Programmable Thermostats that Go Berserk? Taking a Social Perspective on Space Heating in Wisconsin

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ABSTRACT

This paper describes the results related to space heating and thermostat use from a study of owner-occupied, single-family residential housing in Wisconsin conducted by the Energy Center of Wisconsin in 1999. We find that the average self-reported winter thermostat setting does not vary substantially by type of thermostat used, is predictive of heating energy intensity in a way that is consistent with expectations, and appears to be a good indicator of actual thermostat-setting behavior, assuming that the goal is to compare the behavior of households rather than to gather an accurate report of their actual thermostat settings. We also find that attitude toward energy conservation appears to have an indirect effect on household heating energy intensity by way of thermostat-setting behavior. The results offer further evidence in support of including social and behavioral variables in traditional engineering-based studies.

Introduction

For more than a decade, scholars have been calling for an increased focus on the social variables in studies of energy use. Numerous researchers, including Stern and Oskamp (1987), Rosa, Machlis and Keating (1988), and Shove, Lutzenhiser, Guy, Hackett, and Wilhite (1998), have urged those who study energy consumption to pay more attention to the social and behavioral aspects of energy use. Taking such an approach, they point out, can help us to understand such mysteries as why identical dwellings occupied by demographically similar households can vary in their energy use by 200 to 300 percent (Hackett and Lutzenhiser, 1991) or what makes people choose to have an energy audit or retrofit their houses (Stern and Aronson 1984).

One area of residential energy consumption that could benefit from the insights provided by including social variables in the analysis is the understanding of behavior related to thermostat setting. For example, savings estimates for installing a programmable thermostat in a residential dwelling typically assume that the household members learn how to program their thermostat, choose to practice temperature setbacks, and are not already manually setting back their thermostat. But are these assumptions justified? And if not, is the installation of programmable thermostats, especially when funded in whole or part with public money, justified? If public money is to be spent to reduce energy consumption at the thermostat, on which households should it be spent, and how should they be identified?

This paper focuses on answering these and other important questions related to space heating behavior using data from the Residential Characterization study, a study of owner-occupied, single-family residential housing in Wisconsin conducted by the Energy Center of Wisconsin (ECW) in 1999. The design of this study has been directly influenced by the calls for more attention to be paid to the social and behavioral aspects of energy use. For each randomly selected household, ECW conducted a physical audit (tied to a home energy rating) on the dwelling and gathered utility billing data. The survey included a written questionnaire given to household members with questions about behavior, beliefs, and attitudes related to energy use, as well as about individual characteristics such as household income and the age and education. We also followed up with in-person structured interviews conducted with a randomly selected subsample of ten percent of participating households in order to better understand their energy consumption habits and related beliefs.

Theoretical Background and Development of Hypotheses

Since space heating is the single largest user of energy in Wisconsin households (Pigg & Nevius 2000), this paper focuses on what can be learned about respondents' energy consumption for home heating from the combination of social, psychological, economic, and physical variables that were gathered as part of this study, with a particular emphasis on thermostat use. This information sheds new light on the prospects for reducing consumption of home heating, on the role of programmable thermostats in this reduction, and on the relationships between thermostat-setting behavior and attitudes toward energy conservation and efficiency.

Organizations that promote the use of programmable thermostats estimate that installing a programmable thermostat can save 15 percent or more on an individual homeowner's energy bill (e.g., Alliance to Save Energy 2000). These figures imply that, in aggregate, vast amounts of energy could be saved if only homeowners would install programmable thermostats. Cross & Judd (1997), however, found that the actual energy savings from programmable thermostats were less than estimated, due to attrition from the use of programmable thermostats by homeowners and to the fact that customers frequently already practiced a manual setback. They suggested revising the estimates of savings from programmable thermostats downward as a result. We explore both our quantitative and qualitative data in order to better understand the relationship between the use of various thermostat types (manual or programmable) and the prospects for residential energy savings. We also test the hypothesis that programmable thermostat users set their thermostats lower on average than manual thermostat users.

Studies comparing self-reported and observed behavior have shown that self-reported behavior is a less reliable measurement than observed behavior (Heberlein 1981; Weigel 1983). However, several studies have documented that self-reported thermostat-setting behavior can be a reasonably good proxy for actual thermostat use. Kempton & Krabacher (1987) compared self-reports of thermostat-setting behavior with actual thermostat settings among seven households. They found that, although informants under-reported their thermostat settings by an average of 2.2°F, adjusting the reported values upward to make up for this tendency yielded a result that was reasonably close to actual settings recorded from the thermostats. Gladhart, Weihl & Krabacher (1988) and Lutz & Wilcox (1990) found similar relationships between actual and self-reported settings.

While our data cannot determine the degree of over- or under-reporting of thermostat-setting on the part of respondents, it can lend credence to the argument that self-reported thermostat-setting data is a reasonably good indicator of actual behavior, and offer evidence that this self-reported data is at the very least a reliable means by which to compare households' thermostat-setting behaviors. In our questionnaire, we asked homeowners to provide information about the temperature at which they set their thermostats during various times of the day and night. Combined with information about the hours per week that someone was home, we calculated an average winter thermostat setting from the self-reported data. To determine if there is a relationship between self-reported and actual thermostat-setting behavior, we do some exploratory analysis between this average and measured heating energy intensity.

Studies of the relationship between general environmental attitudes and behavior have repeatedly shown weak connections between the two at best (Wicker 1969; Ajzen & Fishbein 1980). However, more recent work indicates that attitude studies of more specific behavior, such as energy conservation or recycling, are likely to yield results showing a greater connection between attitudes and behavior than studies with a more general focus (Heberlein and Black 1976; Vining and Ebreo 1992; Oskamp et al. 1991). With the goal in mind of designing attitudinal measures that might be helpful in predicting energy conservation behavior, we incorporated a series of attitudinal constructs into the questionnaire. One of these was designed to measure attitudes toward energy conservation and efficiency, which we will refer to as "conservation-orientation."[1] Nevius (2000) found several relationships between our measure of conservation-orientation and self-reported thermostat-setting behavior, including a statistically significant correlation between the attitudinal index and the average self-reported winter thermostat setting. Respondents who scored higher on the conservation-orientation index reported lower average winter thermostat settings. In order to determine if this attitudinal measure can indeed be helpful in predicting actual energy conservation behavior, we explore the relationship between this measure and actual thermostat-setting behavior by way of the self-reported winter thermostat setting.

Methodology

Survey Design and Sampling

The Energy Center of Wisconsin conducted a survey of 299 households in Wisconsin in 1998 and 1999 (Pigg and Nevius 2000). The respondents—all of whom were owner-occupiers of single-family, detached housing units—were randomly selected via a multi-stage stratified sampling design and recruited by telephone. The study was designed to yield a sample of households that are representative of the state's population of families living in

[1] Four questions comprised this index: "I am not interested in making energy-saving improvements to my home"; "It's just not worth putting on more clothing in the winter to try to save a little energy"; "I would only conserve energy if I could not afford to pay for it"; and "I am not interested in making my home more energy efficient." The standardized Cronbach's alpha for this construct was 0.6616, indicating a high degree of reliability. The summed index scores were reversed so that respondents who exhibited attitudes more strongly in favor of energy conservation and efficiency received higher conservation-orientation scores (Nevius 2000).

single-family, owner-occupied units in Wisconsin. New construction (defined as houses built within the last five years) and low-income households (defined as households earning up to 150 percent of the federal poverty level) were oversampled to ensure that there would be enough cases for each to make statistically valid inferences about these populations.

Response Rates and Representativeness

Recruiting households that were available and willing to undergo an energy audit (which required a household member to be home for two to three hours while the energy audit was conducted) proved challenging, despite ECW's offering generous incentives.[2] Recruiting was conducted via a CATI system using typical RDD protocol. We were able to complete the recruitment script with 34 percent of households that were within the scope of the study, and about one out of every three of these households agreed to participate.

While the raw data over-represents low-income households and those living in new construction, we developed case weights for each observation to make the final study sample as representative as possible of the overall population. These weights were based on a combination of the 1990 Census and ECW's 1999 Appliance Sales Tracking (AST) study (ECW 1999), a large RDD telephone survey which collected demographic data on a sample of 2,214 households in single-family, owner-occupied units.

When we compared the weighted study sample with the AST data, we found the study sample to be reasonably representative of the larger population of households living in single-family, owner-occupied homes in the state, with comparable basic demographic and individual characteristic data such as age, education, income, etc. We also compared the rates at which qualified households in two samples reported having and using a programmable thermostat. In 1999, 36 percent of households in the AST sample reported that they had a programmable thermostat, a rate only slightly higher than the 33.4 percent of households in the study sample that reported this. Of those households with programmable thermostats, 72 percent of the AST sample and 82.8 percent of the study sample reported that they had used their thermostat's automatic features. These results suggest that while the study sample is not biased toward households that have programmable thermostats, it may be slightly biased in favor of the proportion of these households who use the programmable features. A few other known biases exist in our data that should be kept in mind when generalizing the study's results. The weighted sample appears to somewhat over-represent households with more family members and householders who have lived at their current address for less than a year. It also appears to under-represent householders who say they are never at home during the day on weekdays. In addition, two questions from the four-item scale of conservation-orientation were included in the AST study; a comparison of the results suggests that our sample may be somewhat more favorably inclined toward energy conservation than the AST sample. However, because the data-gathering methods and the order in which the questions were asked differed—which can affect the distribution of results from attitudinal questions (Ajzen & Fishbein 1980)—we do not consider this indicator of bias to be conclusive. Moreover, since the final Residential Characterization study provides representation from households across almost the entire range of the conservation-orientation scale, we can

[2] Incentives were either $50 or $100, depending on which subgroup the respondent fell into.

compare characteristics of those who are less inclined toward conservation-orientation against those who are more inclined.

Results

Thermostat Type and Self-Reported Thermostat-Setting Behavior

Table 1 shows the distribution of types of thermostats in the sample.[3] Two-thirds of households in the sample use manual thermostats to regulate their heating systems, and one-third use programmable thermostats. From questions posed as part of ECW's AST surveys in 1995, 1997, and 1999, it appears that the saturation of programmable thermostats is rising in Wisconsin at an average rate of about 2.5 percent per year, from 25 percent in 1995 to 30 percent in 1997 to 36 percent in 1999.

Table 1. Thermostat Distribution and Use

	N†	Manual	Programmable
		(percent)	
Type of thermostat used	299	66.6	33.4
Percent of those with programmable thermostats who report using its automatic features	99	n/a	82.8
Mean reported temperature during . . .		*(degrees F)*	
Sleeping hours	281	66.9	65.7 *
When someone is awake at home	287	68.7	69.4 *
When no one was home during the day	268	66.4	65.8
When the household was away on vacation	198	61.2	60.9
Self-reported thermostat setpoint (weighted for weekday hours house is occupied; excluding vacation settings)	249	67.8	67.7
Mean hours someone is at home weekdays between 8 a.m. and 5 p.m.	261	28.9	28.1

† Two households without thermostats are not included in the percentages reported on this table.
* p<.05

We asked respondents to tell us at what temperatures they kept their home during sleeping hours, when someone was at home during the day, and when no one was at home during the day. This information was used to calculate both day and night setbacks and an average self-reported winter thermostat setting (weighted for the hours respondents told us someone was at home during weekdays between 8 a.m. and 5 p.m.), to which we will refer as the "self-reported thermostat setpoint." The self-reported thermostat setpoint ranged from 59°F to 74°F, with a mean of 68°F. While both households with manual and with

[3] The thermostat types reported in the text and tables were verified by the auditors when they collected the physical data.

programmable thermostats reported setting back their thermostats at night and during the day when no one is home, we found that their setback practices varied. Table 2 shows that households with programmable thermostats are much less likely to keep their thermostats at a constant temperature, and report steeper setbacks both at night and during the day when no one is home, than do households with manual thermostats. At the same time, households with programmable thermostats report slightly higher settings during the day when someone is home, which we estimate to be the case well over half the time on average. This appears to largely offset the setbacks during other periods of the day, so that the self-reported setpoint is nearly the same between the two groups. If these self-reported data are accurate (an issue we will examine later), it implies that the mere presence of a programmable thermostat in a home has a minimal effect on heating energy use on average.

Table 2. Crosstabulation of Day and Night Setback Practices by Thermostat Type

	Manual	Programmable
Night setback practices (n=278):*	*(percent)*	
Set up	5.9	1.1
No change	49.7	17.2
Setback 1-4 degrees	22.2	47.3
Setback 5+ degrees	22.2	34.4
Column totals	*100.0*	*100.0*
Day setback practices (n=269):*		
Set up	0.5	1.2
No change	53.0	26.7
Setback 1-4 degrees	20.8	39.5
Setback 5+ degrees	25.7	32.6
Column totals	*100.0*	*100.0*

* Chi-square tests for both cross-tabulations are significant at $p<.001$.

Conservation-Orientation and Self-Reported Thermostat-Setting Behavior

Earlier in this paper we mentioned that Nevius (2000) had found relationships between the conservation-orientation index and several measures of self-reported thermostat use. The mean conservation-orientation index score of respondents with programmable thermostats, 14.4 (on a scale from 4 to 16) is slightly higher than that of respondents with manual thermostats, 13.8; this difference is statistically significant ($p<.05$). Table 3 shows correlations among the index and various measures of thermostat setting behavior. These relationships are mixed, with more conservation-oriented households practicing steeper setbacks during the day when no one is home but not at night. However, as was mentioned earlier, there is a negative and statistically significant correlation between conservation-orientation and the self-reported thermostat setpoint, indicating that those respondents who score higher on the pro-energy conservation orientation index report keeping their thermostats set at lower average temperatures.

Table 3. Correlations Among Conservation-Orientation and Selected Dependent Variables[4]

		Conservation-orientation	Self-reported thermostat setpoint	Continuous measure of night setback	Continuous measure of day setback when no one is home
Conservation-orientation	Pearson Correlation	1.0000			
	N	273			
Self-reported thermostat setpoint (°F)	Pearson Correlation	-0.2002 *	1.0000		
	N	234	249		
Night setback (F°)	Pearson Correlation	0.0452	-0.3648 **	1.0000	
	N	258	249	280	
Day setback when no one is home (F°)	Pearson Correlation	0.1789 *	-0.3463 **	0.6335 **	1.0000
	N	251	249	260	267

* p<.005, ** p<.0005

Thermostat Type, Behavior, Conservation-Orientation, and Actual Energy Use: Regression Models

While the self-reported data on thermostat settings suggest little difference in the average winter thermostat setpoint between households with manual or programmable thermostats, it is possible that these data are not accurate, or that setbacks reported by households with programmable thermostats occur more regularly than those reported by households with manual thermostats.

To explore these issues from another angle, we looked at actual heating energy use as a function of thermostat type, reported thermostat settings, and homeowner attitudes about conserving energy. Our analysis is restricted to 147 gas-heated homes for which we had good ability to isolate heating usage from monthly gas usage data.

We fit several regression models to the data, using heating energy intensity (Btu/ft^2/heating degree day) as the dependent variable in order to remove the confounding effects of house size and climate.

We also included two independent variables in the models to help control for differences across houses in insulation levels and air leakage: (1) an insulation control variable, calculated as the total shell conductivity (U-value times area) divided by the house's total conditioned area; and (2) an infiltration variable based on a blower door measurement of air leakage (ft^3/minute at 50 Pascals) divided by the house's total conditioned area. We would note, however, that because these are observational data, there may be other unobserved factors that affect heating and may affect the results.

[4] Adapted from Nevius (2000).

Model 1 (Table 4) shows the results of regressing heating energy intensity on a binary variable for the presence of a programmable thermostat. The magnitude of the programmable thermostat coefficient suggests that homes with programmable thermostats use about 2.5 percent less energy for heating than homes with manual thermostats (0.197 divided by the average heating energy intensity of 6.98 Btu/ft^2/heating degree day), but the result is not statistically significant. The 90-percent confidence interval associated with this estimate suggests that homes with programmable thermostats have somewhere between ten percent lower and five percent higher heating energy intensity than homes with manual thermostats.

In contrast, there is a strong relationship between our calculated self-reported thermostat setpoint and heating energy intensity (Model 2). This model suggests that after controlling for differences across houses in insulation and infiltration, for every degree change in the self-reported thermostat setpoint the homeowner can expect to save about 0.24 Btu/ft^2/heating degree day. This means that an average homeowner from our sample can expect to save a little over 3 percent from his or her heating bill with every degree of reduction in their average winter thermostat setting. A widely used rule of thumb is that each degree of reduction in the thermostat setpoint results in a 3 percent reduction in heating energy use (DOE 1980)—nearly the same as the percent reduction we calculated for our sample. Thus, for the subgroup of houses in our sample that are heated with natural gas, the self-reported thermostat-setting data appears to be a good indicator of actual behavior, assuming that the goal is to compare the thermostat-setting behaviors of households rather than to gather an accurate report of their actual thermostat settings.

Model 3 shows that conservation-orientation on its own does not have any statistically significant predictive power with respect to heating energy intensity. Given that the self-reported thermostat setpoint is significantly correlated with household heating energy intensity, Model 4 suggests that, via the mechanism of respondents' thermostat-setting behavior, conservation-orientation may nonetheless have an effect on heating energy intensity. In future research, we will explore a more fully developed model via a path analytic framework to determine the extent and direction of the indirect effects of conservation-orientation on physical measures of heating energy intensity.

Table 4. Unstandardized Regression Coefficients for Regression of Heating Energy Intensity on Selected Independent Variables

	Dependent Variable: Heating Energy Intensity (B.t.u./square foot/HDD)			
	Model 1 Coefficients (t-values)	**Model 2** Coefficients (t-values)	**Model 3** Coefficients (t-values)	**Model 4** Coefficients (t-values)
Independent Variables				
Thermostat type	-0.197 (-0.681)	--	--	--
Self-reported thermostat setpoint	--	0.180 (2.755) *	--	0.226 (3.206) **
Conservation-orientation	--	--	-0.047 (-0.669)	0.032 (0.452)
Insulation	6.911 (5.950) **	6.507 (5.011) **	7.592 (5.641) **	6.462 (4.872) **
Infiltration	1.242 (5.263) **	1.236 (4.874) **	1.196 (4.376) **	1.262 (4.799) **
Intercept	2.783	-9.316	3.114	-12.953
Adjusted R^2	0.510	0.516	0.491	0.532

* p<.05, ** p<.005

Thermostat Type: Insights from the Structured Interviews

The structured interviews are useful for better understanding thermostat use and the prospects for energy savings from the installation of programmable thermostats. It was clear from the interviews that even after going through the home energy audit and filling out the questionnaire (which described the different kinds of thermostats about which we asked), at least four of the thirty cases interviewed did not know what a programmable thermostat was, and others had not been aware that such thermostats existed before the study.

It is interesting to examine how interviewees with manual thermostats responded to the audit recommendations and savings estimates (based on an 8 hour setback of 5°F) for programmable thermostats. Fourteen cases both had a manual thermostat and were not interested in switching to the programmable variety. Of the seven households with manual thermostats that set their thermostats back manually during the winter, six felt that there would be no point to installing a programmable thermostat for their households, and several expressed disbelief in the annual savings estimated by HERS. Of the seven households with a manual thermostat who indicated during the interview that they kept their home temperature constant, six told us that they would not adopt a setback pattern if they were to acquire a programmable thermostat, and none was interested in acquiring one. The following are the reasons given for not wanting a programmable thermostat:

- They did not believe the savings estimate provided by the HERS audit.
- The payback or the increased convenience were not worth the cost.
- Setting the thermostat would be a "hassle." For example, there would be no point since there was almost always someone at home during the day, and they were not interested in setting the temperature back at night; they were "technologically impaired" and would be unable or unwilling to program the thermostat; or costs might actually go up because their schedules varied so much that programming the thermostat might become impractical, and so their temperature setting would end up being constant whereas currently they were setting back manually.
- Most of their heating comes from a wood stove instead of the furnace.
- They had heard of a programmable thermostat that "went berserk" and overheated a house.

Of the two cases that indicated an interest during the interview in obtaining a programmable thermostat, one did not expect it to change the household's temperature setting habits, but wanted it for convenience, and the other planned to use it to begin setting back the thermostat at night and so felt it would reap cost and energy savings. Of those households that already had programmable thermostats, three were positive about it and felt it saved them money, while two were unhappy with it and had stopped using the thermostat's programmable features. One of these latter cases had lost the instructions, and no one in the household was able to reset the thermostat when the power went out, so they ended up keeping the temperature constant. The other case had been unhappy with the default settings on the thermostat, but had been unable to figure out how to change the settings despite having the instructions, and so used the override function when they wanted to change the temperature setting. These two incidents suggest that programmable thermostats may be too complicated to operate.

The analyses of the self-reported thermostat-setting data and of the interview data indicate that the impact of programmable thermostats on heating energy use in Wisconsin is modest at best. The habits, attitudes, and beliefs expressed in the interviews and the lack of significant difference between the self-reported thermostat setpoints reported by those with programmable and those with manual thermostats suggest very little difference in heating energy use for these two groups.

Conclusions

Several important conclusions can be drawn from our analysis of the winter thermostat use and space heating data from the Residential Characterization study. First, while we acknowledge that with our self-reported thermostat-setting data it is impossible to tell how much respondents over- or under-report their winter thermostat settings, the results of our regression analysis indicate that because self-reported thermostat setting data is a strong predictor of household heating energy intensity, it is a good indicator of actual behavior, assuming that the goal is to compare the thermostat-setting behaviors of households rather than to gather an accurate report of their actual thermostat settings.

Second, despite the emphasis that has been placed on the use of programmable thermostats to reduce thermostat setpoints and so save heating energy, respondents with programmable thermostats report thermostat setpoints that are not substantially different from those of respondents with manual thermostats.

Third, the results of the regression analyses and the significant correlation between conservation-orientation and the self-reported thermostat setpoint suggest that respondents' attitudes toward energy conservation and efficiency may affect their heating energy consumption by way of their thermostat-setting behavior. The path-analytical model to be developed in future research will help us to determine the extent and direction of this relationship.

Taken together, the second and third conclusions suggest a hypothesis. That is, the installation of a programmable thermostat in a household that does not have a favorable attitude toward energy conservation and efficiency is not likely to result in a reduction of the average winter thermostat setting, and therefore not likely to save significant heating energy; at the same time, the installation of a programmable thermostat in a household that does have a favorable attitude is also not likely to save significant heating energy, because such a household would be more likely to already keep a low average winter thermostat setting. Again, the path-analytical model will help us to determine the validity of this hypothesis.

Among the households that participated in the structured interviews, we found that more households with manual thermostats than without already practiced winter temperature setbacks, and that those households with manual thermostats that kept their winter setting constant would not begin to practice a setback if they were to obtain a programmable thermostat. We also learned about some of the myriad reasons why many of these households did not want a programmable thermostat. These details and the conclusions above lead us to suspect that the aggregate savings that can be expected from the installation of programmable thermostats in residential housing is probably quite modest.

Finally, these results provide yet more evidence that combining the study of the social and behavioral aspects of energy use with more traditional engineering-based approaches can be a highly informative research strategy that is well worth pursuing.

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