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A BEHAVIORAL ANALYSIS OF PEAKING IN RESIDENTIAL ELECTRICAL-ENERGY CONSUMERS[1]

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This study was concerned with "peaking", which is the tendency for electrical-energy users to consume at high rates for brief periods during the day. Peaking results in the inefficient use of generating facilities, which may lead to unfavorable effects on the environment, such as the construction of new energy producing facilities or the activation of older, less safe, generating units. A continuous data collection system to monitor consumption of electrical energy was installed in the homes of three volunteer families. Information, feedback, and incentives were evaluated for their effects on peak energy consumption. A combination of feedback plus incentives was most effective and reduced peaking about 50%. Removal of experimental treatments resulted in a return to pre-treatment patterns of consumption.

DESCRIPTORS: energy conservation, electrical energy conservation, peaking

The shape of the demand curve for energy over each 24-hr day for residential consumers contributes, in part, to the electrical-energy crisis. In the morning and afternoon, energy consumption peaks at more than three times the daily average (Seattle City Light, 1973). In the Seattle area, where residential consumption accounts for 40% of the total, the morning peak begins at 8:00 a.m. and ends at 1:00 p.m.; the afternoon peak occurs between 6:00 and 8:00 p.m. Although most electrical energy is consumed by industrial and commercial users, the peaking problem is most pronounced in residential consumers (Seattle City Light, 1973). When the nature of the electrical-energy supply is considered, these peaks have ramifications relevant to the energy crisis and the quality of the environment.

Electrical energy must be produced at the precise moment it is needed. It is not generated at one time and stored for later use. The supplier for such energy must therefore design and build a facility that can meet maximum demand, however short in duration that demand might be. Since there are peaks in demand, generating facilities are used at full capacity for only brief periods of time. Much of the time, some generating facilities are not used. Thus, the increased need for electrical-energy generating facilities is a function of increased demand and of the temporal patterning of that demand.

In areas where fossil-fuel energy sources are used, peaking necessitates construction of new plants and consequent environmental impact. Demand peaks also result in activation of older, less efficient, and less environmentally safe facilities. In the Seattle area, where hydroelectric energy sources are used, peaking adds to the requirement for construction and raising of dams and, at times, the activation of older fossil-fuel facilities. At present, a local controversy surrounds the utilities' plan to raise a dam and consequently flood some 8000 acres of land in the U.S. and Canada.

In response to the peaking problem, two solutions are commonly proposed. The primary approach, a technological solution, is to increase the capability to supply more power. Thus, new sources of electrical power (thermonuclear, geo-

[1]This research was conducted in collaboration with Seattle City Light. Reprints may be obtained from Robert Kohlenberg, Psychological Services and Training Center (NI-15), University of Washington, Seattle, Washington 98195.

thermal, solar) would be developed, and, while needed research and development was going on, more of the present type of power-generating facilities would be constructed.

The second approach, a behavioral solution, is to change the consuming behavior of people such that present electrical energy sources are used more efficiently. The present study was conducted to provide information on variables influencing the consuming behavior of people so that peak demand would be decreased.

The electrical-energy consuming behavior of three families was studied over a three-month period. Twenty-four-hour chart recorders were installed in each residence to monitor total electrical energy consumed in each 15-min interval. The main variables tested were (1) information, that is, subjects were told about peaking and its relationship to the local environment, and the wattage ratings of appliances in their home; (2) feedback, a signal triggered by peaking in the household; and (3) feedback plus a monetary incentive. The effects of these variables were assessed by changes in the peak rate of energy consumption.

METHOD

Subjects

Three middle-class families, living in individual homes, had as primary wage-earners, an engineer, a lawyer, and a businessman. The primary occupation of the wives in all three families was housewife. There were two children, the oldest of which was 11 yr, in each residence. None of the residences was electrically heated, but each had an electric stove, a dryer, a dishwasher, and an electric water heater. Subjects were solicited through a notice in a local conservation club newsletter. In addition to requesting that families volunteer to participate in an environmentally related research study on electric-energy consumption, the notice also stated that devices would be installed in their homes to record energy consumption. The notice resulted in calls to the experimenter by 12 families; all expressed an interest in participating. The criteria for selecting subjects were (1) that they lived in the local utility district, (2) had at least two children at home, and (3) did not use electrical power for home heating.

Procedure

The research spanned three-months from early January through March, divided into six consecutive two-week phases. Each phase was preceded by a visit to the home during which the experimenters gave instructions. The only other interaction between subjects and experimenters occurred when data were collected. Weekly data collection consisted of an experimenter visiting a home and removing the data recorded for the preceding week. Although the experimenters were cordial, they did not supply any information to families while collecting data. The data were automatically recorded on the device described below, and data records were not visible to the subjects.

The sequence of events was as follows:

1. Initial instructions, installation of recording device, beginning of the first two-week phase (Baseline I).
2. Information instructions, beginning of second two-week phase (Information).
3. Feedback instructions, installation of feedback device, begin third two-week phase (Feedback).
4. Baseline II instructions, removal of feedback device, begin fourth two-week phase (Baseline II).
5. Incentive instructions, re-install feedback device, begin fifth two-week phase (Incentive plus Feedback).
6. Baseline III instructions, removal of feedback device, begin final two-week phase. (Baseline III).

In some cases, up to four days elapsed between the two-week phases for which data were obtained. This was particularly true for those phases that involved installation and adjustment of apparatus. As pointed out later, only 13 days of data were obtained in a few conditions because some data were lost during the change, over from one phase to the next.

Initial Instructions

Subjects were informed that a device was to be installed to record normal power use. Subjects were also informed that the researchers would make weekly visits to the home to collect the data and check for malfunctions in the recorder. Finally, they were told that additional instructions would be given later in the experiment. An appointment calendar was given to each family with the request that they record vacations, trips, and meals not taken at home.

Information. The peaking problem and its relationship to the raising of Ross Dam, a subject of local controversy, was presented. The subjects were asked to avoid the use of too much power at any one time, and to try to reduce peaking. They were given a list of 100-W lightbulb equivalents for the power ratings of the electrical appliances they had in their home. For example, a color TV is equivalent to three 100-W light bulbs. If the experimenter was asked, subjects were told that they would be given information as to how they did after the study was completed.

Feedback. A current-sensitive relay was installed on the main service to the home. The trigger level was adjusted such that current levels exceeding 90% of the peak levels recorded in the previous two weeks would close a relay. The relay was in turn connected to a 40-W light bulb installed in the kitchen or immediately outside the kitchen window facing the kitchen counter and sink. The information given during the previous phase was reviewed, along with an explanation of the signal light and how it might be used as an aid to reducing peak consumption.

Baseline II

Subjects were told that the feedback device (signal light) would be disconnected, and if they were engaging in behaviors that reduced peaking, they should feel free to continue such behaviors if they so desired. It was pointed out, however, that during this phase, no particular demands or requests were being made.

Incentive and feedback. Subjects were informed that the feedback condition did reduce peaking behavior, but not markedly. They were asked to make special efforts to demonstrate that it is possible to reduce peaking with highly motivated families. As an additional incentive, they were given the opportunity to earn twice the amount of their power bill. Double the prorated amount of the electricity bill for the coming two-week period of time was to be rebated if they could reduce peaking 100%, compared to baseline amounts. One hundred per cent of the two-week electricity bill was to be paid for a 50% reduction in peaking. Payments of 200% and 50% of the bill were to be made for 75% and 25% reductions in peaking, respectively. In addition to the monetary incentive, the feedback light was reconnected and subjects were instructed how to compute peaking reductions from the chart recorder installed in their home. They were also told to feel free to inspect the chart at any time, and the silver paper covering the chart recorder window was removed.

Baseline III

During this final phase, the feedback light was removed, subjects were told that they were no longer on the incentive system, and that they were free to engage in a pattern of power consumption comfortable for them, and that would be representative of their future habits.

Apparatus and Data Format

Recording equipment consisted of Esterline-Angus, 15-min power recorders. Each 15 min, the recording pen reset to zero. The raw data thus consisted of a long strip chart of vertical lines of varying height; the height of each line represented the relative energy consumed for that 15-min interval. In addition to the Esterline-Angus recorders, current-sensitive relays were utilized as described above.

The data are reported as the number of energy units above a criterion level. The criterion level was determined for each family in the following manner. Each day consisted of 96, 15-min energy assessments. A daily peak level was selected such that it was exceeded by the 10 highest 15-min totals. The criterion level used throughout the study was the average of the first two week's daily peak levels. Peaking was defined as energy consumed in a 15-min interval that was in excess of the criterion level. Calibration of the recording units was arbitrarily adjusted, which precluded a precise determination of the value of an energy unit. Thus, the data provided relative measures of peaking within each family.

RESULTS AND DISCUSSION

The cumulative number of energy units above the criterion for peaking for each family is given in Figure 1. The figure shows that information did not seem to affect behavior resulting in peaks in power consumption. However, it does appear that feedback, to some extent, and the incentive and feedback condition, to a larger extent, did reduce peaking in each family.

Although most of the data in Figure 1 are presented in 14-day blocks, there are three instances in which one day's data were lost. The cumulative records shown in Figure 1 for Family A, Baseline II and Baseline III, and Family B, Feedback, represent 13-day blocks. In the case of Family A, the missing data would enhance the apparent experimental effects shown in the figure. In the case of the Feedback condition for Family B, however, the missing day's data would reduce the overall level of the cumulative record for that condition, and hence reduce slightly the apparent effect shown in Figure 1.

Figure 1 reveals little carryover from an experimental condition to the following baseline period. Although the Baseline III period for each of the three families shows the smallest cumulative number of energy units consumed above peak level, note that this research spanned a period from early January through March. During these months, total power consumption in this area decreases slightly, due to an increasing number of daylight hours and a decreasing use of heating equipment for ignition or forced air.

The information condition had little effect for all three families, consistent with results reported by Herbelein (1974), who attempted to influence consumption of electrical energy by apartment dwellers. There are several interpretations of this finding. The first might be that the nature of the information intervention, which consisted of a brief meeting with the family, was not sufficient to produce changes in the basic pattern of living and lifestyle of the family. The reductions in peaking observed in the feedback and incentive-feedback conditions did require such changes. The times at which dishes were washed, showers taken, and clothes dried were said to be quite inconvenient by each of the families. Second, it is possible that since the present subjects were already concerned with the environment, they had made their maximal response to the information type of intervention; that is, from what they knew of the energy crisis, these families had already reduced their energy consumption and were unwilling to tolerate further inconvenience to reduce peaking. A final interpretation is that the information intervention did result in changes in behavior, but these behaviors were not sufficient to produce significant changes in the dependent variable. For example, all families reported that their main response to the information conditions was to make sure that all unnecessary lighting was eliminated and, in one case, to reduce the power ratings of light bulbs used in the home. Although such behaviors are an improvement, it is unlikely that the dependent variable was sensitive enough to pick up changes of such small magnitude. Also, even though the families had information pertaining to the relative power consumption of various appliances, it was presented in a quantitative form that might not have been maximally communicative.

Although feedback seemed to be effective with each family, the relatively small magnitude of this effect may be indicative of the high strength of the behaviors involved in producing peaks. Certain daily patterns of running a household are thoroughly ingrained. Washing and drying clothes on Monday morning, and taking a shower before work or cooking hot meals at dinner time have probably occurred with regularity for each of these families over the past

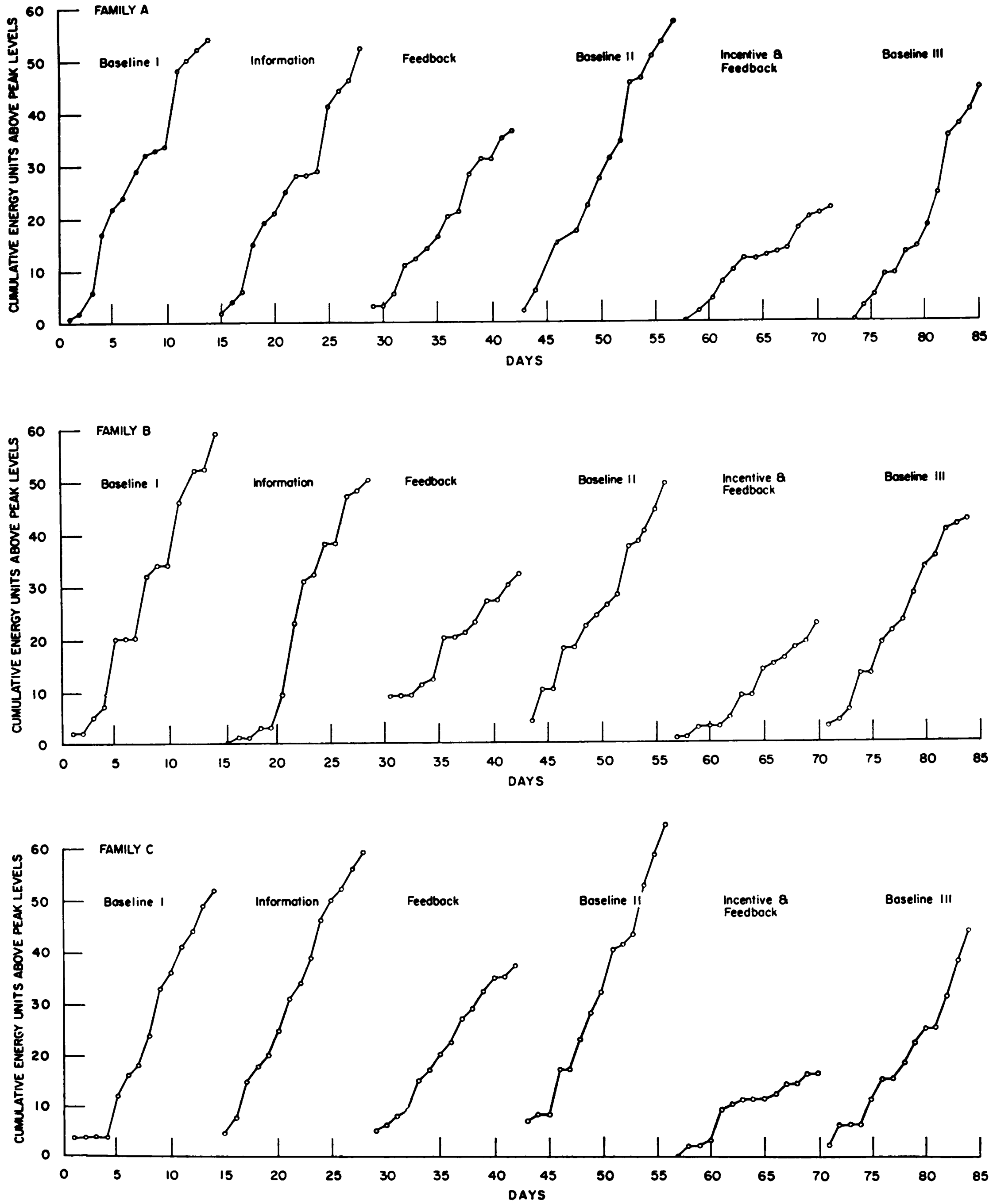

Fig. 1. Cumulative energy units above criterion peak level for each experimental condition and for each family.

several years. On the other hand, the effect that was shown was probably due to the immediacy of the information provided through the feedback device. For example, it may not have occurred to some subjects to delay turning on the dishwasher, which consumes a great deal of hot water, until just before bedtime. All three families indicated surprise at the relationship between activation of the signal light and operation of the hot-water heater; the use of moderate quantities of hot water would result in the signal light going on and remaining on for over an hour. In fact, all three families reported the most difficulty controlling behaviors that resulted in activation of the hot-water heater. Wives felt the main burden in reduced peaking.

The largest effect was shown during the incentive-feedback condition. It should be pointed out, however, that addition of the monetary incentive was confounded with instructions that might tend to motivate the subjects more. They were told basically that "the power company is right, people can't change. We will have to raise Ross Dam". During this condition, families were also given instructions in reading and interpreting the chart produced by the chart recorder. Thus, a great deal of additional information was provided, *e.g.,* a family could easily see at what hours peaks occurred and how they performed compared to the previous day. The difficulty in reducing peaking behavior was clearly illustrated in this condition. Highly motivating instructions, signal-light feedback, monetary incentive, and recorder-chart feedback reduced but did not eliminate peaking.

The generality of the present results is of course limited by the sample size and nature of the families participating. On the one hand, employing subjects already "concerned about the environment" could be interpreted as using a highly motivated group of subjects; thus, the effects observed might be the maximum effects possible with these variables. On the other hand, it can be argued that such concerned subjects have already taken steps to reduce energy consumption and that the magnitude of the effects observed here are diminished by this former effect. On the basis of the present data, one cannot determine how much each of these possibilities might have contributed to the obtained effects. However, the results do indicate that there is a limit to the inconvenience families are willing to tolerate to reduce peaking. That is, if the data obtained during Baseline III conditions are representative of the future peak energy consumption of these families, they do not appear much different from that shown before experimental interventions were introduced (*i.e.,* Baseline I).

Voltage reductions that would dim the lights, or an easily readable watt-hour meter in the home are two of the many possibilities for providing feedback devices that might influence consumption. Although little more than an educated guess, a cost-effective procedure for changing energy consumption might use TV and radio to provide immediate feedback about the consuming behavior of large groups of people. It would seem fairly simple to add this type of information to pleas for changes in energy consumption that are often heard on radio and TV. Best of all, of course, would be a study in which the media were used to provide information both with and without feedback in order to assess experimentally the effect of this variable.

Although this study indicated that it was difficult to change consuming behavior, the data did show that feedback was important in producing the behavior changes observed.

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