SAVE: Self-organizing Air VEnt System

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3. This draft is original and was not submitted to any prior HERC RFPs

4. Executive Summary:

U.S. households rely primarily on electricity and natural gas for heating, ventilation, and air conditioning (HVAC). Even though the efficiency of the HAVC has improved over time, the Department of Energy (DOE) reports that air-conditioning and space heating are still responsible for the greatest share of each household utility bill. The DOE strongly recommends U.S. households to install central programmable thermostats that can save around 10% a year on cooling and heating bills by simply turning the thermostat back 7^{o} -$10^{o}F$ for eight hours a day from its normal setting.

Figure 1: The NEST Thermostat Controller

A prime example of the programmable thermostats is the NEST product shown in Figure 1. Nevertheless, a critical drawback of these programmable thermostats is that they can only accurately control the temperature for a localized zone, and zone-to-zone temperatures can vary significantly. For instance, in a room/space that is poorly insulated, this programmable thermostat can make the room/space *too cold* (over-

cooling) or *too hot* (over-heating), which often results in an unexpected increase in the utility bills. Thus, the objective of the proposed ***S**elf-organizing **A**ir **VE**nt* (***SAVE***) system is to solve this critical drawback associated with the current programmable thermostats.

5. Project Objective and Total Amount Requested

To address the aforementioned over-cooling and over-heating problem, multi-zone HVAC systems have been used. The multi-zone HVAC system is part of the initial HVAC installation and consists of one or more central cooling/heating units, individual zone thermostats, a ductwork system, and dampers for controlling airflow to each zone as well as a central controller. These types of systems are exemplified by the *Lennox* HVAC Zone Control products. The over-cooling and over-heating problem can be mostly resolved since each zone is controlled by its own programmable thermostat. Yet, these systems require extremely high initial installation costs and expensive retro-fits in cases where a single zone system is converted into multi-zone systems (i.e. well beyond $10,000).

The advent of inexpensive low-power microprocessors and cheap IR sensors has led to the introduction of programmable battery powered air vent registers. Each battery-powered vent register can be programmed by its own programmable thermostat or from its IR remote temperature controller, which opens or closes the vent to regulate conditioned air according to a programmed setting. A prime example of these types is the *Activent* Vent-Miser ($20 per unit). Though, the disadvantages of the *Activent* products are threefold. First, the existing vent registers need to be removed and replaced by the *Activent* registers. Second, the *Activent* product does not come with any

central controller, and therefore, it can greatly damage a HVAC when all the vent registers happen to be closed while the HVAC unit is operating. Hence, the *Activent* manual strongly warns and recommends a limit of only one-third of the existing vents be replaced with their products. Finally, an individual within a household is required to program each Vent-Miser thermostat to avoid over-cooling and over-heating, which can be quite difficult to be correct.

The ***objective*** of the proposed ***SAVE*** is to address the problem of over-cooling and over-heating via zone-to-zone automatic temperature distribution mechanism. The ***SAVE*** system will achieve a similar outcome of the *Lennox* types of multi-zone HVAC systems with a surprisingly affordable *Activent* Vent-Miser price. The following are notable features of the **SAVE** system compared to *Lennox* and *Activent* products.

- It does not require a retrofit of an existing HVAC system.
- It does not replace any existing vent registers.
- It does not require any stressful programming of zone controllers or air vent registers. Instead, it dynamically finds ideal vent controls that maintain zone-to-zone even temperature distributions throughout an entire house.
- It is safe to use and will not damage the HVAC unit.
- It is fault-tolerant; it can still operate even if one or more vent registers malfunction.
- It is extremely easy to maintain.

For this **SAVE** project, we are requesting ***$50,000,*** which covers four CS and ECE graduate research assistants summer assistantships, one month of PI Uh's summer

salary, electronic parts and materials to build **SAVE** controllers, and travel costs to introduce the **SAVE** system during the annual HVAC trade show.

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* 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 patent for the ***SAVE*** system also gives us and Boise State University a sellable piece of IP.

8. The Market Opportunity for the *SAVE* Project

I. *SAVE* System Architecture

Automatic zone-to-zone temperature distribution

The battery powered ***SAVE*** system consists of (1) multiple Zone Controllers (ZCs) (Figure 2.a) and (2) one or more registers (Figures 2.b and 2.c) which are wirelessly paired to each ZC (Figure 2.d). The ZC does not operate a HVAC; instead, it continuously repeats the following tasks while the HVAC unit is operating:

- Measuring the current zone temperature
- Wirelessly receiving temperature information from other ZCs
- Controlling the valves of the wirelessly paired ***SAVE*** registers

Figure 2.a
SAVE **Zone Controller (ZC)**

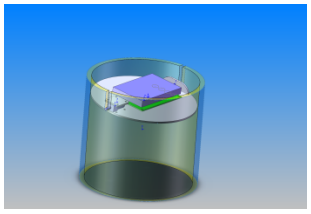

Figure 2.b
SAVE **Register Prototype**

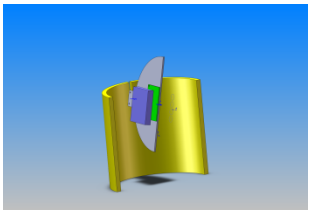

Figure 2.c
Cross-section: ***SAVE*** **Register Prototype**

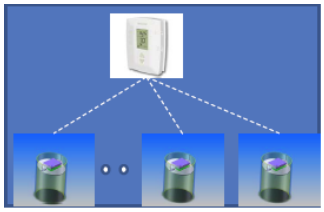

Figure 2.d
SAVE **Zone Controller and wirelessly paired Registers**

The wireless communication for the ***SAVE*** will be done using a low-power RFM12B (433Mhz) radio technology. The radio waves on 433Mhz frequency band, compared to 2GHz microwaves, travel significantly longer, penetrate walls, and leave much better at the same transmission power. Therefore, desired zone-to-zone communication among ZCs can be facilitated for the house size up to 4,000 square feet with RFM12B radio modules without any extra antenna or repeater.

II. How *SAVE* System works

Automatic zone-to-zone temperature distribution

Suppose a house with the proposed ***SAVE*** system, which is configured with three ZCs and each ZC, is paired with two registers as shown in Figure 3.

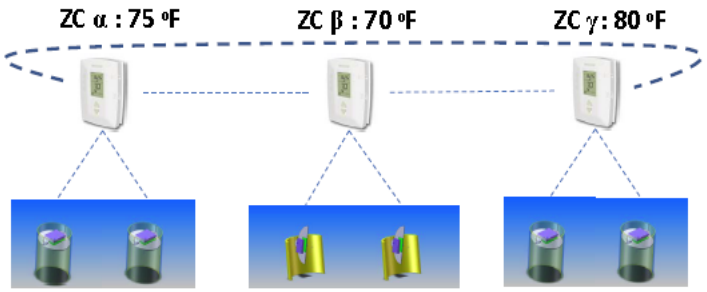

Figure 3. A House with ***SAVE*** : Three Zone Controllers (ZCs) α, β and γ

Additionally assume that the sampled temperatures for ZCs α, β and γ at time t_0 were 75°F, 70°F, and 80°F respectively when the central programmable thermostat turned on air conditioning with 72°F. There are many possible algorithms for automatic controls to achieve an even zone-to-zone temperature distribution. For this project, we will start with a simple algorithm. At any given point of time, the ZC which has the largest delta from the 72°F, opens the valves of its paired registers and all the other registers close their valves. Figure 4 shows the dynamics of the zone-to-zone temperature changes until 72°F.

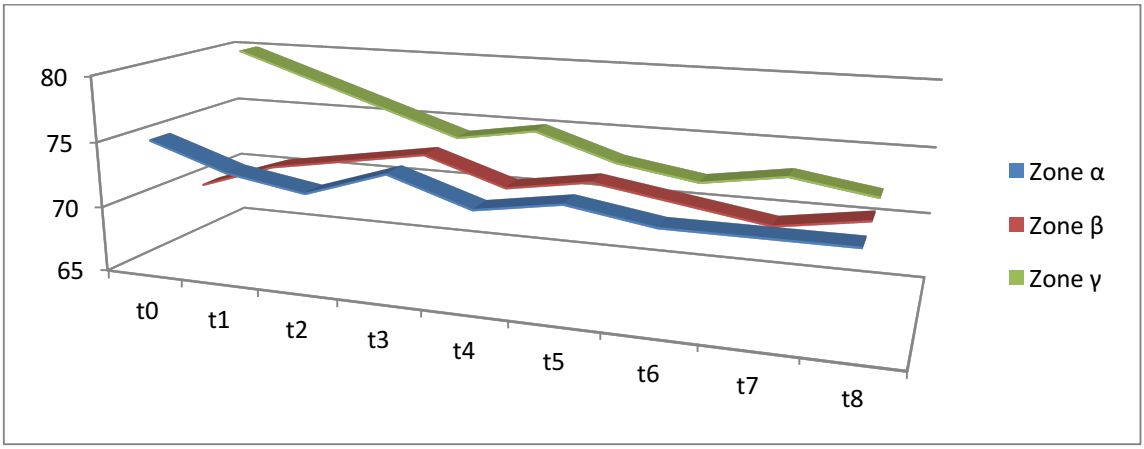

Figure 4. Zone-to-zone automatic temperature distribution with ***SAVE***

III. Where *SAVE* registers will be placed

Automatic zone-to-zone temperature distribution

The ***SAVE*** registers will be installed below existing air vent registers not to interfere with any existing vent fixtures. For easy installation and maintenance (i.e., annual or bi-annual battery replacement), the ***SAVE*** registers (Figure 5.b) will be designed with an expandable rubber insulator to fit securely in either the air duct interface (highlighted in **RED** in Figure 5.a) or the air vent register interface (highlighted in **BLUE** in Figure 5.a.). With this register placement, the ***SAVE*** can be exempt from many mandatory testing required by the Consumer Product Safety Improvement Act.

Figure 5.a.
Air Duct Tubing (Red) and Air Vent Register Interface (Blue)

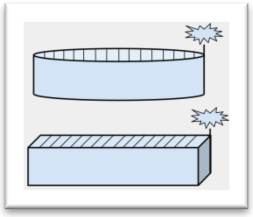

Figure 5.b.
Two types of *SAVE* registers for Air Duct and Air Vent Register Interfaces

IV. Why *SAVE* System is Safe?

Automatic zone-to-zone temperature distribution

Each ***SAVE*** Register is equipped with both temperature and pressure sensors to detect airflow and temperature from an air duct. Each ZC will be able to detect the state of its paired ***SAVE*** Registers, i.e. open, close, or not responding. Each ZC also will be able to detect the health of all the other ZCs and will help prevent the catastrophic case, "*all registers happen to be closed while the HVAC unit is operating*!"

V. Responses to items a), b) and c): *Please refer to Sections 5 and 7.*

9. The Technology and Path to Commercialization

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

- January 2013: Kyle Schwab (ECE/CS graduate student) and PI Uh submitted Creation of Works Disclosure to Boise State University and Industry Ventures.
- February 2013: The University and Industry Ventures at Boise State University assigned the ***SAVE*** project Boise State File #130.
- Since January 2013: With the CS Department Support (Dr. Harold Blackman) and PI Uh's research grants, Kyle Schwab and PI Uh have been building required electronic components for ***SAVE*** Zone Controller (ZC) and Registers.
- March 2013: Jared Law (CS graduate student) and Nathan Riskey (CS graduate student) joined the ***SAVE*** project as graduate research assistants.
- March 2013: Nate Calvin, the head of ***Kinetic Engineering Group*** (http://www.kineticengineeringgroup.com/index.html) joined the ***SAVE*** project as a business partner and he is currently building the mechanical prototypes for ***SAVE*** Registers.
- April 2013: A patent agent examined the ***SAVE*** invention in prior art. He summarized three points of novelty and un-obviousness seen in the **SAVE** according to the Title 35 of the United States Code (numbers 101, 102 and 103).
- May 2013: Gregory Cook (CS graduate student) joined the ***SAVE*** project as a graduate research assistant.

II. *What this funding will accomplish*

- Support the research team to build hardware/software and build a deployable SAVE system for testing and benchmarking.
- Support the research team to develop ***SAVE*** ZC and Register with minimal cost.
- Support the research team to meet HVAC manufacturers

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

- Task: Filing provisional patent for ***SAVE*** project.
- Task: Testing and benchmarking
- Task: Timing of action - Market strategy and planning

  PI Uh submitted a proposal on a ***Flexible Smart System for Lighting*** (**FSS4L**) to HERC-2012, which was not selected for funding. Recently, we found that the LED investment company at the Silicon Valley successfully raised its funding $1.4M with the similar project and technology which we already have. http://www.kickstarter.com/projects/limemouse/lifx-the-light-bulb-reinvented
- Task: Manufacturing plan
- Intended Outcomes: (1) **completion of the provisional patent filing** on the ***SAVE*** system invention and (2) **production of *SAVE* systems that can be deployable at my neighbor's houses.**

10. Commercialization Partners

Nate Calvin, the president of ***Kinetic Engineering Group*** (http://www.kineticengineeringgroup.com/index.html) will be the ***SAVE*** system's commercialization partner. In particular, Nate Calvin and his engineering team will build the mechanical prototypes of the ***SAVE*** system and help us commercialize the SAVE system as a consumer product.

11. Specific Project Plan and Detailed Use of Funds

For the tasks in Table 1, PI Uh will lead the research team of four graduate CS/ECE students – Kyle Schwab, Jared Law, Nathan Riskey and Gregory Cook. All the ***SAVE***

team members have prior industry and academic experience in design and implementation of embedded systems. First, the research team will prepare the electronic and mechanical prototypes for the ***SAVE*** system described above by the 2nd quarter of the project, and we will deploy the prototypes to the houses of the project participants and do the testing and benchmarking the effectiveness of the system during the 3rd and 4th quarters. In addition, PI Uh will prepare the required document for provisional patent filing with the Boise State University. During the 4th quarter, we will begin public ***SAVE*** system demonstrations.

Tasks	1st quarter 7/1/13-9/30/13	2nd quarter 10/1/13-12/31/14	3rd quarter 1/1/14-3/31/14	4th quarter 4/1/14-6/30/14
Electronic prototype				
firmware development				
mechanical prototype				
testing and benchmarking				
patent preparation & filing				
project demonstration				
HVAC trade show				

Table 1. *SAVE* Project Plan

The requested ***$50,000*** will be used to support (1) four CS and ECE graduate research assistants summer assistantships, (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.

12. Institutional and Other Sector Support

Computer Science Department and PI Uh at Boise State University will support the participating graduate students for the ***SAVE*** project by providing research assistantships during the 2014 academic year.