Effect of Enhanced Smart Outlet Control on Energy Efficiency in Low-Income Households

Team Name: The Atlanta Ghouls

Mission Statement: The Atlanta Ghouls seek solutions to minimize the energy consumption from idle plugged-in devices in low-income households. Our team aims to develop the smart outlets market, improve their mobile applications, and bring their benefits to everyone. By reducing energy usage in these households, innovations would actively decrease electricity expenses and reduce toxins released by nonrenewable energy production.

Biographies:

Lauren Johnson is a fifth-year Industrial and Systems Engineering student at Georgia Tech. She is a 2019 ASHRAE scholarship recipient for scholastic abilities and potential service to the Heating, Ventilation, Air Conditioning, Refrigeration (HVAC&R) profession. She is an aspiring data scientist interested in social good and sustainability impacts.

Prahlad Jasti is a second-year computer science major with concentrations in Networks and Intelligence. He is a USACO Platinum winner and has studied topics in algorithm design and cybersecurity. He is interested in applying these sciences to computing ethics and energy infrastructure.

Quan (King) Nguyen is a third-year international Chemical & Biomolecular Engineering student with a minor in Computational Data Analysis. He has a great passion and prior experiences on data science in energy sustainability, bioinformatics & computational biology. He is currently contributing to the international collaboration to develop a global COVID-19 risk assessment tool and website.

Diversity Statement:

The project combines expertise from three energetic undergraduate students at Georgia Institute of Technology representing two Colleges and three Schools. Quan is an international student from Vietnam, he brings his chemical engineering knowledge and data analysis skills to discover the meaning of the datasets and reasoning behind it. Lauren is from Atlanta, Georgia and has a great enthusiasm for investigating how energy consumption impacts elements of our society differently. The final member Prahlad, is from New Jersey and is a talented student in applying algorithm design to energy infrastructure. Our team differs in race, ethnicity, and gender. Coming from multiple academic, cultural, and societal backgrounds, we look at the world and its problems from different perspectives. We are united, however, with the same common passion of reducing energy consumption and protecting our green Earth. Quan was able to determine that low-income households produce the most phantom loads using his skills in data analysis, and Lauren calculated the average energy expenditure of these loads and potential savings due to her background in industrial engineering. Prahlad used his knowledge of designing mobile apps to set up the mockups for our app innovations. With these skills, we focus on delivering solutions that can potentially address the unmet challenge of wasteful sources of energy use. Because of this diversity, we are able to identify the populations that will benefit from our idea the most and apply our technical solutions in accordance with their necessities. The research team recognized the energy overuse and high percentage of low-income households in Georgia, then they decided to connect with other local non-profit organizations to conduct this experiment in this area. The research aimed to bring an impact on reducing energy use in the low-income families in Georgia.

EXECUTIVE SUMMARY:

100 billion kWh (kilowatt-hours) were lost last year to "phantom loads", the electricity used when devices are turned off but still plugged in to wall outlets. This amounts to over $10 billion in energy expenditures. Reducing the impact of these phantom loads would result in energy conserved and money saved. Reduced energy costs have the greatest impact on low-income households (less than $40,000 annually) who on average spend 50% more of their annual income on energy expenditures. A solution to reduce these costs in the market today are smart outlets. These devices can turn off phantom loads from a smart device application. These applications, however, function mostly as switches, without giving the user insights into the impact of the switch. This may reduce the effectiveness of these smart outlets. Our proposal is a randomized experiment that measures the effectiveness of these apps with additional functionality and visualization. Our improvements include the cost estimations based on their device energy consumptions and the reminders to stop the electric use for unused devices every six hours. We seek to form a common habit for everyone to regularly keep track of their household devices to save energy. We hypothesize that adding monetary value will increase the effectiveness of the smart outlets.

BACKGROUND & PROBLEM STATEMENTS:

In a 2015 study by the EIA, low-income households (less than $40,000/year) were responsible for 35% of the total energy consumption in the U.S. (Appendix A). Amounting to over $76 billion in energy expenditures, our study focuses on reducing energy consumption and thereby increasing monetary savings for this population. Although the energy consumption is representative of the portion of the population, we believe the monetary incentive of energy savings will have a larger impact than those of a higher income level.

Plug load devices make up the largest share of appliance-level energy consumption (Appendix B). When devices are plugged in but turned off, they still consume electricity in what is called a "phantom load". It is estimated that 100 billion kWh, which is equivalent to more than $10 billion costs for energy consumption, is lost each year to phantom loads ("Phantom Energy Loss May Be Costing You More Than You Think", n.d). Common devices responsible for these loads include televisions, phone chargers, and computers.

"Smart" outlets were introduced into the market in 2015. These outlets are a relatively new technology that can turn electronics and appliances off from smart-sensing technology and mobile applications. Ranging from $10 to $50, these one-time purchase devices could have a large impact on electricity bills in low-income households. Smart outlets can save energy between 1% and 4.6% on an electricity bill (Christensen & Kemper, 2017). With the purchase of one $10 device, if an electricity bill could be reduced by just 2%, a low-income consumer could regain their investment in just 4 months (Appendix C).

Since the technology to reduce this consumption already exists, our project focuses on advertising these solutions as well as developing a user-friendly mobile app to assist in connecting the smart plug functionality to real-time cost savings. The app would be able to turn appliances off remotely as well as meter how much energy each plug has used this month. This monitoring and alert system will allow the user to be more aware and in control of appliance electricity use. In the next section, we will introduce more details about our proposed solutions in the next section and illustrate how effective they can be to reduce the energy expenses in the low-income families.

PROPOSED SOLUTIONS:

Given the current phantom load problem and demands in reducing energy consumption for the low-income population, we want to propose a randomized experiment to evaluate the effectiveness of smart outlets and our improvements on interactive mobile applications in 300 households in Georgia. Figure 4 (Appendix C) outlines areas with high percentages of low-income people. From the concentrations, this study will focus on sampling in the Southeast United States. Many counties in these states, such as Georgia and Tennessee, have a large number of low-income households (Morrill, 2015). As our team is based in Georgia, we plan to collect the energy consumption data for 300 similar low-income households in the same county or region.

Some effective smart plugs in commercial markets are Kasa Smart ($14.49/2-pack), Meross ($19.99/3-pack), Tp-Link ($17.99/2-pack), etc. These devices are highly rated with thousands of customers on Amazon, with Kasa Smart as the #1 Best Seller for Electric Plugs on

Amazon. These devices have similar options for remote control via an application, legitimizing our research question on their effectiveness.

Currently, these commercial smart devices allow the users control on/off, set up the timers, and express the metrics table for the energy use but they are underestimated and not widely known. They can connect with Alexa, Google Home and Echo and can be activated by voice control. However, these functionalities are not widely known, and these commercial smart outlet app controls do not (or less brands) have any notifications to remind the users which devices are currently used. Our proposed approach aims to emphasize the effectiveness of these smart sockets and their user-friendly mobile apps. We also introduce new functions for the mobile apps, which are cost estimations and reminders of turning off the devices currently draining out electricity unknowingly in households. These new functions will form a new habit/behavior for the users when they are repeatedly reminded to control their unused electrical devices, leading to higher energy efficiency and decrease in monthly budgets. In addition, we are looking forward to collaborating with Kasa Smart, Meross, Tp-Link, or other manufacturers to implement our improvements on their mobile applications. We strongly believe that our collaboration with the Low Income Home Energy Assistance Program and companies that develop smart plugs, along with our new integrations in the mobile apps, increase the prevalence of smart plug usage. Even though we aim to focus on low-income populations in this project, we hope that people from various other backgrounds will purchase these smart plugs.

Research Design

1) *Research Question*: What are the effects of smart outlets on reducing residential energy consumption in the low-income households in the U.S?

2) *Hypothesis*: We hypothesize that energy consumption will decrease if smart outlets and a corresponding mobile application are deployed in low-income households to control plug load devices and track energy expenditures.

3) *Sampling Methodology:*

In Georgia, the Low Income Home Energy Assistance Program (LIHEAP) is actively providing safety and support for families that are in hard situations in managing energy costs (*About LIHEAP*, 2017). We plan to propose our project to LIHEAP and collaborate with them, as they are advocating for the availability of these kinds of federal grants to low-income populations. LIHEA will have lists of eligible low-income families that we can recruit in this project. Georgia Power is also a good contact when we analyze the energy sustainability in Georgia. They have many connections with other charity organizations. For example, United Way and Community Action Agencies, etc provide services, energy assistance and home weatherization. The low-income families from these organizations will be pre-qualified for our project due to their backgrounds. From these organizations, 300 households with similar net income will be contacted as part of a randomized sample. We will encourage people to participate in this project by outlining the potential to improve energy efficiency in their households and reduce their monthly electricity bills. Then, we will choose randomly 100 households to be the control group, which does not have smart outlets to use. The other 100 households will be chosen to just use the smart outlets only. The remaining 100 households will be assigned to be in the treatment group, which will be given access to the application, and their usage data will be analyzed to compare the results with other two groups. The independent variables are the ability to remotely control outlets, the usage metrics generated from them, the ability to set time-sensitive controls, and reminders to turn off unused devices. The dependent variable is how much energy is used (kWh) per household. This study will be conducted in two phases, which include the 6-month baseline period and the application testing periods within 10 weeks (Asensio & Delmas, 2015). The project can be carried out next year when the pandemic has been alleviated to reduce health risks.

Mobile App Design:

The purpose of this application is to let users freely have remote, granular control of their smart outlets, schedule the electric flow of each device, and keep track of their energy usage. The application has multiple sockets representing the connected devices. The users can freely strip the electricity into the devices by turning on and off the smart sockets on the app (Figure 5). Whenever users buy a smart outlet, they will need to give its serial number to the app, and the company developing this outlet will need to give API access to the app in order to allow it to recognize the correct outlet(s). Additionally, this API will allow the users to control the status of all the smart sockets in their households from their phone, as opposed to manually scheduling power flow on the outlet. When they first set up the app, they will need to fill out basic information such as name, state, phone number, work at home status, current schedule, etc. This information will help the application verify the correct electric rates in their state to calculate savings and determine recommendations based on its load identification algorithms on what devices to activate or deactivate.

They can directly change the names of devices that are connected to the sockets so that they can keep track easily. The users can be able to click into a specific device to see their total plugged-in hours, average energy used per hour, and estimated payment for that day, the day before, and the whole week (Figure 5). The usage data will be recorded every hour and automatically updated on the app. This metrics table will help the users visualize easily how much energy they consume and how much they need to pay for that specific device. Thus, people can keep track of their budgets to be better. The payment will be calculated based on the current electric rates per kWh in their state.

In addition, users will have two options for remote control of these outlets. One option will send the user a notification to disable power flow to a certain outlet if it has exceeded the daily recommended energy usage (Figure 5). Additionally, they will be able to schedule a time for disabling or enabling an outlet in case they are not able to access their phone at the necessary scheduled time.

Lastly, the application will have a periodic notification system that reports the status of each device to the user, such as how long a device has been unplugged and its energy usage for the day. The application will detect devices that are plugged in and not used, and will notify users to turn them off.

<u>Building Smart App for Controlling Smart Outlets:</u>

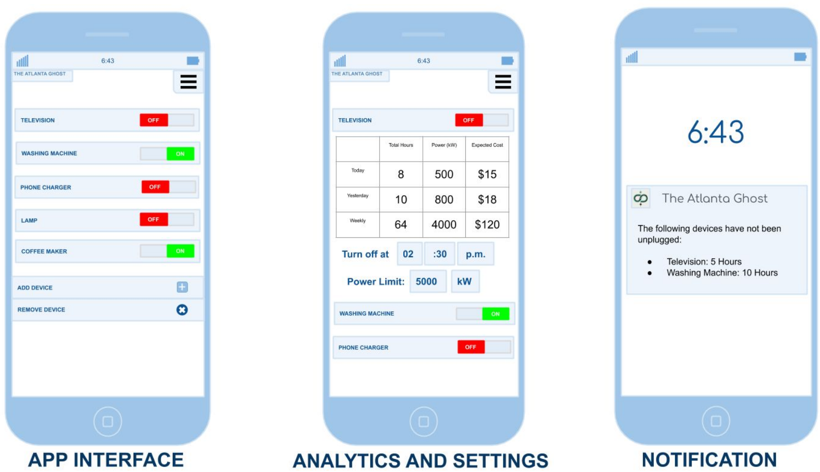


Figure 5: The first interface allows the user to toggle the status of each outlet and add or remove devices. Each device has a card with a dropdown menu, which allows the user to schedule power flow for each device and set a limit to daily power usage. These settings are shown in the second interface. Lastly, every 6 hours, the app will send notifications if daily usage has been exceeded or if a device is unused, which is shown in the phone's lock screen.

Expected Benefits:

If the families can purchase multiple smart outlets at their households and regularly keep track of their socket uses, our team expects that the energy consumption will decrease significantly. We believe that the tracking app is easy to control and the smart plugs are pretty cheap, so the benefits these outlets can bring will be potentially tremendous. People can estimate how much energy they use (Appendix D). The reminders/notifications are also helpful because they will let people recognize what devices they have forgotten to plug out and easily cut off the plug load using the app. Gradually, the users will form a new habit, which checks their plug load devices at home and saves their billing costs (Wax, 2020). In addition, the manufacturers can be benefited from this study that if it is successful, the people will purchase more of these outlets. We would highly recommend the manufacturers incorporating our new innovations in the apps.

We expect to reduce up to 5% of the energy used in the monthly bill within the sample, as found by previous research on how smart outlets save energy in residential households (Christensen & Kemper, 2017). This would account for a significant reduction of $3.5 billion per year for the low-income families calculated using the data from the 2015 RECs survey (U.S EIA, 2015).

Within 300 households in the sample, we expected to reduce totally $216000 per year (Appendix D) if we assume there are at least 5 devices used smart plugs (i.e: phone & laptop chargers, television, rice cooker, washing machine, dryer, lamps, etc). This estimation is only based on the computer plugged-in, which consumes 4.5 kWh per week (Schlossberg, 2016). However, even in the low-income households, we expected people will cost more than this amount of power due to the inefficiency of devices and deteriorative houses and more appliances than just the laptop. The estimated electricity usage (about 324000 kWh) is equivalent to 229 metric tons of CO_2 ("Greenhouse Gas Equivalencies Calculator", 2020). It is the same as the amount of CO_2 emitted from an average vehicle in 568,439 miles driven or charged up to 29,215,204 number of smartphones. However, this is just about 300 households in Georgia; there are still millions of low-income households under $40K in the U.S. We believe that smart plugs will make more impacts in the large populations and reduce much energy use and the greenhouse gas emission.

Data Analysis Plan:

The daily and monthly data will be recorded for every single household and they will be stored on the company's site. The data will be compared between our control group and testing group to analyze if the smart outlets actually bring great benefits and reduce expenses for the low-income population. Additionally, it will help in the development of algorithms such as CNNs that will allow the app to eventually forecast electrical loads and make its own schedules, making the system more autonomous and intuitive. (Electricity Price)

Technology-to-market plan

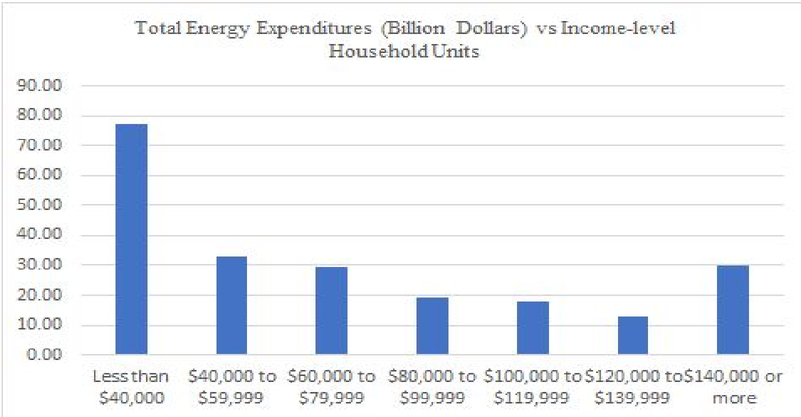
Deployment Plan:

We will deploy this technology throughout low-income neighborhoods near Atlanta, such as Marietta, as it has households with larger families and lower income per capita than other suburban areas (Marietta Demographics, 2018). We have chosen Atlanta, as this is where our team is primarily based. We will provide information through pamphlets outlining the energy waste of phantom loads and potential savings using smart outlets. We will allow each household to use the smart outlets for two months, free of charge, before asking if they want to buy one. Ideally, they will be using at least four outlets, as this is the number of energy efficient features that large households lack over smaller households. (Energy Efficiency) For each household, this solution will cost $40, but this will save about 30% of their current energy usage, which translates to $376 per year. The ideal case occurs when devices attached to a smart outlet have usage and inactivity periods that are mutually exclusive, i.e. the device is never active when it is not used. This ideal case will result in savings of about 48.5%, or $524 per year. (Energy Efficiency) Although this may not be possible due to issues such as devices that need to be pre-activated e.g. water heaters, we hope that our scheduling options and remote control capabilities for reducing unnecessary loads will create a significant improvement over existing smart outlets that use manual or daylight-based scheduling.

Privacy Protections:

We will be collecting data on energy usage for various types of devices across two months to determine large periods of time where energy usage dipped for an appliance. We will choose common appliances so that they can not be identified to an individual, and we will de-identify this usage data. Although children may use some of these devices, we are collecting and analyzing data from households as a whole rather than just children, so it is not necessary to provide special protections under IRB law.

<u>**Appendix A**</u>



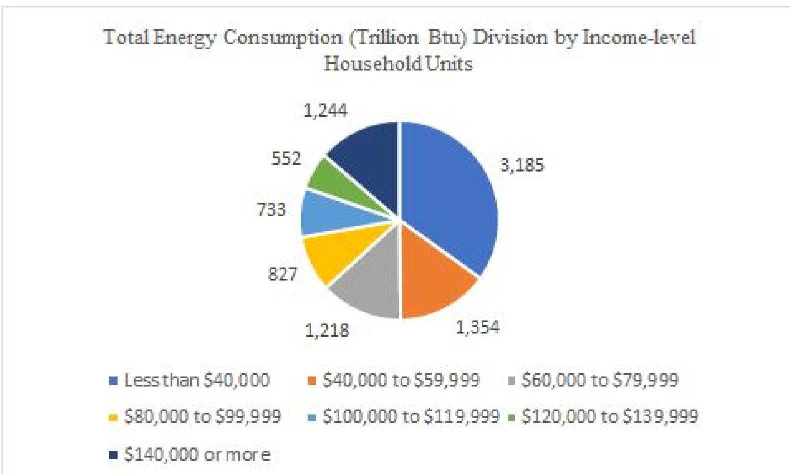


Figure 1 & 2: The bar and pie charts illustrate that the households with income less than $40,000 take up about 35 % the total energy consumption in the U.S and are double or triple other income-level households.*

*These charts are generated from the 2015 Residential Energy Consumption Survey: Energy Consumption and Expenditures datasets.

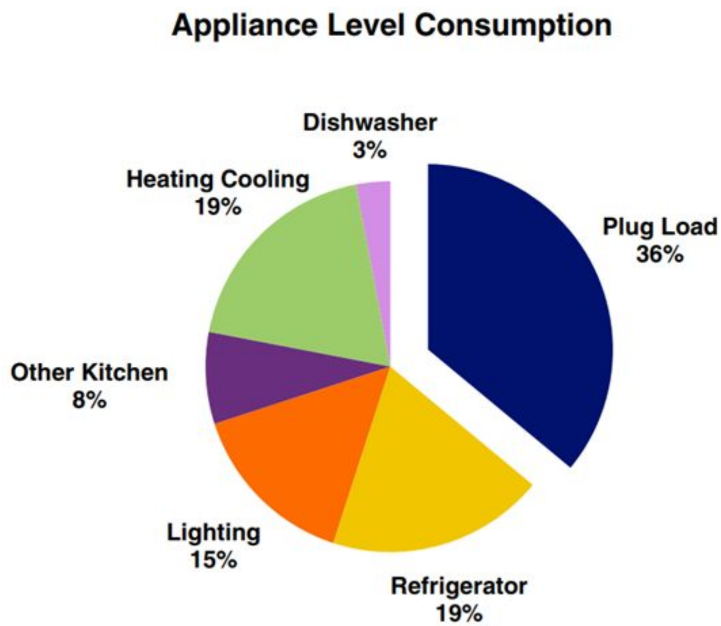


Figure 3: Appliance-level electricity measurements (Asensio & Delmas, 2015). Plug Load is considered as the most energy use in the residential households (36%). People tend to leave the devices plugged-in and this costs lots of energy unknowingly. The weighted average of household electricity use data was directly measured and not estimated by any modelling. The figure is directly referred from the paper "Nonprice incentives and energy conservation" of Dr. Asensio and Dr. Delmas, published in the Proceedings of the National Academy of Sciences in 2015.

Appendix B

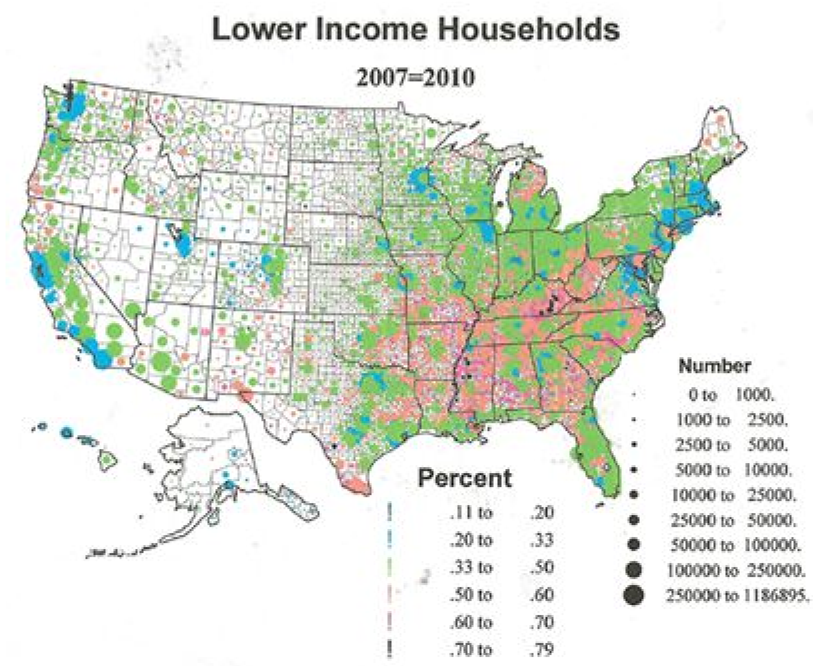


Figure 4: The geography of low-income Households in the United States in 2010. The U.S South region has many poor counties (income less than $40000). The pink, orange, & black represent areas with the largest share of lower income households (Morrill, 2015). The choice of sampling is randomly taken in the rural of the State of Georgia. The figure indicates that our study is focusing on the high impact region, which can correlate to other locations. Also, the Atlanta Ghost team is based in Georgia, so we decided to conduct the experiments here to reduce the travel and miscellaneous costs.

Appendix C

<u>Household savings from smart outlet:</u>

Average electricity bill: $1525/year* x 2% savings = $30.5 saved annually

Cost of smart plug: $10

Time to regain investment: $10 plug cost/($30.5 annual savings) = 0.328 years ≈ 4 months

*2015 Residential Energy Consumption Survey: Energy Consumption and Expenditures Tables

Appendix D

	Total Hours	Power (kWh)	Estimated Costs
Today	8	0.5625	\$0.03
Yesterday	24	1.6875	\$0.095
Weekly	64	4.5	\$0.255

Cost Calculations

$$Estimated\ Costs\ for\ Daily/Weekly = Power\ (kWh) * \$0.056582$$

$$Estimated\ Costs\ for\ Monthly = \$10\ (base) + Total\ Power\ (kWh) * \$0.056582\ \ + 7\%\ (sale\ tax)$$

$$I.e\colon Estimated\ Costs = \$10 + 18 * \$0.056582 + 7\% * (\$18 + * \$0.056582) \approx \$12/\text{device}$$

$$Estimated\ Costs\ for\ 5\ devices = \$60/households$$

$$Estimated\ Costs\ for\ 300\ low - income\ households\ in\ Georgia = \$18000/month$$

$$Estimated\ Costs\ for\ 300\ low - income\ households\ in\ Georgia = \$216000/year$$

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