Prospectus

Powell Rangers: Smart Mini Thermostat

(Technical Report)

A Community-Based Solution to Energy Inequity

(STS Research Paper)

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Introduction

Families in America with the least means pay disproportionately more for their electricity. Over 35% of families with incomes under $20,000 have to sacrifice power or other home necessities for at least 1 month per year. (Howat, Colgan, Gerlitz, Santiago-Mosier, Rábago, 2019) The poverty line is at $21,330 (Poverty Guidelines, 2019) for the average family of 3 (US Census Bureau, 2018) - a lot of people are being hurt. Yet, these same families use under 10% of the total energy annually. Because utilities unequivocally bill customers for energy, those that can pay are able to continue - a positive feedback loop. The situation will not change by petitioning for price cuts. Instead, we must look towards communities; by encouraging energy generation among more financially capable customers, we can free up energy supplies. With increased supply comes relief for the energy-poor.

To effect change, the Energy Gang seeks to develop collaborative energy awareness campaigns spawned from within communities rife with energy inequity. These community research projects will employ independent hybrid energy sources to empower those capable of making changes. But simply informing people of the existence of the problem and its solutions likely cannot solve energy inequality - how can we effectively incentivize participation? How can we grab community interest and steer it towards the adoption of hybrid energy technology and a renewed commitment to be responsible? What are the characteristics of successful energy awareness incentive programs, and how do they engage communities in making real, unified efforts towards energy equity?

Technical Topic

Our Electrical Engineering Capstone advisor was Harry C. Powell and our group consisted of Keerthi Radhakrishnan, Jimmy Howerton, Kevin Dela Merced, and Nathan Olszewski. Our general research problem was to design technology to empower smart, effortless energy conservation. Automating steps of the energy conservation process with practical, simple technology would greatly accelerate our plans.

In search of energy efficiency and conservation, our goal was to design an automated heat-lamp based temperature regulator for reptile owners. The system was designed to automate the proper care of reptiles, as reptiles need specific parts of their cages heated to specific temperature ranges. To generate the minimum heat to do this, the system duty-cycled the heating element through a feedback control mechanism. Furthermore, in search of increasing heat lamp lifespans (thereby reducing waste production) from electrical strain, the system was designed to automatically synchronize to power lines so that energy transfer to the heating element was maximized. Lastly, our goal was to provide a quick, simple user interface to adjust the setpoint temperature through a web application or a knob.

Competing solutions to this problem failed to provide all of our features together. For instance, the iPower digital thermostat (“Amazon”, 2019) was a device that plugged into the wall, had a connected thermometer, and had a port for a heating device to plug into. However, it used archaic LED displays and buttons to show and control the heat. There also was no way to 'schedule' its activity throughout the day. Another one, the Inkbird ITC-308 (“Inkbird”, 2019) digital thermostat accomplished the same goal with a lower max output of 1100 W and with 2 input plugs but was largely the same. Neither solution provided any sort of IoT integration or real-time control.

In designing the product, our system had to meet electrical standards. The device was designed to plug into a standard outlet and had to run off 120V AC power, with a maximum power budget of 1800 W to avoid tripping the breakers. It also had to meet National Electrical Manufacturers Association (NEMA) enclosure ("NEMA", 2019) safety standards including: 1) water resistance, 2) dirt resistance, and 3) protection against accidental contact with live circuitry. It also had to include an intuitive user interface accessible in multiple ways. The overall product was required to come in at under $250 (automation of manufacturing would reduce prices) by employing cheap, readily available electrical components.

In designing, we applied theory from coursework, simulated potential designs, and rapid-prototyped each subsystem. We scoured application notes in data sheets for each subsystem topology. We ported these designs to a circuit simulator called Multisim ("National Instruments", 2019), where we simulated and integrated them into a final schematic. We also prototyped each subsystem on a breadboard. Using logic analyzers and oscilloscopes ("National Instruments", 2019), we characterized subsystem inputs and outputs, comparing them against an extensive test plan that examined every current path in the system. Beyond the circuits, the system required a software stack to handle power line synchronization, lamp duty-cycling and other soft real-time tasks. To debug this, a development environment called Code Composer Studio ("Texas Instruments", 2019) was used.

We ultimately succeeded in implementing the system: it automatically handled power line synchronization on boot and periodically corrected against deviations, duty-cycled the power source to minimize wasteful power consumption, provided a responsive, simple interface through an LCD screen and knob, and ran a very basic website on-board.

STS Thesis

Electricity is a modern necessity for all families, equally important as food, water, and shelter. Electricity is mandatory to heat one's room and cook food, for instance. The Energy Gang believes that all people should have access to enough reliable electricity to power their homes - energy inequity is a violation of human rights (UN, 2019). In tackling energy inequity, we seek to analyze the potential of independent hybrid energy sources as methods of equalizing the energy economy. To incentivize adoption of these, we must examine energy awareness incentive programs, identify what community engagement tactics they used to spawn interest in the issue, and how these programs succeeded in: 1) transforming attitudes towards energy inequity and 2) increasing adoption of hybrid energy sources as a means of reducing it.

Community attitudes towards energy provisioning, production and consumption may vary despite the physical similarities between towns. In transforming beliefs, existing assumptions must be challenged on the community's terms; we must create desire to change through the assets and beliefs within a community. In evaluating energy incentive programs, we judge them through the lens of participatory action research (PAR). PAR is an approach to research in communities that emphasizes participation and action. It seeks to understand the world by trying to change it, collaboratively and following reflection. PAR emphasizes collective inquiry and experimentation grounded in experience and social history. ("Wikipedia", 2019) We believe that only in meeting communities 'where they stand' will we actually be able to encourage change.

In answering the big question, we had to answer a few guiding questions: 1) how do we do PAR right? 2) what effect do different awareness campaign methods have on community beliefs? 3) what kind

of incentives increase interest in activism? 4) what does it take to get people to invest in renewable energy sources?

Starting with the first question, we looked for examples of good PAR. The biggest difference between traditional research and PAR is that it “pays careful attention to power relationships, advocating for power to be deliberately shared between the researcher and the researched” (Baum, 2006). To perform participatory active research is to directly involve oneself in the subject’s life. PAR facilitates discussion - it draws upon the “lived experiences” of others for content instead of issuing general statements about topics. For instance, we design interview questions that “ensure that participants are given maximum opportunity to present events and phenomena in their own terms and to follow agendas of their own choosing” (McDonald, 2012) instead of requiring general statements. We could also be participant-observers, where we become a member of the crowd we are studying and takes detailed field observation. A participant-observer “not only observes activities, participants, and physical aspects of the situation, but also engages in activities appropriate to the social situation” (McDonald, 2012). A good example of a PAR process is having community members interview one another through community get-togethers (date nights, etc.) where we also allow ourselves to be interviewed (Watters, Comeau, Restall, 2010). To understand what energy inequity looks like, we have to bring diverse groups together to discuss their perspectives and additionally interact with them. We are part of the dataset, possibly even part of the problem. With first-hand accounts, we can tell data-driven stories that add weight to our project marketing materials.

Moving on to the second question, we investigated awareness campaign techniques and their impacts on public perception. We found that workshops and other in-person campaigns (peer education programs, arts projects, public lectures) had tangible effects in changing public perceptions, while social marketing campaigns increased short-term awareness and enabled debate and discussion. For instance, a “large-scale study in four areas involving distribution of information about palliative care found a small positive trend in its perceptions over three years” (Seymour, 2011). Starting from a "very low level there were increases in awareness exceeding 10%" (Hirai, Kudo, Akiyama, Matoba, Shiozaki, Yamaki, Yamagishi, Miyashita, Morita, Eguchi, 2011) Social media campaigns can also massively increase awareness in a short period of time - “in Ireland, a one week social marketing campaign to raise awareness and understanding of palliative care resulted in as much as 46% of people being aware of the campaign” (Seymour, 2011). Unfortunately, there is "little evidence on 'outcomes' from social marketing" (Seymour, 2011) and so we cannot rely purely on it to be successful. Successful campaigns have to provide information from trustworthy sources and provide human evidence that the audience can sympathize with. For instance, “public deliberation methods (e.g., citizen panels and juries, consensus conferences) help bring insights into social values, improve understanding of complex issues (particularly ethical and social dilemmas) and enhance civic mindedness.” (Seymour, 2011) Connecting this to our project, to really increase awareness, we will need to draw on PAR methods to create workshops that bring real people their stories to the forefront and employ social media as an amplifier.

Moving to the third question, we investigated what a bad incentive is (e.g. bribing a target to care). A good incentive should create renewed and increasing interest in a topic. However, literature that outlines the specific methods for our topic is missing. But there are quite a lot of related resources; for instance, 'how to create incentive programs that actually boost worker productivity'. While similar in scope, a connection between these methods and our goal of increasing activism has to be made before we can use them. Paying salaried employees to work harder is not the same as trying to change their thinking.

Finishing with the fourth question, we investigated interest in adopting independent hybrid energy sources. We found that as recently as 2010, a small number of people even knew about the availability of renewable power purchase options, coming in at < 14% of respondents. Additionally, the number of respondents who actually were willing to pay for renewable energy sources actually decreased from ~35% to ~20% over 2007 - 2010, as price sensitivity increased to levels as high as 69%. > 60% of respondents were not even willing to spend an extra $5-20 a month to support renewables (Sumner, Bird, 2011). Yet the now-defunct California Solar Initiative from a couple of years ago "blew through all state incentives and surpassed renewable power generation targets by hundreds of megawatts." (Lacey, 2014) What caused this was a substantial state subsidy of "$2.50 / watt (of installed peak capacity)" (Borenstein, 2013). The interest is there, but clearly work has to be done in educating people on renewable options and somehow creating big financial incentives.

Integrating this information, our strategy would be to make tangible psychological impacts on our audience with workshops and viral marketing. We need to highlight the staggering gap in energy consumption between subsets of our community with real data, testimonies, visualization, and most importantly, stories. We'd follow by drawing attention to renewable options. We'd have to make the sale by showcasing big incentives and following through.

This could go very wrong though. We have failed to consider the impact of our technology on people's homes and living spaces. We could potentially ruin entire neighborhoods with the extra space needed for our renewable technologies. We also have to do work to motivate people without dangling money in front of them. What if our plans are as successful as the California Solar Initiative for some time, but the long-term impact proves to be nil? Our future work has to be more forward-thinking than this, but we can certainly get started.

References

Amazon.com : iPower 40-108°F Digital Heat Mat Thermostat Controller for Seed Germination, Reptiles and Brewing : Pet Supplies. (n.d.). Retrieved from https://www.amazon.com/iPower-40-108°F-Thermostat-Controller-Germination/dp/B01E9IO6N0.

Baum, F. (2006). Participatory action research. *Journal of Epidemiology & Community Health*, *60*(10), 854–857. doi: 10.1136/jech.2004.028662

Baum, F., MacDougall, C., & Smith, D. (2006, October). Participatory action research. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2566051/.

Borenstein, S. (2013, June 24). The California Solar Initiative is ending. What has it left behind? Retrieved from https://energyathaas.wordpress.com/2013/06/17/the-california-solar-initiative-is-ending-what-has-it-left-behind/.

Code Composer Studio (CCS) Integrated Development Environment (IDE) CCSTUDIO. (n.d.). Retrieved from http://www.ti.com/tool/CCSTUDIO.

Hirai, K., Kudo, T., Akiyama, M., Matoba, M., Shiozaki, M., Yamaki, T., … Eguchi, K. (2011). Public Awareness, Knowledge of Availability, and Readiness for Cancer Palliative Care Services: A Population-Based Survey across Four Regions in Japan. *Journal of Palliative Medicine*, *14*(8), 918–922. doi: 10.1089/jpm.2010.0529

Lacey, S. (2014, November 4). The End of a Solar Era: The Legacy of the California Solar Initiative. Retrieved from https://www.greentechmedia.com/articles/read/the-legacy-of-the-california-solar-initiative.

McDonald, C. (2012). UNDERSTANDING PARTICIPATORY ACTION RESEARCH: A QUALITATIVE RESEARCH METHODOLOGY OPTION. *Canadian Journal of Action Research*, *13*(2), 34–50. Retrieved from https://pdfs.semanticscholar.org/3b78/ecfe0b4a0a7591d2ea068c71e8ea320ff451.pdf

Nema. (n.d.). About NEMA Standards. Retrieved from https://www.nema.org/Standards/About-Standards/pages/default.aspx.

Participatory action research. (2019, September 19). Retrieved from https://en.wikipedia.org/wiki/Participatory_action_research.

Seymour, J. (2018, January). The Impact of Public Health Awareness Campaigns on the Awareness and Quality of Palliative Care. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5733664/.

Sumner, J., & Bird, L. Consumer Attitudes About Renewable Energy: Trends and Regional Differences, Consumer Attitudes About Renewable Energy: Trends and Regional Differences (2011). Retrieved from https://www.nrel.gov/docs/fy11osti/50988.pdf

Temperature Controller ITC-308: INKBIRD. (n.d.). Retrieved from https://www.ink-bird.com/products-temperature-controller-itc308.html.

Universal Declaration of Human Rights. (n.d.). Retrieved from https://www.un.org/en/universal-declaration-human-rights/.

Watters, J., Comeau, S., & Restall, G. (2010). University of Manitoba - Faculty of Health Sciences - College of Rehabilitation Sciences. Retrieved from http://umanitoba.ca/rehabsciences/.

What Is Multisim™ for Education - National Instruments. (n.d.). Retrieved from http://www.ni.com/en-us/shop/electronic-test-instrumentation/application-software-for-electronic-test-and-instrumentation-category/what-is-multisim/multisim-education.html.

What Is VirtualBench? - National Instruments. (n.d.). Retrieved from http://www.ni.com/en-us/shop/electronic-test-instrumentation/virtualbench/what-is-virtualbench.html.