Advanced Heat Pump Cooling and Heating Energy Savings

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In 1986 the national research organization which is funded cooperatively by investor-owned electric utilities began investigating the new technologies which should be "cost effective" in an advanced heat pump. From these studies a national manufacturer won the competition to pursue such an "advanced" appliance. The manufactured unit (produced in 1989) achieved ARI ratings of 13.35 $SEER_{rated}$ (Cooling Seasonal Energy Efficiency Ratio)/ 8.75 $HSPF_{rated}$ (Heating Seasonal Performance Factor) for a 2-ton unit. These ratings ignore any benefits of hot water supplied by the device. Between January 1990 and June 1992, 31 2- and 3-ton units were field tested across the nation. The average for all these tests was $SEER_{actual}$ = 14.1 and $HSPF_{actual}$ = 9.05. [Note that these numbers labeled "actual" are found by monitoring the space conditioning energy produced at the appliance in the occupied residence for a season and dividing that energy by the amount of electricity used during that time. The relationship of such "actual" numbers to the "rated" numbers has not been established, however, the 'fleet averages' for all 31 units at locations across the continental United States for this specific group were near the "rated" numbers.]

This paper discusses the actual savings of both energy and money at a hot/humid test site in Wilmington, North Carolina. The specific performance in this location was significantly different than the "rated" numbers but the resulting energy and money savings indicated that the unit actually provided "advanced" performance. The Wilmington site measured (total cooling)/(total electricity used) = $SEER_{actual}$ = 9.05 and, similarly for heating, $HSPF_{actual}$ = 13.01.

The savings provided by the new heat pump in this residence was found by modeling the replaced heat pump and solar domestic hot water system using four years of monthly electric usage records. The performance of the modeled replaced heat pump using the actual weather of the test period was then compared on seasonal bases to the monitored advanced heat pump numbers. This approximate analysis indicates that the replaced unit was providing $SEER_{actual}$ = 3.09 and $HSPF_{actual}$ = 5.59.

The family occupying the house was very conscious of energy and knew that they were using approximately 11,000 kwh/yr for space conditioning with about 60% of that for cooling and 40% for heating. Based on these rough numbers and a guess that their ten-year-old heat pump would have been rated at a SEER of about 6.5 and an HSPF of about 4.7, they hoped to reduce their annual space conditioning energy use by about half.

The advanced unit performed very well in this residence and climate, saving 71.8% of the cooling energy and 50% of the heating energy, for an annual savings of 63.6%. Because the local utility prices are higher during summer, the annual money savings were even greater. This was a savings of over $50/month to this family whose bills were already the lowest in their subdevelopment. This case study indicates the degree to which different climates and family life styles can affect actual seasonal performance of heat pumps.

Introduction

The test site chosen for a hot/humid climate location of the Advanced Heat Pump in North Carolina was the Hill residence situated south of Wilmington, between Wilmington and Carolina Beach. The climate at the test location is classified as hot/humid and is similar to the climate conditions of a more southerly location such as Jacksonville, Florida. The test house is a 1680 square feet, two-story, open design, tract house occupied by an employee of the local electric utility, his wife and their three children. The family has long been interested in energy and they have gained a reputation for following a very energy-conservative life style, using less energy than most equivalent income families. Because of this usage life style and the fact that the family had optimized their habits for low energy bills, the monetary savings which they experience from more efficient space conditioning equipment represents close to a minimum return expectation. Families who live more typical suburban lives should expect greater monetary savings than were recorded at the Hill test house. The house was equipped with a reasonably typical heat pump (1980 vintage) prior to the installation of the advanced heat pump test unit [estimated (if rated) SEER = 6.5 and HSPF = 4.7] as well as a solar water heater system which provided all of their hot water.

No modifications were made to the house or to the duct system at the time of the installation of the test heat pump (although the addition of an upstairs air return duct was recommended, it was not added). This situation provided an excellent opportunity to estimate the energy savings of the new heat pump versus the long history of the replaced heat pump. This report concludes that within the accuracy of the assumptions of this simplified analysis, there was a space conditioning annual electrical energy savings of approximately 60% in comparison to the previous heat pump.

For this test house and this family, the advanced heat pump provided a cost savings in their space conditioning energy of slightly over $50 per month (at $0.09 per kWh) and, as an added bonus, provided essentially all of their domestic hot water needs.

Analysis Method

The method used to establish space conditioning energy savings attributable to the advanced heat pump is simplified and no strong claims are made for accuracy. The detailed monitoring instruments recorded the actual space conditioning energy produced at the indoor air handler and the electrical energy used by the entire conditioning equipment. The actual seasonal energy efficiency of the equipment ($SEER_{Actual}$) is determined by summing the energy produced and the electricity required over a season and then dividing the sums. This result by itself tells how efficiently the equipment has operated, however it does not necessarily provide an answer to how much money or energy this equipment "saved" versus some alternative. The alternative savings can be estimated if there is data on alternative equipment in the same house either before or after the test equipment and test period. By using alternative tests before or after the prime test period a number of important variables are held constant, i.e., the actual duct system and house and the family lifestyle. The other known first order variable is the actual weather of the test period for which an analytical correction must be applied to the comparison data.

The test house had a solar domestic hot water system prior to the beginning of the test and thus any savings for a typical situation provided by the test unit supplying domestic hot water is not applicable for this specific residence. The national results of the advanced heat pump test program indicated that monetary savings from domestic hot water frequently exceeded the savings from reduced energy used for space conditioning.

The total electric test residence had a record of billed monthly electricity use since 1986. The family occupying the residence included an employed father, a full-time mother, and three children under seven years of age. There was thus a very similar lifestyle throughout the billing record and this lifestyle continued throughout the advanced heat pump test year. The advanced heat pump was installed in October 1990 and was intensively monitored until July 1992. The test period used to estimate the space conditioning energy savings due to the advanced heat pump in this report was October 1990 through September 1991.

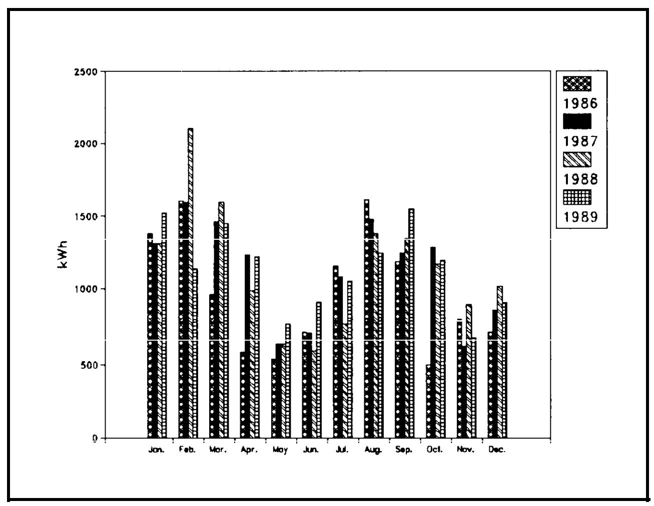

Figure 1. Monthly Electric Energy Use - 1986-1989, Wilmington Test Site

The basic analysis method used the four years of recorded monthly electricity usage to calibrate a simulation model of the house with the original (replaced) heat pump. The residential energy computer model used was the EPRI - ESPRE Residential Energy Analysis Package. The recorded actual energy use is shown in Figure 1. The predicted space conditioning energy use from the calibrated model for the standard weather year was the weather normalized for the test year and the results compared to the actual monitored energy use with the advanced heat pump. The calibration of the computer model was based only upon a reasonable prediction of total annual energy use (i.e., within 10%). The four years of model calibration energy use are shown in Table 1.

Table 1. Seasonal Electrical Energy From Billing and From Model

Condition	Heating kWh	Cooling kWh	Annual kWh
"Calibrated" Computer Predicted Space Conditioning Energy Use (typical weather year)	5585	5945	11,530
1986 Actual Electrical Use Corrected to typical weather	6460	4860	11,320
% From Model Prediction	+15.6%	-18.3%	-1.8%
1987 Actual Electrical Use Corrected to typical weather	5675	4685	10,360
% From Model Prediction	+1.6%	-21.2%	-10.0%
1988 Actual Electrical Use Corrected to typical weather	6360	4980	11,340
% From Model Prediction	+13.8%	-16.0%	-1.6%
1989 Actual Electrical Use Corrected to typical weather	6475	5600	12,075
% From Model Prediction	+15.9%	-5.8%	+4.7%

It is easy to see that more work or perhaps use of a seasonal criteria for calibration could produce a more accurate model; however, for this study the ±10 %, consistently low heating energy prediction and consistently high cooling energy use prediction is judged sufficiently accurate to indicate a "real" savings (see Table 1).

Weather adjustment of the actual electrical energy use is accomplished by using the following assumptions and formulas:

(a) Heating months are November - March = 5 months.

(b) Cooling months are May - September = 5 months.

(c) April and October are considered "neutral" months for space conditioning.

For heating -
[A] $kWh_{comparison} = kWh_{actual}(HDD_{normal}/HDD_{actual})$

For cooling -
[B] $kWh_{comparison} = kWh_{actual}(CDD_{normal}/CDD_{actual})$

Results

Table 2 provides summarized monitored results for the test site for a test year. These summarized results show that the equipment worked extremely well and that the family maintained a comfortable indoor environment. Figure 2 shows the monitored monthly efficiency ratios of space conditioning energy provided, divided by the monthly electrical usage by the equipment.

Table 2. Monitored Test Year Results

Average outdoor temp. (actual)	65.8°F
Average outdoor temp. (historical)	61.7°F
Average indoor temp. (winter/summer)	72.4/73.8°F
% DHW from heat pump	100%
% Heating BTUs from strip	3.5%
Seasonal monitored SEER	13.01
Seasonal monitored HSPF	9.05

The results of the energy analysis comparison are presented in Table 3. Note: For this test year comparison the model predictions are adjusted for actual weather and compared to the monitored electrical energy use.

Table 3 shows that the advanced heat pump system used only 36.4% of the electrical energy that the calibrated model predicted the old heat pump would have used for October 1990 through September 1991. This is an estimated savings of 63.6%.

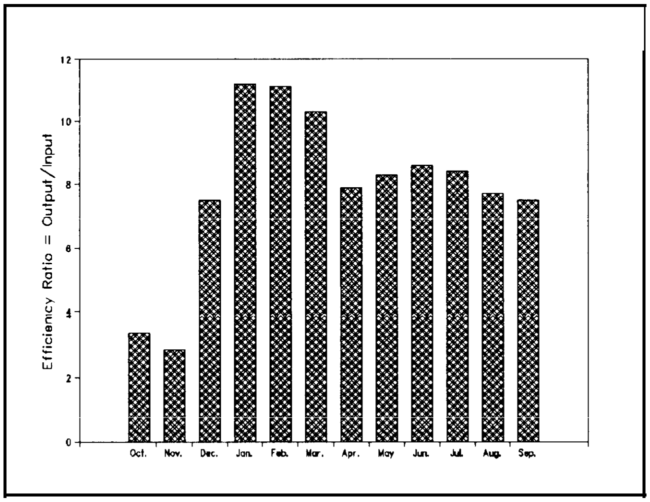

Figure 2. Monitored Monthly Efficiency Ratio = Energy Out/Energy In

The indicated heating season savings is 50% and the indicated cooling season savings is 71.8%.

Because Table 1 shows that the calibrated model consistently underpredicts by up to 16% the heating energy which the family actually used, we can estimate a range of energy use of 1.16 X 4255 kWh = 4930 kWh. If we use this as the monitored heating season model prediction, the savings would still be 57%. Similarly, the model consistently overpredicts by as much as 22% the energy the family actually used for cooling. Using this as an extreme error, the predicted cooling energy would be 6899 kWh/ 1.22 = 5655 kWh. Using this range of prediction value still indicates a cooling energy savings of 66%. The yearly energy predicted by the model with these extreme adjusted values would be 10,585 kWh and the actual energy use with the advanced heat pump still provides a savings of 61.6%.

Conclusions

At the hot humid test house location near Wilmington, North Carolina, a typical, approximately ten year old heat pump was replaced by a 2-ton, advanced heat pump. This house is 1680 square feet and it is occupied by an energy conserving family of two adults and three elementary-school-aged children.

The advanced heat pump provided over 95% of the domestic hot water needs of the family throughout the entire monitored period (100% from January 1991 through February 1992).

Using a calibrated computer model of the household space conditioning energy use with the replaced, approximately 1980 vintage heat pump, the advanced heat pump provided space conditioning energy savings of approximately 64%.

The monitored data from this site shows that the advanced heat pump delivered an annual HSPF = 13.01 and SEER = 9.05.

At a cost of $0.09 per kWh, the family in the test site house experienced a savings of over $50 per month in their electric costs due to the more efficient space conditioning of this advanced heat pump. The family was on an "equal pay" electrical bill plan with the utility and discussions with the family after the test period revealed that only a portion of this savings was taken in money. The family decided to use part of their "savings" in increased comfort and set their thermostat at less stringent settings. The "equal pay" plan of the utility offered a reduction of $70 per month in the billing of the residence, however the family choose to reduce the payment by only $50 per month and to increase their comfort. This phenomenon of

Table 3. Comparison of Seasonal Electrical Energy Use - Advanced versus Replace Period Covered by This Comparison: October 1990 - September 1991

	Heating kWh	Cooling kWh	Annual kWh
Predicted Electrical Space Conditioning Energy Use (If old equipment were used)	4255	6899	11,154
Monitored Electrical Space Conditioning Energy Use (Advanced Heat Pump)	2115	1944	4059

using energy savings in increased comfort is not uncommon in conservation or demand side programs, especially when a participant is making decisions based upon an established money flow for which the budget is currently being met.

In addition to the above savings in space conditioning energy, the advanced heat pump provided almost 100% of the domestic hot water needs of this family. No additional monetary savings for this service are estimated because the family had used a solar domestic hot water system prior to the installation of the advanced heat pump. For a more average situation with electric hot water, the energy savings for hot water would certainly represent an additional savings of about $10 per month (actually $10.77 per month for the test household at $0.09 per kWh).

In summary, a family in eastern North Carolina with an average house (about 1700 square feet), a ten year old heat pump, and electric hot water could reasonably expect a minimum monthly electric cost savings of $60 if the old equipment were replaced with an advanced heat pump system.

It is also concluded that "rated" seasonal energy performance factors are not accurate in predicting actual energy savings in a particular occupied house. For this specific home the actual energy savings were significantly greater than the ratings number predicted.

Acknowledgments

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