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Two Theories of Home Heat Control*

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People routinely develop their own theories to explain the world around them. These theories can be useful even when they contradict conventional technical wisdom. Based on in-depth interviews about home heating and thermostat setting behavior, the present study presents two theories people use to understand and adjust their thermostats. The two theories are here called the feedback theory and the valve theory. The valve theory is inconsistent with engineering knowledge, but is estimated to be held by 25% to 50% of Americans. Predictions of each of the theories are compared with the operations normally performed in home heat control. This comparison suggests that the valve theory may be highly functional in normal day-to-day use. Further data is needed on the ways this theory guides behavior in natural environments.

Human beings strive to connect related phenomena and make sense of the world. In so doing, they create what I would call folk theory. The word "folk" signifies both that these theories are shared by a social group, and that they are acquired from everyday experience or social interaction. To call it "theory" is to assert that it uses abstractions, which apply to many analogous situations, enable predictions, and guide behavior. I would con-

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trast folk theories with institutionalized theories, which are used by specialists and acquired from scientific literature or controlled experiments.

In the present study I analyze folk theories for home heating control, particularly thermostats. From interviews with Michigan residents, folk theories were inferred using methods developed by Lakoff and Johnson (1980; also see Lakoff and Kövecses, 1985) and Quinn (1982, 1985). The inferred folk theories were compared with behavior guided by the theory, using both observed behavior and self-reported behavior. The interviews also elicited lists of devices analogous to thermostats and a history of usage in present and past residences.

THE CONCEPT OF FOLK THEORY

Anthropological interest in folk theory continues the expansion of cognitive anthropology from folk categories to more complex structures, such as sets of propositions (D'Andrade, 1981; Kay, 1966), inference rules (Cole & Scribner, 1974; D'Andrade, 1982; Hutchins, 1980), cognition in everyday activities (Holland, 1985; Lave & Rogoff, 1983; Murtaugh, Faust, & de la Rocha, 1980), and connections in discourse (Agar, 1980; Rice, 1980).

Recent discoveries by psychologists and educators provide the most precisely defined examples of folk theory to date. Related cognitive structures have been called "naive theory" (diSessa, 1982; McCloskey, 1983; McCloskey, Caromazza, & Green, 1980), "mental models" (deKleer & Brown, 1983; Gentner & Stevens, 1983; Johnson-Laird, 1981), "naive problem representation" (Larkin, 1983; Larkin et al., 1980), or "intuitive theory" (McCloskey, 1983; see diSessa, 1985 for a contrasting view[1]). I describe one study to provide an example of folk theory and to show how my perspective differs. The study compared folk theories of motion with physicists' theories of motion:

> People develop on the basis of their everyday experience remarkably well-articulated naive theories of motion. . . theories developed by different individuals are best described as different forms of the same basic theory. Although this basic theory appears to be a reasonable outcome of experience with real-world motion, it is strikingly inconsistent with the fundamental principles of classical physics. In fact, the naive theory is remarkably similar to a pre-Newtonian physical theory popular in the fourteenth through sixteenth centuries. (McCloskey, 1983, p. 299)

[1] diSessa (1985) argues that the things McCloskey calls single coherent theories are in fact data-driven collections of heterogeneous "phenomenological primitives." These primitives originate in superficial interpretations of reality applied to common situations via recognition. The data in this paper argue for more connectedness than diSessa sees, although I acknowledge the possibility that the word "theory" conveys more consistency and coherence than is appropriate.

To paraphrase McCloskey, the folk theory of motion: (1) is based on everyday experience, (2) varies among individuals, although important elements are shared, and (3) is inconsistent with principles of institutionalized physics. McCloskey makes a fourth finding, that the folk theory persists in the face of formal physics training. Students simply reinterpret classroom material to fit their preexisting folk theory (McCloskey, 1983, p. 318). The physics instructors would not usually even be aware their students had a preexisting folk theory.[2]

To an anthropologist, the nonrecognition of conflicting systems and the persistence of the folk system both resemble phenomena at a cultural boundary. Isolated elements and terms diffuse across the cultural boundary, but they are incorporated into prior folk theory rather than inducing change. There is also a parallel in that one culture seems dominant: When the folk and institutional theories differ, the folk theory is considered wrong. The above-cited research does not question the correctness of the institutional theory because a major objective of the classroom studies has been to improve teaching.

Wiser and Carey caution that we cannot understand folk theory by simply diagnosing its failure to solve problems in the domain of the expert. We must find the problems it does solve correctly, and examine the explanatory mechanisms it uses to do so (Wiser & Carey, 1983, p. 295). Anthropologists' naturalistic proclivities have led them away from folk theory in the classroom and toward the environments where folk theory earns its keep in everyday use (for example, see studies in Holland & Quinn, 1985).

RESIDENTIAL THERMOSTATS

The present study deals with home heating thermostats for several reasons. Home heating systems are fairly simple and well understood. Information about them is communicated almost entirely through folk channels—no one must study thermostats in high school or pass examinations; there is no widespread institutionalized dogma. Yet many people adjust their thermostats, typically more than once per day, so they must have some principles or theories which are guiding this behavior. Also, because the range of behavior affected by the theory is very restricted—turning a single dial—behavioral records can be collected automatically. By comparing behavior patterns with interviews, we can better infer how folk theory guides the behavior we observe. Finally, this domain was selected because an improved understanding of what people do with thermostats would have significant practical consequence for national energy programs.

[2] Nonrecognition of cognitive variation within a culture, and even within a single family, seems common (Kempton, 1981).

The following discussion draws from two sets of interviews and one set of behavioral data. The first set of interviews, with 30 Michigan households, elicited general information about energy management. Because these interviews were exploratory, they often did not go into much detail on thermostats. The second is a set of 8 interviews, with 12 Michigan informants, which focussed on thermal comfort and especially dealt with thermostat control. I use the interview data to infer folk theory, which in turn is compared with behavioral patterns. The data on behavior derive from automatic recordings of thermostat settings in 26 houses in New Jersey. (Unfortunately, we do not have interview data from these 26 houses.) Finally, my analysis draws from discussions with heating specialists and energy conservation analysts, and from technical energy articles.

I will hypothesize that two theories of thermostats exist in the U.S. (and perhaps throughout the industrialized world). One, the feedback theory, holds that the thermostat senses temperature and turns the furnace on and off to maintain an even temperature. The other, which I shall call the valve theory, holds that the thermostat controls the amount of heat. That is, like a gas burner or a water valve, a higher setting causes a higher rate of flow. Technically knowledgeable readers of the present study have commented that the feedback theory is correct and the valve theory is wrong. However, as we shall see, both folk theories simplify and distort as compared to a full physical description, each causes its own types of operational errors and inefficiencies, and each has certain advantages.

RECORDS OF THERMOSTAT USE

Behavioral records of thermostat settings have been collected by Princeton University's Center for Energy and Environmental Studies (Dutt, Eichenberger, & Socolow, 1979; Socolow, 1978). Over a 2-year period, automatic devices recorded hourly thermostat settings (and many other energy variables) of 26 upper middle class families in identical townhouses. Here I examine 2 of those homes to illustrate two patterns of thermostat adjustment which I will link to the two folk theories.

Figure 1 shows hourly measurements of thermostat settings in one house over a 3-day period in the winter of 1976. The solid line shows the hourly thermostat setting, and the dotted line shows the room temperature. We see that the thermostat usually is changed at times when occupants and activities change: 8 a.m., noon, and 5 to 8 p.m. During other periods, not shown in Figure 1, the thermostat may be left at the same setting for several days. I conclude that the thermostat setting is changed when the desired temperature changes: when waking or going to sleep, when entering or exiting the house, and around mealtime.

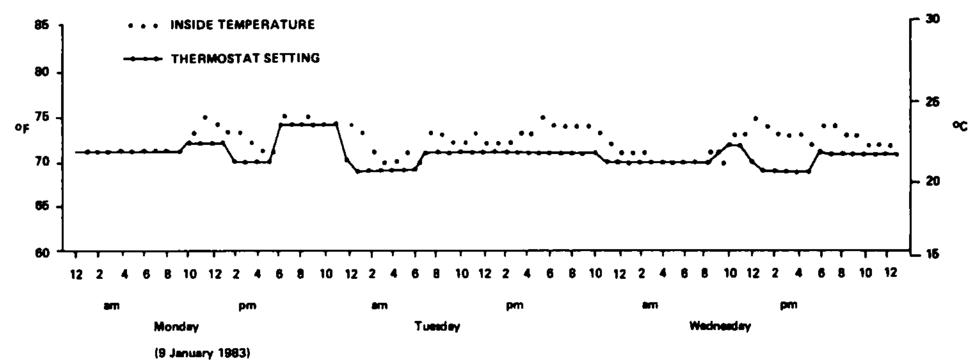

Figure 1. Pattern of thermostat and adjustments consistent with the feedback theory.

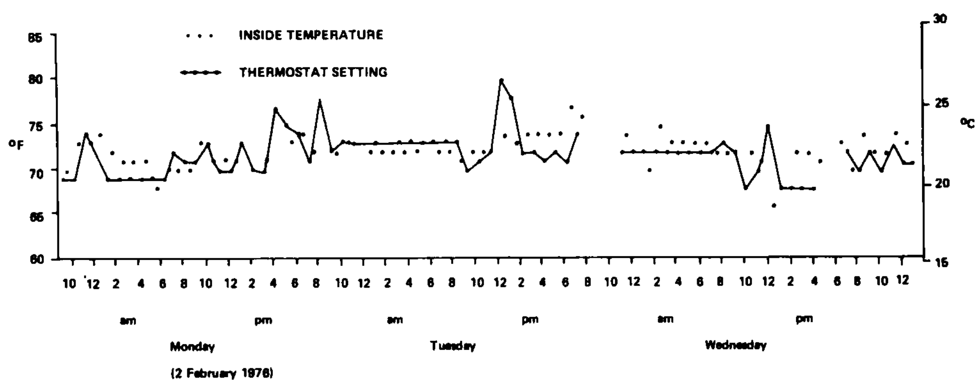

Figure 2. Pattern of thermostat adjustments consistent with the valve theory.

Figure 2 shows hourly thermostat settings for a second house, also during winter, 1976. In this house, the thermostat is often changed between each hourly datum. In fact, the only times on the figure when the thermostat is not changed are probable sleeping times, for example, from 1 a.m. to 7 a.m. Monday, and from 10 p.m. Monday to 8 a.m. Tuesday. It appears that, whenever someone is awake in this house, the thermostat is adjusted at least hourly. Examination of the full 2 years of data (not shown here) also shows many thermostat adjustments, not at regular times, and a wide range of settings (from 61° to 85°F; 16° to 29°C).

I hypothesize that the frequent thermostat settings of this second household result from the residents having a valve theory of their thermostat.[3] Although I could not interview the households shown in Figures 1 and 2, informants in my interviews do report following similar patterns (though rarely as extreme as Figure 2). I next discuss interview evidence for the two theories.

[3] Although I propose folk theory as an explanation of the pattern in Figure 1, many factors contribute to thermostat setting, and frequent shifts could be due to other causes such as domestic conflict over desirable setting.

THE FEEDBACK THEORY

According to the feedback theory, the thermostat turns the furnace on or off according to room temperature. When the room is too cold, the thermostat turns the furnace on. Then, when the room is warm enough, it turns the furnace off. The setting, controlled by a movable dial or lever, determines the on–off temperature. Because the theory posits that the furnace runs at a single constant speed, the thermostat can control the amount of heating only by the length of time the furnace is on. Thus, if the dial is adjusted upward only a little bit, the furnace will run a short time and turn off; if it is adjusted upward a large amount, the furnace must run longer to bring the house to that temperature. Left at one setting, the thermostat will switch the furnace on and off as necessary to maintain approximately that temperature.

Heating engineers are fairly comfortable with the folk theory described earlier—they consider it simplified, but essentially correct. However, as I will show, their evaluation of correctness may be based on irrelevant criteria.

In interview segments such as the following (from a Michigan farmer), I would infer that the feedback theory is being used:

> You just turn the thermostat up, and once she gets up there [to the desired temperature] she'll kick off automatically. And then she'll kick on and off to keep it at that temperature.

From anthropomorphic statements such as the above, and others about the thermostat "feeling it is too cold," I infer the following metaphor (Lakoff & Johnson, 1980) for the feedback theory: The thermostat is a little person with a switch controlling the furnace. The little person turns the switch on and off, based on perceived temperature.

Thermostats, and the mathematical description of self-regulating devices (Wiener, 1948) are new to this century. These devices trace their ancestry to Watt's steam engine governor. Thermostats are the only self-regulating devices whose operation is visible in the average home (most homes have visible thermostats not only for the furnace control, but also in the refrigerator, oven, portable heater, etc.).

THE VALVE THEORY

I will elucidate the valve theory first through interview material from a single informant, then present evidence that it is held by a substantial proportion of Americans.

The valve theory was most clearly articulated by Bill, a well-educated man in his 30s. Bill was raised in California but has lived in Michigan for 3 years. As shown in the following quotation, Bill described the thermostat dial as not just switching on and off, but controlling the rate of heat flow. (In dialogue, "W" labels my question, whereas "B" labels Bill's response.)

W: What would the system do at 68° versus 85°? How did the number on the thermostat dial relate to anything that was going on with the furnace?

B: Well, you could feel the heat coming up the vent. There'd be less, less warm air, less hot air at the different setting. I mean—that was clear.

Similarly, indescribing the house in which he grew up:

> I do remember, as a kid, the heat vents were more or less hot to touch—to the hand as a sensor near the vent—at different settings...

When I asked Bill for a description of how the thermostat works, he said that he could not describe it technically. However, when I asked him to explain how it works in relation to what he did with it, he immediately explained:

> I think it's pretty simple really. Um, I assume, um, that there is some kind of linear relationship between where the lever is and the way some kind of heat generating system functions. And, um, that it's like stepping on the gas pedal; that there I have a notion of hydraulics, you know, the harder you push there is, the more fluid gets pushed into the engine, and the more explosions there are, and the faster it goes. And so here, the, the harder or the more you push the lever or twist the lever in —there is a scale which indicates, you know, regular units—the...more power the system puts out to generate heat...

Bill's analogy of an automobile gas pedal describes the continuously varying flow of heat which he believes he is regulating.

To elicit operational practices, I posed hypothetical situations. Bill's practices were consistent with his theory and his metaphor:

W: Let's say you're in the house and you're cold...Let's say it's a cold day, you feel cold, you want to do something about it.

B: Oh, what I might do is, I might turn the thing up high to get out, a lot of air out fast, then after a little while turn it off or turn it down.

W: Un-huh

B: So there are also, you know, these issues about, um, the rate at which the thing produces heat, the higher the setting is, the more heat that's produced per unit of time, so if you're cold, you want to get warm fast, um, so you turn it up high. Um, my feeling is, my, my kind of Calvinist or Puritan feeling is that that's sinful. That, that really ought to turn it to the setting, the warmth setting which you think you'll eventually be comfortable and just bear the cold until the thing slowly heats up the house to that level.

Although Bill believes that a higher setting would cause the house to heat up faster, he may refrain from doing this because he considers it wanton. Thus, for reasons other than the theory of the thermostat itself, he sometimes operates the device in the same way as someone who holds the feedback theory.

His conceptualization of why the house maintains a steady temperature is quite different from that predicted by the feedback theory.

> W: OK, so how would you use the thermostat and, and how would it be different from the way you used that oven?
> B: Um, well, I guess you'd find some kind of moderate, steady, steady setting, setting for the thermostat to maintain a comfortable temperature in a steady state.
> W: OK, and that would be something intermediate between having it cranked all the way up for heating up quickly, which would be too much, and having it all the way down, which would not be enough?
> B: Right, yea.
> W: So what, what's this, what's steady state about? You're trying to balance off what against what?
> B: Humm. Uh, well I guess basically, the amount of heat that comes into the system has to equal the amount that's somehow disappearing.

In this passage, Bill states that an even temperature is not maintained by the thermostat itself, rather, it is a balance set by the human operator. The operator adjusts the rate of heat entering the system to equal the amount leaving or dissipating. The operator's balance of energy input against dissipation is also captured by the gas pedal analogy which Bill referred to frequently. When Bill says that the thermostat is like a gas pedal, he is using what Gentner (1983) calls analogy or structure mapping—the gas pedal is analogous to the thermostat because they both have the same relation between objects and actions, not because they have similar attributes or appearances.

A person who is attempting to balance heat against dissipation would reasonably change the thermostat setting frequently. The result would be a pattern of many adjustments like that seen in Figure 2.

Because our environment contains many more valves than feedback devices, everyone is likely to have a valve theory (applied to water faucets, etc.). Those who have a feedback theory will also have a valve theory, and will apply the feedback theory to only a small set of devices. To elicit devices Bill saw as similar to thermostats, I suggested that the burner on a gas stove operates like Bill's description of the thermostat; the higher you turn it, the more heat you get. He agreed, so I asked which other devices would be similar:

> I just flashed to electric mixers. The higher you turn them, the faster they go...the harder you push on the gas, the faster the car moves... turning on the faucet...you can see the water squirting out in greater volume at a greater rate, you know, as the lever is increased to turn it up.

By contrast, he discards on–off controls as different:

> What other analogies might I think of? Uh, turning on and off the lights just, uh, that's a more binary kind of process.

Bill's device analogies are consistent with his abstract description, his reported operational practices, and the metaphors he uses to describe the thermostat.

Bill recognized that his model of thermostat operation may be different from that of specialists. In fact, early in the interview he described himself as not having any knowledge about thermostats. He thought that someone had given him a formal explanation, but he could not remember it. Because he could not reproduce the institutionally sanctioned explanation, he describes himself as "ignorant":

> B: Now um, I really am ignorant about the functioning of these devices. . .once or twice, somebody might have described to me how the thermostat operated, but, my reaction at the time was maybe comprehension, but the sense of feeling out of control. And, maybe partly because of anxiety or lack of familiarity with the device, I've since forgotten what I was told.
>
> W: That's fine.
>
> B: Yea, so, this really would be, if I tried speculating on how they worked, it would really be just that.
>
> W: Speculation.
>
> B: Sort of de novo.

Bill's denial of a solid understanding here is belied by the other quotations, which show a detailed and complete theory of thermostat operation, including a set of predictions, past perceptions, and operating rules consistent with his theory. Further, this theory is stable enough to resist change. Later in the interview, he hypothesizes a possible second "level of sophistication," which some thermostats might have, in order to explain why his parents' furnace seemed to turn on and off without human intervention:

> B: . . .I can imagine the devices at varying levels of sophistication and you'd have this, uh, kind of, feedback arrangement on, that exists for my parents'.
>
> W: Un-huh.
>
> B: Uh, where, uh, you know, it's not the human, the human operator isn't the only person that—the only agent that—turns the system on and off. The system itself is self-regulating. So, hm, in the course of the night, you know, it could turn on and, and off according to some measurement that it's making of the temperature, in the room. And um, um, you know, in my parents' house you could hear that thing going on and off in the course of the night making those irritating, windy sounds.
>
> W: Irritating, windy sounds. This is the drafts you were talking about before.

> B: Right. Um, now, I can't remember whether the thermostat in this other house had that self-control, kind of procedure. I don't think it did and I think that might have been one of the reasons why we couldn't leave it on all night.

Bill proposed the above partial feedback theory to explain what he could not explain with his valve theory, but he seems to consider the feedback thermostat (in this parents' house) to be a special case. In discussing my analysis with Bill 7 months later, he described this partial feedback theory as transitory:

> I didn't have the feedback theory until your questioning forced it upon me...I discovered it for the moment, but later forgot it. When I went back to using the thermostat, I probably went back to doing it the same way.

Bill's reported return to the valve theory suggests that folk theory is resistant to change.

Informal data suggest even more than the above that the valve theory is resistant to change. In casual discussions of this material with proponents of the feedback theory, I was told by three individuals that their spouse turned up the thermostat to heat the house faster, that this practice was ineffective, and that their repeated attempts to convince their spouse of this had failed. Their failures may be attributed to the proselytizers' working to convey an individual belief, when they needed to convey an entire theory. Worse, they had to supplant a theory which was already working satisfactorily, and which was not explicitly acknowledged as existing.

To summarize the valve theory as described by Bill, the thermostat controls the rate at which the furnace generates heat. People maintain a constant temperature in their houses by adjusting the setting so that the amount of heat coming in just balances the amount being dissipated. Devices which operate similarly include the water faucet and the gas pedal on an automobile. Bill allows that some sophisticated systems may consider temperature and automatically adjust the heat from the furnace. Even though Bill's theory resists change, he devalues his own theory relative to the institutionally sanctioned one. Despite having a fully elaborated conceptualization and complex operating rules, he describes himself as "ignorant about the functioning of these devices."

Is Bill's valve theory unusual? No national survey data exist on this issue, but estimates can be made. Of the 12 informants in my focused interviews, the valve theory was given in full form by 2, and in partial form by at least 3 more; data was indeterminate in some of the more brief interviews. Another study, in Wales, interviewed residents of 38 new thermostatically controlled rural houses. When asked whether a cold house would warm up quicker to the desired level if the thermostat were turned up full, past its normal setting, 62% said it would (O'Sullivan & McGeevor, 1982, p. 104). A third study asked 43 college students in Cambridge, Massachusetts to assume they entered a cold house and wanted it to heat up as quickly as possible. Those who would turn it above the desired temperature for faster heating ranged from 24% to 46%, the percentage varying with prior questions about analogous situations (Gentner & Tenney, unpublished 1983 data). Therefore, from these limited studies I estimate that 25% to 50% of the U.S. population uses at least part of the valve theory. My sense, which I do not yet have formal data to support, is that the majority of the population holds a combination of these two theories.

FUNCTIONALITY OF THE TWO THEORIES

In many anthropological studies, it would be nonsensical or impractical to evaluate the functionality of a folk theory. In the present study, the domain and the goals of the folk are fairly straightforward. Known scientific theories describe home heating systems, and the major goals of using them are presumably to be comfortable without spending too much money. Thus, the functionality question can be addressed by asking how well each folk theory meets the goals of its users (this approach is advocated in more detail by Rappaport, 1979; and by Kempton & Lave, 1983).

Management Effort and Thermal Comfort

The valve theory does rather well in many situations. For example, if one assumes that thermostats do not have feedback mechanisms, a house would become colder when the weather is colder. The corresponding management rule is: When it is colder outside, you must turn up the heat. This practice is rationalized by the device model itself. Conversely, with a feedback device model, this adjustment would not seem necessary. In fact, the valve theory leads to correct management because in many houses infiltration and distribution asymmetries will cool marginal rooms in cold weather.

A second issue is whether a higher setting provides faster warmup. The feedback theory denies faster warmup because the furnace runs at a constant rate. However, due to human comfort factors and characteristics of interacting systems, a person entering a cold house from outside will not feel warm when the air first reaches the correct temperature.[4] Thus, greater

[4] This can be demonstrated by a simple thought experiment. Upon entering a warm building with a point-source of heat (say, a wood stove), a person feels cold although the building is warm. That person will choose to stand near the point source, despite the higher than normal temperature. After they have "warmed up," they will choose a normal temperature. In the case of turning the thermostat up upon entering a cold house, there appear to be two physical causes: (1) The cold near-body masses—clothing, skin surface, and trapped surface air—are heated more rapidly by warmer ambient temperature; and (2) When air temperature rises but (slower heating) wall and furniture surfaces are still cold, a person will feel colder than air temperature because of infared radiation losses. A more complete analysis of these effects would require quantitative analysis of their relative magnitudes and time constants.

comfort would be realized if the thermostat were set high, to raise the air temperature above normal initially, then returned to the normal setting. Again, the correct action would logically follow from the valve model, but not from the feedback model.

Energy Use

The valve theory correctly predicts a third fact of considerable importance to the user: More fuel is consumed at higher settings than at lower ones. The prediction is correct, even if the explanation is wrong (higher fuel use is not the result of a valve opening wider, but because higher inside temperatures cause more heat loss through the shell of the house). Nevertheless, higher use is a direct prediction of the valve theory, not of the feedback theory. Consequently, some interviews suggest that valve theorists are more likely to correctly believe that night setback saves energy. The following quote illustrates how the informant's husband follows the logic of the feedback theory to an erroneous conclusion:

> Now, my husband disagrees with me. He, he feels, and he will argue with me long enough, that we do not save any fuel by turning the thermostat up and down. . . . Because he, he feels that by the time, you turn it down to 55 and all the objects in the house drops to 55°, and in order to get all the objects in the house back up to 65°, you're going to use more fuel than if you would have left it at 65 and it just kicks in now and then.

The above error is due to having the feedback theory without having additional theories of the interacting systems, particularly a theory of heat loss at different indoor temperatures. The feedback theory would work if it were augmented. But the necessary augmentations would complicate the model considerably—perhaps beyond the level of complexity most people are willing to bother learning about home heating. By contrast, if one considers the thermostat to be like a valve, these problems are solved with little effort.

The above points favor the valve theory. However, it seems to encourage frequent unneeded adjustments of the thermostat. This may induce considerable waste of time and human effort. Frequent adjustments will not necessarily increase energy consumption, as long as the thermostat is turned back down as soon as the house becomes warm. If the occupant forgets, energy will be wasted.

The Expert's Perspective

Another problem with the valve theory is that it does not correspond to the mechanism inside the device. Inside, one sees a temperature-activated switch, that can be on or off but cannot control the amount of heat from the furnace. This will seem a decisive failure to the few technically minded people who might actually look inside, but it is of little consequence for normal use of the thermostat.

Why do heating experts consider the valve theory incorrect when it provides its users with about the same number of useful predictions as the feedback theory? After their training, experts possess a full, institutionally sanctioned theory. This full theory can be arrived at from the feedback theory by simply adding details and adjacent systems. By contrast, arriving from the valve theory requires a conversion—at some point the learner will say something like, "Oh, I see, it's not a valve, it's an automatic switch." The technical experts will evaluate folk theory from this perspective—not by asking whether it fulfills the need of the folk. But it is the latter criterion upon which the anthropologist will rely, due to her methodological training, and upon which sound public policy must be based.

CONCLUSIONS

In studying residential heat control I found that two folk theories were applied to thermostats. Of the two, the feedback theory is more closely related to expert theory.

Home heating, like many other areas of knowledge in our society, has a "correct" set of theories defined by experts and their institutions. Informants who held the valve theory were insecure about it—they denied understanding the device, even when they had complete descriptive models and elaborate procedures for using it. This insecurity has also been manifested on several occasions of giving this paper as a talk. Some questioners seem to be inhibited by feeling that they may have a "wrong" theory, and they do not want to be embarrassed by their questions. One might suppose that choice of the correct theory for thermostats concerns straightforward technical facts, and presume that the experts must know how thermostats really work—after all, they design them! But we have seen that the folk theory that is endorsed by the experts may not work as well in practical day-to-day application. A theory that is useful for designing thermostats is not guaranteed to be a good theory for using them.

More needs to be known before this research could see any practical application. In earlier work on household methods for measuring energy, my colleagues and I have argued that many folk measurement methods are counterproductive, and that individuals would benefit if folk methods were made more similar to expert ones (Kempton & Montgomery, 1982; Kempton, Gladhart, Keefe, & Montgomery, 1982). In the case of folk theory for thermostats, the jury is still out. If people converted from the valve to the feedback model, they would save management effort by not having to adjust the thermostat so often, and they would occasionally save energy by not forgetfully leaving it set high. However, widespread conversion to feedback theory would risk eliminating the theoretical rationale for night setback—an immensely larger penalty. This is because a simple valve theory always predicts less use from lower settings, whereas some simple feedback theories (like that quoted on page 86), will predict that savings from setback would be cancelled by later set up.

More research is needed, because two problems with the valve theory do argue for conversion. First, the problems with the first order feedback theory can be solved by simply adding on, whereas problems with the valve model require ad hoc repairs (as in Bill's Calvinism) or replacement of the entire model. A second argument, based on data in Kempton (1985), is that when the operation of the system is made visible, the folk, on their own, choose feedback theory.

POSTSCRIPT: THERMOSTAT MANAGEMENT AS AN INDUSTRY

I close with a down-to-earth question: What is thermostat management worth? Although no national data exist on thermostat energy savings, rough estimates can be made. During the 1982 heating year, U.S. households spent $85 billion on direct energy purchases, averaging $1022 per household (Department of Energy, 1983). Since the 1973 oil embargo, households have decreased their energy use by about 15% (Crane, 1984; Williams, Dutt, & Geller, 1983), which represents a current savings of $15 billion per year. Heating accounts for roughly half of residential energy cost; because consumers know far more conservation methods for heating than for appliances, I estimate that heating accounts for two thirds of the savings, or $10 billion annually. The only reliable estimate of actual thermostat savings has been made by Fels and Goldberg (1983), who analyzed New Jersey residential gas consumption. By a statistical procedure that compared monthly gas use with weather fluctuations, they were able to separate the effects of thermostat setting from other factors such as home improvement (e.g., insulation) or more efficient appliances. They estimate that more than half of the natural gas savings were due to lower thermostat settings. If we assume the same proportion applies generally to heating fuels[5], $5 billion is saved annually due to changes in home thermostat use since the oil embargo. To put this number in perspective, Socal's recent agreement to purchase Gulf for $13 billion was the largest corporate acquisition in history (Cole, 1984). With 3 years of thermostat savings, American households could have outbid Socal and purchased Gulf Oil for themselves.

Although the dollar figure is an approximation, one can safely conclude that thermostat management provides American households with an-

[5] This figure probably underestimates the thermostat's proportion, because Fels and Goldberg (1983) calculated it to be 50% of all gas conservation, whereas I consider it only 50% of heating conservation.

nual savings in the billions. Yet little reliable data link my aggregate national estimate to specific behavioral changes (e.g., nighttime setback vs. constant lower settings), or to the cognitive and social systems which generate the behavior. Whatever the cause, increased household thermostat management now provides disposable income for other spending. Thus thermostat management can be considered a multibillion dollar cottage industry. Further study of this industry's production methods would seem warranted.

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