FEEDBACK AS A MEANS OF DECREASING
RESIDENTIAL ENERGY CONSUMPTION

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Abstract

When residential units are analyzed in human factor terms, it is apparent that the consumption level feedback (typically a bill, calculated once a month, over all appliances) is inadequate to give the resident useful information about his energy consuming actions. The present study tested the hypothesis that providing immediate feedback to homeowners concerning their daily rate of electric usage would be effective in reducing electric consumption. In the studied homes, central air-conditioning is the largest single source of electricity during the summer. Accordingly, it was possible to predict the household's expected electric consumption in terms of the average daily outdoor temperature. Predicted electric consumption was derived from a previous month's modeling period during which a regression line was fitted to predict consumption from average daily temperature, for each home. Feedback was expressed as a percentage of actual consumption over predicted consumption. Feedback was displayed to homeowners four times a week for approximately one month. The results confirmed the prediction. Before feedback began, the feedback and control groups were consuming electricity at approximately equal rates. During the feedback period, the feedback group used 10.5% less electricity. The effectiveness of the feedback procedure was explained in terms of its cueing, motivational, and commitment functions.

Feedback as a Means of Decreasing Energy Consumption

The world is in an "Energy Crisis." Energy costs are increasing rapidly and can be expected to continue to do so. Various kinds of fuel and energy shortages have been experienced. Not surprisingly, a great deal of attention has been focused on the development of alternative sources of energy and more efficient energy utilization technologies. The physical and engineering sciences have been heavily involved in these efforts, the social sciences less so.

The present study is concerned with energy conservation in residential housing. For several reasons this is important: In the United States, the residential sector consumes approximately 20% of the total energy demand, and almost 60% of residential energy use is accounted for by space heating and air-conditioning (Note 1). The potential for energy conservation is considerable. For instance, in the summer, in a climate similar to the Northeastern United States, a one degree (Fahrenheit) increase in thermostat setting could result in a 12% air conditioning usage savings (Note 2). Second, many "public service" campaigns during the most visible periods of fuel shortage were directed at producing energy conservation in the private sector. And "voluntary" techniques can be expected to be the governmentally preferred ones. It would be well for social science to have some voluntary techniques to recommend that have some chance of effectiveness.

The central analytic concept of the present study is taken from human factors psychology (McCormack, 1957). The house is analyzed as a man-machine system in which there are various energy consuming loops that are closed by the presence of the human operator in the system.

In general, human engineering research has discovered that performance feedback, displayed to the human operator, is critical in producing accurate man-machine system performance (McCormack, 1957). The more unequivocally the feedback gives information about isolatable elements of the control system, the more effectively it works (Senders & Cruzen, 1952). During the human operator's learning of the control tasks, informational feedback has been repeatedly shown to improve the rate and level of learning (Ammons, 1956; Bilodeau & Bilodeau, 1961; & Thorndike, 1927). It also improves motivation to perform the task (Locke, Cartledge, & Koeppel, 1968) and in general the more closely the feedback follows on the control action, the better the operator's performance will be (Ammons, 1956).

If one considers the typical American house with regard to its potential for facilitating energy conservation, it becomes clear that, from the feedback perspective, it is designed inadequately. Appliances are run, the air-conditioning goes off and on, hot water is used, the furnace runs, and the homeowner has no way of determining what amounts of energy are used by these devices. The utility bill that the homeowner gets does not break down energy usage into these components. Nor does it appear close in time to the energy usage; it arrives on a monthly basis at best. Frequently, the bill is an estimate rather than an actual meter reading. Given all this, it is questionable whether the home can be considered a closed energy consumption loop at all.

Recently, two studies have been done which included an assessment of the effects of some kind of feedback in reducing residential energy

use. Seaver & Patterson (in press) presented feedback to a group of homeowners that expressed the amount of fuel oil that their home had consumed relative to the same period the year before, and corrected for differences in coldness of the two winters. In the period following the delivery of the feedback, it was found that the feedback group did not consume less fuel than a control group, which did not receive the feedback. The only group in the study that did conserve fuel oil was a group that received consumption feedback and a decal stating "We Are Saving Oil". The authors discussed the effects of the decal in terms of its symbolic reward function, which would suggest that a combined feedback and reward technique was effective in reducing consumption. The feedback used in the Seaver & Patterson study was not provided immediately or frequently to the homeowner and the feedback given covered the fuel usage of the entire previous month. Given this, the failure of feedback alone to produce a change in fuel consumption is not surprising, since the feedback was not organized in a way to provide information to the homeowner about the variations in his actions that would lead to fuel conservation.

The second experiment employing a feedback procedure was conducted by Hayes & Cone (in press). The authors were interested in the effects on electricity consumption of (1) information describing ways to reduce consumption, (2) feedback concerning daily electricity use, and (3) monetary payments given according to how much electricity was conserved. Four apartments were looked at in detail. Each apartment received multiple treatments over time. Sometimes one treatment was given separately for several days, sometimes a treatment was given in combination with another treatment, and at other times no treatment was given. Each apartment received a different combination of treatments and no treatment

over time. The results showed that for all four units, payment was most successful in reducing electricity use. Combinations of payment and either information or feedback produced no greater effect than payment alone. However, compared to baseline (no treatment), feedback alone and information alone were relatively successful. Unfortunately, the results of the experiment are difficult to interpret unambiguously. Only one apartment unit received the feedback alone treatment. And particularly because for all four apartments the first treatment received was payment, it would be difficult to extrapolate the results to suggest the effects of single treatments.

The purpose of the present study was to determine the effects of an immediate and unequivocal energy consumption feedback procedure on the reduction of electric energy consumption. Electric consumption was examined because the study was conducted during the summer, when electricity is the major source of energy used in the homes of the research sample. Subjects were assigned to either a feedback or a control group. In accordance with the human engineering model, feedback was provided almost daily and subjects were to use the feedback to guide their energy conservation attempts.

METHOD

Subjects and Setting

In two respects, the research setting available for the present study was unique: Since 1972, a group of engineering scientists has been studying the energy consumption characteristics of the residences in a three thousand unit planned urban development in central New Jersey (see Note 2). The present study relied on the knowledge of the energy

consuming properties of the homes they had developed, as well as some elements of their data recording systems. Because of the nature of a planned urban development, it was possible to find identically designed and constructed homes, thus sharply reducing the variations in consumption data due to non-psychological factors.

Previous research revealed that, surprisingly, some physically identical houses consume twice as much energy as do others (Note 2). This is all the more surprising because the residents of the community are relatively homogeneous with regard to such demographics as age, income, and religion.

Forty homeowners from physically identical dwelling units were recruited to participate in the present study. Each home was a three bedroom townhouse located in the interior of a row of townhouses. In these homes, electricity is used for central air conditioning, lighting, refrigerator, and whatever other electrical appliances (such as a television set) that the owner has purchased. The hot water heater, the kitchen range, and the clothes dryer run on natural gas, and hence are excluded from the electricity consumption system. In these homes, investigations had revealed that the central air conditioning accounts for approximately 70% of the summer electric consumption. The forty subjects were randomly assigned to either a feedback condition or a control. One subject in the feedback condition dropped out of the experiment, because he did not want to be bothered anymore. During the experiment, four subjects in the feedback group and 6 in the control took vacations of between 5 and 15 days; their data were excluded from the data analyses.

Designing the Feedback System

As indicated before, the human engineering approach emphasizes the importance of feedback that follows immediately on the controlling action and that can be unequivocally associated with that action. Applied to residential electricity consumption systems, this suggests metering every appliance with a feedback device that immediately reads out the energy consumption statistic for that appliance. This is by no means beyond the range of engineering technology; electrical components are available from which such a system could be constructed.

Needless to say, we did not do so for the present study. Although the contemplated devices are well within the state of the art, costly and time consuming problems are involved in producing a few hundred devices that would be reliable and not overly costly. Until research indicates more clearly the potential effectiveness of such devices, it did not seem sensible to devote the time and resources necessary for their construction. Nor would they be cost effective on energy consumption subsystems that consumed relatively little energy, or on systems that consumed considerable energy, if the use of that system was not modifiable by the homeowner.

The present study represented a compromise between the theoretically perfect feedback system and the one used in previous studies. For two reasons it focused on the air conditioning system: first, the air conditioning system consumes 70% of the electricity used by these houses in the summer. Second, intuitively, air conditioning usage can be to a large degree modified by the homeowner. Unlike heating, air conditioning is still regarded by many as a luxury. Also unlike some other appliances, its use can be modified in more than an on-off fashion. As noted earlier,

a one degree (Fahrenheit) increase in thermostat setting would result in approximately 12% savings in air conditioning consumption.

Drawing again on the general human engineering model, some insights were gained about how the feedback ought to be presented to the residents. In general, the most effective display systems organize information in a way that is useful to the human operator. One frequently used display shows actual performance as a deviation from some theoretically expected performance, thus facilitating performance corrections. Applying this to the air conditioning system, this suggested the following: if the air conditioner is set to hold the house at a constant indoor temperature, then the air conditioner's energy usage will be a function of the outdoor temperature. The hotter it is, the more energy the air conditioner expends keeping the house cooled to a set temperature. Therefore it seemed important to correct for the temperature in the information we presented to the homeowner.

From July 7, 1975 to August 12, 1975 the electric meters at each home in both groups were read by a research assistant each weekday afternoon. Obviously it would have been preferable to take a measure of air conditioner electric energy usage rather than total system energy usage, but this would require the installation of some kind of metering device. Since the air conditioning was known to account for approximately 70% of electric energy usage, and other electric usage is relatively constant on a daily basis, the house meter reading provided a reasonable approximation to the more complex air conditioning meter. A weather station at the site provided temperature readings each hour. A daily average temperature was computed from the hourly readings for each day (the 24 hour day began at 5 PM to coincide with the meter

readings). Information was collected for five weeks. For each house in the feedback group, a regression line was plotted to predict daily electric consumption from daily average temperature. The R^2 of these regression lines ranged from .57 to .98. (Interestingly, adding humidity and solar flux as variables did not significantly improve the goodness of fit of the regression.) Notice that the large amounts of variance accounted for by the regression lines indicated that the outdoor temperature was the major determinant of the home's electric energy usage. By inference, the electric meter reading was proportional to a reading that would have been taken from a meter on the air conditioning system plus a constant.

For each house, then, it was possible to predict its future rate of energy usage based on outdoor temperature. The feedback to each house consisted of giving a score to each homeowner in which his actual daily electric consumption was expressed as a ratio of his predicted consumption. If the homeowner's past performance suggested that on a hot August 15th he would use 10 units of energy, and he actually used 8 units, then his display for that day would read "80%." Note that this means that each household in the feedback condition attempted to improve its electric consumption relative to a standard derived from itself, rather than some theoretical standard, or one derived from other units.

Procedure

Rather than developing physical systems to process the feedback information, for the reasons suggested earlier, it was done by people. This necessitated the constraint that feedback could be given only Tuesday through Friday. (We could not find people to be available reliably to read the meters on weekends). Each weekday, at approximately

the same time of day, a research assistant went to each house in the feedback and control groups and read the meter. Tuesday through Friday, just prior to reading the meters, he called the project office and was told the predicted consumption rates for the houses in the feedback group. (This was based on the immediate 24 hour's temperature readings inserted into the regression equation for each house.) He then went to the houses, read the electric meters, calculated the day's consumption, and for the houses in the feedback group, calculated the ratio of actual over predicted consumption, and recorded this percentage in a display accessible to the homeowners.

A lucite display was attached to the outside of the kitchen window in each home of the feedback group. The display was approximately 5" by 3" and small plastic numbers could be put into the display to show the percentage consumption reading.

The Pre-Feedback Communication

The feedback extended from August 13 to September 4. The same day the feedback began each household in the feedback group received a letter explaining the feedback procedure.

Based on the data we have collected so far we can make predictions about how much electricity you are likely to use each weekday. We can do this because for the past month we have been matching your daily electric usage to the daily weather patterns. Thus as soon as we know the weather for a particular day, we can look at a chart showing how the weather should affect your electric usage and make a prediction.

We have installed a lucite display on your patio window so that we could give you daily information (Tuesday through Friday

and possibly Monday) about how your actual electric usage compares to our predictions. We will give you this information as a percentage. This means that if the display shows 100%, you are using electricity at the same rate, relative to the weather, as you did last month. If the display shows a number greater than 100%, it means that you are using electricity at a greater rate, relative to the weather, than you did last month. In other words, numbers greater than 100% mean you are using too much electricity according to the rate you have established yourself in the last month. If the display shows a number less than 100%, it means that you are using electricity at a lesser rate, relative to the weather, than you did last month. That is, numbers less than 100% mean you are conserving energy according to the rate you have established yourself in the last month.

Second, the homeowner's attention was focused on air conditioning, they were told that in the summer the largest use of electricity was due to air-conditioning and that the best way to reduce consumption was to use less air conditioning.

We hope that this study, which is concerned with electricity usage, will encourage you to save energy whenever possible. In the summer, the greatest use of electricity is due to your air-conditioning needs. Therefore, by using your air-conditioning a little less each day (that is, by turning your thermostat up higher) you will save a great deal of electricity.

The control group was sent the same letter except for the part dealing with the feedback procedure. Therefore, summarizing the similarities between conditions, all households, regardless of condition, had their electric meters read five days a week, were told they were in an energy study, were told that air conditioning was the largest use of electricity, and that we hoped they would reduce their air conditioning usage. Thus both demand characteristics to reduce electricity consumption and information received about how to do it were the same for both groups.

RESULTS

First it is necessary to test whether the experimental and control groups differed in their energy consumption levels prior to the introduction of the experimental treatment. The average daily consumption in the pre-treatment period was computed. The feedback ($\underline{M} = 68.33$, $\underline{SD} = 10.45$) and control ($\underline{M} = 69.14$, $\underline{SD} = 11.04$) groups did not differ on this score, $\underline{F}(1,27) = 0.04$.

There are two scores to use to assess the effectiveness of the treatment. One is the average daily consumption for each group during the treatment period; the second is the average percent reduction achieved in each group. (The "percentage reduction" is defined as the pre-treatment daily consumption minus the treatment period daily consumption score, divided by the former.) As suggested by Keppel (1973),

the most sensitive analysis for both scores is one involving blocking the subjects by their pre-test scores. Based on Feldt's (1958) procedures, the optimal number of blocks proved to be four. The mean daily consumption of the feedback group during the feedback period was 48.56 ($SD = 7.94$); the mean daily consumption for the control group during the same time period was 54.25 ($SD = 5.12$). In an analysis of variance that included blocking, as well as treatment, as a factor, a main effect of treatment was obtained, $F(1,21) = 4.81$, $p = .04$. The treatment by blocking interaction was not significant. A similar result emerges if the percentage reduction scores are compared. The feedback group achieved a mean reduction of 29.28% ($SD = 8.79$) and the control group a reduction of 22.40% ($SD = 7.48$). Again using an analysis that included a blocking term, a main effect of treatment was obtained, $F(1,21) = 4.77$, $p = .041$. Again there was no significant interaction effect.

To summarize, the control and feedback groups did not differ in their electric consumption prior to the feedback period. The feedback caused the group that received it to use 10.5% less energy than the control group. Comparing the two groups' percentage reduction score, the feedback group reduced their consumption 30.71% more than the control group.

The reader will have noted that the during-treatment consumption scores for both groups are considerably lower (19.77 kilowatt hours less for feedback, 14.89 less for the control) than during the pre-treatment period. It is tempting but inappropriate to interpret this reduction as a conservation effect. Unluckily, the average outdoor temperature was cooler during the treatment period than during the pre-treatment period, and consequently the need for air conditioning was less.

The degree-day model is too imprecise to partition the effect into its

two possible components.

One would also like to know how the effects of the feedback occurred over time. Figure 1 suggests that the savings of the feedback over the control group appeared early in the feedback period and were maintained at a relatively constant rate. Supporting this, no treatment

Insert Figure 1 about here

by time interaction was significant in a treatment period analysis.

Who in the experimental condition was most successful in using the feedback information to reduce their energy consumption? One aspect of this question asks whether it was the initially highest energy users who most reduced their air conditioner use. To examine the relationship between pre-treatment level of consumption and extent of electric conservation during treatment, correlations were computed between mean daily electric consumption during pre-treatment and the absolute reduction (pre minus during) achieved by the householder during the feedback period. In neither the feedback nor the control group was this correlation ($r=.06$ and $.31$, respectively) significant. For the feedback group this means that a household's initial consumption level was not related to the size of the reduction in consumption that it was able to achieve. Households that initially used less energy were able to reduce their energy consumption as much in absolute units as households that initially consumed more energy. As this statement implies, in the feedback group those who initially consumed less energy were actually able to achieve a greater percentage reduction than were the initial high users. The correlation was calculated between initial consumption and the percentage reduction score. The correlation was $-.59$ for the feedback group ($p < .005$) and

-.17 for the control ($p = \text{N.S.}$).

DISCUSSION

The results have shown that the present feedback procedure is an effective strategy for conserving electricity. Households that received the feedback were able to use it to achieve a reduction in their electric energy consumption. In measures of absolute and percentage reduction, the feedback group used 7.8% less energy and reduced their consumption 30.8% more than did the control group. The level of energy conservation obtained was unrelated to the initial level of energy use. Lower users were able to achieve as large an absolute reduction in energy use as were initially higher users; their percentage saving was therefore greater. This suggests that energy conservation campaigns need not be aimed solely at the relatively higher energy consumers; lower users are also capable of further conservation.

Daily energy consumption feedback was the technique used in the present study to achieve this consumption reduction. The actual feedback technique used had several elements, any or all of which may account for its effectiveness. One explanation of the effect would focus on the effects of the feedback per se. Another would emphasize the attentional and commitment-producing "by products" of the feedback technique. The explanation centering on the feedback procedure would claim that timely feedback is helpful in guiding people to effective conservation behavior, in convincing them that their conservation techniques are effective, and in motivating them to achieve the goal of energy reduction. But of course, other aspects of the treatment of feedback may have at least partially accounted for the energy reduction. By agreeing to take part in an experiment which

demands that he allow a stranger into his backyard to read the electric meter, to have a lucite device attached to his kitchen window, and to spend a few minutes each day considering his percentage score, the homeowner has committed himself to the experiment (see Pallak & Cummings, 1976). In line with predictions derived from either cognitive dissonance theory (Festinger, 1957), or attribution theory (Bem, 1972), attitudes favorable to conservation probably developed and helped to sustain the motivation to conserve.

Future research will be needed to determine whether the feedback or the commitment and attentional aspects of the present treatment procedures should be emphasized in accounting for their effects. However, the real world possibilities of application of feedback techniques need to be kept in mind. Any large scale realistic application of feedback techniques will be of a sufficiently voluntary nature to produce similar commitments in future users. From this perspective, the enhancement of commitment to voluntary conservation should be seen as an important consequence of the feedback procedure. Feedback per se may be effective in reducing energy consumption or it may be a successful way to commit people to the idea of energy conservation. Of course, instrumenting feedback will be a somewhat costly process. Therefore further research will need to determine whether other energy consumption reduction techniques with their concomitant commitment procedures are as effective as feedback procedures in reducing energy consumption. Still, since feedback of some sort is essential in demonstrating to homeowners that other techniques are actually effective, all conservation tactics are likely to contain some feedback components.

Feedback is generally thought to be effective for two reasons:

First, feedback serves to motivate individuals to adopt a goal and to try to achieve it (Locke, Cartledge, & Koeppel, 1968). In the present situation, we know from informal conversations with the homeowners that they were motivated to save energy in order to save money. We may have imposed on top of this long term motivation a short term motivation to do well in our energy study. Second, feedback also cues individuals to the procedures that are most successful in achieving the task. Feedback given frequently to homeowners can show them which of their several attempts to reduce energy was effective. Of course, in the present study homeowners were cued right from the beginning to focus on their air-conditioning system. However, by attending to the feedback homeowners may have found other ways to conserve energy.

Open-ended interviews conducted after the experiment was over suggested that both of these components of the feedback process were working in the present study. Many of the homeowners in the feedback group were excited by the study, used the feedback to monitor their behavior, and made alterations in their habits in the hope of getting better feedback ratings in the future. For example, Mrs. Z said "When someone came to my house and asked what those numbers were I'd say, I'm taking part in something important. I felt I could see what I was doing. When the numbers went over 100, I really tried. I kept the shades down to keep the sun out." Another participant, Mrs. P. said, "I enjoyed seeing the feedback, my family liked being part of the study and it gave us a sense of being involved. I felt encouraged and saw savings." Mrs. Z and Mrs. P had the two best conservation ratios in the study. On the other hand, the feedback made less of an impact on other people. For example, Mr. B said "I found I was using the same or more energy.

On occasions when I saw I was using more, I lowered it, but I usually wouldn't make myself uncomfortable." Other people expressed a feeling that they were not given enough support. Mr. F said "if support had been given to the participants then the study would have been more important. The idea was good but lacked backing." It is hard to pinpoint exactly what support means, but it seems from some of the residents' comments to be a combination of a desire for specific information about the study and how to conserve, as well as for more attention and concern for how they were doing on the part of the researchers.

This suggests that in future feedback research, members of the research team might work actively with the participants in developing strategies and techniques on energy consumption. Even in as simple a matter as air conditioning there are tactics available that can achieve relatively large energy savings with relatively little increased discomfort to the participants; the physical scientists and engineers who have studied these systems can suggest these techniques. Here the scientists would be functioning like the agricultural extension agents who the government stationed in farming counties to mediate the introduction of new farming methods. It is possible to conceive of an urban counterpart, an "energy conservation agent" functioning in a similar fashion.

Future research involving energy consumption feedback will need to address the question of the optimal nature of the feedback for various energy control systems, and perhaps for various groups. In the present study the feedback was organized in terms of deviations from the consumption pattern predicted by the person's own past energy usage basis. Moderate energy users were as affected by this kind of feedback

as were high users. High energy consumers might be more affected by feedback that allowed for comparisons across individuals. The persistence of consumption reductions following the cessation of feedback also needs to be studied.

All of these questions, and many more, await further research. The results of the present study, which used a rather crude, approximate, and incomplete feedback technique, suggest that this future research, using better designed and better estimated techniques, is likely to be both theoretically and practically productive. If this proves to be so, it is not impossible to envisage large scale feedback systems becoming an integral part of residential design.

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Footnote

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Figure 1. Mean daily consumption for feedback and control groups at eight different times.