COMPARISON OF SELF REPORTED AND MEASURED THERMOSTAT BEHAVIOR IN NEW CALIFORNIA HOUSES

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Thermostat setpoints are one of the most important determinants of heating and cooling energy consumption in residential buildings. This paper presents the results of research carried out to improve the California Energy Commission's standard thermostat assumptions used in developing building energy efficiency standards. Twenty five hundred randomly selected occupants of single family houses built since 1984 characterized their thermostat management style in a mail survey. They also specified their usual thermostat settings for 4 periods of typical days. We randomly selected 40 of these houses and monitored indoor, outdoor and duct temperature on a 2 minute cycle for 5 weeks in each house. We used this data to determine thermostat setpoint temperatures.

The mean discrepancy between self reported and observed thermostat setpoints was 1 to 4 degrees F, depending on the time of day. Respondents under reported their heating setpoints and over reported their cooling setpoints. Discrepancies on thermostat settings were highest at night and lowest for the evening. People who use an unattended thermostat management strategy are more accurate in their reported thermostat settings.

The thermostat management style of the occupants were characterized by visual inspection of graphs of house temperature during HVAC operation by time of day. We classified management styles into unattended operation (setback or constant) almost twice as often as manual operation. Occupants self reported management styles were evenly split into manual and unattended operation during heating. This indicates people are often able to maintain a regular thermostat pattern when using manual control.

INTRODUCTION

The California Energy Commission's Residential Standards Evaluation Project is a study to update and revise the assumptions built into the energy efficiency standards for new single family detached houses in California. One of the crucial assumptions in the standards are the thermostat settings and operation. In a mail survey of 2500 occupants of new single family homes we included questions about thermostat management style and temperature settings for 4 periods of the day. A subset of 40 of these houses were chosen at random for 5 weeks of detailed monitoring. The detailed monitoring included measuring indoor, outdoor and duct temperatures at 2 minute intervals.

This data was analyzed to determine effective settings. Thermostat management style was determined from visual inspection of plots of house indoor temperature during HVAC operation by time of day. The setpoints and thermostat management styles were compared with the occupants' self reported thermostat settings and management style from the mail survey.

The purpose of this part of the project was to develop a set of thermostat settings which could be used in the CEC's public domain simulation programs. When combined with the CEC's other assumptions about houses and their occupancy, the simulations should predict indoor temperatures and energy use which match the data for typical houses. Since it is expensive to monitor temperature set points, it was proposed to collect data using survey techniques on a large number of home occupants self reported thermostat set points. These self reported set points would then be compared to measured data for a small number of houses to determine their utility.

METHODOLOGY

Mail Survey

As part of California Energy Commission's Residential Standards Evaluations Project a mail survey was sent to occupants of 4000 new single family detached houses throughout the state. The mail survey was returned by approximately 2500 households. Included in the survey were 4 questions relating to thermostat settings and use. Two questions asked people to list the temperature setting on their thermostat by time of day. There were separate questions for heating and cooling settings. Each weekday was divided into 4 periods; morning (8AM - 12NOON), afternoon (12NOON - 6PM), evening (6PM - 11PM), and night (11PM - 8AM). They were also asked to indicate when the systems were usually off. The other two questions asked occupants to choose an option which best describes how they use their thermostat. For heating the choices were: manually operate the thermostat and turn it off when they leave the house; keep the thermostat at a constant setting and turn it off when they leave the house; always keep the thermostat at a constant setting; set it at specified temperatures at different times of the day and mostly leave it alone; or very rarely use the main heating system. For cooling the options were the same without choice to keep the thermostat at a constant setting and turn it off when they leave the house. The survey also included questions about how often occupants were home during the day on weekdays.

Thermostat Set Point Measurements

The temperatures were measured and recorded by small, unobtrusive battery operated dataloggers the monitoring technician placed in the house at the beginning of the monitoring period. At the end of the monitoring period the technician returned to the house, gathered the dataloggers and down loaded the data onto a portable computer. The dataloggers take measurements every 8 seconds. The temperature readings were averaged and recorded for 2 minute intervals. The memory capacity of the dataloggers allowed slightly more than 5 weeks of measurements to be collected at this rate. The monitoring was done in sets of ten houses at a time. The first set of monitoring equipment was installed in August of 1989. The last set was retrieved in March of 1990.

One datalogger was placed at each thermostat to record indoor air temperature. One datalogger was placed outside in a sealed plastic bag on the north side of the house, in a safe location, out of any direct sun. This was usually just below the eaves. Another datalogger was placed in the ducts behind a register close to the air handler in each HVAC system.

Determining HVAC Operation from Temperature Data

The reformatted and calibrated temperature data files of outdoor, indoor and duct temperatures were used as input to custom software developed for this project. The status of the HVAC system was determined by the change in duct temperature from one record to the next, the difference between the duct temperature and the zone temperature, the outdoor temperature, the status of the HVAC system during the previous record, and whether heating or cooling was recently used. Some of the systems monitored had a short cycling period during heating. If the duct temperature was still high from an earlier heating period (in the heating mode), the furnace coming back on was indicated by only a small jump in duct temperature. If the system had been off for a long period (in the waiting mode), there was a large change in duct temperature when the furnace was turned on. To differentiate the rise in duct temperature when the furnace turned on from the rise in duct temperature after the air conditioner turned off, we assume that the furnace is on only if the duct temperature is above the zone temperature. If the heat was on during the previous record and the duct temperature held steady or rose, then we concluded that the heat remained on. The logic to determine when the air conditioner was on is the reverse of the logic for determining when the furnace was on. The outdoor temperature was used as an indicator to avoid false readings, such as the duct temperature rising because of high attic temperatures due to solar gain on the roof. These outdoor temperature limits were 80 degrees for heating and 55 degrees for cooling. The data collection and analysis procedures are described in detail in a project report. (ref Monitoring Protocol and Test Results.) The data collection and analysis procedures are described in greater detail in an earlier report for the same project (Berkeley Solar Group and Xenergy 1990).

Analysis of House Temperature During HVAC Operation

Summarizing Setpoint Data. We collected summary statistics for the house temperature during HVAC operation by hour of day. This was done separately for heating and cooling operations. The statistics collected were the mean, maximum, minimum, and standard deviation of all observed house temperatures during each hour and a count of the records during each hour of the day. The hours of the day were divided into five periods.

Thermostat Management Styles. We used two types of graphs to summarize the house temperature data during HVAC operation. The most useful of these is a scatter plot showing indoor temperature during system operation by hour of day. The observed thermostat management style was deduced from visual inspection of these scatter plots. Setback control and constant thermostat settings show up very clearly on this type of plot. A solid band with very little variation indicates a thermostat with a constant setting. See Figure 1, for an example of this. If the temperature plot shows a consistent band with abrupt steps in temperature this is an indication of setback thermostat control. A good example of this is Figure 2. When the temperature plot is very erratic and shows many long climbs in temperature this is an indication of manual control, see Figure 3.

The thermostat management styles were classified into the same categories as in the mail survey. These categories were; manual operation, constant setting, setback control, and rarely use. An additional choice of constant setting and turn it off when not at home was included for heating, but not for cooling. These options were chosen based on previous reports (Gladhart, Weihl and Krabacher 1988; Kempton 1986; and Kempton and Montgomery 1982) of the differing models people have of thermostat operation. Of course many of the graphs were not as distinct as the ones shown here. And several of the houses had very little heating or cooling operation so positive identification of management style is difficult.

Thermostat Setpoints

We observed enough conditions of heating operation in the monitored houses that comparisons can be made with the self reported heating setpoints. We observed fewer conditions of cooling operation in the monitored houses. A summary of setpoints by period of day for the 40 monitored houses is shown in Table 1. The summary data table is listed separately for observed and self reported setpoints, and by heating and cooling. Included in each period are the houses for which we observed more than 6 seconds of HVAC operation per day during that period of the day for that house. We only included self reported setpoints for those periods which the occupants indicated a setting in degrees Fahrenheit. Not included in the summary table are those periods which the occupants indicated their thermostat was off or did not put any answer.

Summary data of the differences between the observed and self reported setpoint temperatures are listed in Table 2. For heating the occupants on the average report a lower thermostat setting than we measured. The mean differences ranged from 1.2 to 4.3 degrees. Our data is consistent with that reported in other studies (Vine and Barnes 1988; Ternes and Stovall 1988; and Kempton and Krabacher 1987). The periods of the day when people are most likely to be aware of the house

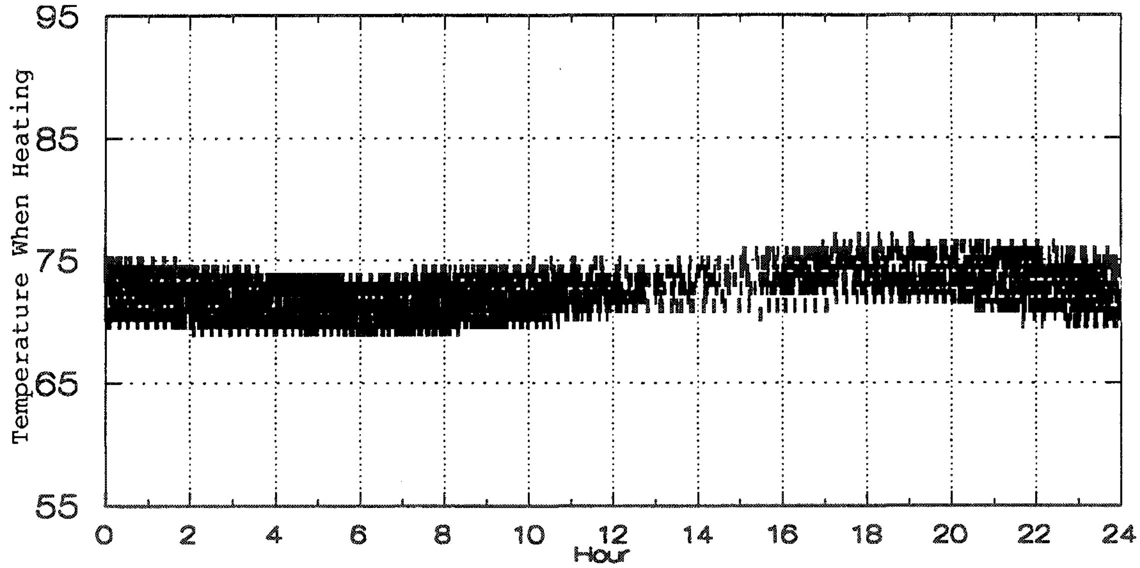

Figure 1. Example of Living Zone Temperature Apparently Under Constant Setting Management Style

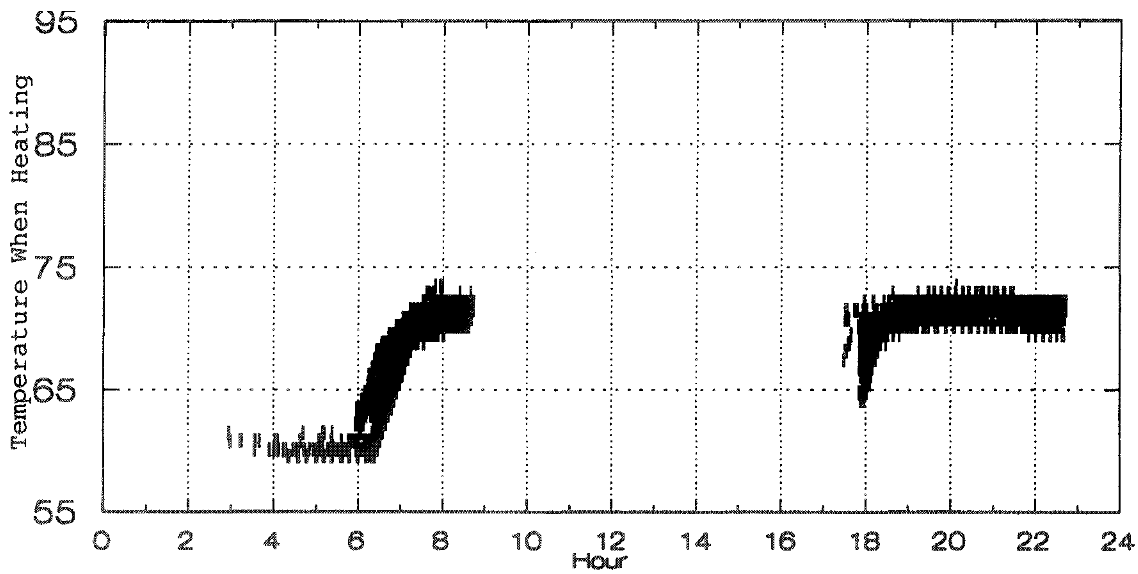

Figure 2. Example of Living Zone Temperature Apparently Under Automatic Setback Management Style

temperature, morning and evening, were the periods where there was the closest agreement between observed and self reported setpoints. The discrepancies at night were the largest. This data also supports earlier studies (Stovall and Fuller 1987).

The setpoints observed by our monitoring procedure are slightly underestimated for heating. We used the mean of the indoor temperature during heating operation for each period as the setpoint. Many of the indoor temperature traces show a prominent rise. The mean will be in the middle of this rise, while the actual thermostat setting would be at the top to the rise.

There was a similar trend for the mean cooling setpoints. The mean difference between observed and self reported setpoints were lower than the

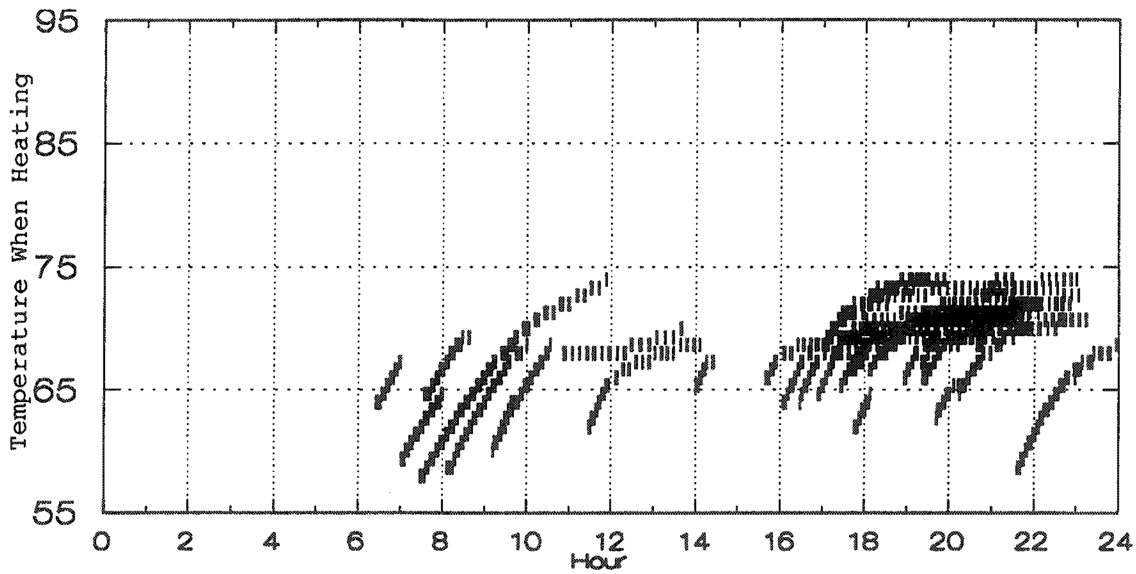

Figure 3. Example of Living Zone Temperature Under Manual Control

setpoints in all the periods. However there is not enough data about cooling setpoints to allow any definitive comparison to be made. In this analysis we exclude cases when the HVAC system never came on or the occupants reported the system was off or did not give a number for the thermostat setting. Because of this both the reported and observed mean setpoints may be too high for heating and too low for cooling.

Comparison of Observed and Self Reported Setpoints. Two scatter plots, Figures 4 and 5, are included which show the observed setpoints against the self reported setpoints for heating and cooling for all periods. From these plots it can be clearly seen that observed heating setpoints are above the self reported setpoints in the majority of cases. The converse is true of cooling setpoints although the pattern is not as distinct.

Range of Observed and Self Reported Setpoints. Two box plots, Figures 6 and 7, show the full range of discrepancies between observed and self reported heating and cooling setpoints. The data in these plots is divided by period of day. As the data shows the discrepancy between observed and self reported heating setpoints is highest at night and lowest during the evening.

Management Style

Table 3 lists the observed versus self reported management styles for heating and cooling control. As can be seen in the heating control strategy table, we credited occupants with using unattended thermostat operation, constant or setback, nearly twice as much as they reported. This means that the occupants were acting according to a regular pattern, manually approximating an automatic thermostat.

The range of the discrepancies split by self reported thermostat management style is shown in Figure 8. For this graph we divided management into manual and unattended thermostat control strategies. We included constant setting, but turning the thermostat off when leaving the house in the manual setting. The setback and constant setting styles are both included in the unattended management style. Occupants reporting a manual thermostat control strategy under reported thermostat settings more than the occupants using an unattended thermostat strategy. The range in errors is similar in both cases.

Unconditioned Periods

Most houses in our sample had significant periods of time where the measured indoor temperature was

Table 1. Setpoints by Period of Day

Observed -- Heating

	Morning	Afternoon	Evening	Night
Count	25	27	27	29
Mean	68.9	70.2	70.3	68.7
S.D.	3.6	3.7	2.9	4.0

Self Reported -- Heating

	Morning	Afternoon	Evening	Night
Count	26	21	31	22
Mean	67.5	67.1	69.2	64.1
S.D.	4.3	4.5	3.0	5.7

Observed -- Cooling

	Morning	Afternoon	Evening	Night
Count	6	11	9	4
Mean	76.6	77.5	77.4	74.6
S.D.	2.5	2.6	2.7	2.6

Self Reported -- Cooling

	Morning	Afternoon	Evening	Night
Count	8	18	18	11
Mean	80.6	79.3	76.6	76.6
S.D.	3.3	5.0	3.8	4.8

Table 2. Differences Between Observed and Self Reported Setpoints by Period of Day

Heating

	Morning	Afternoon	Evening	Night
Count	16	12	12	11
Mean	2.2	2.7	1.2	4.3
S.D.	4.7	2.3	2.5	5.7

Cooling

	Morning	Afternoon	Evening	Night
Count	2	8	6	2
Mean	-5.7	-1.4	-0.4	-1.8
S.D.	0.1	3.0	3.6	0.4

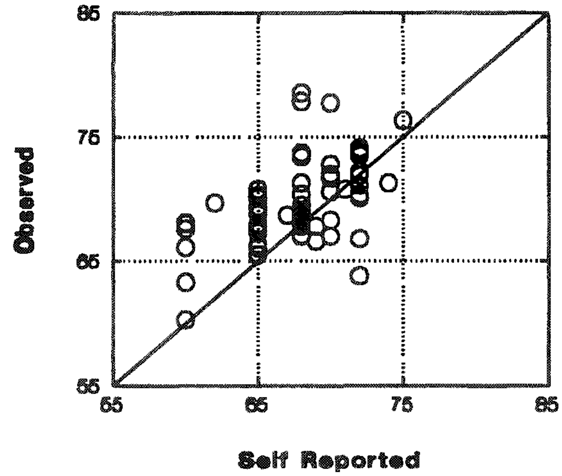

Figure 4. Observed vs Self Reported Thermostat Setpoints During Heating

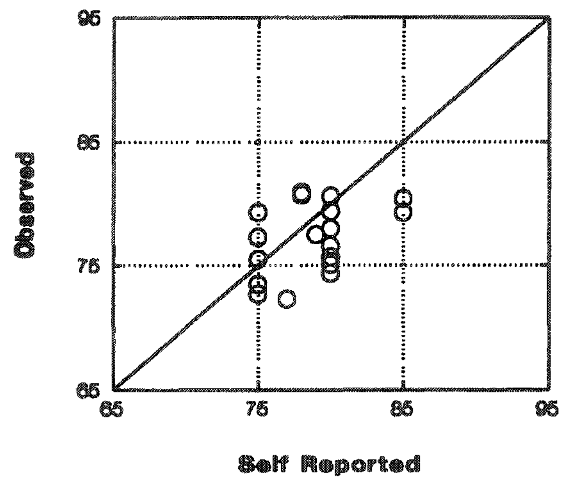

Figure 5. Observed vs. Self Reported Thermostat Setpoints During Cooling

outside of the setpoints measured for the house. This is due to periods of time when the occupants are not maintaining the indoor temperature at their average setting. For occupants with the manual style this will occur whenever they turn the setpoint down below their average setting. For occupants with scheduled or constant styles, these periods occur when they are away from home and turn off their systems. For the 40 houses as a whole, the indoor temperature is outside the average set points a significant amount of the time. Figure 9 shows the distribution of measured indoor temperatures in

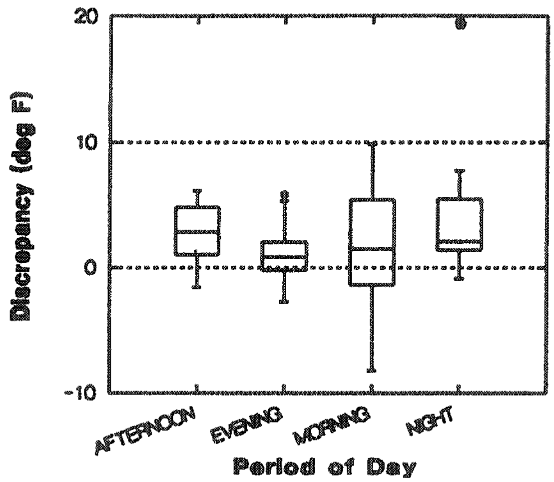

Figure 6. Differences Between Observed and Self Reported Setpoints During Heating by Period of Day

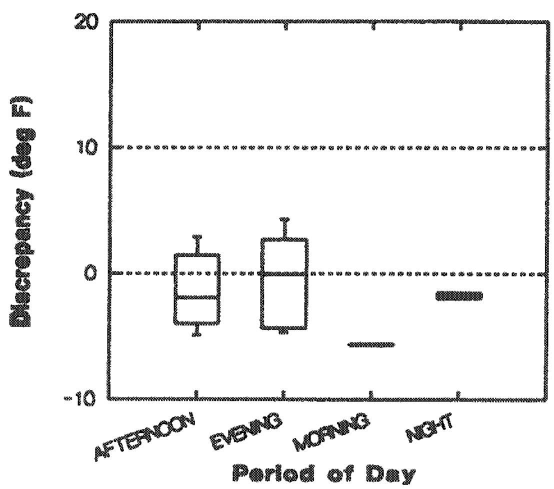

Figure 7. Differences Between Observed and Self Reported Setpoints During Cooling by Period of Day

reference to the average setpoints for the afternoon period in all the houses. Note that the indoor temperature is above the average setpoint more than 10% of the time and below the heating setpoint more than 20% of the time. Figure 10 and 11 show similar results for the evening and night period. The measured temperature in the 40 houses is below the average heating setpoint for the same houses more than 40% of the time.

Table 3. Observed and Self Reported Thermostat Control Strategies

Heating

Self Reported by Observed (columns by rows)

	Manual	Const/Off	Constant	Setback
Manual	6	0	0	1
Const/Off	0	0	0	1
Constant	3	2	2	1
Setback	3	1	0	5

Cooling

Self Reported by Observed (columns by rows)

	Manual	Constant	Setback
Manual	1	1	1
Constant	0	2	0
Setback	0	0	0

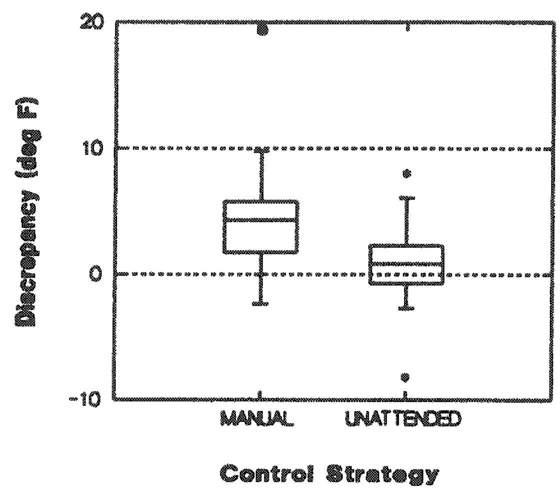

Figure 8. Differences Between Observed and Self Reported Setpoints During Heating by Self Reported Thermostat Management Style

If we simulate the energy performance of the all the houses using the average setpoints, we will maintain the temperature in the houses within much tighter temperature limits than was found in the real

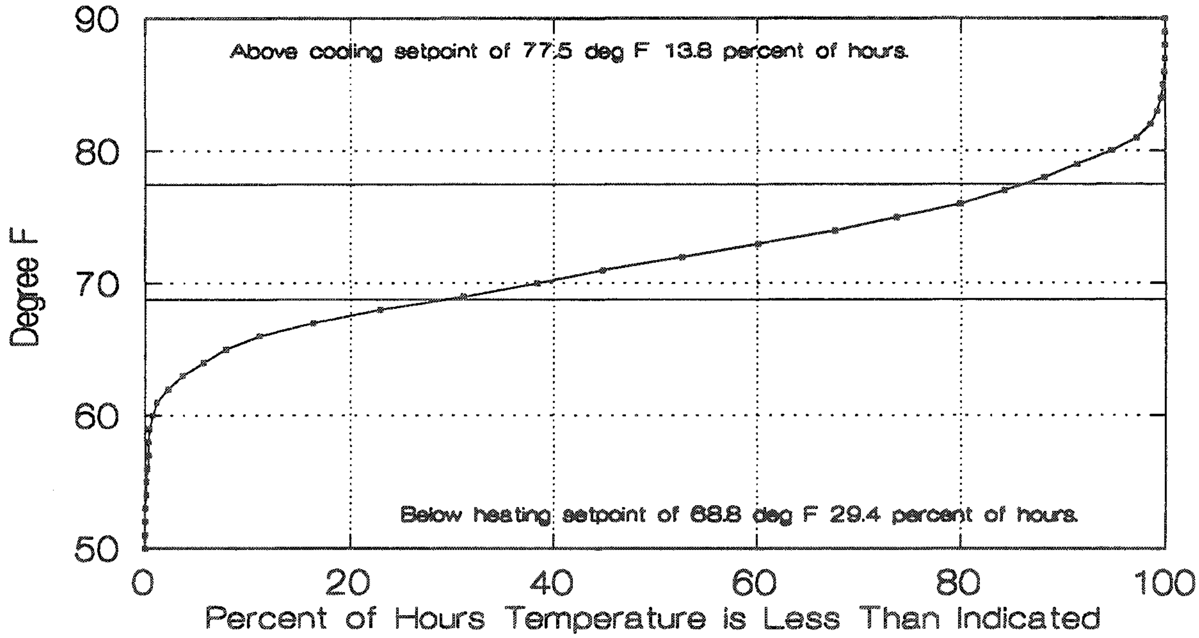

Figure 9. Distribution of Measured Indoor Temperatures with Average Setpoints for the Afternoon Period

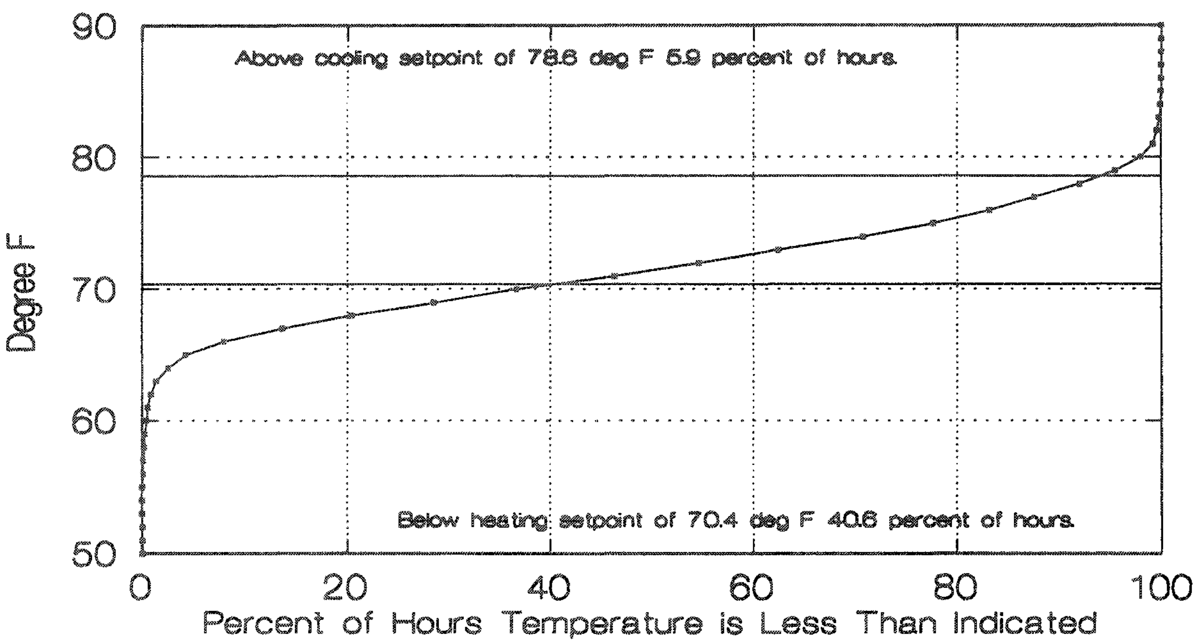

Figure 10. Distribution of Measured Indoor Temperatures with Average Setpoints for the Evening Period

houses. This will result in predicting higher energy consumption than really occurred. Our proposed solution to this problem is to use simulation thermostat setpoints based on the average measured set point, but assume the system is off (or radically set back) part of the time. We have tested heating thermostat settings that have the heating off three days a week and the preliminary results look good.

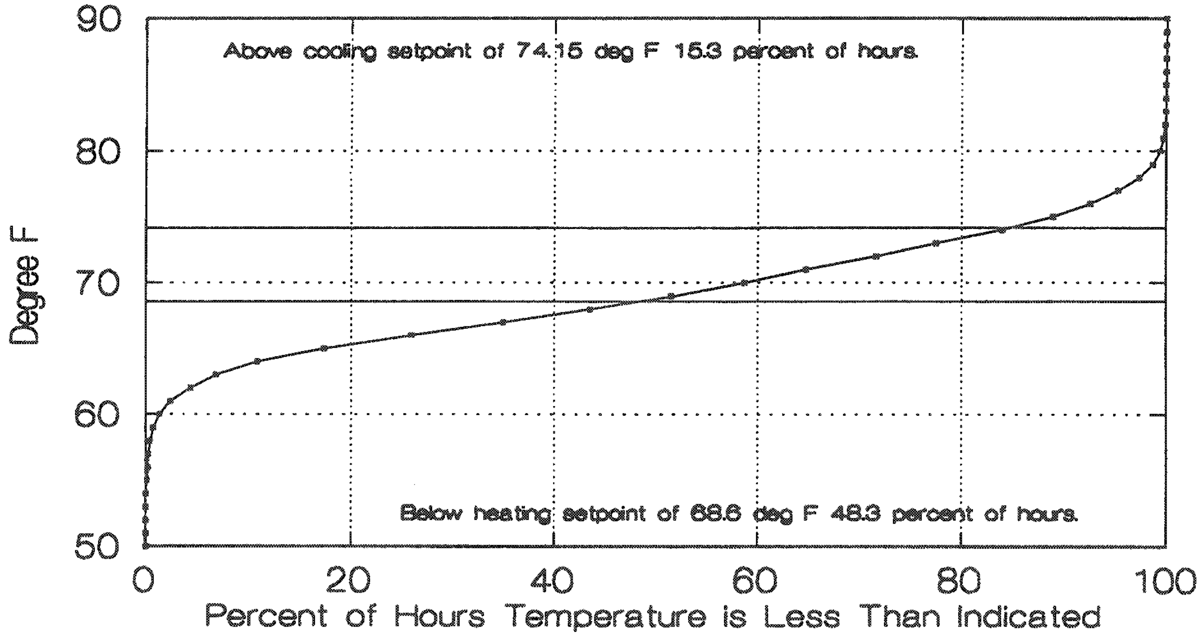

Figure 11. Distribution of Measured Indoor Temperatures with Average Setpoints for the Night Period

SUMMARY

For the houses we monitored the discrepancies between observed and self reported heating thermostat setpoints averaged 1 to 4 degrees F. The discrepancies were smallest during the evening when people would most often be home and awake. The largest discrepancies were at night when people are unaware temperature. People who reported using an unattended thermostat management strategy were more accurate than those using a manual strategy. We observed fewer houses during the cooling season, so this data cannot be reliably analyzed.

The mean discrepancy between self reported and observed thermostat setpoints was 1 to 4 degrees F, depending on the time of day. Respondents under reported their heating setpoints and over reported their cooling setpoints. Discrepancies on thermostat settings were highest at night and lowest for the evening. People who use an unattended thermostat management strategy are more accurate in their reported thermostat settings.

A comparison of our interpretations of occupants' thermostat management style with their self reported thermostat management style shows that reported manual control to be tight enough to be considered constant or setback control in about half the cases. Our characterization of management style shows occupants about evenly divided between manual control, constant setting, or setback control. This contrasts with about half of the occupants reporting manual control, and about a quarter indicating constant setting or setback control.

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