Energy and Buildings, *13* (1989) 11 - 18

The Data Behind The Hood River Analyses

ALAN MEIER and BRUCE NORDMAN

Lawrence Berkeley Laboratory, Berkeley, CA 94720 (U.S.A.)

N. E. MILLER and DON HADLEY

Pacific Northwest Laboratory, Richland, WA 99352 (U.S.A.)

ABSTRACT

Five houses from the Hood River Conservation Project data base were selected and their energy use patterns individually evaluated. The conclusions derived from visual inspection of the data were compared to the PRISM analyses. The houses used a surprisingly high proportion of electricity for non-space-heating end uses. The impact of the retrofits was nevertheless easily seen in the energy use graphs for some houses. The anomalous PRISM results for one house were explained by irregular use of a wood stove. When dealing with large data sets, it is essential to trace individual cases through each step of the analysis. In this way, one obtains a better appreciation of the capabilities and drawbacks of the assumptions and the techniques that were applied.

INTRODUCTION

The other articles in this special issue devoted to the Hood River Conservation Project (HRCP) present statistics on large samples of homes, and focus on single end uses — space heating, water heating, and indoor temperatures. This is a reasonable approach given the policy objectives of the HRCP, that is, to determine aggregate energy savings of an intensive retrofit program. It is also the first logical analytical step given the wealth of data available. However, such analyses do not give the reader any appreciation of the interplay among the end uses and behavior that occurred in individual homes. Nor do they fully represent the individual differences that are smoothed over by aggregate statistics.

This article examines five houses in detail and describes the impact of the retrofits on energy use. Limited information from occupant surveys and retrofit reports, such as the number and types of appliances present, are also used in the examinations. The purpose of this paper is to convey to the reader a flavor of the information collected in the Hood River Conservation Project. To keep the discussions reasonably concise, only the unusual aspects of each house's energy profile are discussed. The key steps in the transformation of the raw monitored data to PRISM estimates of normalized annual consumption (NAC) and other parameters are also presented.

Our approach emphasizes the qualitative and graphic aspects of the data. The findings and discussion should be viewed as anecdotal; other articles in this issue apply the statistical rigor required to reach more definite conclusions.

SAMPLE HOUSES FROM HOOD RIVER

Five houses were selected to represent a range of energy savings and conditions encountered in the Hood River Conservation Project. These houses were selected from the 320 submetered houses rather than the larger group with monthly billing data used in other analyses. More details of individual variations can be seen in the submetered houses because they have more energy data (three end uses every fifteen minutes compared to monthly whole-house use for the other six thousand houses). Two houses were chosen because they saved a large amount of energy, two because they saved little or none, and another because it used a wood stove. Within these categories, the houses were chosen arbitrarily.

Each house had three kilowatt-hour meters: one for total use, one for space heating, and one for water heating. The appliance energy

Elsevier Sequoia/Printed in The Netherlands

TABLE 1

Annual energy use for each end use before and after the retrofit based on metered data and normalized PRISM estimates. Some metered data were lost for every house, so missing values were estimated to be the average value for the existing periods. The gaps were generally short, so only a small error is introduced

House no.	Channel	Hood River Consumption Data					
		Metered data (kWh/year)		PRISM results (kWh/year)		Missing weeks	
		Pre	Post	Pre	Post	Pre	Post
4083	Total	22000	21000	21500	20500	1	0
	Space	8700	8300	9500	5000		
	Water	5800	5100				
	Other	7500	7700				
4121*	Total	33800	38500	28600	34200	12	9
	Space	14000	18200	8900	12800		
	Water + other	19800	20300				
4122	Total	15700	15600	15200	14500	1	0
	Space	5200	6000	5200	6900		
	Water	4900	4600				
	Other	5700	5000				
4181	Total	16100	12400	15700	12000	1	0
	Space	4700	3500	6600	3600		
	Water	5500	3700				
	Other	5900	5100				
4321	Total	29900	22700	27600	20600	1	5
	Space	8900	3000	9900	6400		
	Water	5900	3800				
	Other	15100	15900				

Totals may not add due to rounding.
*House with wood heat sensor.

use could be inferred from three meters as the residual energy use not accounted for as space or water heat. In one hundred houses with wood stoves, the water-heater submeter was replaced with a sensor on the wood stove. Inside temperature data were also collected.

Annual energy consumption data are often the easiest values to compare. Table 1 shows the annual energy consumption of the five houses, before and after the retrofits, for each end use. The electronic data-loggers occasionally failed, so weeks with less than 85% of the data present are listed as "missing".

The 15-minute data were aggregated to weekly periods for these analyses. Weekly intervals show major trends in energy consumption but dampen the inevitable scatter that appears in hourly or even daily data. The PRISM approach for estimating normalized annual energy use, which was used throughout this special issue as the means of measuring energy performance, relied upon monthly, whole-building energy use. Input data for PRISM are plotted in Figures for each house. Table 1 also shows the PRISM estimates of annual energy use (NAC) and space heating.

WEATHER DATA

The weather data were collected by specially installed weather stations. Figure 1 shows average weekly temperatures for the two heating seasons. The second winter was slightly colder than the first (3370 vs. 3270 degree-days, base 18.3 °C); however, the temperature patterns of the two winters were very different. An unprecedented cold wave struck in late November of the second year and the spring was unusually mild. Note the data-logger failure in August 1984. This illustrates one of the many data collection problems encountered in any project of this scope.

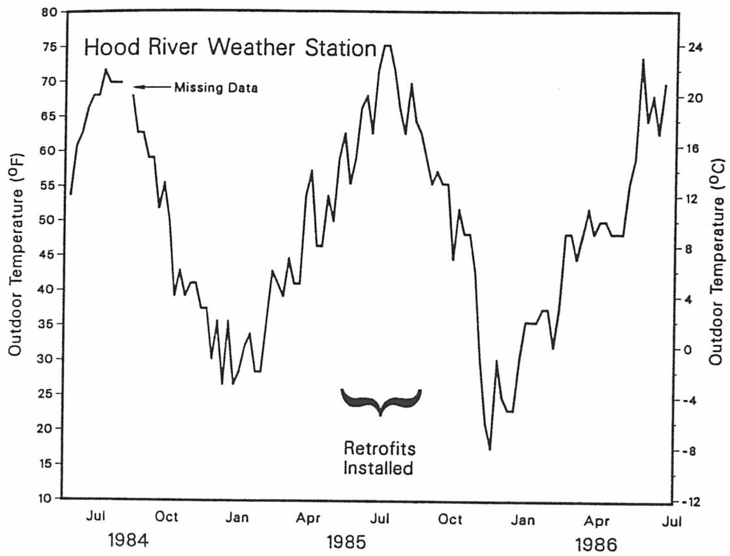


Fig. 1. Weekly average temperatures for the pre-retrofit and post-retrofit winters at Hood River. The space-heating and water-heating retrofits occurred during the summer in the period marked.

HOUSES WITH LARGE SPACE- AND WATER-HEATING SAVINGS

House 4321

House 4321 demonstrates the impact of significant space-heating and hot-water conservation measures. This house saved more than twice that of the average Hood River house. The energy-use profile and PRISM results are shown in Figs. 2(a) and 2(b). In the year prior to the retrofits, the house consumed roughly 15 000 kWh for space and water heating; after the retrofits, it consumed about 7000 kWh.

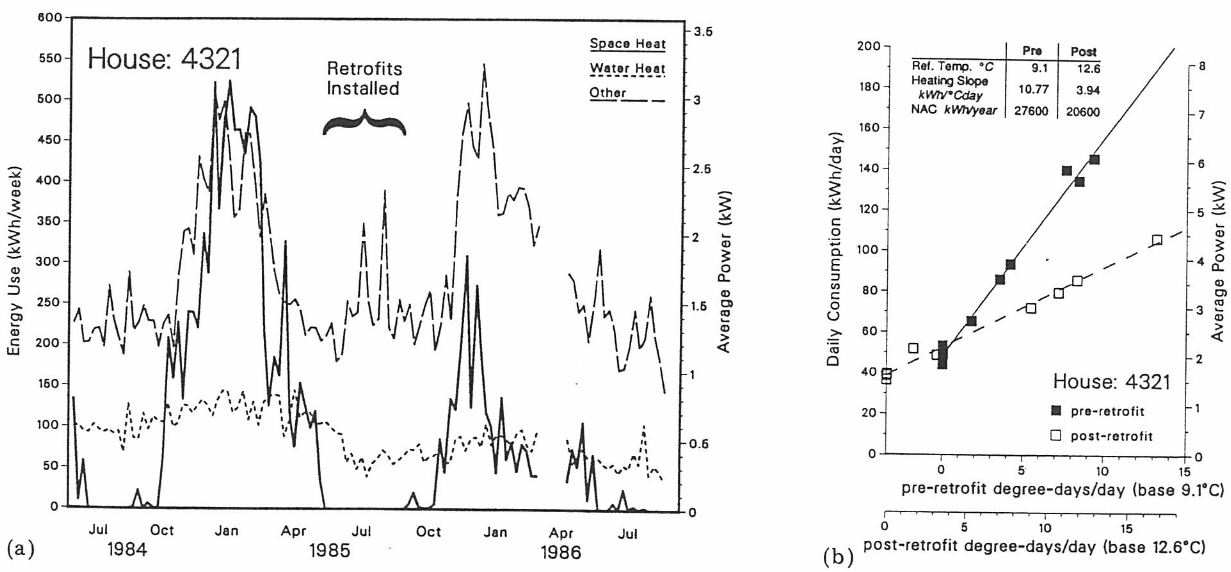


Fig. 2. (a). Energy profile for house 4321. (b). Regressions for determination of PRISM values for house 4321. PRISM finds a new reference temperature for each year; as a result, the degree-day scales for the pre-retrofit and post-retrofit years are not directly comparable. The Figure shows one degree-day scale offset by the difference in the reference temperatures. Even with this adjustment, a slight discrepancy remains at the lower end (i.e., during warmer weather). Nevertheless, the use of offset scales permits a rough comparison of the house's performance before and after the retrofits. The solid and dashed lines represent the best fit for the pre- and post-retrofit data, respectively.

This 160 m^2 wood-frame house was built in 1907 and is heated with electric baseboard panels. The space-heating retrofits consisted of insulation in the attic, attic kneewalls, walls, and under the floor. Double-glazed storm windows were mounted over the existing single-glazed windows. Insulated doors were installed and window and door frames were caulked. The major water-heating retrofits consisted of water-heater tank insulation, low-flow showerheads, and hot-water pipe insulation.

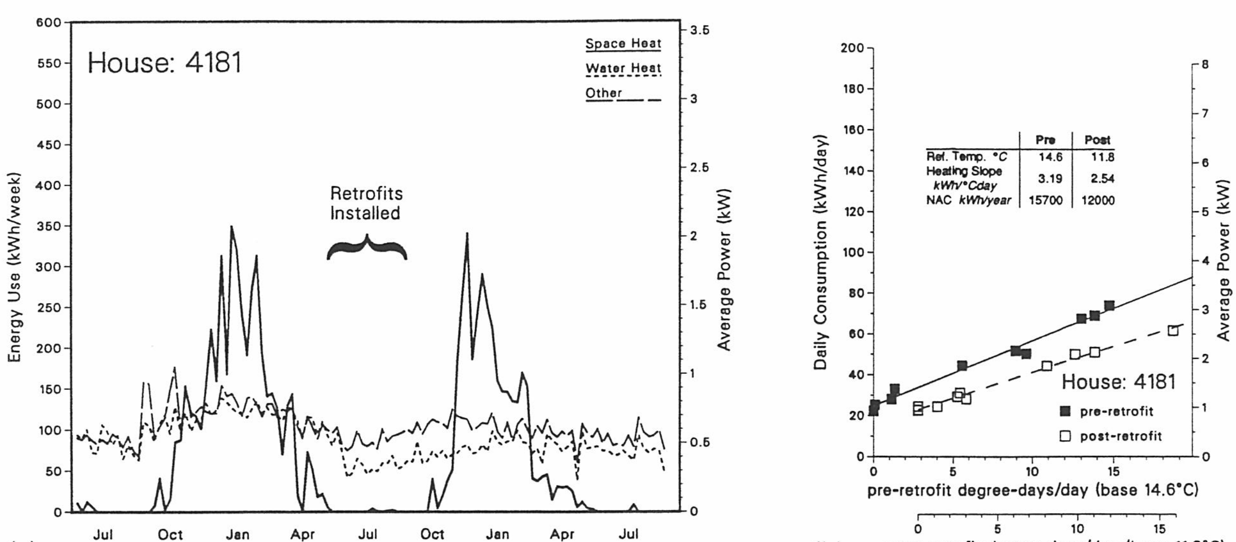
The space heat profile in the second year clearly changed as a result of the retrofits. The profile is significantly smaller and narrower. The raw energy-use data confirm the visible reduction in space heat; *metered* space heat use dropped by two-thirds. Total energy use only fell 26% because such a large amount was used by appliances and water heating. The water-heating retrofits cut water-heating energy use by about 2000 kWh/year, or 35%.

PRISM estimated less space heat savings than indicated on the meters, 36% versus 67%, but PRISM's estimated NAC savings were identical to the metered savings (26%). These results are not surprising because the NAC is generally considered to be a more robust measure of energy performance. With respect to the allocation of the savings, PRISM attributed too much of the NAC savings to reduced base load (including water heating). The misattribution is best shown in Table 1.

This house used over 15 000 kWh/year for appliances and water heating. The high appliance consumption is partly due to the presence of a well pump and a waterbed heater. Note the strong seasonality of the appliance energy use. The appliance energy-use profile, which closely parallels the space-heating profile during the winter, reflects the use of a portable resistance heater to supplement the baseboard system. Since the appliance energy use did not drop following the retrofits, the occupants may have been heating an uninsulated garage with the portable heater. The portable heater — a common appliance in Hood River — was noted on the audit report. The house's room air conditioner was probably responsible for the two 150 kWh spikes in weekly appliance energy use during the summer.

House 4181

House 4181 is an example of a house where PRISM estimated a high percentage of space heat savings (45%) but the absolute amount was relatively small. Indeed, more energy was saved through water-heating retrofits. House 4181 is a small house (84 m^2), built in 1947, and heated with baseboard panels. This house received insulation in the ceiling and floor, double-glazed windows (over single-glazed



(a) (b)

Fig. 3. (a) Energy profile for house 4181. (b) Regressions for determination of PRISM values for house 4181. The solid and dashed lines represent the best fit for the pre- and post-retrofit data, respectively.

windows), insulated doors, and caulking around door and window frames.

The energy profiles show that the house used less space heat and that its heating season was shortened due to the lower reference temperature. The peak post-retrofit space-heating consumption, which occurred during the historic November cold wave, was no greater than the coldest week in the pre-retrofit winter. House 4181 started with a low space heat use prior to the retrofit (about 4700 kWh/year). This is partly due to its small size and the relatively low average inside temperature (17.8 °C) maintained by the occupants.

The average inside temperature rose over 1 °C in the post-retrofit winter. A behavioral or physical explanation is possible. The increase may be due to a higher thermostat setting, in which case the energy savings should be adjusted upwards. However, the higher average temperature is more likely due to the modified thermal performance of the house. With the reduced heat loss, the house temperature will float more often above the thermostat setting. This is especially true during the evenings when the occupants lower the thermostat settings. The increased thermal resistance of the building envelope will slow the temperature decay and thus cause a higher average temperature. The two effects, higher thermostat settings and increased temperature floating, cannot be disentangled with the data collected. Dinan and Trumble [1] and Hirst *et al.* [2] discuss this identification problem and offer some conclusions based on a much larger sample of HRCP homes.

The water-heating savings are just as clear in 4181 as in 4321. The water-heater wrap, low-flow showerheads, and pipe wraps cut annual energy use by about 1800 kWh, or 32%. Based on data from the entire HRCP sample, Brown *et al.* [3] estimated that installation of all three measures would reduce annual water heating by 1020 kWh per year. It also appears that the seasonality of energy use was reduced. Note that the metered water-heating savings exceeded the space-heating savings (1800 kWh versus 1170 kWh).

HOUSES WITH LITTLE OR NO ENERGY SAVINGS

Many houses in the Hood River Project failed to show any significant savings from the retrofits [4]. Explanations for the lack of response include decreased reliance on wood heat (and a corresponding increase in electric heating), higher thermostat settings, and failure of the retrofits to operate as designed.

House 4083

House 4083 showed only a 5% reduction in total metered energy use and NAC. House 4083 is relatively small (117 m^2) and was

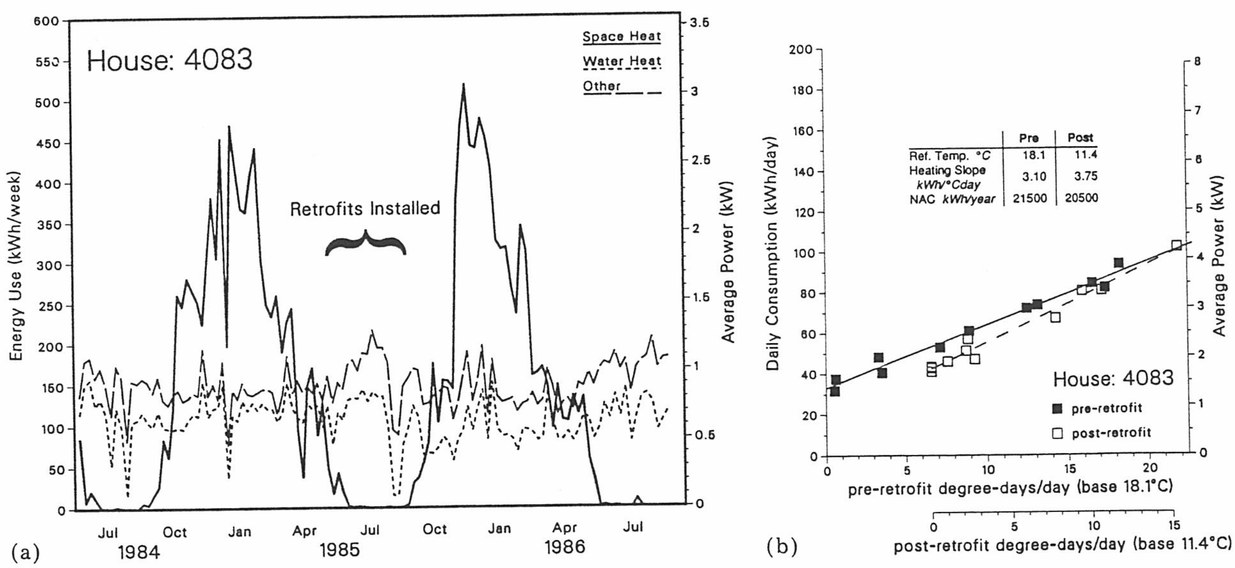


Fig. 4. (a) Energy profile for house 4083. (b) Regressions for determination of PRISM values for house 4083. The solid and dashed lines represent the best fit for the pre- and post-retrofit data, respectively.

built in 1964. It is heated with electric baseboard panels. The only significant space-heating retrofit was the addition of double-glazed storm windows to the existing single-glazed windows.

The average indoor temperature fell about 0.5 °C after the retrofits. A drop in inside temperature suggests that the occupants lowered the thermostat setting in the second year, although a change in behavior, such as leaving windows open, could also cause the decrease. The space-heating energy-use profiles for the two years did not significantly change. The fluctuations in space heating suggest that the occupants often left the house. For example, they probably were absent during the 1984 Christmas/New Year holidays because energy use for all activities dropped sharply during this week. Less frequent absences (as evidenced in the more stable water-heating use) in the second winter may partly account for the lack of energy savings.

The water-heating retrofits consisted of only the pipe wrap and low-flow showerheads. In spite of significant fluctuations, the overall water-heating energy use dropped 13% (about 800 kWh). The savings, while not large, were still significant.

There is no single obvious explanation for absence of energy savings in house 4083, other than the lack of major retrofits. Irregular occupancy may have been partly responsible.

House 4122

The metered and PRISM results for house 4122 differed in the amounts and sources. The metered total energy use of house 4122 decreased by 1% after the retrofits, but space heat increased 16%. In contrast, PRISM estimated that the NAC decreased 5%, and space heating increased 33%. The metered use and PRISM estimates also differed with respect to base load (or appliances plus water heating) energy use. The metered base-load use fell 9% compared to the PRISM-estimated drop of 25%. This discrepancy in allocation of changes in energy use suggests that PRISM may be unreliable in some cases. Again, the NAC is generally considered more robust than the space-heating fraction alone.

One possible reason for no space-heating savings in house 4122 was the lack of major insulation measures. No insulation was added to the ceiling, walls, or floor. It did, however, receive double-glazed storm windows to supplement the existing single-glazed windows, weatherstripping, caulking, and infiltration gaskets. With the exception of the window improvements, these measures are generally suspected of providing little, if any, energy savings. At the same time, an energy-consuming heat exchanger was installed. Thus, a second explanation for the lack of space-heating savings, is that the heat exchanger increased air change rates and overall heating load. The sole clue supporting this

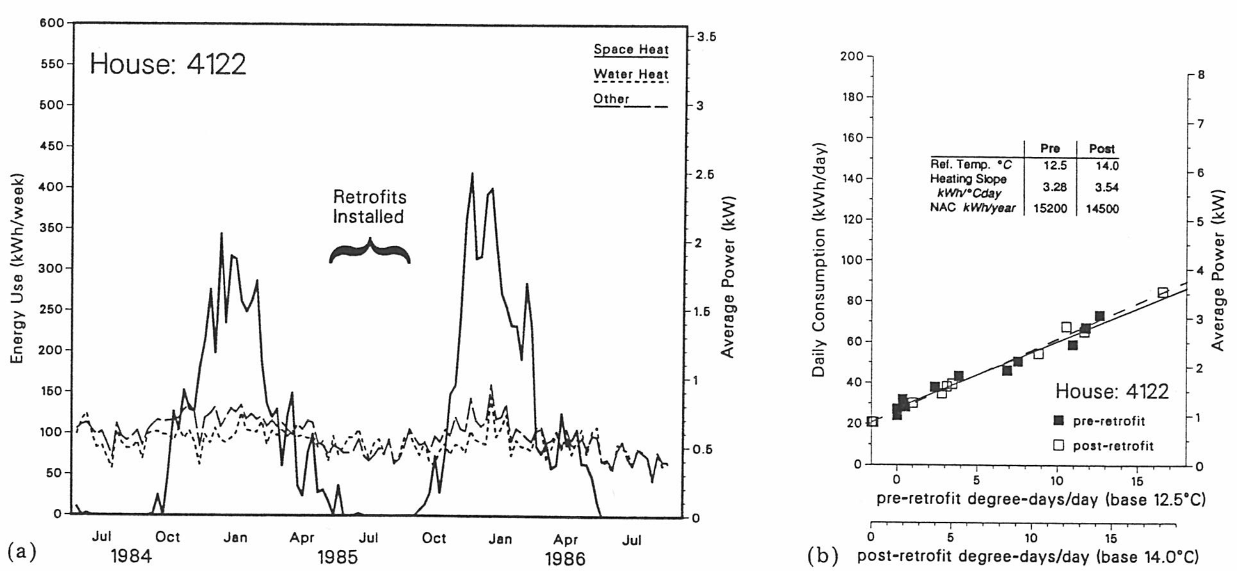


Fig. 5. (a) Energy profile for house 4122. (b) Regressions for determination of PRISM values for house 4122. The solid and dashed lines represent the best fit for the pre- and post-retrofit data, respectively.

hypothesis is that the appliance use became more peaky in the winter of the second year when the heat exchanger (which was on the appliance circuit) was used.

A complete package of water-heating conservation measures was installed here: a tank wrap, low-flow showerheads, and pipe wraps. The energy savings found from these measures in other houses did not appear here. The water-heating profiles show no clear reduction in the second year, although the yearly water-heater consumption actually fell 6%.

A HOUSE WITH WOOD HEATING

Wood heating was an expected complication in the Hood River Conservation Project. As a result, one hundred houses were equipped with a sensor to detect wood stove use [4].

House 4121

House 4121 is an example of a house with a wood stove. This 154 m^2 house is only 10 years old and therefore may have had much more insulation than most houses in Hood River. In this house, greater electricity savings might have been achieved through modification or replacement of the appliances rather than further thermal improvements.

It is heated with a central electric furnace with an attached central air conditioner (note the summer air-conditioning peaks on the "heating" channel). As a result of its recent construction, the space-heating retrofits were limited to window upgrades, caulking, and weatherstripping. An air-to-air heat exchanger was also installed.

House 4121 was a high energy user. In the first year, it consumed almost 34 000 kWh. More than half of it (20 000 kWh) was used for water heating and appliances. Since the third channel on the data-logger monitored the wood stove, water heating and appliance energy use could not be separated.

After the retrofits, total metered consumption increased 14% and space heating increased 30%. PRISM estimated a 20% increase in the NAC and a 44% increase in space heat. The increased space heat occurred in spite of a 1.2 °C drop in the average inside temperature in the post-retrofit year, which, alone, should have caused an observable reduction in space heat use. One possible explanation for this anomaly is that the temperature sensor was in the same room as the wood stove.

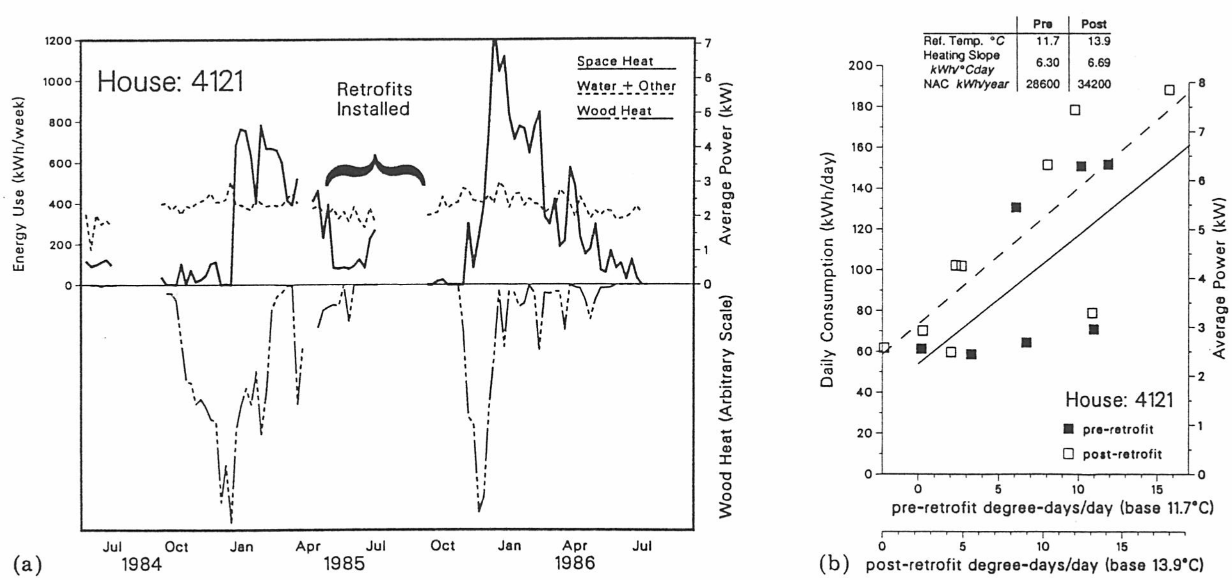


Fig. 6. (a) Energy profile for house 4121. This house was partly heated with a wood stove. The combined profile of water heating and other uses are plotted because one of the channels was devoted to the wood-stove sensor. The wood stove use is plotted instead (below axis) at an arbitrary scale. It can be seen that wood heating dropped significantly in the second year and was replaced by conventional electric resistance heating. (b) Regressions for determination of PRISM values for house 4121. The points below the regression lines are months when the occupants burned wood for most of their space heat. The solid and dashed lines represent the best fit for the pre- and post-retrofit data, respectively.

The wood stove was clearly responsible for the anomalous behavior. The wood stove sensor made it possible to identify the days in which the wood stove was used and eliminate them from a thermal analysis. The occupants in house 4121 significantly reduced their wood stove use in the post-retrofit winter and relied more on their conventional heating system. The change in behavior is particularly evident in the late autumn. In the pre-retrofit autumn, wood burning provided almost all the heat whereas significant electrical heating began in October of the post-retrofit year. The wood heat profile also shows that significant wood stove usage occurred throughout the pre-retrofit year compared to only intermittent use in the post-retrofit year. Miller [5] removed those days when the wood stove was used in both years and performed a regression analysis similar to PRISM, but based on daily, rather than monthly, periods. Miller found that post-retrofit space-heating requirements dropped 30% for days where only electric heating was used. If the occupants had heated the house similarly in both years, then the savings would have been much larger.

The only water-heating conservation measure installed was low-flow showerheads. Since houses with wood heat sensors did not have submeters, it is impossible to estimate the water-heating energy savings. In any event, the showerheads' impact must have been negligible (or offset by an increase someplace else) because the appliance + water-heating profile did not change after the retrofit.

CONCLUSIONS

Even this small sample yields insights into the performance of various retrofits. For example, those houses which received no insulation retrofits had little or no space-heating savings. Additional glazing and infiltration reduction measures, such as caulking and weatherstripping, caused no observable drop in energy use. Water-heating energy conservation measures appeared to be consistently successful. In several cases, water-heating energy was cut 30%.

Non-space-heating energy use in these houses was surprisingly high. Even in this diverse sample, all but one house used more electricity for appliances and water heating than for space heating. Unfortunately, the end-use breakdown was not accurately known prior to the Hood River Project, at which time much of the appliance energy was attributed to space heating. This error partly explains the lower-than-expected overall savings achieved by space-heating retrofits. The high appliance energy use also suggests that future retrofit programs should investigate more cost-effective conservation measures for water heating and appliances.

To be sure, the inspection of data from individual houses often raises more questions than can be answered with the available data. Nevertheless, it provides insights that might not be available through aggregate analyses.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the assistance of Kenneth Keating, Frances Petersen, and Richard Gillman (Bonneville Power Administration), and Elaine Betts and H. Gil Peach (Hood River Conservation Project). The authors also gratefully acknowledge the comments of Margaret Fels and Cathy Reynolds (Princeton University), and Marilyn Brown (Oak Ridge National Laboratory). The Hood River end-use metered data were made available from the End-Use Load and Conservation Assessment Program (ELCAP). That program is funded at Pacific Northwest Laboratory under an intra-agency agreement with the Bonneville Power Administration. This work was supported in part by the Assistant Secretary for Conservation and Renewable Energy, Office of Building and Community Systems, Building Systems Division of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

REFERENCES

1 T. M. Dinan and D. Trumble, Temperature takeback in the Hood River Conservation Project, *Energy Build.*, *13* (1989) 39 - 50 (this issue).
2 E. Hirst, R. Goeltz and D. Trumble, Effects of the Hood River Conservation Project on Electricity use, *Energy Build.*, *13* (1989) 19 - 30 (this issue).
3 M. A. Brown, D. L. White and S. L. Purucker, Energy savings of water heater retrofits: evidence from the Hood River Conservation Project, *Energy Build.*, *13* (1989) 51 - 61 (this issue).
4 B. Tonn and D. White, Monitored wood use in Hood River homes: saving energy or saving electricity, *Energy Build.*, *13* (1989) 63 - 72 (this issue).
5 N. E. Miller, *Thermal Performance of the Hood River End-use Metered Homes, PNL-6595*, Pacific Northwest Laboratories, Richland, WA, April, 1988.

****
*** ACTIVITY REPORT ***
****

TRANSMISSION OK

TX/RX NO.	4314
CONNECTION TEL	88p2026467843
CONNECTION ID	
START TIME	04/24 08:48
USAGE TIME	10'27
PAGES	9
RESULT	OK