Stanford Sensor and Energy Behavior Initiative

About the Initiative:

- The goal is to leverage pervasive sensors, like smart meters, in combination with behavioral approaches to achieve large scale energy savings. The effort currently focuses on the stationary residential sector\(^1\) though work is applicable to and has explored transportation, water, and commercial applications.
- The Initiative is comprised of 20 projects, overseen by teams spanning CS/EE, CEE, MS&E and economics, and ME\(^2\) and design, as well as psychology, education, communications, symbolic systems, and behavioral epidemiology through the School of Medicine.
- Phase I of the effort emphasized the development and evaluation of the projects independently, whereas Phase II will focus on the integration of effective project elements into more comprehensive intervention(s), medium scale pilots (thousands to tens of thousands of participants), and the transition to commercialization.

The Stanford Engine is a conceptual framework illustrating how the various projects each play a strategic role in using energy use data to effect behavior change. The projects fall within three main buckets: technology, behavioral interventions, and evaluation. The projects include:

TECHNOLOGY

1. Communication network. Levis, in collaboration with a many others, helped establish the first Internet standard for home area networks (HANs), which is being adopted by industrial consortia such as WirelessHART and ZigBee. Specifically, they created an open standard for TCP/IP in home area networks (HANs) as well as an open-source reference implementation of the standard for others to copy, extend, re-use, and improve. This technology will provide greater freedom in data collection, representation, storage, and communication between devices of different manufacturers, as well as lower the barriers to entry, all leading to innovations and improvements in human interfaces to sensor-actuator networks.

   As a second deliverable, this team developed a wireless power plug meter that automatically joins a self-assembling, ad-hoc wireless mesh network to deliver data to collection points (see Figure 1). The open-source design has been used by several follow-on efforts by other groups. Further, the deployed network of 200 such meters in the Stanford CS building for two years to obtain long-term, fine grained power draw measurements allowed the team to publish detailed data at a scale orders

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\(^1\) Targeted actions include purchasing and installing energy efficient technology, reducing waste (e.g., unplugging extra refrigerators), shifting settings and installing controls (e.g., adjusting pool pump cycles, installing timers and motion sensor light switches), repairing items or performing maintenance, and adjust patterns of use and habits (e.g., closing drapes and windows on hot days).

\(^2\) CS = computer science, EE = electrical engineering, CEE = civil and environmental engineering, MS&E = management sciences and engineering, and ME = mechanical engineering
of magnitude greater than other, similar efforts, as well as establish the basic methodologies one should follow to measure computing energy. These results are being used by several green computing companies to write future energy standards for computing systems.

2. Stanford Energy Services Platform. This provides the computational backbone for our behavioral interventions and includes three layers: data collection and storage (user, energy, website activity, weather, property, and project data), services (analytics like baselining and peer comparison, registration, surveys, experimental condition assignment, alerts), and presentation (API, widgets, drupal modules). The software is being prepared and documented for use by others.

Algorithms

3. Segmentation and targeting algorithms. See other Summit posters for more info. We utilized anonymized data from 250,000+ California utility customers with at least one years worth of hourly smart meter data, as well as 10 minute data collected on over 1,000 Google employees. The algorithms developed decompose a customer’s consumption into daily load shapes; load shapes are then analyzed in aggregate to obtain a small number of typical loads shapes that characterize the whole population. These shapes can be then utilized to build behavioral models for customers; examine features such as variability, amount of kWh consumed, and thermal response; and more effectively target customers for energy programs. Finally, we developed innovative methods to quantify the energy efficiency of buildings. Tests of the algorithms in utility programs are in the planning phase.

4. Learning algorithms to enhance automation. This project automated the activity of TVs and lights based on human activity, preferences, and energy savings criteria. Data was collected from the electronics and also low resolution cameras that monitored human activity, and machine learning algorithms were developed that incorporated user models and decision-making to predict user behavior, as well as user feedback for refinement. The models were tested with real world data.

Disaggregation. This is the statistical separation of the whole building energy signal into appliance level energy use data. There were three discrete projects:

5. A comprehensive review paper evaluating the benefits of disaggregation, algorithm requirements, and the ability of smart meters to meet these requirements. (tens of thousands of downloads to date).

6. Development of a high frequency data set, to aid algorithm development, testing, and benchmarking. Data was collected for three weeks from each of ~40 homes in Boston, MA and the Bay Area, CA, including 16 kHz whole home data, 3 sec circuit level data, and 1 min plug level data. Data available upon request, and will be publicly posted soon.

7. Algorithm development. Disaggregation algorithms using sparse coding methods were developed to advance the state of the art.

BEHAVIORAL INTERVENTIONS

Target Behaviors
A list of target behaviors is useful for populating consumer facing recommendation systems with energy saving actions, and in guiding future work on the development of new energy saving actions. The two discrete projects included:

8. A database of 250 actions that directly reduce stationary residential energy use, and each action’s ratings on nine different attributes (e.g., energy savings, fiscal cost, frequency of the action, skill demand). Actions were implementation in Bidgely Inc.’s online recommendation system. This project also analyzed how the actions clustered based on the attributes so they could be more effectively “bundled” in behavior change programs.

9. A collection of energy saving actions from other cultures and throughout history as inspiration for modern day energy saving innovations; their potential energy savings across U.S. climate zones were quantified to provide an opportunity map for future design efforts. (work in progress)

**Media Interventions**

10. Social norms. 800 self-selected residences received feedback about their energy consumption, energy saving tips, and normative framing in emails sent every other week. It was found that when energy-saving tips were organized thematically (e.g., all heat saving tips, rather than a random mix of tips), the collective-action frame (“We’re doing it together!”) led to significantly greater reductions than descriptive norms (“Residents here have reduced their energy use by x% this year.”) or the thematic recommendations alone.

11. Online game. This multiplayer game and supporting social media is suitable for use in experiments and deployment in utility smart meter trials. Power House incorporated real world energy data into some of the game play, leveraged social competition, and retrained habits through reinforcement. In a laboratory experiment and field study, participants respectively increased their short term energy efficient behaviors (turning off devices) and used significantly less energy during the weeks they used the game. This project received Phase II funding to deploy the game through Facebook.

12. Immersive reality. This work created an immersive virtual shower world and measured its impact on energy related hot water consumption behavior, with results suggesting that vivid visualizations of energy consumption (e.g., amount of coal instead of KWh) are more important than the personalization afforded by avatars.

13. Facebook applications. This project developed three Facebook applications to match the range of motivations exhibited by individuals: Power Tower is social in that it allows one to collaborate with others in a Tetras-like puzzle where pieces are granted based on multiple participants’ energy savings; Kidogo is affective in that it allows one to compute their real world energy savings and then microfinance individuals in developing countries based on these savings; and Powerbar is cognitive in that it primary displays energy feedback data. Partner workshops planned for Phase II funding period to disseminate findings.

**Policy Interventions**

14. Appliance calculator. This application has been used by over 60,000 people via Google Ads. By testing changes in the interface we have found, contrary to expectations, that projecting out cost...
savings over time does not appear to prompt more energy efficient refrigerator browsing, whereas simply changing the default sort order to put the most efficient appliances on top reduced the average kWh consumption of items selected by 10-20% – this suggests that simply implementing the most effective behavior change techniques may be a more effective strategy than a traditional route of analyzing the underlying cause of a problem then trying to address it.

15. Raffle incentive. The Insinc sweepstakes or raffle-like incentive program recruited 21,000 users in six months, with 7.5% of all Insinc trips shifting off peak to reduce congestion and associated fuel waste, 11% shifting by those previously making regular peak-hour trips, and significant shifting to the use of public transit. A computational platform was also developed (separate from project #2) to support this and similar programs.

Community Intervention

16. Community program. Community-based programs can be much more effective than traditional marketing communications when strategically tapping into existing social networks and providing close support from peers (e.g., 10 vs. 85% in the Hood River Project). Here we developed a five lesson Girl Scout program that resulted in significant changes in self-reported home energy saving actions for both girls and their parents. Phase II funding will link the Girl Scout and Integrative (#20) projects and scale the project to other regions of the U.S.

DATA EVALUATION AND MODELING

17. Google Powermeter evaluation. Over 1000 individuals participated in a randomized controlled trial and showed an average of 6% energy savings in the first month or two of using the interface, which resembled many interfaces used on utility or other energy feedback websites. The study thus provided a benchmark for the comparison of other interventions, as well as a rigorous example of experimental and analysis methods for such work. (A note regarding persistence - it may be substantially improved with periodic reminders, as reported by Hunt Alcott (NYU) regarding the Opower program.)

18. Twitter explorer. This project developed Twitter Explorer to mine and analyze data from ongoing Twitter and other social media conversations about energy. For a one year period, Tweets were collected if they contained ~150 energy related linguistic terms. Using content, network, and semantic analyses of Tweets and hashtags, we assessed engagement, identified influencers, and identified word-of-mouth communities. Further work can enable an understanding of how to create, grow, and sustain word-of-mouth acceleration of energy behavior change.

19. Diffusion modeling. This project developed a simulation methodology and tool that allows one to model the energy savings of behavioral interventions according to parameters such as time, behavioral technique used, and social network distance and type. This tool could serve as a foundation for developing similar but more sophisticated tools enhanced with additional parameters and empirical data that could eventually lessen time and cost of developing interventions through predictive modeling, or, used in another way, to choose in which real-world settings to deploy different manipulations.