Data Acquisition and Analysis for Residential Probabilistic Demand Response Modeling

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Abstract—**There is a demonstrated need for ways to combat the growing demand for power across the United States. With unrenewable resources becoming ever more scarce and renewable resources being more expensive and difficult to efficiently harness, meeting this demand by simply increasing power production capacity is becoming impractical. Though, a different solution is proving to be very beneficial by reducing demand at peak times rather than increasing power production. This solution is in the form of demand response (DR) programs. While DR programs prove very useful in the industrial and commercial sector of the U.S., their potential has yet to be proven in the residential sector. This paper presents the beginnings of data acquisition and analysis from residential power consumers such that a probabilistic model can be developed to show the potential benefit of incentive based DR programs. A model of this type could be combined with models that simulate residential loads to show to overall effect of particular DR programs on the expected demand of a region.**

Index Terms—**Demand response, probabilistic modeling**

I. Introduction

In recent years, demand for power across the U.S. and the world have been on the rise along with new and improved ways to combat the growing consumption [1]. More efficient appliances and technology have been released and encouraged by utility companies along with improved ways of producing the power itself. Another method pushed by utilities to solve the growing power demand is demand response (DR) programs. DR programs have shown to be very beneficial in the industrial and commercial sectors to both the utility companies and the participating consumers [2].

The use and demonstrated benefit of DR programs in the residential sector, however, has been relatively low compared to that of the industrial and commercial sectors. Though, the need for useful DR programs in the residential sector has been shown to be high as during periods of high demand, residential consumers have been shown to account for up to 50% of the total load on a utility company [3]. With the success of DR programs in the industrial and commercial sectors and the demonstrated potential of the success of these programs in the residential sector, this paper presents the beginning of a study designed to acquire data from residential power consumers about their power consumption habits and willingness to participate different incentive based DR programs.

The remaining parts of this paper are organized as follows. Section II introduces the research design for acquiring the data from residential consumers. Section III shows the results gathered from the study and draws final conclusions on the findings. Finally, Section IV describes the next steps to be taken to improve data acquisition and develop a probabilistic model based on the data gathered.

II. Research design

To collect the data from residential power consumers, a survey was created. The survey was used to understand the influence of financial incentives, demographics, habits, and social psychological factors on certain DR programs during peak hours. This survey was collected across 4 states: California, Texas, Virginia, and Tennessee. To increase the accuracy of the data collected, the survey was taken by a representative sample based on census data to meet the representation of gender, income, and race among those who paid utility bills and could make household decisions.

The Survey was broken down into 6 categories of questions: Introduction questions, A/C devices and settings, DR questions, Customer Segmentation Variables, Habits, and Demographics. For the purposes and time-frame of this portion of the study, only the A/C devices and settings and DR questions were analyzed.

The A/C Devices and Settings questions were designed to give insight on how much energy a participant regularly consumes. The questions analyzed were the following:

1. At what times of the day is someone at your home?
2. What type of cooling system do you have at home during the summer?
3. What type of heating system do you have at home during the winter?
4. What is your cooling temperature setting when someone is at home during the summer?
5. What is your heating temperature setting when someone is at home during the winter?
6. What is your cooling temperature setting when someone is NOT at home during the summer?
7. What is your heating temperature setting when someone is NOT at home during the winter?
8. What is your monthly electric bill in the winter?
9. What is your monthly electric bill in the summer?

Questions 1-3 allowed for participants to "select all that apply" and questions 4-7 allowed for "N/A" as an option is participants did not use heating or cooling.

The DR questions were designed to indicate how likely participants are to join certain DR programs with or without certain given incentives. The DR programs offered and analyzed for this portion of the study were as follows:

- Installation of an A/C switcher
- Installation of an automatic A/C thermostat adjusting device
- Installation of a heat pump switcher

- Installation of an automatic heat pump thermostat adjuster

The A/C and heat pump switchers are devices that receive a signal from the participant's utility company telling the device to shut of the A/C or heat pump during times of high demand. The A/C or heat pump still allows the inner fan to run, but shuts down cooling and heating capabilities for a short time. The A/C or heat pump thermostat adjuster receives a similar signal from the participant's utility company during times of high demand which adjusts the thermostat setting by a maximum of 3° F to save energy. The questions analyzed were the following:

1. Would you install an A/C switcher given no incentives other than to save electricity?
2. What is the minimum monthly reward per month ($) that you would accept to install the A/C switcher?
3. Would you install an A/C switcher given any of 3 provided incentives?
4. Would you install an automatic A/C thermostat adjusting device (+3° max) given no incentives other than to save electricity?
5. What is the minimum monthly reward per month ($) that you would accept to install the automatic A/C thermostat adjusting device?
6. Would you install the automatic A/C thermostat adjusting device given any of 3 provided incentives?
7. Would you install a heat pump switcher given no incentives other than to save electricity?
8. What is the minimum monthly reward per month ($) that you would accept to install the heat pump switcher?
9. Would you install a heat pump switcher given any of 3 provided incentives?
10. Would you install an automatic heat pump thermostat adjusting device (-3° max) given no incentives other than to save electricity?
11. What is the minimum monthly reward per month ($) that you would accept to install the automatic heat pump thermostat adjusting device?
12. Would you install the automatic heat pump thermostat adjusting device given any of 3 provided incentives?

Questions 3, 6, 9, and 12 mention three provided incentives. These three incentives were chosen based on rewards typically offered by leading utility companies at the time of the development of this survey. The three provided incentives were the following:

- $30 reward per summer/winter
- Up to $15 per month reward depending on the amount of energy saved using the device installed
- With the option to override the settings or action made by the device installed

III. Results and Conclusions

The final survey sample for this analysis included 813 participants: 215 from Tennessee, 164 from Texas, 225 from California, and 209 from Virginia.

A. A/C and Devices

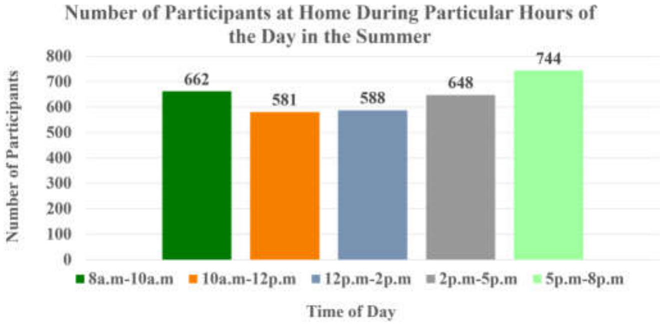

Fig. 1. Number of participants at home at particular times of the day in the summer.

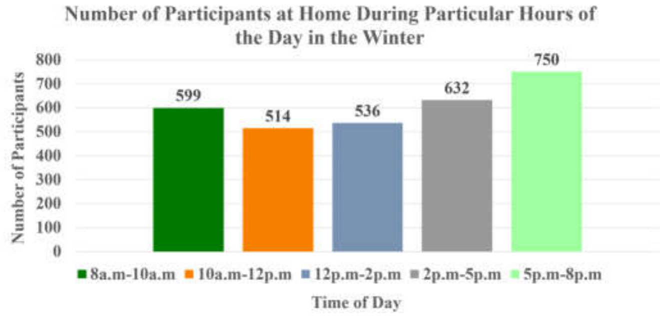

Fig. 2. Number of participants at home at particular times of the day in the winter.

The analysis begins with the A/C Devices and Settings questions. Figures 1 and 2 show the results indicating at what times someone is at a participant's home during the summer (figure 1) and during the winter (figure 2). From figures 1 and 2, at all times questioned more than 50% of the participants have someone present at their home. Furthermore, during peak times (2pm-5pm in the summer and 5p.m-8p.m in the winter) 79.7 % and 92.2 % of the participants have someone present at their home respectively.

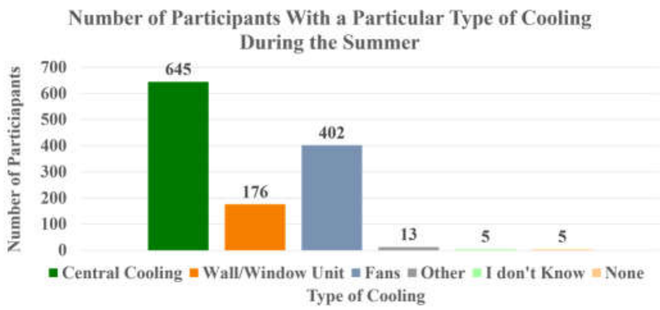

Fig. 3. Number of participants with a particular type of cooling system during the summer.

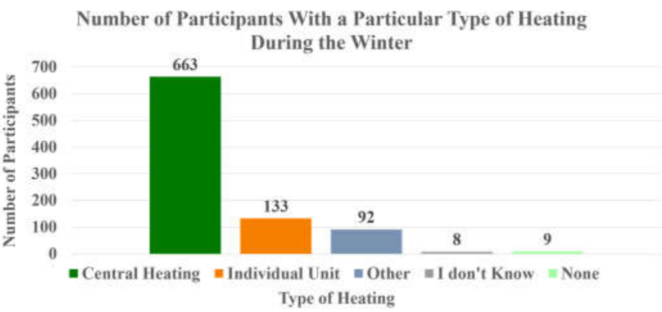

Fig. 4. Number of participants with a particular type of heating system during the winter.

Figures 3 and 4 show the results indicating the type of cooling system and type of heating system a participant primarily has in their home respectively. One of the largest energy consuming appliances in the average home is the HVAC system, so this question is especially important to understand the amount of consumption expected from a residential consumer. The leading cooling system type was central cooling with 79.3% of the participant's indicating it as one of the primary cooling systems in their home. Fans were also very prevalent with 49.4% of the participants indicating them as a primary cooling system in their home. For heating, the primary system was central heating units with 81.5% of participants indicating central heating as a primary heating system in their home. Central heating and cooling were expected to be leading results of this question, but unfortunately they are also the highest consumers of power.

The next questions analyzed were the participant's temperature settings when someone was and was not at home during the winter versus during the summer. In the summer, regardless of whether someone was present at the participant's home or not, the leading temperature setting range was between 72°F and 75°F with 36.8% of participants choosing that range when someone was at their home and 33.7% of participants choosing that range when someone was not at their home. Similarly, in the winter, regardless of whether someone was present at the participant's home or not, the leading temperature setting range was between 68°F and 71°F with 33.5% of participants choosing that range when someone was at their home and 30.9% of participants choosing that range when someone was not at their home. It is to be noted however, that in the summer when someone was not present at the participant's home, the temperature distribution was higher above the peak setting.

The final questions analyzed in the A/C Devices and Settings were the average monthly bills of each state in the winter versus in the summer compared to the average monthly bills of the whole sample.

TABLE I

Average Monthly Electricity Bills

Sample	AVG Summer Monthly Bill	AVG Winter Monthly Bill
Total Sample	$158.25	$160.16
Tennessee	$145.13	$166.71
Texas	$184.63	$148.95
California	$144.96	$140.72
Virginia	$165.21	$182.83

This was the most direct question finding out a participant's power consumption. The results (Table I) of the total sample indicated that, across all four states, the average monthly bill was about even for winter and summer months. Tennessee and Virginia showed higher bills in the winter while Texas and California showed higher bills in the summer.

B. DR questions

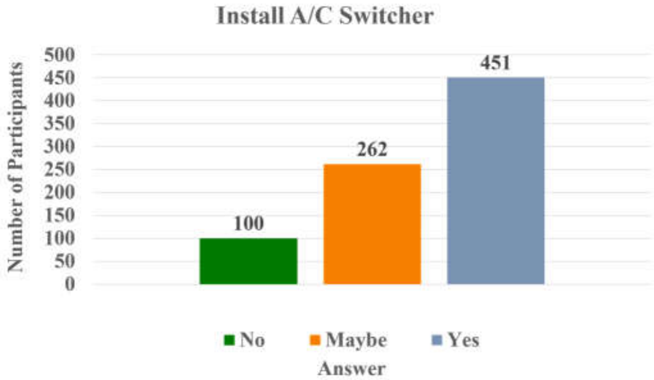

Fig. 5. Participants willing to install A/C switcher.

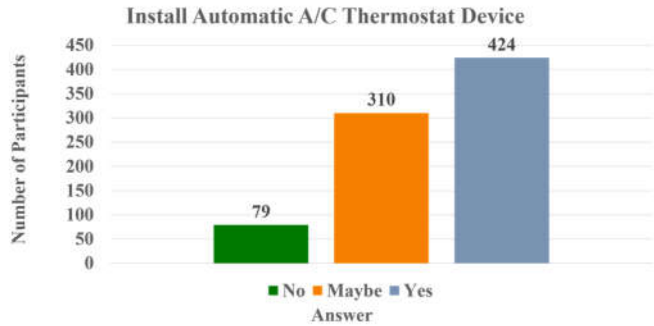

Fig. 6. Participants willing to install automatic A/C thermostat device.

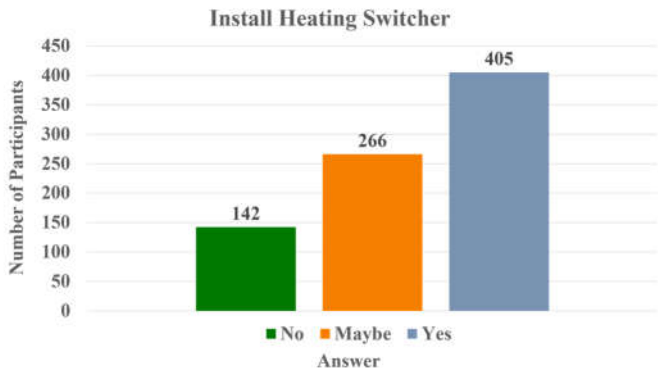

Fig. 7. Participants willing to install heating switcher

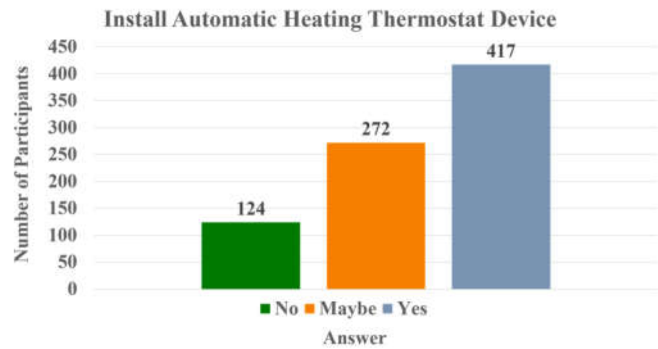

Fig. 8. Participants willing to install automatic heating thermostat device.

The second half of the analysis was concerned with the demand response questions. These questions asked the participants whether or not they would be willing to participate in a particular DR program without incentives. If the participant answered “No” or “Maybe” they were given two more questions:

- What is the minimum reward per month ($) that you would accept to participate in the program?
- Would you participate in the program given any of the three given incentives?

In figures 4 through figure 8, we see the number of initial answers reported when asked about each DR program without incentives. Each program indicated an acceptance rate of around 50% without any incentives.

TABLE II

Increase in acceptance rate given incentives.

DR program	Increase in Acceptance $30 reward per season	Increase in acceptance override option	Increase in acceptance $15 reward per month
A/C Switcher	13%	19%	8.6%
A/C Thermostat Device	17%	21%	13%
Heating Switcher	16%	20%	9.8%
Heating Thermostat Device	14%	18%	9.5%

The other approximately 50% of the participants that chose “No” or “Maybe” then showed the highest increase in acceptance rate when offered an override option to the program switcher or thermostat adjusting device. A close second place was the $30 reward per season even though the $15 per month reward had the potential to be more profitable. These results showed that a participant’s control over their home was a more important factor than a monetary incentive.

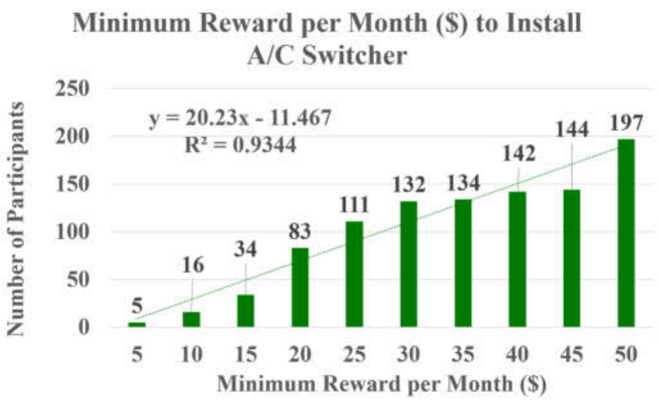

Fig. 9. Minimum reward per month ($) to accept A/C switcher.

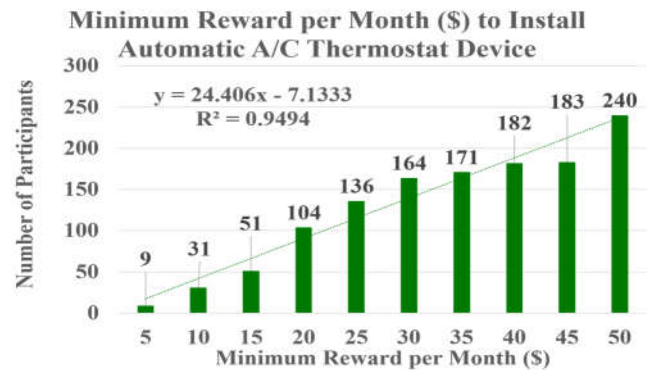

Fig. 10. Minimum reward per month ($) to accept automatic A/C thermostat adjusting device.

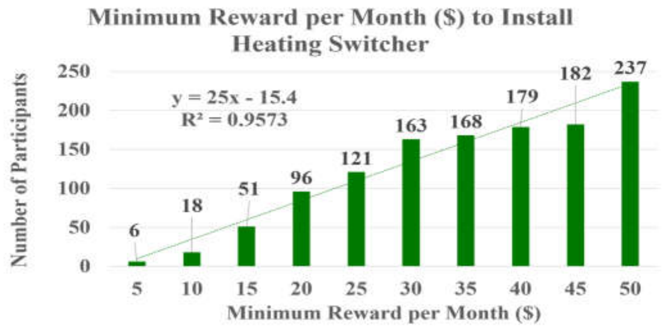

Fig. 11. Minimum reward per month ($) to accept heating switcher.

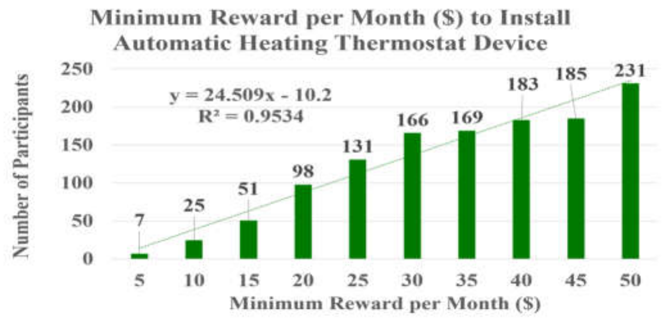

Fig. 12. Minimum reward per month ($) to accept automatic heat pump thermostat adjusting device.

Those participants were then asked to input their minimum monetary reward per month that they would require to accept each DR program. These results are shown in Figures 9 though figure 12. Each of the graph results from this question allowed for a slope to be drawn which gives a general linear approximation of the increase in acceptance given a certain amount of money per month. It is important to note here that in the individual state breakdown, Texas showed a much lower slope in the results concerning A/C devices than the results concerning heating devices. This is most likely due to the difference in climate between Texas and the other states surveyed.

There are two major conclusions to take from this portion of the study. It is clear that climate/weather and degree of control are big influences in the acceptance rates of DR programs. While monetary incentives do increase the acceptance rate in a useful way, giving a linear relationship, the acceptance rate increased more from simply providing an override option. This shows that a participant’s control and comfort are more important to them than a reasonable monetary reward. Also, climate proved to be a big influence in the results, as the monthly bills in Texas as well as the acceptance rates differed much from the other states involved in the survey.

IV. FUTURE WORK

This study is far from complete as the survey contains much more information such as demographic information, general electricity efficiency habits, customer segmentation variables, and manual consumption reduction DR programs. In the future, the rest of this data will be reviewed and analyzed along with correlations between acceptance rates and demographic information. Social and psychological impacts on acceptance rates will also be reviewed as the results of this survey continue to be analyzed.

Once all the information is analyzed, the next step is to improve upon this survey to make it more valid for probabilistic modeling. The questions will be updated to have answers based on likelihood of accepting certain programs rather than binary “yes” and “no” style answers. The survey will also be updated to include new DR programs being pushed by leading utility companies now. The survey also proved to very long and tedious so it needs to be shortened to provide a more concise and less confusing form of questioning. The states being surveyed will also be limited to two and those two states will be of similar latitude and climate to eliminate weather and climate as a factor.

A final step will be to develop an actual probabilistic model that can show the potential benefit of incentive based DR programs in a residential setting. The new survey that is to be created will hopefully provide the right information for this model to be developed and improved. This model would be of great importance to leading utility companies trying to create new incentive based programs.

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