Final Technical Report
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Project Title: Recovery Act: Water Heater ZigBee® Open Standard Wireless Controller

Project Period: August 13, 2010 to April 30, 2014

Recipient Organization: Emerson Electric Company - White-Rodgers Division

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1. Project Objective: The objective of Emerson's Water Heater ZigBee® Open Standard Wireless Controller is to support the DOE's ARRA priority for Clean, Secure Energy by designing a water heater control that levels out residential and small business peak electricity demand through thermal energy storage in the water heater tank.

2. Executive Summary: The vast majority of the 43 million existing electric water heaters in the U.S. are resistance type heaters with electro-mechanical controls. These heaters have no microprocessor based electronics and are controlled by a bi-metal snap disk thermostat that makes, or breaks, the electrical connection to the resistance heater. This project developed a commercial product for electric water heaters that reduces the barriers to broader adoption of connected water heaters.

To accomplish this goal, the project team decided to focus our R & D efforts in 3 core areas:

1) Improved installation:
   Installation cost of load control switches can exceed the cost of the box itself. There is a high degree of variability in installations of water heaters, coupled with high voltage and various code requirements. Early in our development, we identified the need to
   -Mount directly to the water heater.
   -Have an integrated junction box
   Our design will reduce variability and cost of installation. This is seen as critical to entering and growing the market. It is also the driver for significant job creation in the installation of devices.

2) Radio Modularity:
   There are multiple radio technologies competing in the market place. A modular design that allows our device to be used with multiple technologies is required. We developed our own ZigBee 1.1 radio with LS Research, but we found that limiting our device to ZigBee would greatly limit its potential applications. We considered developing our own radio modules, but the CEA 2045 effort that joined the USNAP and EPRI efforts into a single module standard fit what we wanted to accomplish. Emerson joined the CEA 2045 effort. We modified our Zigbee 1.1 radio to work within the CEA basic standard and became the first end device to demonstrate the modular concept.

3) Develop value added software capability based on market inputs:
   This is Task 3 in the SOPO. Our original concept for pro-active DR has limited marketability based on our research, so we investigated a number of options for this task. With temperature sensor input, we demonstrated we could reduce the potential for cold water during DR events. In the last year of the project, the market began moving to a cloud based model, instead of stand-alone devices making independent decisions.

Installation:

Installation cost of load control switches can exceed the cost of the box itself. There is a high degree of variability in installations of water heaters, coupled with high voltage and various code requirements. Early in our development, we identified the need to

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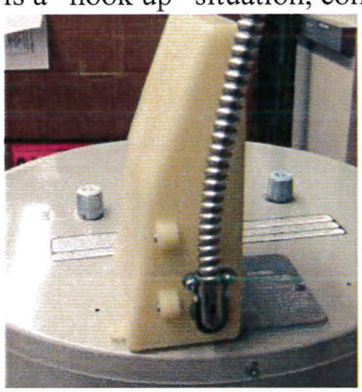
2) Have an integrated junction box

We had multiple meetings with UL, including a face to face in Chicago. This meeting was extremely valuable since it drew both UL teams together to agree to some key provisions of our control.

Including:

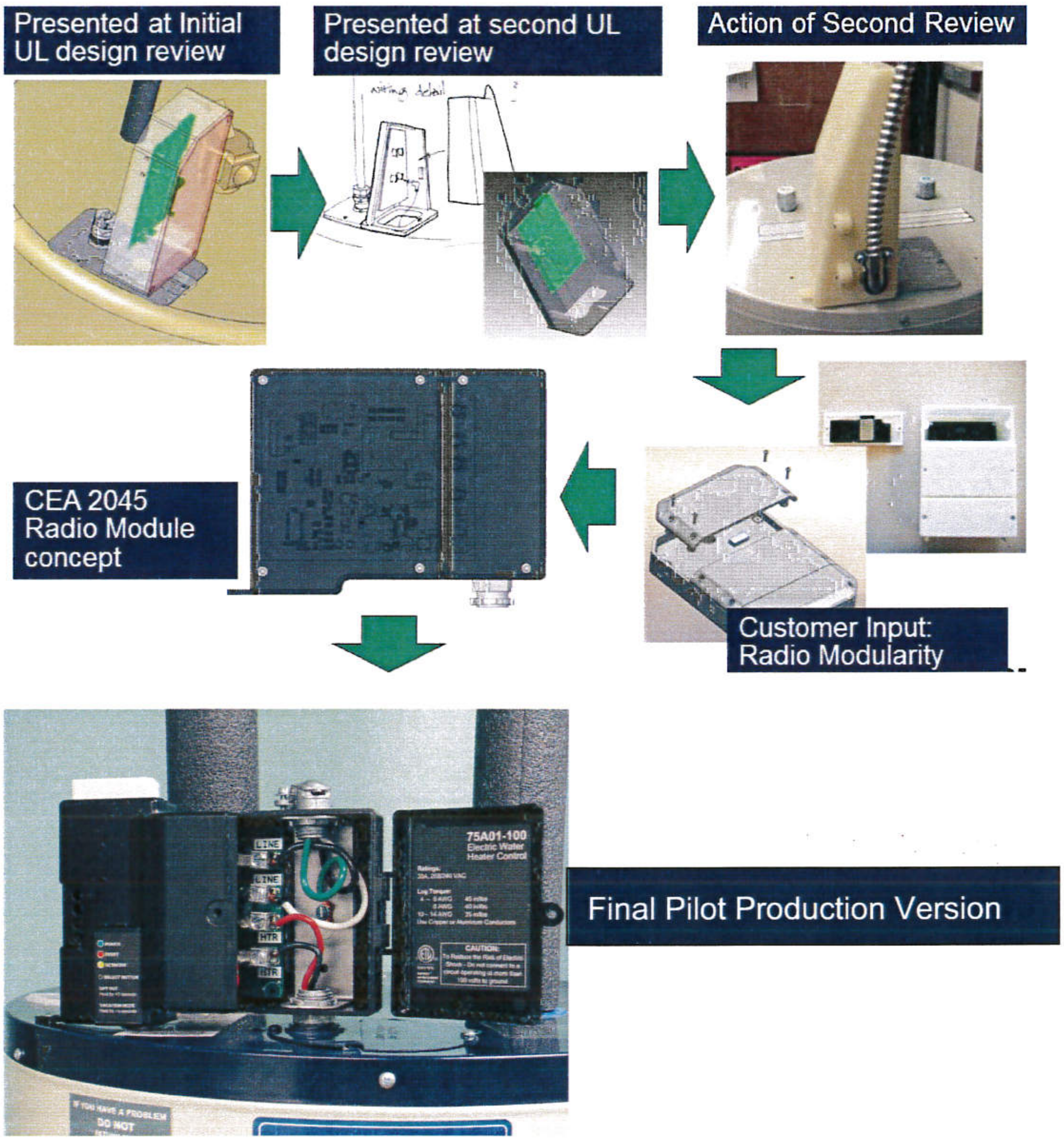
1) Classified vs. Listed requirements
2) Allowed modifications to the water heater, including the allowance for mounting screws driven into the top pan of the water heater to be UL approvable.

This is one of the early UL listed design concept that mounts via a threaded nipple to the knock out hole on the top of every water heater. What makes this design unique is we are moving the connections out of the water heater junction box, and into our device. This has 2 big benefits. First is it reduces the potential for it to be installed improperly. Since there is no wiring added, there is no risk of added wiring not being the proper specification for the load. Due to this reduced risk, some municipalities will not require a building permit for this installation, since it is a "hook up" situation, compared to a wiring infrastructure change.



UL Listed Design – Mounts to existing knock out hole, the electrical service enters on the side of our box.

The following graphic shows the progression of the box development through the project:

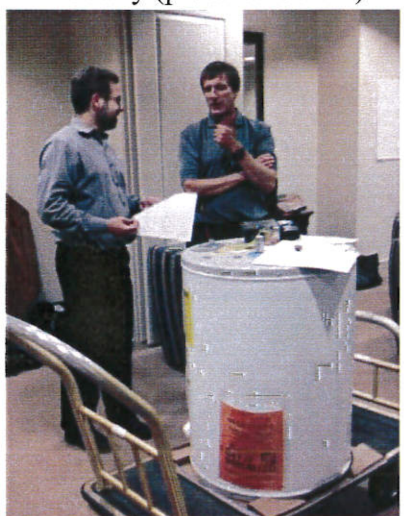


A commercial relationship was developed with a rural co-op in north Georgia to demonstrate our new device. The goal was to facilitate a field pilot run and demonstrate the improvements to installation that our device could demonstrate.

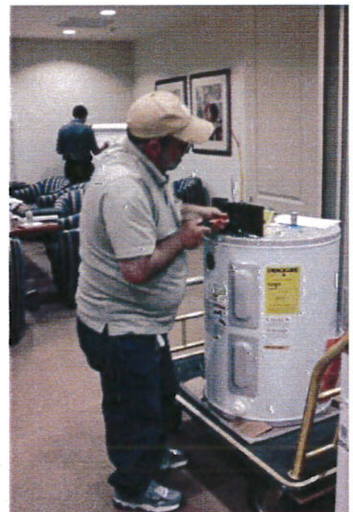
<u>Contractor Review:</u>
A hand's on training session was scheduled for June 17 through 21, 2013, in Alpharetta Georgia. Participants from HEMC, EnerSphere Communications, NexGen, Emerson White Rodgers, and Bellbrook Energy participated in the training and testing.

A training facility (right) was rented by the installation company so as to be centrally located among the participants. Unfortunately the internet access was not able to keep up with the demands of near real time data needed during the testing and training. The crew moved to a different location that had a 25 MB/s down and 6 MB/S up internet connection. This greatly improved the function of the equipment and allowed for complete testing of all of the devices.

A 30 gallon water heater was purchased locally (pictured below) so that the installation crew could practice installing the White Rodgers load control switch. The installation electrician was very impressed with the ease of installation and did several installs in ten minutes each. This compared favorably with the 30 to 45 minutes for the Jetlun hot water heater load control switch.



Matt Smith (Jet Lun) and Tom Buescher (Co-PI) discuss water heater control



NexGen Installer and Tom Buescher (Co-PI) develop time study tasks for water heater installs

A live demonstration was held for Habersham Electric Membership Corp. personnel. All aspects of Demand Response setup and execution were successfully demonstrated. The HEMC VP of Engineering gave the team the go ahead to do the pilot installation in their service territory.

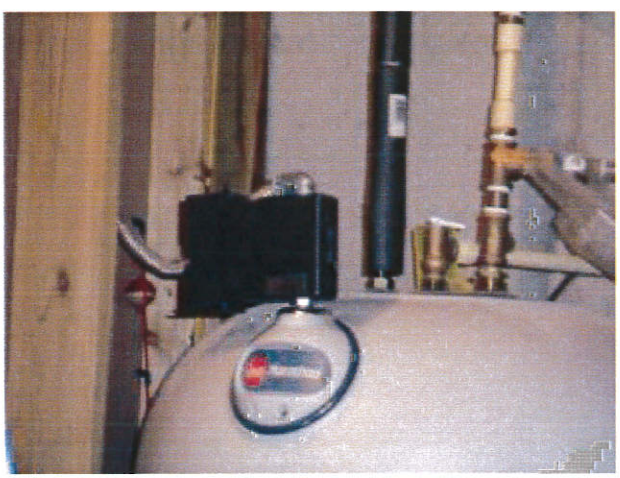
Installation Field Study:

We did a field pilot to confirm our installation improvements. Time study data for the pilot installation was gathered, analyzed and used to write a report on the Emerson Water Heater Switch (WHS).

The Emerson installation had a minimum of 16 minutes, a maximum of 25 minutes, and an average of 19.4 minutes. The table below shows a summary of the data. The total times are the recorded times not the sum of the columns.

Emerson WHS Installation					
Function	**Minimum**	**Maximum**	**Average**	**Median**	**Std. Dev.**
Unwire WH	3 Min.	10 Min.	6.1 Min.	5.5 Min.	2.6 Min.
Mount WHS	5 Min.	8 Min.	6.9 Min.	7 Min.	1.1 Min.
Wire WHS	5 Min.	8 Min.	6.4 Min.	6 Min.	1.2 Min.
Total Time	16 Min	25 Min.	19.4 Min	18.5 Min.	3.3 Min.

Even though very little variation is shown in the summary, it can be seen by looking at the recorded data that a learning curve took place and the total time was settling around 16 minutes. The longest time was for house number three. It was the first time the team had encountered a Marathon water heater with a round top and it took ten minutes instead of the usual five to figure out how to mount the WHS. The team decided that if a 1" straight nipple was used, the tab on the WHS would sit on the flat spot at the top of the water heater. The mounting in the picture below does not show the WHS swung back into place because we did not have the 1" nipple with us.

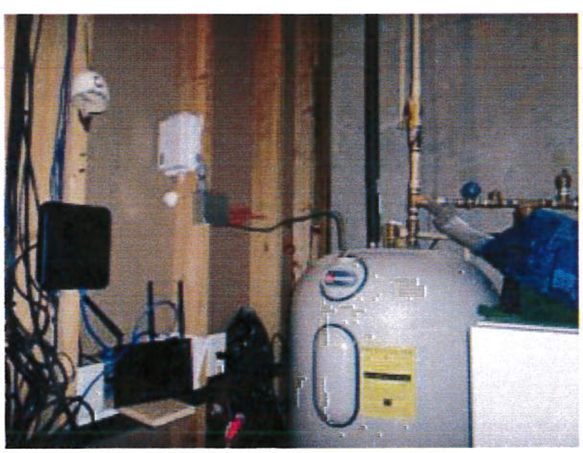


In the three homes with Tendril LCS units in place (2, 6, 9), the LCS was left as-is when installing the Emerson WHS. It wasn't necessary to disturb the current electrical supply to the water heater to install the Emerson WHS.

The median time, 18.5 minutes, is a better indication of central tendency (less susceptible to a large exceptional value in the data) than the arithmetic mean of 19.4 minutes. The installation times for the Emerson WHS are all in the same population even though the water heater installation environments varied widely. This is due to the fact that most water heaters have flat pans at the top where the WHS is mounted as opposed to having to find someplace on a wall to mount the LCS. Even though the Marathon water heater has a rounded top, it is not enough of a difference to cause a great variation in installation time.

The baseline installation had a minimum of 37 minutes, a maximum of 129 minutes, and an average of 55.2 minutes. The table below shows a summary of the data. The total times are the recorded times not the sum of the columns.

Baseline LCS Installation					
Function	**Minimum**	**Maximum**	**Average**	**Median**	**Std. Dev.**
Unwire WH	3 Min.	9 Min.	5.7 Min.	6 Min.	2.3 Min.
Mount LCS	13 Min.	90 Min.	29.4 Min.	21 Min.	25.1 Min.
Wire LCS	14 Min.	32 Min.	20.1 Min.	18 Min.	6.2 Min.
Total Time	37 Min	129 Min	55.2 Min.	47 Min.	30.3 Min.



The learning curve to install the baseline LCS was steeper than for the Emerson WHS because it required a wire junction box to be attached to the LCS with conduit and the entire one foot tall assembly had to be attached to a vertical surface near the water heater. When installing in unfinished or crawl spaces, a vertical surface was hard to find. It usually turned out to be a wooden beam which meant the two boxes needed to be wired side by side. There was a lot of variation in the amount of wall space that was available for mounting the two boxes.

The house with the longest install time was again house number three shown to the left. There was not enough flat surface to mount the units vertically so a right angle conduit fitting had to be installed in the LCS and the junction box mounted on the stud ninety degrees to the LCS.

The time to wire the junction box to the water heater decreased as the crew gained experience but also because they ran into more Romex instead of conduit (3 & 5) in the later houses.

Two houses (1 & 8) had crawl space installations. The first is shown to the right. This installation is problematic because the status lights are not easily seen by the homeowner and pushing the Opt-Out button requires crawling into the crawl space several feet. A WHS on the water heater was considerably more accessible than one mounted on a floor joist.

An easier installation is seen to the on the left. The Tendril unit that had been installed previously in three homes (2, 6, & 9) had to be replaced with the baseline LCS. The junction box and wire to the water heater were used as-is and the baseline LCS was mounted in place of the Tendril unit. Times would have been longer without the Tendril LCS junction box in place. A ladder would be required to push the Opt-Out button in all three Tendril replacements because the homeowner would have to reach over the hot water heater plus the LCS junction box combination added about a foot to the height of the installation putting the Opt-Out button out of reach of most homeowners.

It may be appropriate to use the median time of 47 minutes for the baseline LCS because of the large variation (25 minutes vs. 1.1 minute for the Emerson WHS) in mounting situations however understating the time would not be appropriate for installer planning and scheduling. There are many outliers for mounting the LCS which makes predicting and scheduling an installation crew difficult. The time it takes to install the LCS cannot be reasonably predicted until a visual inspection of where the water heater is and what flat surfaces are available to install the two boxes is completed. The standard deviation of 30 minutes means that it could take up to 2.5 hours to install the LCS and still be within normal distribution. Compare this to the Emerson WHS where a normal install time would vary by only ten minutes. That makes scheduling crews much easier and intrusion into the homeowner's life much more palatable. The Emerson unit is also a good choice to replace other manufacturer's LCS units because they can be left in place and the electric supply line going to the water heater can be connected directly to the Emerson WHS without using any additional wiring.

Radio Modularity:

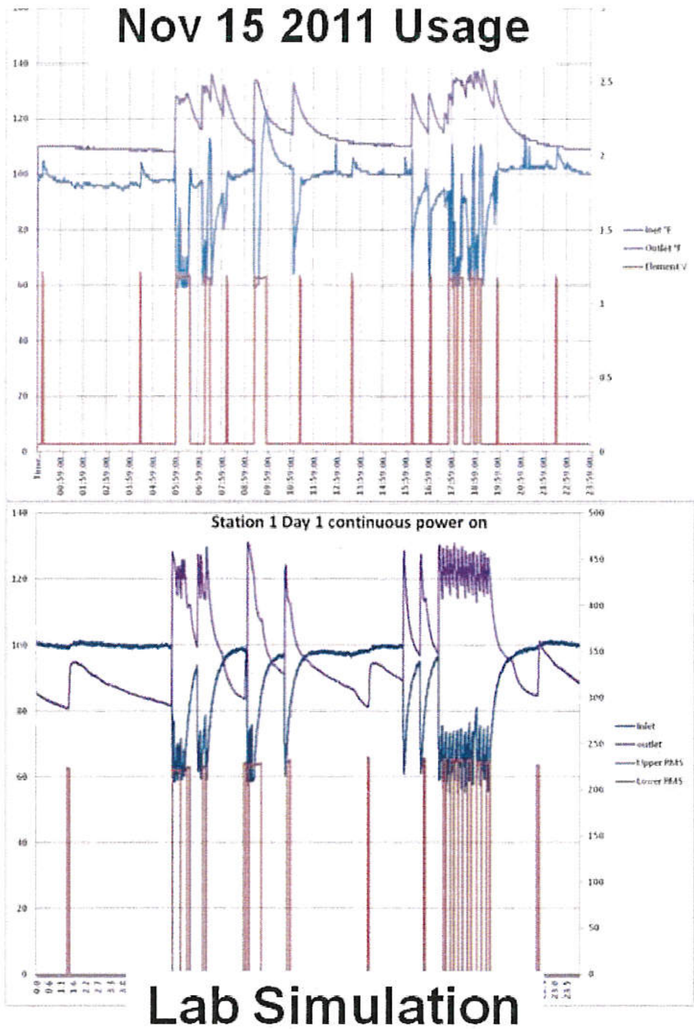
We started the project developing a Zigbee radio using an off shoot of the open "ClimateTalk" standard. Mechanically, we planned to have the radio be an integral part of the controller. It became apparent that radio modularity would be a key feature of our commercial product, due to the fragmentation and rapidly changing radio connectivity landscape as there was no clear winner between Zigbee, Wi-Fi, Z-Wave, Bluetooth, Cellular, etc
The question became what modular standard to use. There were 3 options:

1) Develop our own proprietary standard: This was done by many existing device manufactures, so their load control and thermostats could use the same radio. We developed some concepts for this but determined that this would require us to develop radios specific for our device, and we would not be able to develop radios for all the options out there.
2) USNAP: This protocol was developed by a thermostat company and was thermostat focused. There were some radio options available.
3) EPRI: EPRI had been promoting a simple protocol for the smart home.
4)

As the project progressed, USNAP and EPRI had combined their vision into the CEA 2045 protocol that allowed a very simple first level of On/Off, but could be expanded to more in depth protocols for specific appliances or thermostats. Emerson, as part of this project, got involved early in the specification development, helping define the mechanical and connection parameters. Emerson became a member of the CEA 2045 committee and modified the Zigbee radio that was supported by this project to the CEA 2045 standard. Our device was the first end device manufacturer to demonstrate CEA 2045 radio interchangeability at a Duke Energy lab in Florida. It accepted load control commands from our internally developed CEA 2045 radio, as well as another Duke vendor's independently developed CEA 2045 radio.

Value Added Software:

Our initial plan was to target a proactive DR model that would track use patterns, then switch heaters off in low use times, and re-charge in high use times. Marketing research in this area showed this was of little interest in the field. The decision was made to look more closely at potential efficiency gains based on usage patterns. We used field recording to monitor electric water heaters in employee homes to determine a typical week day usage. We developed a usage profile to simulate this home. In the following charts, you can see the actual data from the home site on Nov 11, 2011. Below it is the simulation in our lab.

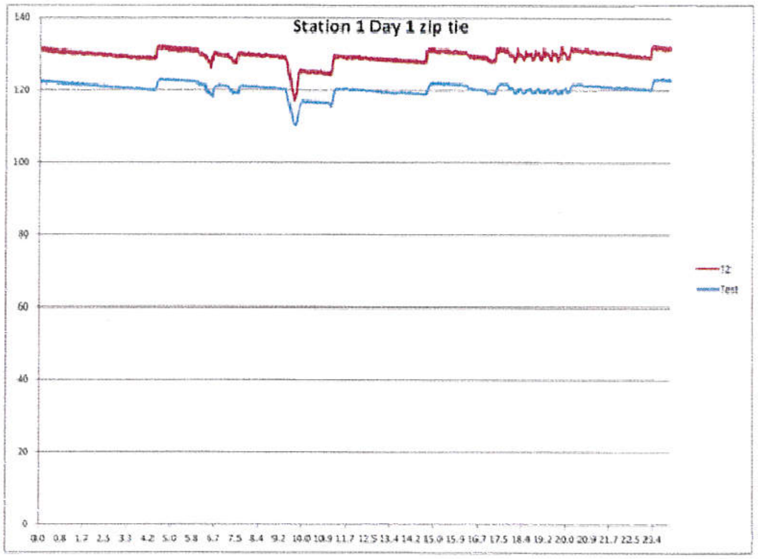


The plan for the efficiency algorithm was to reduce the number of heating cycles required in a day due to small water draws and recoveries. What we found is that there is a very limited amount of improvement available in the algorithm. In the data shown below, our total energy savings in a day was 2.5%. A 40 gallon water heater has an estimated energy cost of $585 a year, and a 2.5% savings would only amount to a $15 a year savings.

Additional testing was planned to focus on non-utility features, but a Tennessee Valley Authority Request for Information changed our focus back to utility. We used the test systems to show how our device could use learning and temperature feedback to reduce cold water complaints during load shed events. This data was summarized and included in our submission.

Using the test setups in our lab, we found that a sensor connected to the base of the T&P valve is closely correlated to the internal temperature of the tank. In our testing we used a simple zip tie around a thermocouple. The valve was covered with the standard insulation that was supplied with the tank. A copper tube was also installed in the valve with standard copper pipe foam insulation around it.

The relationship between internal water temperature (Red) and the external T&P valve temperature (Blue) is show in the following chart.



We then used our typical day scenario, adding an extra shower at the end of the shed event to simulate a potential cold water scenario.

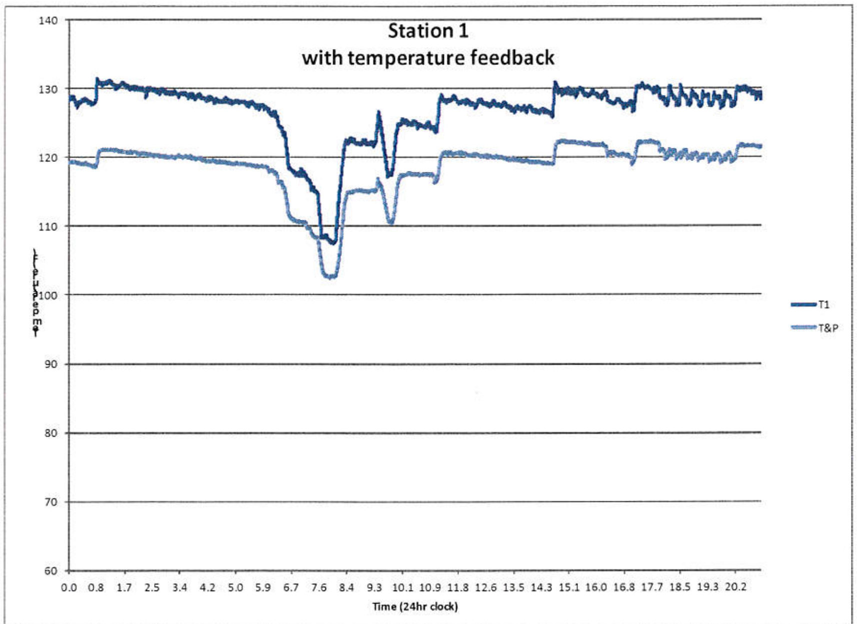
Cold Water Risk Scenario

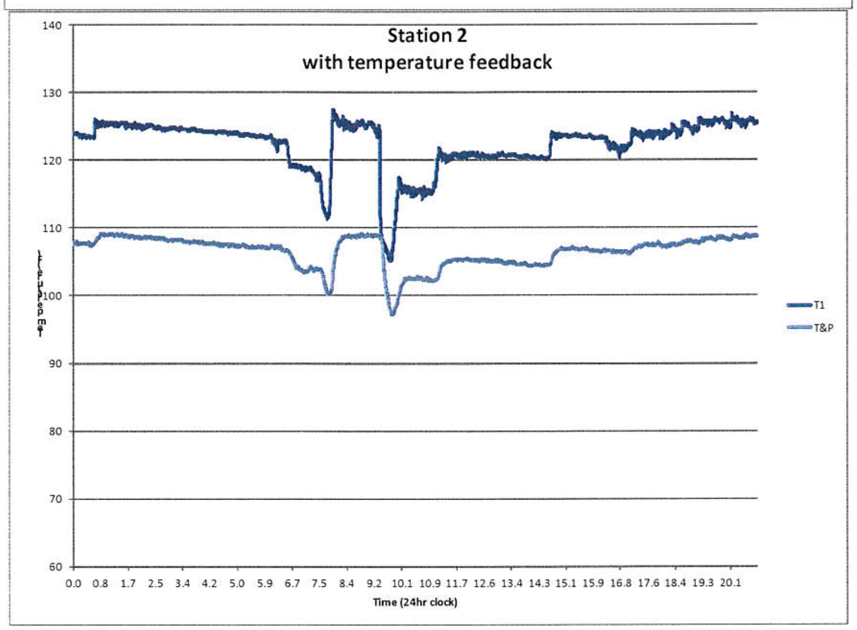
Load Shed time (power removed): 5am – 9am

Typical day water usage

index	24 hr clock	Gallons	Description	Rate (gpm)
1	6.0	1	Sink	1
2	6.3	2	Sink	0.5
3	6.4	1	Sink	0.5
4	6.5	10	Shower	1.5
5	7.1	1	Sink	0.5
6	7.3	1	Sink	0.5
7	7.5	10	Shower	1.5
8	9.3	17	Shower	1
9	11.0	1	Sink	0.5
10	16.3	1	Sink	0.5
11	17.0	1	Sink	0.5
12	17.8	2	Laundry/Dishwashing/Cooking	1
13	18.0	2	Laundry/Dishwashing/Cooking	1
14	18.2	2	Laundry/Dishwashing/Cooking	1
15	18.3	2	Laundry/Dishwashing/Cooking	1
16	18.5	2	Laundry/Dishwashing/Cooking	1
17	18.7	2	Laundry/Dishwashing/Cooking	1
18	18.8	2	Laundry/Dishwashing/Cooking	1
19	19.0	2	Laundry/Dishwashing/Cooking	1
20	19.2	2	Laundry/Dishwashing/Cooking	1
21	19.3	2	Laundry/Dishwashing/Cooking	1
22	19.5	2	Laundry/Dishwashing/Cooking	1
23	19.7	2	Laundry/Dishwashing/Cooking	1
24	19.8	2	Laundry/Dishwashing/Cooking	1
25	20.0	2	Laundry/Dishwashing/Cooking	1

We developed and ran our comfort algorithm on these tanks and were able to reduce the cold water risk dramatically. In both tanks, the above water draw pattern would have caused a cold water complaint. In the following two charts you can see our minimum delivered water temperature stays above 104 F (T1 is temperature of the water leaving the tank).





Based on the results of this testing, we developed and implemented a comfort algorithm that can monitor tank temperature, and automatically allow the device to opt out of a low priority shed event if the tank temperature drops below a learned temperature. Although this capability can be activated in the device software, the market at this point appears to be focused on remote based "cloud" control of devices based on energy supplier needs.

Summary:

Emerson's goal for this project was to commercialize an innovative electric water heater control with wireless capability that would allow more penetration of water heater load control into the US market. At the end of the project, we have a UL approved design, that reduces the applied system cost of a water heater load control device, which also deals with the fragmented radio market, and it is ready to be produced at a U.S. based contract manufacturer. The product has been well received with multiple commercialization paths in process, in both rural co-ops and investor owned utilities. Emerson has resources committed in sales, marketing, and engineering to support these commercialization efforts after the funding period has ended. The project also supported the creation of a new small business, Bellbrook Energy, LLC, which continues to support other companies in the utility market at the conclusion of this project.

Publications/Presentations/Commercializaion:

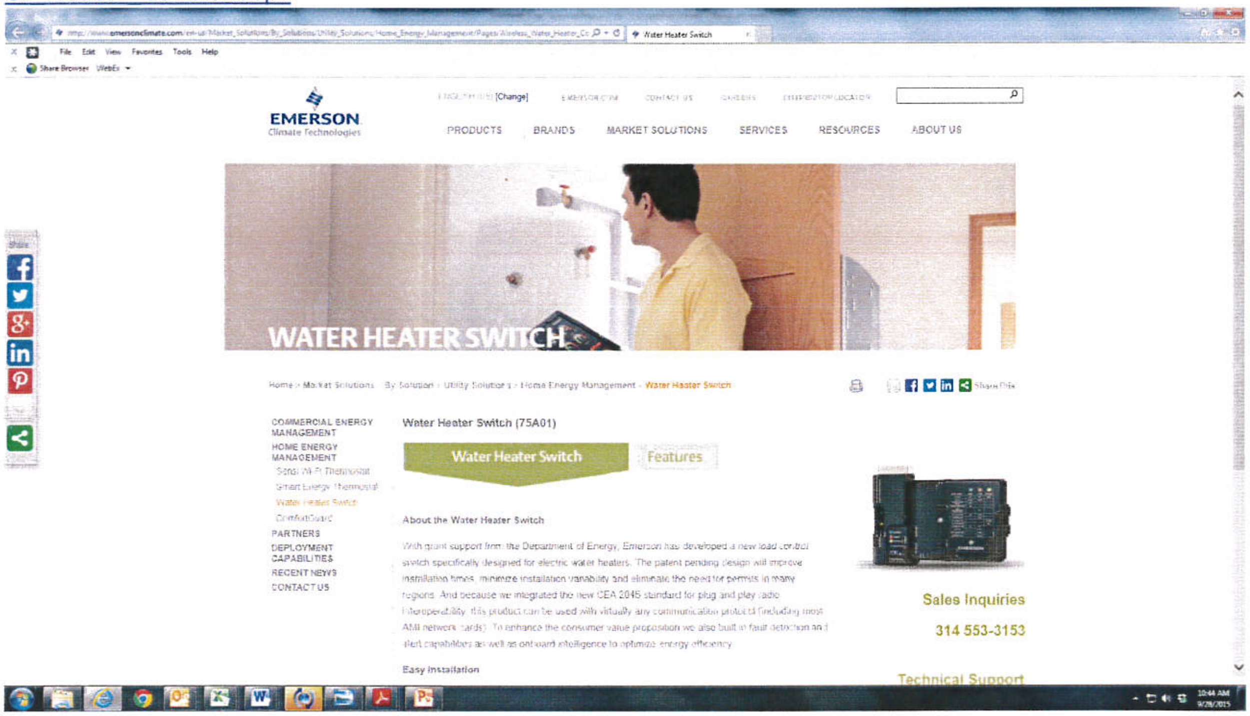
Press Article
http://www.greentechmedia.com/articles/read/the-water-heater-to-smart-grid-connector-goes-commercial
http://www.theenergycollective.com/jeffstjohn/205076/how-broadband-may-help-roll-out-rural-smart-grid

Peak Load Management Alliance (PLMA) Presentation October 2013
http://c.ymcdn.com/sites/www.peakload.org/resource/resmgr/2013fallarchive/emerson_show.pdf

Booth at PLMA conference:

Internet Presence:

http://www.emersonclimate.com/en-us/Market_Solutions/By_Solutions/Utility_Solutions/Home_Energy_Management/Pages/Wireless_Water_Heater_Control.aspx



Patent Applications:

App Number	Title
20140144395	Water Heater Valves and Controllers and Methods of Mounting the Same
20130200168	Smart Energy Controlled Water Heater
20130193221	Water Heater Control Using External Temperature Sensor
20120118989	Smart Energy Controlled Water Heater