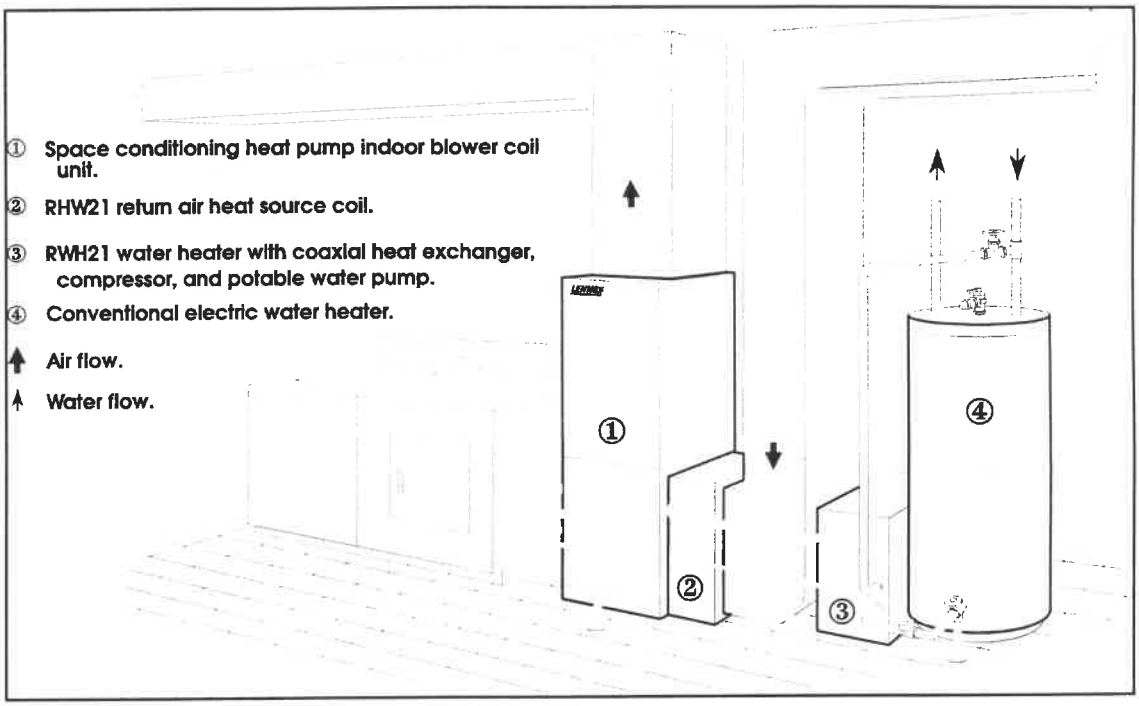

Figure 3: Typical Arrangement of the Lennox Integrated Heat Pump System

electric water heater is energized at the same time that a space conditioning heat pump is operating.[8] This doubling of kW requirement is illustrated in Figure 4(a), where bar graphs (summer/winter) portray separate and combined heat pump and instantaneous water heater power demand for a single system.[9] As seen here, the instantaneous power demand when both systems are operating is over 8 kW.

Figure 4(b) indicates the power demand for a typical residence if the water heater is considered on a diversified basis.[10] Combining the water heating power demand with that of the space conditioning heat pump, a representative kW requirement (for both functions) seen by a utility is approximately 4 kW.

Figure 4(c) illustrates the benefits when the water heating is fully integrated with the space conditioning functions. During summer operation, the heat content from inside the residence is used to generate hot water. Since this is "waste heat" (e.g., free heat) that would otherwise be rejected outdoors, the resultant hot water is obtained without additional kW demand. During winter operation, heat content is obtained from outside the conditioned space (for the NORDYNE unit) or from the occupied space (for the Lennox

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8 Assumes a nominal 10.5 kW (36,000 Btu/hr, 10 SEER/6.8 HSPF) heat pump and a conventional 4.5 kW electric water heater are utilized.

9 A water heater's average power demand is a function of the daily water-usage pattern and the total water used.

10 For any given residential neighborhood, not all individual water heaters activate at the same time. Hence, U.S. electric utilities generally consider an individual water heater element to represent about 0.6 kW on a diversified basis.

unit). In the first case, the space conditioning heat pump has to run longer since some of the heat content is directed to production of hot water as opposed to comfort conditioning. In the latter case, the space conditioning heat pump also has to run longer because additional heat content is required to overcome the detrimental cooling effect generated during the hot water production. Although the heat pumps run slightly longer during the winter, integrated operation lead to lower overall energy requirements due to high energy efficiencies.[11]

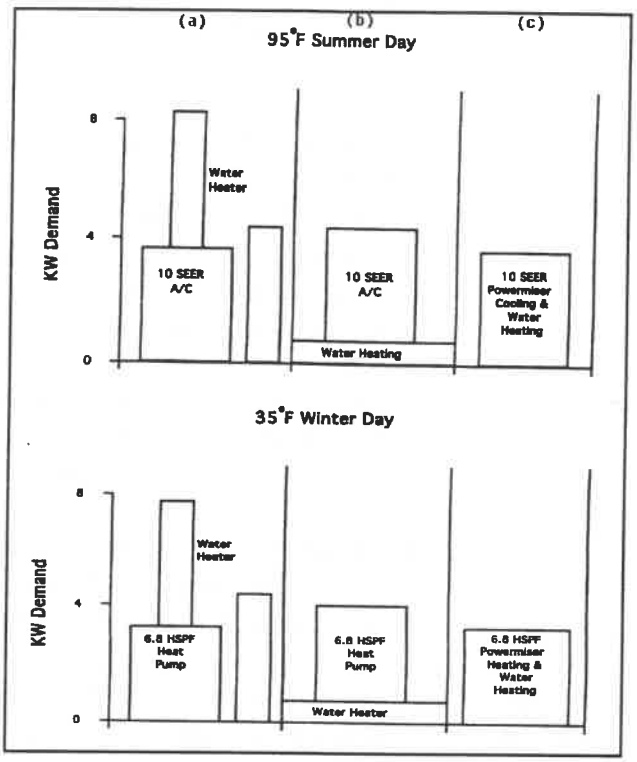

Figure 4: Power Demand Profiles for Combined Space Conditioning (Summer/Winter) and Water Heating.

Hence, not only do heat pumps aid in balancing a utility's summer and winter electricity loads, integration of water heating with space conditioning allows for a reduction in peak power demand.

Consumer Benefits

Integrated heat pump systems offer multiple modes of operation to minimize energy costs and maximize occupant comfort:

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11 Depending on the outdoor temperatures, generation of hot water during the winter can be produced at coefficients of performance (COPs) ranging from 2.0 to 3.5; the higher COP value is for winter water heating when space heating is not being performed.

space heating/cooling	The system operates as a normal heat pump, providing heating or cooling as required by application demand.
space heating with water heating	The system operates to supply heat to the residence while also using some of the heat content to produce hot water. Hot water can be generated at about one-third to one-half of the cost of a conventional electric water heater.
space cooling with water heating	By utilizing heat content drawn from the house (that would otherwise be discarded to the outdoors), hot water is obtained at no additional cost. Considering this "free" hot water, the summer energy savings of an integrated 10 SEER heat pump approaches that of an equivalent stand alone 20 SEER cooling system.
dedicated water heating	When used for water heating, integrated systems can operate at approximately 50% of the energy needed by conventional electric water heaters.
dedicated water heating with dehumidification	Same performance as the dedicated water heating mode with the extra benefit of free dehumidification during the spring and fall seasons.

Additionally, as a result of their high energy output and fast response times (as compared to conventional electric water heaters), integrated heat pump systems offer longer periods of continuous hot water (refer to Figure 5) and faster hot water recovery.

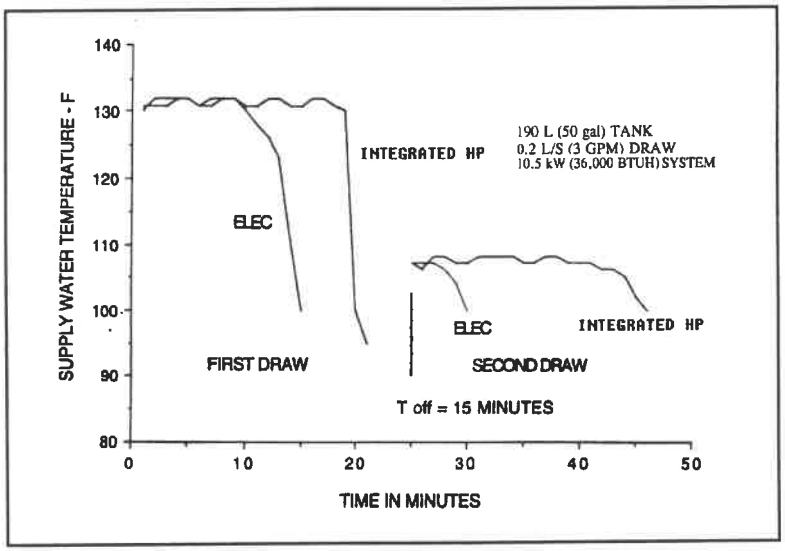

Figure 5: Comparison of Water Supply Temperatures

APPLICATION

As evidenced by Figure 1, significant reductions in water heating costs will have a dramatic impact on the overall energy bill. Figure 6 seeks to identify those periods when space conditioning and water heating occur simultaneously. As seen in the figure, during 11% of the year the need for space cooling coincides with the need for water heating. During 25% of the year, the need for space heating coincides with the need for water heating; however, integrated water heating cannot occur for 5% of this since the system heat pump is operating below its thermal balance point and is running full time just to satisfy space heating demands. The remaining 63% of water heating demand must be met by dedicated water heating, thermal storage (e.g., storing heated water for later use), or by supplemental backup heat (e.g., electric heater elements in the hot water tank); 38% is for heating water during the heating season [12] and 25% for heating water during the cooling season.[13]

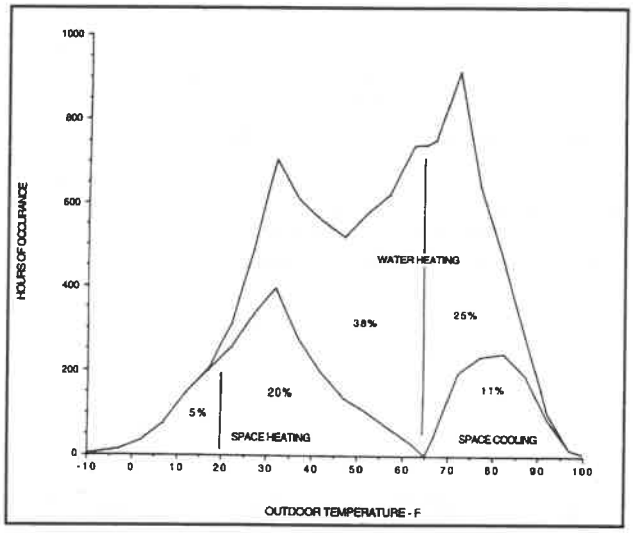

Figure 6: Occurrence of Water Heating vs. Occurrence of Space Heating and Cooling

By assuming a typical water draw pattern, size of the hot water storage tank, water heating capacity, and building load profile, a characterization can be developed for the total annual residential water heating requirements that can be satisfied by coincident water heating from an integrated heat pump system. This characterization is presented as Figure 7,

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12 The heating season is considered to be those portions of the year when the outdoor temperature is below 18.3°C (65°F). For U.S. Region IV, the winter heating season represents approximately 65% of the annual hours.

13 The cooling season is considered to be those portions of the year when the outdoor temperature is above 18.3°C (65°F). For U.S. Region IV, the summer cooling season represents approximately 35% of the annual hours.

plotted as a function of energy (e.g., kWh) per outdoor degree bin. This figure, similar in shape to Figure 6, includes the "flywheel effect" from a 190 liter (50 gallon) hot water storage tank.[14] As seen in Figure 7, 47% of the annual water heating can be satisfied when the space conditioning system is in the heating mode, and 27% can be satisfied when the space conditioning system is in the cooling mode. An additional 21% of the annual water heating requirements can potentially be fully satisfied by dedicated operation of the system to heat the water.[15] The final 5%, during the coldest portion of the winter, requires supplemental heating to satisfy the hot water load.

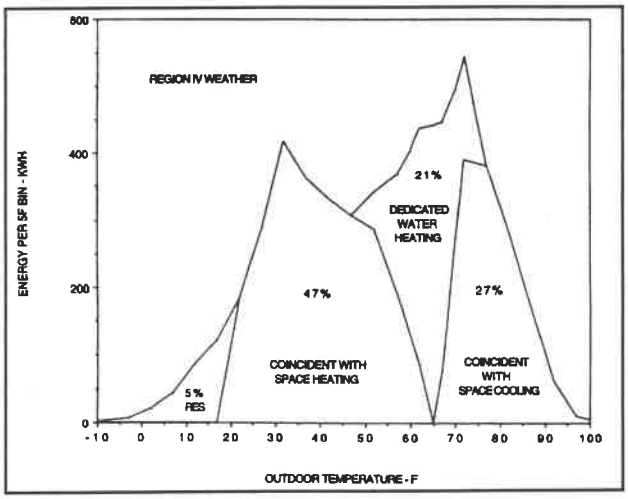

Figure 7: Operating Mode vs. Outdoor Temperature for an Integrated Heat Pump with Dedicated Water Heating

ECONOMICS

As discussed above, integrating water heating with space conditioning saves a considerable amount of energy. To ascertain the monetary impact on a typical U.S. residence, the following analysis compares a nominal 10.5 kW (3 ton) 10 SEER/6.8 HSPF heat pump system (with a separate conventional electric water heater) against a fully-integrated heat pump system. U.S. Region IV weather is selected as a representative U.S. application, and an average electricity cost of $0.0841/kWh is assumed.

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14 190 liter (50 gallon) hot water storage tanks are the prevalent size in the U.S.

15 It should be recognized that supplemental heat (i.e., from electric heater elements) may be required during periods of excessive water draw or for during periods when water heating is needed when space conditioning is not in operation.

Cooling Mode

Figure 8[16], composed of three elements, indicates the power requirements for a standard heat pump and a conventional electric water heater during cooling mode operation (i.e., summer). The far left bar indicates a cooling season cost of $303 for the standard 10 SEER heat pump. The far right bar indicates the water heating costs for an 0.87 efficient electric water heater. As shown here, summer water heating costs are approximately one-half that of the heat pump's cooling costs. The middle bar indicates the total costs for both functions (note that the total cost bar is double the scale of the space conditioning and water heating cost bars).

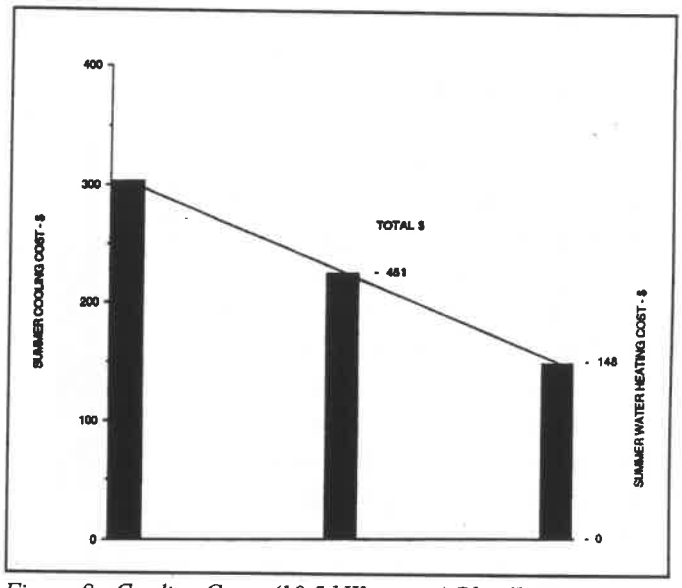

Figure 8: Cooling Costs (10.5 kW system) Plus Water Heating Costs; U.S. Region IV, $0.0841/kWh

In summer operation, an integrated heat pump system would allow "free heating" of water. However, during the summer there may be periods in which space cooling is not required but hot water demand continues, hence, the integrated system would be operated in the dedicated water heating mode. Also, during periods of excessive hot water usage, electric resistance heat may be required to maintain water temperatures. As indicated in Figure 9, an integrated system would have a summer water heating cost of $36 (approximately 25% of the normal cost). As the middle bar indicates, the "new" total cost is $340.

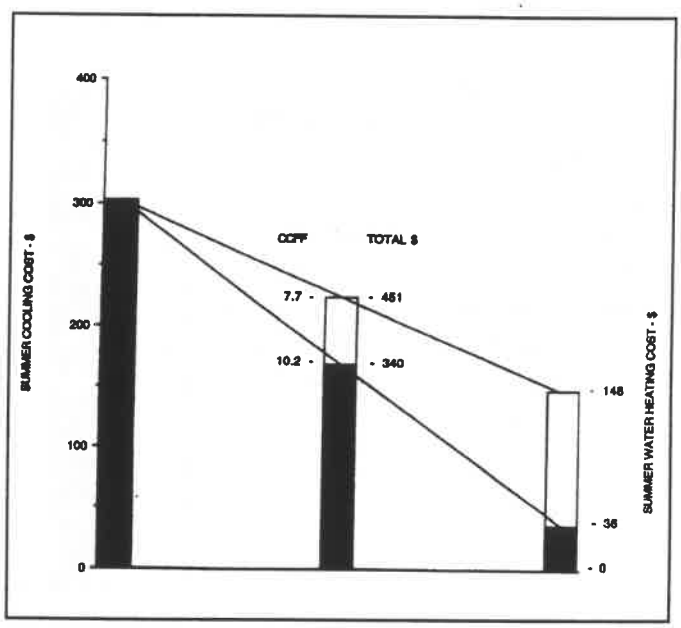

Figure 9: Cooling Costs (10.5 kW system) Plus Water Heating Costs -- Integrated Water Savings; U.S. Region IV, $0.0841/kWh

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16 This "nomogram" format is as presented in a prior paper (Reedy, 1995).

Therefore, a 10 SEER heat pump system with integrated water heating results in a summer savings of $111 over separate stand-alone components.

If a fully-integrated system was not used, and the customer still wanted to save $111 during the summer period, Figure 10 indicates that the space conditioning costs would have to be reduced from $303 to $192. This implies that the stand-alone heat pump would need to operate at a 15.8 SEER (as opposed to the base unit of 10 SEER), quickly reaching the limit of today's technological capability for single-capacity equipment.[17]

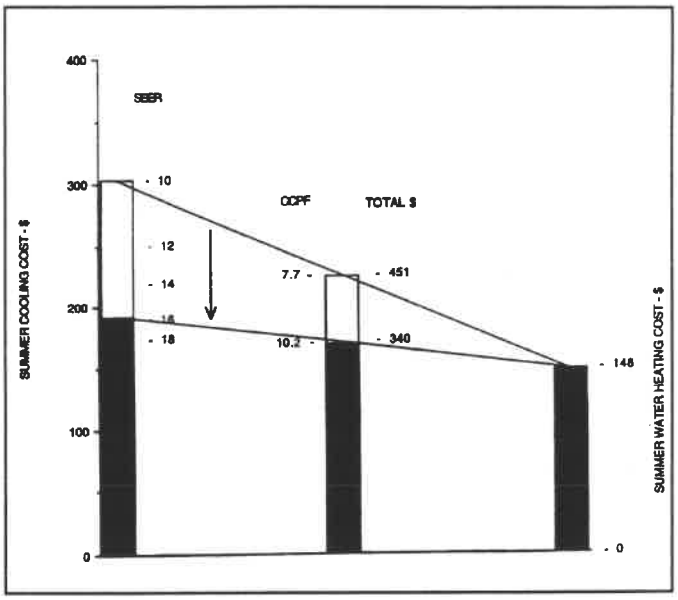

Figure 10: Cooling Costs (10.5 kW system) Plus Water Heating Costs — Effective Base System Efficiency; U.S.Region IV, $0.0841/kWh

Heating Mode

Similar to the cooling mode discussion above, an identical analysis can be created for the heating mode. Figure 11 indicates that in winter the space heating cost is $673 (far left bar) for a 6.8 HSPF heat pump, and the winter water heating cost is $276 (far right bar); total cost is $949 (center bar).

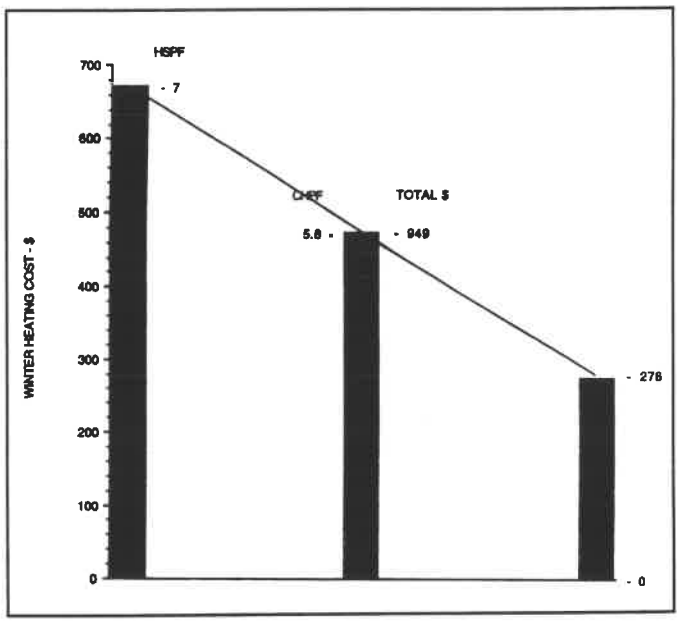

Figure 11: Heating Costs (base 10.5 kW system) Plus Water Heating Costs; U.S. Region IV, $0.0841/kWh

17 Previous integrated heat pump offerings used variable-speed compressors to increase equipment capacities for higher overall efficiency ratings. However, the added complexities and costs caused the products to be poorly received in the marketplace.

After factoring in the cost of operating the integrated system in the dedicated water heating mode, and inclusion of electric resistance heat for periods of excessive hot water draw-downs or when the outdoor temperature is below the thermal balance point, an integrated system can heat water at approximately 50% (52.5% used in the example) the cost of a standard electric water heater. As shown in Figure 12, the water heating savings of $131 resulted in a decreased total winter utility cost (for space heating and water heating functions) from $949 to $818.

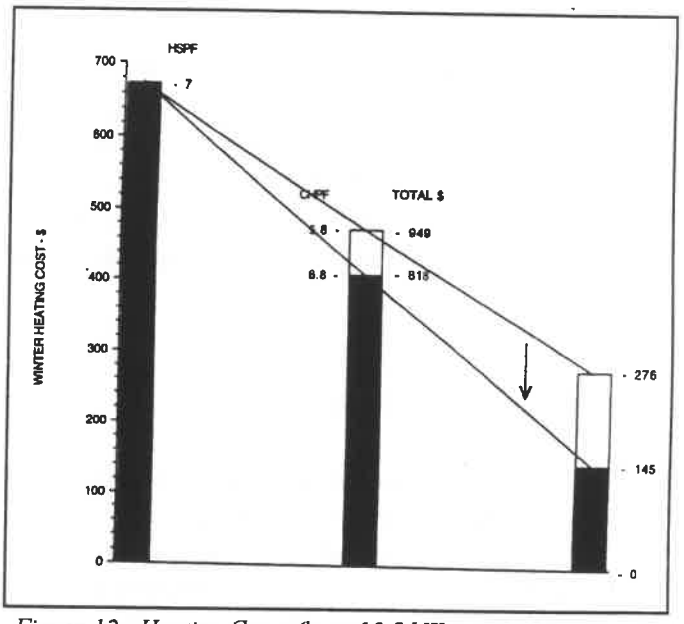

Figure 12: Heating Costs (base 10.5 kW system) Plus Water Heating Costs -- Integrated Water Savings; U.S. Region IV, $0.0841/kWh

To achieve $131 in savings from the space heating function only, space conditioning costs would have had to decrease from $671 to $542 (see Figure 13). This implies that a stand-alone heat pump would need to increase its HSPF from 6.8 to 8.7 (again, above today's technological capability for single-capacity equipment[18]).

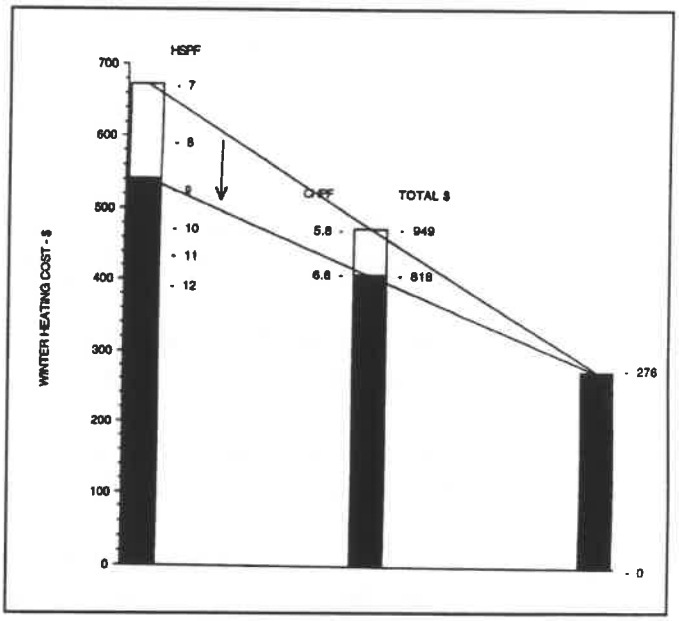

Figure 13: Heating Costs (base 10.5 kW system) Plus Water Heating Costs -- Effective Base System Efficiency; U.S. Region IV, $0.0841/kWh

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18 Previous integrated heat pump offerings used variable-speed compressors to increase equipment capacities for higher overall efficiency ratings. However, the added complexities and costs caused the products to be poorly received in the marketplace.

It is estimated that the premium for installing a fully-integrated 10.5 kW (3 ton) heat pump system, as opposed to the conventional configuration of a separate heat pump system with an electric water heater, is approximately $1,200 [Gilles 1994, Reedy 1995]. However, as illustrated above, the integrated heat pump system offers $242 in annual savings (e.g., $111 from summer operation and $131 from winter operation), resulting in a straight payback period of five years. This payback period becomes smaller, and the system even more economically attractive, if rebates are offered as further incentive to install integrated heat pump systems.

CONCLUSIONS

Integrating water heating requirements with space conditioning applications enables significant energy reductions. The new generation of integrated heat pump systems entering the marketplace realizes these energy savings while maintaining comfort and hot water needs, and offering attractive pay back periods. In recognition of new possibilities offered by this type of equipment, the existing U.S. Department of Energy (DOE) test and rating procedures are being revised to recognize these applications.

ACKNOWLEDGEMENT

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REFERENCES

1). Ted Gilles, *Combining HPWHs with Residential Conditioning*, IEA Heat Pump Centre Newsletter, vol. 12, No. 3, September 1994

2). Alan Kessler, *Innovative Water and Space Heating Heat Pumps*, 11th Energy Technology Conference, 1984

3). Wayne Reedy, *Integrated Heat Pumps: Advanced in Systems and Equipment*, Proceedings of the Fourth IEA Heat Pump Conference, April 1993

4). Wayne Reedy, *Power Demand Reduction with Integrated Heat Pumps*, IEA Heat Pump Centre Newsletter, vol. 12, No. 2, June 1994

5). Wayne Reedy, *Is There an Integrated Heat Pump in Your Future?*, Meeting Customers' Needs with Heat Pumps Conference, St. Louis, MO, December 1995