SAVE: Self-organizing Air VEnt System

1. **Boise State University**
2. **Principal Investigator (PI): Gang-Ryung Uh**
3. ***SAVE* was submitted to the HERC RFP FY 2014**

The ***SAVE*** proposal was awarded in the amount of $46,000. This project is to specifically resolve **THREE KEY COMMERCIALIZATION CHALLENGES** of the ***SAVE*** system which we encountered during the HERC FY 2014,

i. How to reduce the liability of icing HVAC (air-compressor) coils?

ii. How to measure the HVAC airflow rate and detect overall HVAC system health?

iii. How to prolong ***SAVE*** battery life and energy efficiency through the use of energy harvesting and enhanced wireless communication protocols?

4. Executive Summary

U.S. households rely primarily on electricity and natural gas for HVAC. The Department of Energy (DOE) reports that air conditioning and space heating make up the greatest share of household utility bills. For this reason, the DOE strongly recommends U.S. households install programmable thermostats, e.g., *NEST* thermostats, to save around 10% a year on cooling and heating bills. However, a critical drawback of these programmable thermostats is they can only accurately control the temperature for a localized zone, and room-to-room temperatures can vary significantly. In a poorly insulated zone, programmable thermostats can over-cool or over-heat the space. This often impairs the comfort level of the household and results in an unexpected increase in utility bills.

There are over 130,000,000 homes in the US. In addition, an average of one million new US homes are built every year. It is notable that most houses were typically built with cheap HVAC products, and therefore, an average household commonly experiences the overcooling and overheating problem. The business opportunity (over $20B/year US home upgrade industry) is to develop an economical and non-invasive consumer product to solve overcooling and overheating problem in a residential building. The main market solutions for overcooling and overheating are either costly with extensive retrofits (e.g., *Lennox*), or far from being satisfactory (e.g., *Activent* and *Airflow*). This project aims to enhance the ***SAVE*** SYSTEM, which we developed during HERC FY 2014, in both safety and energy efficiency. Thus, we can penetrate the US residential HVAC upgrade industry with the enhanced ***SAVE*** system, ***WHICH CAN ECONOMICALLY AND EFFECTIVELY SOLVE OVERCOOLING AND OVERHEATING PROBLEMS WITHOUT RETROFIT AS AN ATTRACTIVE CONSUMER PRODUCT.***

5. Project Objectives and Total Amount Requested

For overcooling and overheating, multi-zone HVAC systems (e.g., *Lennox*) have been used. Yet, these systems require extremely high initial installation costs and expensive retrofits to convert an existing single-zone to a multi-zone system (well beyond $10,000). Nevertheless, overcooling and overheating problem within a given zone still remains. Another market solution is the programmable vent registers (e.g., *Activent* and *AirFlow*). However, to solve the overcooling and overheating problem with these programmable vent registers, a homeowner is required to manually program each register, which can be quite difficult to do correctly when programming more than two registers. The ***SAVE*** proposal for the HERC FY 2014 was targeted to develop a consumer solution to achieve a similar outcome of traditional multi-zone HVAC systems such as *Lennox*, at an affordable *Activent*'s (or *Airflow*) register price.

The ***SAVE*** project was selected for funding and we developed a prototypical system that incorporated automated zone-to-zone temperature distribution during FY 2014. This accomplishment included creating customized development boards (Figure 1) and an HVAC simulation testing chamber (Figure 2) to enable rapid system testing and design. In addition, we invited Mark Rudin (VP for Research and Development at BSU), Harold Blackman (Associate VP for Research and Development at BSU), John Gardner (Director of the CAES Energy Efficient Research Inst), and other local industry key members to our lab and we successfully demonstrated (proved) that the ***SAVE*** system can solve the overcooling and overheating problems in a residential house setting.

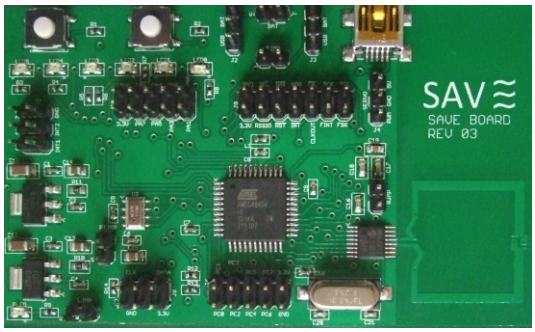


Figure 1: Electrical Development Board

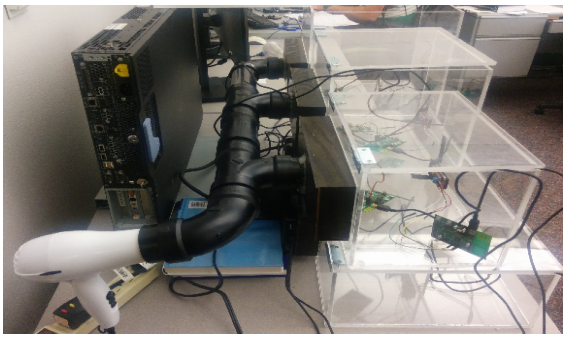


Figure 2: Testing Chamber

While actively interfacing with local software companies and HVAC manufacturer FAMCO for the ***SAVE*** commercialization, we identified three key system challenges that would be imperative to the success of the project when going to market. The **first** of these challenges is to reduce the probability of damaging the HVAC (air compressor) coils by putting too much stress on the HVAC system. It is found that most residential HVAC systems are installed as cheaply as possible, meaning that any additional components added to the system run the risk of damaging the HVAC coils. The ***SAVE*** system should be able to detect these conditions and either warn the users, or take immediate action to eliminate the risk.

The **second** challenge identified was to additionally detect and measure airflow rate at the vent registers. This allows for a wide variety of analytical possibilities, but also enables the ***SAVE*** system to better measure the health of the HVAC system. To detect airflow rate, we will incorporate a miniature wind turbine to measure airflow.

The **third** challenge in conjunction with the first is how to use the miniature wind turbine for energy harvesting to increase the life span of the battery-powered ***SAVE*** system vent registers. It is important for the ***SAVE*** project to reduce the power requirements and increase battery life as much as possible, and energy harvesting is an attractive solution. We will also continue to work on improving the ***SAVE*** wireless communication protocols for system reliability and energy efficiency.

To address three challenges (objectives) described above, we are requesting $50,000**,** which supports two CS and ECE graduate research assistants for FY 2015, one month of PI Uh's summer salary, electronic parts and materials to enhance the system, and travel costs to introduce the system during the annual HVAC trade show in Las Vegas (March 2015).

6. Resource Commitments that Reflect Boise State's Priorities

Since 2005, the University has dedicated resources to the Office of Campus Sustainability led by Dr. John Gardner. In 2010, Boise State became the leading institution in the new Energy Efficiency Research Initiative at Center for Advanced Energy Studies (CAES). The mission of the new Initiative is to increase education and research in energy efficiency, which represents the ultimate objective of the **SAVE** System.

7. The SAVE System's Potential Impact to the Economy of Idaho

There are several significant ways in which ***SAVE*** will positively affect the economy of Idaho. First, the ***SAVE*** system can be supported by the State Legislatures for energy efficiency, and it can be supported by Idaho local utility companies as a consumer commodity for the same reason. Second, as long as the ***SAVE*** system implementation, testing and market acceptance look promising, it can easily augment various HVAC products from the *Nest*, *Lennox*, *Activent, Airflow* and other suppliers, which will help U.S households save cooling and heating bills. By approaching existing manufacturers with enhanced and working versions of their own products by the ***SAVE*** system, we can make it easy for them to visualize the ***SAVE*** system's Intellectual Properties (IPs) in their product line. Third, a provisional/non-provisional patents for the ***SAVE*** system also gives Boise State University a sellable piece of IP.

8. The *SAVE* Market Opportunity

a) Describe need the project address: There are over 130,000,000 homes in the US. In addition, an average of one million new US homes are built every year. It is notable that most houses were typically built with cheap HVAC products, and therefore, an average household commonly experiences the overcooling and overheating problem.

b) Describe market size and demand projections: The US home upgrade industry is estimated to exceed $20B/year. The main market solutions for overcooling and overheating are either costly with extensive retrofits, or far from being satisfactory. This project aims to penetrate the US residential HVAC upgrade industry to effectively address overcooling and overheating problems by enhancing the ***SAVE*** system a consumer product. For the ***SAVE*** demand projections, we set the goal as the initial sales of 10,000 vent registers. This equates to 500 houses (average of 20 vent registers per a single home house) in the first year. If the sales grow at 75% for 5 years, we anticipate that the ***SAVE*** system will be distributed to just

under 5,000 homes (quite conservative considering the market size). The ***SAVE*** system's financial projection goal is to achieve $1,000,000 operating profit by FY 2020.

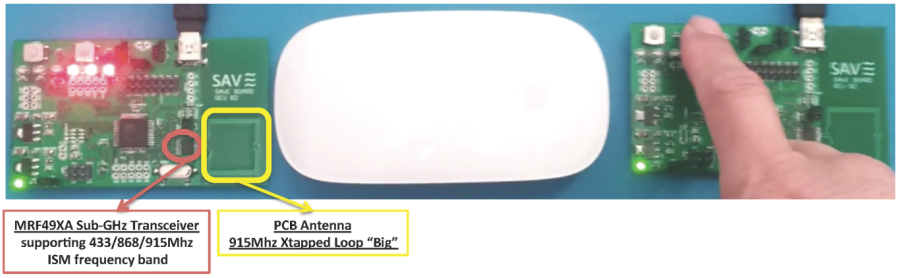
c) Describe the barriers to market entry: One of the more challenging aspects of bringing the ***SAVE*** system to market is how to best package and distribute the system to consumers. ***SAVE*** would like to position itself to be sold in piecemeal, allowing a greater flexibility for consumers to tailor the system to their needs and or budgetary requirements. However, the ***SAVE*** system is most effective when installed as a complete system, which then necessitates higher upfront costs. This dichotomy between effectiveness and flexibility will be an area of concentration for the ***SAVE*** project to solve when looking for a balance between the two.

9. The Technology and Path to Commercialization

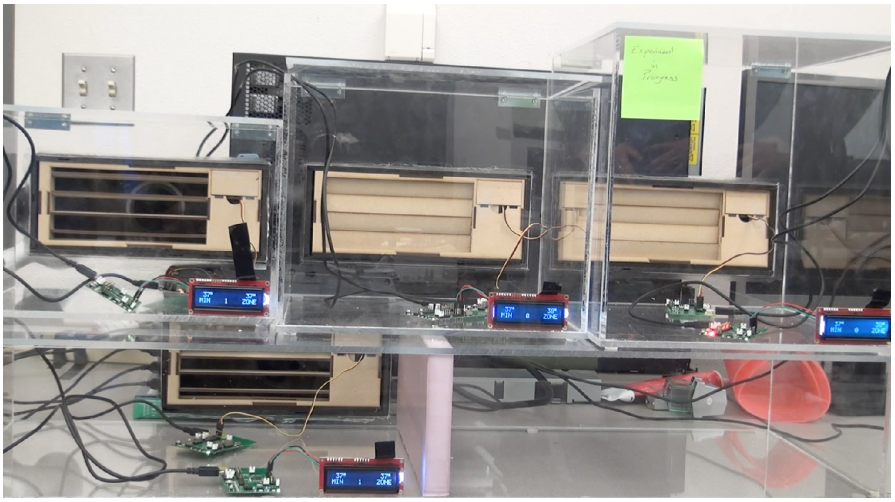
i. *What stage in the process SAVE project is currently at*

- July 2013: Kyle Hoff (Mechanical Engineering undergraduate student) joined the ***SAVE*** research team to design ***SAVE*** Registers which are closer to the final air vent product.
- August 2013: The ***SAVE*** was selected for presentation in Business Venture Challenge at UKC 2013 conference. Kyle Schwab (CS graduate student) presented the ***SAVE*** and the project was selected as a runner-up among the 50 research/business teams competition.
- September 2013: We created a Xtapped loop PCB antenna on 933 Mhz spectrum to enable wireless communication across ***SAVE*** Zone Controller (ZC) and Registers. We have achieved wireless communication over a 150 feet non-line-of-sight distance.
- October 2013: We designed and sourced method for the ***SAVE*** custom electrical board, which is small to fit inside the air vent register developed by Kyle Hoff.

- December 2013: We fully tested the ***SAVE*** electrical board and developed a task-based software stack (abstract layers) for the firmware (program) on the ***SAVE*** electrical board. Figure below demonstrates wireless communication between two ***SAVE*** electrical boards programmed with our task-based firmware.



- January 2014: We created partnerships with local software companies IdeaRoom Technologies Inc (CEO Russ Whitney) and SMARTdwell Inc (CEO Steve Taylor) to create a new venture and smart home service business.
- March 2014: Designed new mechanical prototype to be dimensionally accurate as the desired finished product (under 1" thick).
- April 2014: we built an HVAC simulation environment to test whether the programmed ***SAVE*** system can regulate air vent registers to achieve even distribution of air temperature throughout the entire house.



- May 2014: We created partnership with a local HVAC manufacturer FAMCO (CEO Marty A. Artis) to find a way to commercialize the ***SAVE*** system.

ii. What this funding will accomplish

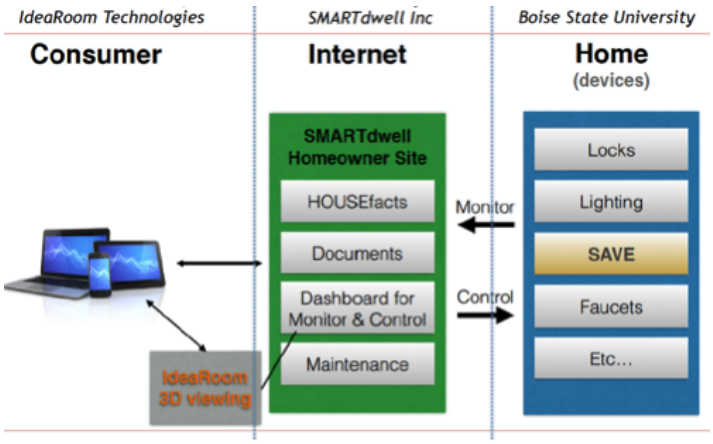
- Support the research team to develop hardware/software to measure CFM at the ***SAVE*** air vent registers to reduce the liability of icing HVAC (air-compressor) coils.
- Support the research team to optimize system to prolong ***SAVE*** battery life and energy efficiency through the use of energy harvesting (using a small wind turbine) and enhanced wireless communication protocols.
- Support the research team to meet HVAC manufacturers for the system commercialization and to participate HVAC trade show(s).

iii. What tasks are required to move the SAVE project to the next stage and the intended outcome

- Task: Filing provisional/non-provisional patent for ***SAVE*** project.
- Task: Thorough testing and benchmarking.
- Task: Update mechanical and electrical prototypes to incorporate miniature wind turbine for energy harvesting and air flow measurement.

- Task: Implementing Market strategy and planning.

  The ***SAVE*** team has been actively interfacing with the local software companies *IdeaRoom Technologies Inc* (CEO Russ Whitney) and *SMARTdwell Inc* (CEO Steve Taylor) to create a new venture on smart home service business.



- Intended Outcomes: (1) **completion of the provisional/non-provisional patent filing** on the ***SAVE*** system invention, (2) **production of *SAVE* systems that can be deployable in houses,** and (3) **collaboration with industry partners to submit an NSF proposal (**either PFI or SBIR programs**) to secure continuous funding to enhance the *SAVE* to next level(s).**

10. Commercialization Partners

Martin A. Artis, the president of **FAMCO** (http://www.famcomfg.com/) will be the ***SAVE*** system's commercialization partner during HERC FY2015. In particular, Martin Artis and his engineering team director (David Davis) will help us (1) design and implement safe (as a consumer product) and energy efficient mechanical and electrical prototypes of the ***SAVE*** system and (2) commercialize the ***SAVE*** system as a consumer HVAC supplement.

11. Specific Project Plan and Detailed Use of Funds

For the tasks in Table 1, PI Uh will lead the research team of three graduate CS/ECE students – Kyle Schwab, Jared Law and Paul Molloy (Low power system engineer at Micron). All the

SAVE team members have prior industry and academic experience in design and implementation of embedded systems.

Tasks	1st quarter 7/1/14-9/30/14	2nd quarter 10/1/14-12/31/14	3rd quarter 1/1/15-3/31/15	4th quarter 4/1/15-6/30/15
Electronic prototype				
firmware development				
mechanical prototype				
testing and benchmarking				
patent preparation & filing				
project demonstration				
HVAC trade show				

Table 1. *SAVE* Project Plan for HERC FY 2015

First, the research team will prepare the electronic and mechanical prototypes for the ***SAVE*** system described above by the end of the 2nd quarter. The mechanical and electrical prototype upgrades for the first two quarters involve the necessary changes needed to incorporate the miniature wind turbine for energy harvesting and air flow measurements. This scheduled work also includes the firmware enhancements needed for incorporating the management of the updated rechargeable battery and wind turbine interactions.

Second, we will then install the ***SAVE*** system in team member houses to test, benchmark, and validate the ***SAVE*** system design during the 3rd and 4th quarters. Specifically, the ***SAVE*** team will be focusing on firmware based power optimizations and wireless protocol design for real world conditions. A large focus will be placed on stabilizing the system reliability and getting the firmware base to pre-production quality. Validation will also include data mining for ***SAVE*** system characteristics and the impact on household energy savings. In addition, PI Uh

will prepare the required documentation for provisional/non-provisional patent filing with the Boise State University. Lastly, in the 4th quarter we will begin public ***SAVE*** system demonstrations.

The requested ***$50,000*** will be used to support (1) two CS and ECE graduate research assistants during HERC FY 2015, (2) one month of PI Uh's summer salary, (3) electronic parts and materials, and (4) travel costs to introduce the ***SAVE*** system during the annual HVAC trade show at Las Vegas in 2015.

12. Institutional and Other Sector Support

Computer Science Department and College of Engineering at Boise State University will support the ***SAVE*** project by offering the lab space and computer systems in MEC 302-R for the proposed research activities.