SAVING ENERGY THE EASY WAY: AN ANALYSIS OF THERMOSTAT MANAGEMENT

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ABSTRACT

One of the most effective and least expensive means of reducing household energy use is to maintain low indoor temperatures during the winter and high indoor temperatures during the summer. There is a need to determine how households are managing their thermostats in order to: (1) estimate energy- and cost-effectiveness of energy retrofits for individual households, utilities, and the nation; (2) improve the marketing of energy-reducing programs; (3) estimate the potential for energy reduction in homes; and (4) improve our general understanding of thermostat management.

We analyzed data on self-reported winter and summer thermostat settings and control strategies that were collected in recent surveys by utility companies, and state and federal energy agencies. We constructed several hypotheses to examine how thermostat behavior was related to conditions internal and external to the occupants: socioeconomic characteristics of occupants (age, education, income, home ownership, and race), building characteristics (house type, size, and age), space conditioning fuel and system, climate, and energy audits. We also examined thermostat management during the day (time-of-day) and over time and analyzed its relationship to energy use.

We found that thermostat behavior (especially during the summer) was not fixed, but varied and was sensitive to some conditions. Certain groups--younger people, better educated individuals, audited households, multi-family households, and residents of warmer climates--were responding to energy reduction at a greater rate than their counterparts. Households were lowering and raising their thermostats during the day and during different seasons and were also shutting off their heating and air conditioning systems when their home was unoccupied. In fact, many households reported settings below 68^{o} in the winter and above 78^{o} in the summer, the standard temperatures used in many energy models and programs. We were unable to find consistent relationships between self-reported thermostat settings and several other variables (e.g., income, home ownership, dwelling size, and race). Because of the difficulty in interpreting the relationships between thermostat behavior and its correlates, we believe that larger sample sizes, uniform sampling designs and instruments, and multivariate analysis will produce more consistent results. In addition, metered temperature and thermostat setting data should provide a more reliable and accurate measure of indoor temperatures and thermostat management than self-reported data.

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INTRODUCTION

One of the most effective and least expensive means of reducing household energy use is to maintain low indoor temperatures during the winter and high indoor temperatures during the summer.** The monetary savings of thermostat management can be substantial: it has been estimated that $5 billion has been saved annually in the United States due to changes in home thermostat use since the oil embargo of 1973 (Kempton, 1983). Of course, this type of behavior may be merely transitory, and if people believe the energy shortage has ended, then they may start to keep their homes warmer in the winter and cooler in the summer, resulting in a loss of $5 billion or more. This "rebound effect" may have already occurred for some households that have weatherized their homes: they may now feel that they can increase their indoor comfort level since the cost of energy is perceived to be less expensive for them than before weatherization. Thus, there is a need to determine how households are managing their thermostats in order to estimate the potential for energy reduction in homes.

Another reason for examining thermostat settings in detail is to explore the amount of variability in the way people manage their indoor comfort. While average thermostat settings may be useful for modelling energy use in unoccupied or occupied homes, estimating energy use for a large sample of homes, and evaluating the impact of an energy-reducing program for a utility service area, average settings are not appropriate for estimating energy use in individual homes. Previous work in this area has shown that a few degrees difference can have a substantial impact on the energy use consumed in the home. A difference of several degrees can affect the consumers' willingness to invest in energy efficient products. Thus, knowledge of the amount of variability in thermostat settings will be useful, for example, in performing sensitivity analyses to estimate energy- and cost-effectiveness of energy retrofits for individual households, utilities, and the nation.

Thermostat settings are also useful as indicators of the type of energy-reducing behavior being practiced by individuals. Thermostat management is usually one of the first actions an occupant takes in reducing energy in the home and is often the predecessor for more time consuming and expensive energy-reducing measures (e.g., ceiling and wall insulation). Moreover, by examining the correlates of thermostat settings (e.g., size of a dwelling, household income, and age of the respondent), one can improve the marketing of energy-reducing programs by focusing on those variables that are highly

*This paper is a condensed version of a large report that contains a detailed analysis of the data, extensive references and tables, and an annotated bibliography (Vine, 1984).

**For example, a 1°F increase in the summer thermostat setting can reduce cooling energy use by 4.6% in the Central Valley of California (Vine et al., 1982).

correlated with thermostat management.

Ideally, one would like to monitor the indoor temperatures of residential households to determine if people are adjusting their thermostats to reduce energy use. However, the metering of thermostats is expensive and time-consuming: there have been few studies that have monitored indoor temperatures (Vine, 1983). A less expensive, albeit less reliable, surrogate for measuring indoor air temperature is occupant-reported thermostat setting. The use of self-reported data raises some methodological and validity issues: without objective confirmation, one does not know the veracity of an individual's reported behavior. Anecdotal data suggest that there is a discrepancy between self-reported thermostat settings, actual thermostat settings, and indoor temperatures. So far, no one has been able to accurately estimate the relative importance of two possible sources of error--instrumentation error and respondent reactivity--to account for this discrepancy.* Until we have a more reliable method of measuring indoor temperatures, self-reported data will remain useful for improving our understanding of thermostat management.

Conceptual Model and Hypotheses

In this paper, we analyzed data on self-reported winter and summer thermostat settings and thermostat control strategies that were collected in recent surveys by utility companies, state and federal energy agencies, and in our own studies at Lawrence Berkeley Laboratory. We were interested not only in the distribution of thermostat settings but also in the dynamics of thermostat management. Hence, we examined how thermostat behavior was related to conditions internal and external to the occupants: socioeconomic characteristics of occupants (age, education, income, home ownership, and race), building characteristics (house type, size, and age), space conditioning fuel and system, climate, and energy audit programs, to the extent possible. We also examined thermostat management during the day (time-of-day) and over time and analyze its relationship to energy use. We developed a conceptual model of thermostat management to examine these variables (Figure 1).

*Instrumentation error occurs, for example, when changes in the calibration of a thermograph, which measures indoor temperature, may produce changes in the obtained measurements. Respondent reactivity occurs, for example, when respondents seek to present their most favorable image to the interviewer and provide socially desirable responses.

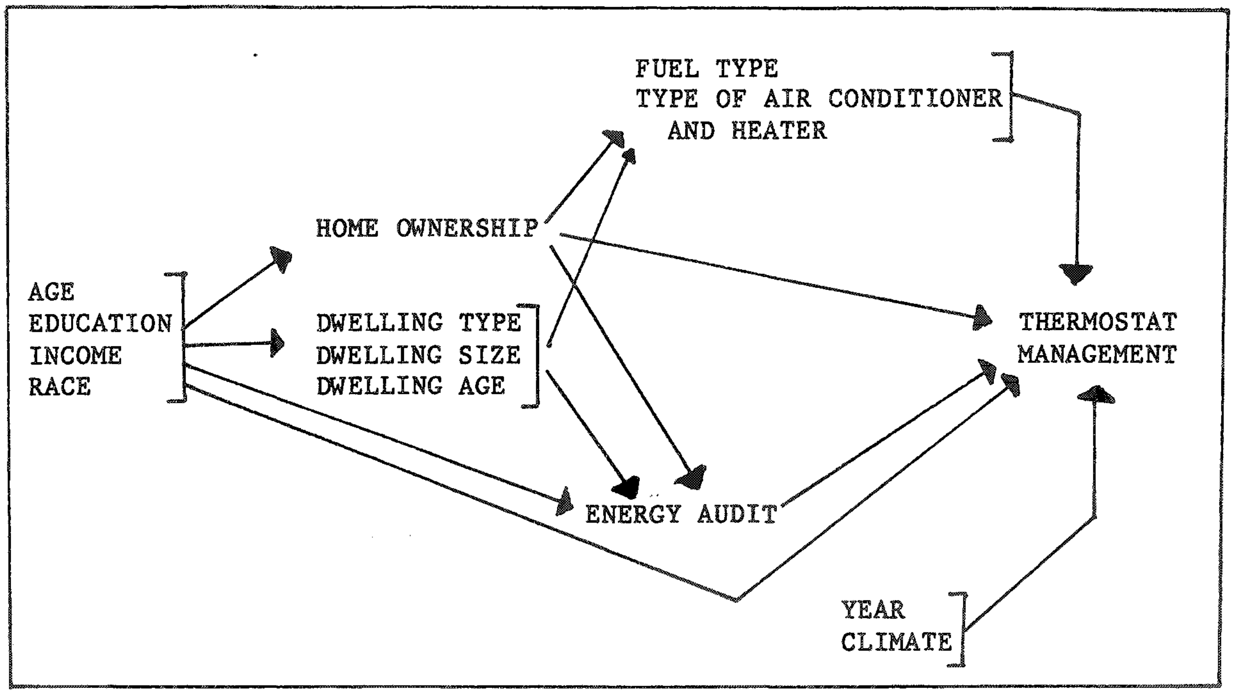

Figure 1. Conceptual model of thermostat management.

We have drawn arrows to indicate some of the possible relationships between the variables and thermostat management. We believe that the primary sociodemographic variables (age, education, income, and race) affect the type, size, and age of the dwelling one occupies which then affect the type of space conditioning system and fuel used in the home. The primary sociodemographic variables also affect one's chance of owning a home. The chance of receiving an energy audit is affected by many of these variables. Winter and summer thermostat settings and thermostat control are affected by all of the above variables in addition to being influenced by climate and history (year). These relationships should also be present for specific time periods during the day (time-of-day). Using this model, we constructed several hypotheses on the relationship between thermostat management and its correlates. Due to the lack of referenced literature on this subject, we developed these hypotheses based on our experience with the energy use literature, discussions with experts in the field, and common sense. In several cases, we included competing hypotheses (excluding the null hypothesis) to indicate alternative relationships.

1. Age. (a) We hypothesized that elderly people maintained higher winter settings and lower summer settings than younger people because we believed that elderly people were more sensitive than younger occupants to extreme winter and summer temperatures and were less flexible than their counterparts in adapting to a wide range of temperatures. (b) We hypothesized that elderly people maintained lower winter settings and higher summer settings than younger people because we believe that elderly people living on fixed incomes were willing to live with uncomfortable temperatures in order to reduce their utility bills.

2. Education. (a) We hypothesized that better educated occupants maintained lower winter settings and higher summer settings than less educated individuals because we believed that the former had more access to and knowledge of energy-reducing practices and measures. (b) We hypothesized that better educated individuals maintained higher winter settings and lower summer settings than less educated people because education was often highly correlated with income (see below).

3. Income. (a) We hypothesized that higher income households maintained higher winter settings and lower summer settings than poorer households because the former could afford the cost of energy and because the latter were already using minimal amounts of heating and cooling energy and would find it difficult to cut back further. (b) We hypothesized that higher income households maintained lower winter settings and higher summer settings than poorer households because income was often highly correlated with education (see above) and with home ownership (see below).

4. Race. We assumed that there were cultural norms attached to indoor comfort levels, perceived causes of illness, etc., that affected the setting of thermostats and which might distinguish white from non-white households. We did not know how these norms specifically affected thermostat behavior (e.g., higher or lower settings in the winter). Race needs to be controlled by education and income to deter the misinterpretation of results.

5. Home ownership. (a) We hypothesized that homeowners maintained higher winter settings and lower summer settings than renters because home ownership was often highly correlated with income (see above) and because we believed renters were more likely to adopt low cost energy-reducing practices, such as thermostat management, than to install expensive energy-reducing measures. (b) We hypothesized that homeowners maintained lower winter settings and higher summer settings than renters because the former directly received the total benefits of their energy-reducing actions and were frequently the typical recipients of government and utility energy-reducing programs.

6. Dwelling type. (a) We hypothesized that residents of single-family houses maintained lower winter settings and higher summer settings than other residents because the former's total fuel bills were larger than their counterparts, single-family households were the typical recipients of government and utility energy-reducing programs, and because we suspected less air leakage problems (see below). (b) We hypothesized that residents of single-family houses maintained higher winter settings and lower summer settings than other residents because of their higher household income (see above), and, because of their greater size, we suspected greater air distribution problems (see below). In addition, we believed it would be easier to maintain lower winter settings and higher summer settings for residents of apartments that capture "waste heat" from attached units.

7. Dwelling size. (a) We hypothesized that residents of larger homes maintained lower winter settings and higher summer settings than residents of smaller homes because of the former's higher fuel costs, ability to close off more rooms, and, because of their smaller surface area-to-volume ratio, we suspected less air leakage problems. (b) We hypothesized that residents of larger homes maintained higher winter settings and lower summer settings than residents of smaller homes because of the high correlation between size and income (see above) and the difficulty in maintaining comfortable temperatures in large homes (where air distribution posed a greater problem).

8. Dwelling age. (a) We hypothesized that residents of recently built homes maintained lower winter settings and higher summer settings than residents of older homes because of improved construction practices and materials (including additional insulation), and because we suspected greater air leakage and distribution problems in older homes. (b) We hypothesized that residents of recently built homes maintained higher winter settings and lower summer settings than residents of older homes because, after investing in a more energy efficient home, we believed the cost of energy would be perceived to be less expensive for residents of new homes.

9. Heating fuel. We hypothesized that electrically-heated households maintained lower winter settings than gas-heated households because of the relatively high cost of electricity.

10. Air conditioner type. We hypothesized that owners of room air conditioners maintained lower summer thermostat settings than owners of central air conditioners because the conditioned space was often smaller (see above) and because we believed that owners of room air conditioners used them less than their counterparts.

11. Energy audit. (a) We hypothesized that audited households maintained lower winter settings and higher summer settings than before the audit and in comparison to non-audited households because the former were more knowledgable about how to save energy. (b) We hypothesized that audited households maintained higher winter settings and lower summer settings because, after investing in energy-reducing measures, we believed that the cost of energy would be perceived to be less expensive for them than before weatherization. However, because there is a large amount of variability in the audit process--how the auditor conducted the audit, the kind of information presented, the deliverance of free low-cost weatherization, etc.--and because the effects of the audit may be transitory, the differences between audited and non-audited households may be negligible. Furthermore, control samples and pre-audit data are essential for accurately determining the effect of the audit on behavior.

12. Climate. We hypothesized that residents of cold climates maintained lower winter settings and residents of warm climates kept higher summer settings because of high fuel costs and severe climates.

13. Year. (a) We hypothesized that more households maintained lower winter settings and higher summer settings over time because we expected energy information and incentive programs to become more widespread and the cost of energy to increase over time. (b) We hypothesized higher winter settings and lower summer settings over time because we expected households to become more complacent and/or less interested as a result of the short-term phenomena of "energy gluts" and the rise in importance of other national issues (e.g., unemployment, inflation, and crime).

14. Time-of-day. We hypothesized that households maintained the lowest winter settings and highest summer settings at night (when they were asleep) and the highest winter settings and lowest summer settings during the evening (when people were home). During the day (when the home was often unoccupied), we expected settings to be maintained between night and evening settings.

We did not expect to confirm or disprove any of these hypotheses in this investigation. We conceived of this study as exploratory in nature in our attempt to synthesize data from diverse sources and in our quest for understanding the dynamics of thermostat management.

We found that thermostat behavior (especially during the summer) was not fixed, but varied and was sensitive to some conditions. Certain groups--younger people, better educated individuals, audited households, multi-family households, and residents of warmer climates--were responding to energy reduction at a greater rate than their counterparts. Households were lowering and raising their thermostats during the day and during different seasons and were also shutting off their heating and air conditioning systems when their home was unoccupied. In fact, many households reported settings below 68° in the winter and above 78° in the summer, the standard temperatures used in many energy models and programs. We were unable to find consistent relationships between self-reported thermostat settings and several other variables (e.g., income, home ownership, dwelling size, and race). Because of the difficulty in interpreting the relationships between thermostat behavior and its correlates, we believe that larger sample sizes, uniform sampling designs and instruments, and multivariate analysis will produce more consistent results. In addition, metered temperature and thermostat setting data should provide a more reliable and accurate measure of indoor temperatures and thermostat management than self-reported data.

METHODOLOGY

Data on self-reported thermostat settings and control strategies were primarily obtained in a survey of major utility companies and all state energy conservation offices during the Summer of 1983. While we recognize that this survey does not include all the utilities in the country or research being conducted in academia, we do feel that the survey is representative of recent thermostat management behavior in the United States. The number of households in each study numbered 50 or more. Some of the data were collected in utility customer surveys, residential energy audits, and residential energy audit evaluation surveys. In these surveys, data were collected using diverse methods: mail questionnaire, telephone interview, and face-to-face interview. We augmented this data base with data collected in household surveys conducted by Lawrence Berkeley Laboratory (LBL) in the past several years in the cities of Davis and Lodi, California, and Pensacola, Florida.

It is important to note the different types of problems associated with the use of secondary data. Because of the diverse methods used to collect thermostat data and because of the different objectives each organization has in collecting and presenting data, it was very difficult to synthesize the findings from these studies. We were dependent on what the author(s) presented, or did not present, in their documents. For example, the statistical significance of the results was not reported in many of the studies that we examined, making it very difficult to report definitive conclusions. Similarly, many of the reports did not contain information on missing cases for particular questions: we can only assume that most of the sample in these studies did respond to the selected questions. The importance of missing cases should not be underestimated: for example, we did not analyze data from one utility company because of the large percentage (50 to 70%) of customers not responding to several questions, although they presented a fairly thorough analysis of thermostat settings. We felt that the results presented by this utility would not have been representative of their service area.

An associated problem was the absence of thermostat data in many surveys conducted by utilities and state energy offices. Of the organizations that did collect these data, many did not present the data in their reports (i.e., the question was listed in the questionnaire without any discussion of the results in the text). And of the ones that did report the data, most of the data were presented as frequencies (without criteria of statistical significance) and rarely as cross-tabulations. Accordingly, we were left with only a few data sources for each category of thermostat settings that were of interest to us (e.g., age, income, and house size). We attempted to remedy this omission by using data from our own surveys.

RESULTS AND DISCUSSION

We summarize our findings using the conceptual framework presented at the beginning of this paper. Our conclusions are generally conservative and often support the null hypothesis (no relationship) when there is a large amount of indeterminacy.

1. Age. No consistent relationship seems to exist between winter thermostat settings and age, since two studies found no significant differences, one survey found lower winter settings among younger people, and a fourth study found lower winter settings among older people. All (four) studies found higher summer thermostat settings among younger respondents.

2. Education. No consistent relationship seems to exist between winter thermostat settings and education, since two studies found no significant differences, and a third survey, which found lower winter settings among less educated respondents, had serious methodological problems. Most (four) studies found higher summer thermostat settings among higher educated respondents, although one survey found lower summer settings at night among higher educated respondents.

3. Income. No consistent relationship seems to exist between winter thermostat settings and income, since five studies found no significant differences, and two studies found lower winter settings among higher income respondents. Also, no consistent relationship seems to exist between summer thermostat settings and income, since four studies found no significant differences, and two studies found higher summer settings among higher income groups.

4. Race. The racial basis of thermostat settings and control was examined in only one report. Black households maintained warmer homes in the winter and cooler homes in the summer than white households, but black households also reduced their heating and cooling energy use by turning off their space conditioning systems.

5. Home ownership. No consistent relationship seems to exist between winter thermostat settings and home ownership, since one study found no significant differences, a second study found lower winter settings among homeowners, and a third study found mixed results for a number of heating practices. Home ownership was not related to summer thermostat settings in all (three) studies.

6. Dwelling type. Most (five) surveys found lower winter thermostat settings among multi-family homes, although two studies found no differences. No consistent relationship seems to exist between summer thermostat settings and type of dwelling, since three studies found no significant differences, a fourth survey found higher summer settings among residents of single-family houses, and a fifth study found higher summer settings among residents of multi-family homes.

7. Dwelling size. There was only one study that examined the relationship between dwelling size and winter thermostat settings, and no significant differences were found. Also, size of dwelling was not related to summer thermostat settings in all (three) studies.

8. Dwelling age. No consistent relationship seems to exist between winter thermostat settings and age of dwelling, since three studies found no significant differences, and one survey found lower winter settings among residents of newer homes. No consistent relationship seems to exist between summer thermostat settings and age of dwelling, since two studies found no significant differences, and two studies found higher summer settings among residents of newer homes.

9. Heating fuel. No consistent relationship seems to exist between winter thermostat settings and heating fuel, since two surveys found no significant differences, and two studies found lower winter settings among electric-heated homes (in contrast to non-electric-heated homes).

10. Air conditioner type. There was only one study that examined the differences in summer thermostat settings between central and room air conditioners, and the results were inconclusive: households with room air conditioners maintained both higher and lower settings than households with central air conditioners.

11. Energy audit. No consistent relationship seems to exist between winter thermostat settings and energy audits, since most (six) studies found no significant differences, although three surveys found lower winter settings among audited households. Most (five) surveys found higher summer thermostat settings among audited households, although one study found no significant differences.

12. Climate. In the only study that examined the relationship between climate and thermostat settings, homes in warmer climates turned the heater off and maintained lower winter settings than homes located in other climates. The relationship between climate and summer thermostat settings was not examined in any studies.

13. Year. No consistent relationship seems to exist between winter thermostat settings and year, since four studies found no significant differences, seven surveys found higher winter settings over time, and four studies found lower winter settings over time. No consistent relationship seems to exist between summer thermostat settings and year, since seven surveys found higher summer settings over time, and three surveys found lower summer settings over time.

14. Time-of-day. Most (27) surveys found significant differences in winter thermostat settings during different periods in the day, although one study found no significant differences. The typical pattern was: lowest settings at night, highest settings in the evening, and daytime settings between evening and night. No consistent relationship seems to exist between summer thermostat settings and time-of-day, since two studies found no significant differences, two surveys found lower settings as the day progressed, and three surveys found higher settings as the day progressed.

In summary, we found that thermostat behavior (especially during the summer) was not fixed, but varied and was sensitive to some conditions (Table I).

Table I. Significant correlates of thermostat management.

	Winter Thermostat Settings		Summer Thermostat Settings	
	Lower (Cooler)	Higher (Warmer)	Lower (Cooler)	Higher (Warmer)
Age	---	---	Older	Younger
Education	---	---	Less	More
Dwelling type	Multi-family	Single-family	---	---
Energy audit	---	---	Non-audited	Audited
Climate	Warmer	Colder	---	---

In sum, these results strongly supported three summer thermostat management hypotheses posited at the beginning of this paper (1a, 2a, and 11a) and partially supported two winter thermostat management hypotheses (6b and 12). Certain groups--younger people, better educated individuals, audited households, multi-family households, and residents of warmer climates--were responding to energy reduction at a greater rate than their counterparts. Households were lowering and raising their thermostats during the day and during different seasons and were also shutting off their heating and air conditioning systems when their home was unoccupied. In fact, many households reported settings below 68^{o} in the winter and above 78^{o} in the summer, the standard temperatures used in many energy models and programs.

We were unable to find consistent relationships between self-reported thermostat settings and several other variables (e.g., income, home ownership, dwelling size, and race). We experienced difficulty in interpreting the relationships between thermostat behavior and its correlates for a number of methodological reasons:

1. For a number of cases--black households, younger households, and low income groups--the sample sizes were very small, and small sample sizes make it very difficult to obtain statistically significant relationships.

2. The results were based on a single respondent's response (e.g., age, education, and thermostat setting) and may not accurately reflect how a household is actually behaving: that is, thermostat managment may be a family or household decision rather than an individual decision (based on a response to a survey).

3. Self-reported data are known for their methodological limitations; without objective confirmation, one does not know the veracity of an individual's reported behavior. These methodological problems may make this kind of data unreliable for statistical analysis. In fact, the self-reported incidence of energy-reducing actions was reported in one study as "uniformly (and suspiciously) high", indicating a possible upward bias.

4. Diverse methods were used to collect the thermostat data (mail questionnaire, telephone interview, and face-to-face interview), making it difficult to synthesize the findings from these studies. Different types of samples and different sampling periods also make it difficult to arrive at a consensus.

In addition to these methodological problems, we encountered an interpretation problem: in several studies, the data were contradictory to one another, making it difficult to draw general conclusions. For example, we found higher summer settings among residents of single-family houses in one study, and, in another study, we found high summer settings among residents of multi-family homes. This indeterminacy may reflect regional differences, or it may be the resultant of competing hypotheses. Finally, for many of the hypotheses, the number of studies examined was small, leading to greater uncertainty.

We believe we need a more reliable method of measuring indoor temperatures. Advances in metering technology and computerized data collection and analysis offer the potential of measuring occupant behavior relatively inexpensively and efficiently. The problems of intervention in the household remain, but the potential rewards are great. Metered temperature and thermostat setting data should provide a more reliable and accurate measure of indoor temperatures and thermostat management than self-reported data.

It is also important to note that one of the key differences between energy-reducing practices (e.g., lowering thermostat settings) and measures (e.g., installing attic insulation) is that the former are relatively more transitory while the latter are relatively more permanent. Several studies have reported an attrition in energy-reducing behavior over the last three to five years. Also, one study found that all energy-reducing practices had dropped over a four year period while all of the more permanent energy-reducing measures had increased. Nevertheless, there seems to be room for improvement in reducing energy through air conditioning and heating practices. Until new metering technology is used on a more widespread basis, we should continue to monitor thermostat behavior to improve the accuracy of our energy models, the effectiveness of our energy programs, and our understanding of occupant behavior and energy use. To further these objectives, we plan to conduct a multivariate analysis of self-reported thermostat settings in Davis, Lodi, and Pensacola, Florida, and we intend to test the sensitivity of variations in thermostat settings on energy use using computer models developed at LBL.

ACKNOWLEDGEMENTS

We would like to thank Steve Gold for his assistance in collecting the data used in this project. We would also like to thank the following for their helpful comments: Rick Diamond, Chuck Goldman, Joe Huang, Willet Kempton, Mark Levine, Jim McMahon, Max Neiman, Ron Ritschard, Mike Rothkopf, and Tony Usibelli. This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Building Energy Research and Development, Building Systems Division of the U.S. Department of Energy under Contract No. DE-AC03-76F00098.

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