Energy and Buildings, *13* (1989) 31 - 37

Load Shape Impacts of the Hood River Conservation Project

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ABSTRACT

As a part of the Hood River Conservation Project (HRCP), 320 homes were monitored to measure electrical energy use on a 15-min basis. The total electrical load, space-heating load, water-heating load, woodstove heat output, and indoor temperature were monitored for one full year both before and after retrofit. Special weather stations collected detailed local weather information, also on a 15-min basis.

This data base was used to evaluate the load savings attributable to HRCP. Two methods of weather normalization were used and showed close agreement. Measurable demand and energy savings were achieved by the HRCP. These savings are significant in magnitude and are available at the time of the system peak load.

The weather-normalized diversified residential load savings on the Pacific Power & Light system and Hood River area peak days were greater than 0.5 kW/household. Savings were greatest in single-family electrically heated homes where the diversified seasonal peak was reduced by 0.8 kW/household. The load factor for the diversified residential load decreased following the conservation retrofit actions because heating equipment modifications (such as reductions in name-plate ratings or efficiency improvements) were not included in the program. Conservation programs could avoid this load factor reduction by decreasing the heating system capacity of each home commensurate with its thermal shell improvements. Demand savings in wood-heated homes were less than in electrically heated homes, but the sensitivity of the electrical system to future fuel-switching was reduced.

INTRODUCTION

Because power-plant costs have increased so dramatically over the past 15 years, investments in conservation have been suggested as an alternative way to meet increases in electrical demand. The concept of using conservation to displace a power production facility followed naturally upon the successful use of conservation to displace fuel used for power production. Conservation can also affect transmission and distribution facilities and costs. These impacts are less visible than the savings in power plants but range from reductions in the required sizes of pole-top transformers serving small groups of (or individual) customers, to reductions in the high-tension transmission facilities that accompany power production facilities. The requirement that power supplies, both generation and transmission, be dependable made it necessary to test the availability of conservation as an alternative power source before this concept could be implemented in regional utility planning efforts.

To displace a power-producing facility, energy conservation must save both energy (kilowatt-hours) and capacity (kilowatts). Such capacity savings will be most valuable if they occur at system peak times. Capacity savings are time-dependent and vary just as electrical loads vary. For example, morning loads may be higher because homeowners use space-heating, water-heating, cooking, and small grooming appliances all at the same time. Afternoon loads would typically be less because fewer appliances would be used simultaneously. A conservation retrofit that decreases space-heating energy requirements may affect the time at which the space-heat

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Printed in The Netherlands

appliance is used as well as the running time required to heat the home. These changes in time and duration of the electrical loads, averaged over many homes, can lead to capacity savings which reduce the utility's need for generating facilities.

Advance planning for such facilities requires dependable estimates of the capacity savings available from conservation programs. Direct measurements of capacity savings, in an appropriate sample of customers, are necessary to provide a reliable basis for these estimates. This measurement question was carefully addressed during the design of the Hood River Conservation Project (HRCP). Because monthly energy bills fail to reflect the variation of energy use with time, 320 homes were equipped with monitors to record each home's energy use every 15 minutes. Also, to permit a better understanding of how energy is used and conserved, several energy end-uses were monitored in addition to the total energy consumption. These end-uses included space heating and water heating (in 200 homes). Indoor air temperatures and the radiant heat flux from wood stoves (in 100 homes) were also monitored. See Hirst for an overview of the Hood River Conservation Project [1].

The HRCP focused on winter savings because the Hood River area is a strictly winter-peaking situation. Unlike most other regions, summer loads are much lower and are therefore of little interest or consequence.

ANALYSIS APPROACH

Average household load impacts attributable to the HRCP conservation actions were estimated by comparing the pre- and post-conservation loads. Weather normalization was necessary to identify the effects of the HRCP separately from the effects of differing weather conditions before and after the conservation actions. Such weather normalization is difficult to provide on the necessary 15-min basis. Therefore, two independent methods of weather normalization (on a 15-min basis) were used to improve the reliability of the results.

The first method is based on choosing pairs of similar days for comparison. Similarity is defined as matching the day of the week, the daily minimum outdoor temperature within 5 °F, and the average outdoor temperature within 5 °F. Other weather variables including wind speed and solar radiation were also considered in the selection (see Stovall for more details [2]). Using these criteria, a set of 28 pairs of days was chosen to represent the December through February period for the 1984/1985 and 1985/1986 winters. The distribution of average and minimum outdoor temperatures for this set of 28 days was selected to match the distribution of temperatures for the entire three-month period. The number of weekdays and weekend days were also chosen to represent the proper proportions. In addition to this representative set of similar days, an individual pair of days was chosen for special attention and comparisons. These chosen days represented a very cold winter weekday and were matched based on their 15-min temperature, insolation, and wind profiles as well as on their daily average and minimum temperatures.

The second method is based on generating a multi-variate regression model of the pre-conservation diversified, or average, load of 314 monitored homes. Because the model was developed for the diversified load, it is not applicable to subsets of these homes or to individual homes. The regression model is actually a composite of four models that differ for weekdays and weekends and for daytime and nighttime. Weather and lifestyle-related variables thought to influence total household load were tested in the derivation of these models. Those found to be statistically significant (the significance varies for the different time periods) were retained and include: the value of the total load for the previous 15-min period; the difference between the indoor and outdoor temperatures; the wind speed multiplied by the outdoor temperature; the water-heating energy use; the indoor temperature; the indoor temperature for the previous 15-min period; a collection of cosine and sine terms based on 8, 12, and 24-hour periods; the solar radiation; the solar radiation 30 minutes previously; the hour of the day; and a dummy variable with a value of one between 12:00 and 16:00 and a value of zero all other times. The model was tested by applying it to the pre-conservation weather and comparing the resulting load profile prediction to the measured load profile [2]. The model was then applied to the post-conservation weather to generate an estimate of what the pre-conservation load would have been for the post-conservation weather.

These two normalization methods are complementary. The regression model is useful for examining the days during which the system peak occurs and for which similar days are not usually available. The similar days model is useful for examining subsets of customers for which regression models were less accurate due to smaller sample sizes. Both models are useful for seasonal comparisons (and give similar results for these comparisons).

RESULTS

Load shape impacts

System peak days are obviously of interest when examining capacity savings. On both the Pacific Power and Light system and Hood River area peak days, the weather-normalized post-conservation peak load was lower by more than 0.5 kW/household (about 8%). The time of the residential peak shifted slightly (from 07:30 to 07:15) as Fig. 1 shows. The hourly system peak occurred at 08:00 on this day and the hourly (as opposed to 15-min) residential load at this time was reduced by 0.7 kW.

Over the winter season, the distribution of the diversified residential load is useful in determining not only power production requirements, but those of transmission and distribution also. For example, some distribution equipment is rated at given load levels for

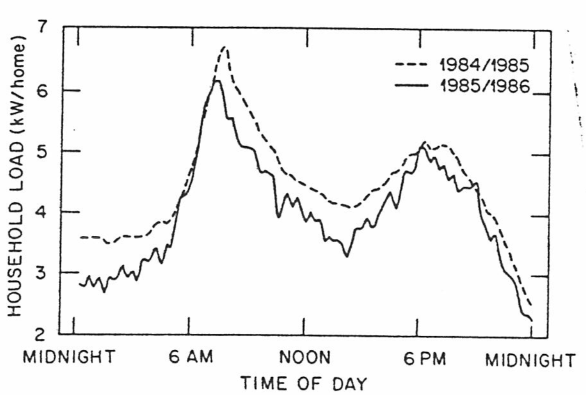

Fig. 1. Diversified ($N = 314$) household load on Hood River area peak day, Monday, November 25, 1985, weather-normalized using regression model.

restricted periods of time. If the customers served by a particular component, such as a transformer, reduce the amount of time spent at these higher levels, smaller equipment with lower ratings may be used. Figure 2 shows that the number of time periods spent at loads higher than 4.5 kW/household decreased by 35% following conservation retrofits. Diversified loads up to 6.8 kW/household were measured the first season while the second season showed loads only up to 6.4 kW/household.

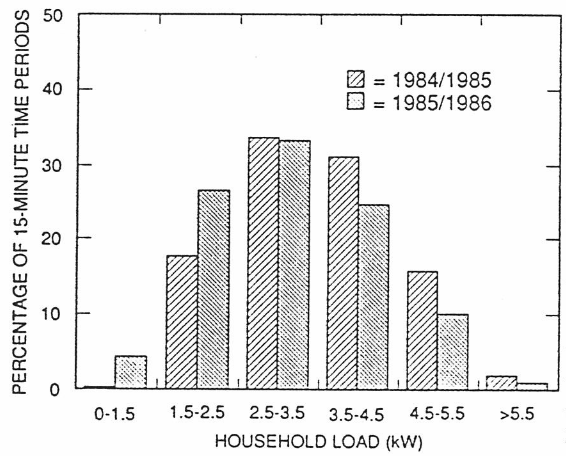

Fig. 2. Distribution of winter diversified residential loads.

The diversified load of the average customer in the HRCP sample, both before and after the conservation retrofits, was observed to be about 0.5 kW/household lower than reported by other load research investigations in the Northwest region [3]. These other programs were not an attempt to represent a regional estimate but were restricted to single-family homes with all-electric heat (i.e., high-use customers). The difference between the loads recorded in Hood River and those recorded in these other programs was attributed to the inclusion of multi-family and the large proportion of wood-heated homes in the HRCP. Therefore, a closer examination of single-family homes heated mainly by electricity was made to enable a direct comparison with the previous investigation.

The pre-retrofit diversified load of the single-family homes and their load savings were comparable to those measured in these other conservation programs. Also, a comparison of this subset of homes to the total sample of monitored homes is shown in Tables 1

TABLE 1

Seasonal savings estimates in Hood River

Weather normalization method	Period	Average monthly energy use[a] (kWh)	Diversified household 15-min load[b] (kW/household)		Load factor
			Average	Maximum	
Total sample of monitored homes					
Regression[c]	Before	2500	3.4	6.7	0.51
	After	2200	3.0	6.2	0.49
Savings		300	0.4	0.5	
Similar days[d]	Before	2500	3.4	6.1	0.55
	After	2200	3.0	5.9	0.50
Savings		300	0.4	0.2	
Single-family electrically heated homes					
Similar days[d]	Before	2940	4.0	6.2	0.65
	After	2500	3.4	5.4	0.61
Savings		440	0.6	0.8	

[a]Calculated from average load based on 736 h/month.
[b]Based on 314 customers.
[c]Based on the weather during the period December 1985 - February 1986.
[d]Based on 28 pairs of days chosen to represent the seasonal weather distribution.

TABLE 2

Diversified load on selected similar cold days, single-day comparison[a]

Weather-normalization method	Household load (kW/house)	
	Average	Maximum
Total sample of monitored homes		
Regression model		
January 15, 1986[b]	3.3	5.2
January 15, 1986	2.9	4.7
Savings	0.4	0.5
Similar days		
January 16, 1985	3.4	5.4
January 15, 1986	2.9	4.7
Savings	0.5	0.7
Single-family electrically heated homes		
Similar days		
January 16, 1985	4.2	6.2
January 15, 1986	3.2	4.8
Savings	1.0	1.4

[a]N = 314.
[b]Loads were estimated for this day's weather by using the preconservation regression model.

and 2. These Tables show that the peak-load savings for this subset of customers is almost twice that of the overall sample of monitored homes. The energy savings shown by monthly energy use and average load are also about 50% higher for this group of customers. (The load factors shown in Table 1 are discussed later in this article.)

The savings shown in Table 2 are based on a consideration of two similar cold days. These two cold days were selected to avoid the averaging, or flattening, effect that occurs when the average loads of many days are considered. The diversified loads of the total monitored sample on these two days are shown in Fig. 3. The diversified loads of the single-family homes heated mainly by electricity on

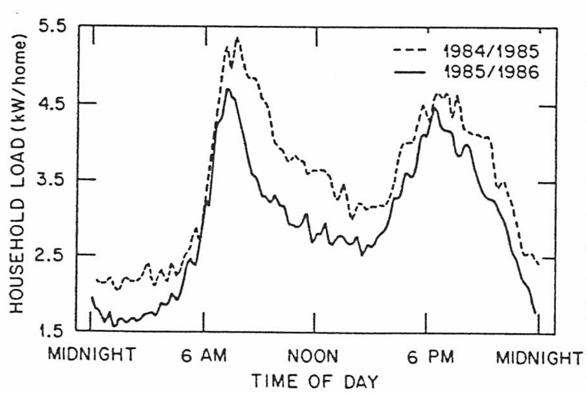

Fig. 3. Diversified household loads for January 15, 1986 and January 16, 1985, comparison based on two similar cold days (N = 314).

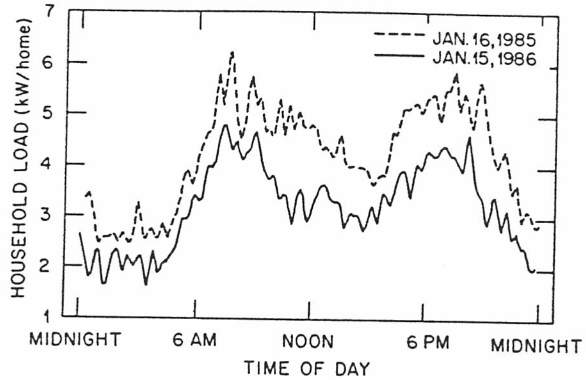

Fig. 4. Diversified household load profiles for electrically heated single-family homes, January 16, 1985 (N = 97), and January 15, 1986 (N = 98).

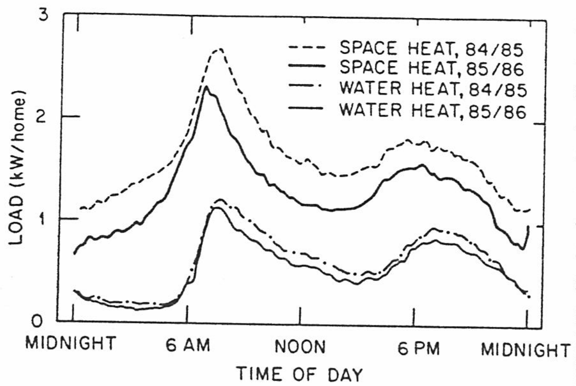

Fig. 6. Diversified winter-weekday space (N = 314) and water-heating (N = 200) 15-min load profiles, comparison based on selected sets of 28 similar days.

these same two similar cold days are shown in Fig. 4. Comparison of these Figures emphasizes both the greater magnitude of the pre-conservation loads and the larger savings achieved in the single-family homes.

The savings on these two similar cold days were examined in great detail. The load savings were calculated for each 15-min interval for each individual customer. These savings were then averaged for each time interval and the standard errors calculated for each value. The results of this examination are shown in Fig. 5. They show that the savings are significantly greater than zero for 92 out of the 96 measured values and are greatest during the peak morning hours. A seasonal comparison of the space and water-heating loads over the selected sets of 28 days in Fig. 6 shows that while most of these savings are due to space-heat savings, some were due to reductions in water-heating loads [4].

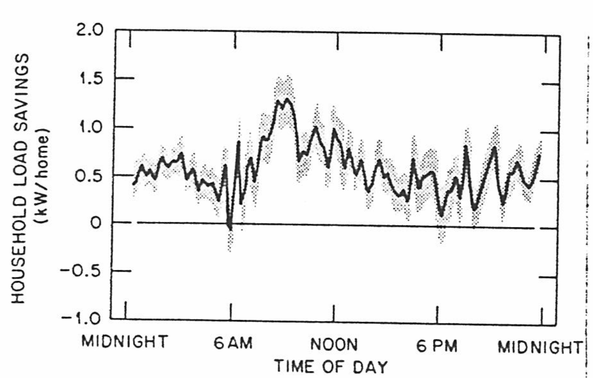

Fig. 5. Diversified household load savings with standard error bounds for January 15, 1986 and for January 16, 1985, similar cold days (N = 314).

The seasonal savings shown on Table 1 were compared to the savings achieved on selected pairs of very cold days, like those shown on Table 2. This comparison suggests that the load reductions attributable to the HRCP retrofits increase during colder weather. This would mean that the HRCP reduced the diversified residential load's sensitivity, in terms of kW/house, to extremely cold weather (which is precisely when system demands are highest). As the next Section will show however, the relative sensitivity, in terms of kW/kWh, was not reduced.

Load factor issues

The load factor is defined as the ratio of the average load to the peak load. Load factors can be calculated for the entire system, for the diversified load of a large group of customers, or for individual households. High system load factors are desirable because they indicate that power-producing facilities are more efficiently used. High load factors for large groups of customers can improve the utilization of transmission facilities. And high load factors for individual households could improve the utilization of endpoint distribution equipment. As Table 1 shows, the load factors for the diversified load of the monitored homes decreased slightly following the retrofits. Figure 7 shows that the load factors of individual households also shifted to slightly lower values following the retrofits. This decrease was caused by peak load savings that were proportionally less than the average load savings. The program's effect on the households' peak loads was less than the

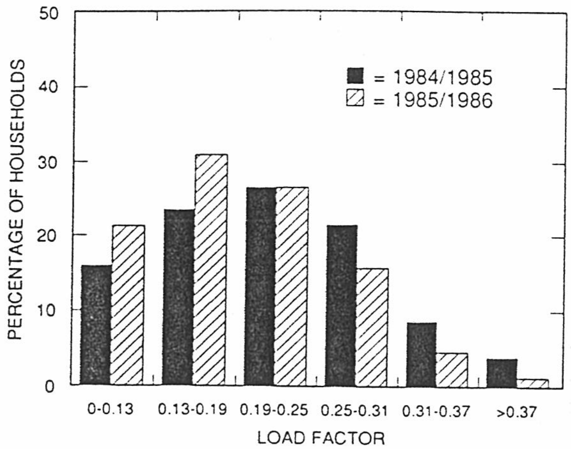

Fig. 7. Distribution of individual-household winter load factors, comparison based on similar days selection, weekdays only.

effect on the average loads because space and water-heating equipment modifications were not included in the program. Without such derating modifications, this equipment puts the same instantaneous load on the system whenever it runs as before the program. The savings that are achieved are therefore due only to the reduced running time requirements.

The distribution of winter maximum loads for individual households was not really changed by the conservation retrofits. To reduce these maximum loads and thereby avoid load factor reductions, a conservation program may need to include equipment modifications (i.e., reductions in name-plate ratings) along with weatherization improvements. Indeed, weatherization improvements often cause the existing heating system to be grossly oversized by reducing the structure's need for heat. In these situations, heating system modifications will not only reduce the household's maximum load but will also improve the system's operation by avoiding excessive cycling losses [5].

Wood heat issues

There was a surprisingly large amount of wood-heat used in the Hood River community. This may have been caused by a combination of recent utility price increases and the local availability of inexpensive firewood. About half of the monitored homes used wood as a major source of home heating. Although this complicated the analysis of program savings, it afforded an excellent opportunity to examine the interrelationships between utility conservation planning and uncontrolled alternative fuel use [6].

Figure 8 shows several points of interest in comparing wood-heat users to homes heated exclusively by electricity. First, it demonstrates the value of time-dependent load data by showing both the average load (the flat, horizontal lines) and the 15-min load data (the two-humped profiles). The average loads are equivalent to information derived from monthly billing data and show that the wood-heated homes use a much lower average amount of electricity. However, the load profiles show that the peak load in the wood-heated homes is almost as high as that of the electrically heated homes. Therefore, although the smaller average energy-saving potential of wood-heated homes makes them a poor economic choice for an energy conservation program, their demand savings potential is almost as large as that of the electrically heated homes.

Another factor to consider when deciding whether or not to include wood-heated homes in a conservation program is the changeable nature of this customer class. A homeowner may elect to use wood or electricity to heat their home at any time and in any combination. Wood use may be affected by utility prices, wood prices, environmental regulations, and the amount of work needed to harvest and burn the wood. Therefore, there is no assurance that a home currently heated by wood will continue to be so heated. If a

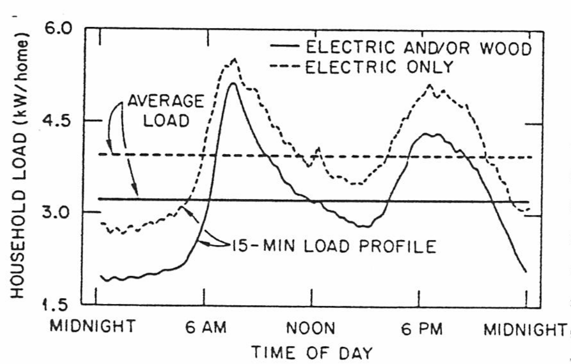

Fig. 8. Preretrofit comparison of the diversified load of homes heated solely by electricity to that of homes heated by electricity and/or wood, winter weekdays (from the selected set of 28 similar days) only.

home is excluded from a conservation program because of wood-use and that wood-use is subsequently discontinued by the homeowner, the utility will be faced with a sudden large increase in electrical demand. Although this increase in demand would be accompanied by a larger increase in energy use (as shown by Fig. 7), and therefore an improvement in load factor, overall the demand increase could cause a large impact on the system. Based on radiation measurements on many monitored stoves, wood-heat savings of about 28% were achieved by the HRCP retrofits [6]. These savings could moderate the sudden impact of any future fuel-switching choices made by the homeowner.

These potential savings could be especially valuable in light of their potential effect on the system peak. A demand contribution is calculated by dividing the load of a particular customer or group of customers at the time of the system peak by the system's peak load. (For example, if the system peaked at 200 MW at 08:00 on January 2 and the combined load of all wood-heated homes served by the system at that point in time was 2 MW, the demand contribution of that group of homes would be 2/200 or 0.01.) The demand contribution per household of wood-heated homes rose from about 60% to 70% of the demand contribution per household of electrically heated homes following the HRCP retrofits [2]. This shows that a large portion of the HRCP savings are being taken in the form of a reduction in wood-energy use rather than electrical-energy use. It also shows that the program has moderated the potential demand surge that could occur following a widespread swing back from wood heating to electrical heating. For example, if a group of wood-heated homes had switched to electrical heat before the HRCP, their diversified peak load would have jumped from about 5.5 kW to about 9.2 kW, an increase of 3.7 kW. After the HRCP, the increase would be reduced to about 2.4 kW (a peak-load increase from 5.5 to 7.9 kW). This is a conservative example because the post-HRCP peak load would actually be lower than the pre-HRCP peak load.

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