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Installation and Data Acquisition Study to Test Circuit Solver TRV Devices

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Abstract

A Circuit Solver Thermostatic Recirculation Valve (TRV) manufactured by Therm-Omega-Tech Company is a self-actuating thermostatic recirculation valve which automatically and continuously maintains the end of each domestic hot water supply line at the specified water temperature. This simple inline valve completely eliminates the need for time consuming and expensive manual balancing procedures and equipment. Therm-Omega-Tech is a major supporter for Sam Houston State University (SHSU) whose goal is to extend academic studies for future engineering technology students. A group of engineering technology students and residence life office staff have been challenged with a multi-year instrumentation project. The study started in May 2012 and continues to challenge young minds after multiple phases of the project have been completed. Students were given multiple tasks to install circuit solver TRV valves in university dorms to test the valves. The first task was to work with an engineering firm to learn the required design work. After approval of the design work, students worked with plumbers to install circuit solver-TRV valves to university dorms. Following the installation, data acquisition devices were identified and purchased to determine the temperature of the water at several locations (bathtub, restroom, and kitchen) in the university apartment complex. Wireless transceivers are used to report this data to a main server computer for further data-mining. All the collected data were analyzed and findings were reported to Therm-Omega-Tech for future investigation by the engineering technology students.

Introduction

In large residential complexes with multiple hot water delivery fixtures; e.g. showers, tubs, faucets, in hotels, condominiums, apartment buildings, schools, dormitories; the domestic hot water system should be designed so that hot water is readily available without wasting water going down the drain while waiting for hot water to arrive. The purpose of a recirculating domestic hot water system is to assure a readily available supply of hot water to each user. A properly sized recirculation pump is used to circulate just enough hot water through all branches to offset the heat losses and keep the hot water at the desired temperature. The layout of a hot water piping system is almost never symmetrical, with each piping branch presenting a different resistance to the flow of water. Because of these asymmetrical resistances, simply turning on the recirculation pump will not assure that hot water flows to each hot water supply branch. Branches at farther distances or branches at higher elevations or with smaller piping sizes present more resistance to flow. The closer, lower resistance branches will be satisfied while these higher resistance branches will be starved of hot water. To overcome this imbalance, each hot water supply piping branch must be "balanced" so that the flow resistances are nearly equal. The traditional and most common way of balancing these domestic hot water (DHW) branches is by using fixed flow balancing valves, often called circuit setters. Each balancing valve must be set so that the resistance to flow in each branch is about equal. However, this is a very challenging task, especially in large multi-story buildings. In practice, the end result is that the systems are never optimally balanced; manual balancing valves must be set to flow more than is really required to offset the piping heat losses. This inevitably leads to oversizing the recirculation pumps which increase installation and operating costs. The flow velocities are then higher than necessary, often leading to flow induced erosion of the piping which eventually results in water leaks and high repair and replacement costs [1-6].

Domestic hot water recirculation and keeping consistent hot water temperature at the sinks and bath tubs are important, especially in the buildings there is a colder climate. If the temperature of the hot water keeps dropping, the user will wait until hot water flows at the bath tub or sink. This creates a water consumption issue, because the user uses more water. Awareness of total water consumption results in more attention to how water recirculation systems can be beneficial. Usually in colder climates, people may need to wait for hot water in the shower or in the kitchen, which is not only an inconvenience, it also wastes valuable energy and resources. In America, a typical single-family home wastes about 10 gallons of water a day down the drain and that adds up to $11 billion per year in heating and waste-water treatment. Home owners seek ways to learn about how water circulation and delivery systems can be implemented which will not waste water. The key to the system is to keep the volume of water in the branch lines as small as possible and to eliminate standing water that accumulates and quickly cools in the pipes when hot water is not running. By making the branch lines short, the waste of colder water is diminished as a person waits for hot water. In addition, all of the hot water lines, loops and branches included, are insulated. This keeps hot water from the water heater at a hotter temperature until it reaches the tap. Although it is not unusual for plumbers to install circulation pumps to improve home hot-water circulation, this system is unique in that the pump runs only when hot water is needed, which eliminates the wasted energy used by other systems whose pumps run continuously. The pump is a small energy-efficient unit installed close to the water heater. It is activated on-demand using a switch or motion-sensing device located near each faucet [7-10].

There must be a better way to balance these DHW systems that still assures hot water is available upon demand and does not result in all the collateral problems with oversized pumps and eroding hot water piping, and a recent valve development solves this problem by using thermostatic recirculation valves rather than fixed flow manual balancing valves. The Circuit Solver is a unique thermostatic flow control valve designed to provide optimal recirculation flow rates. Since the goal is to maintain the desired hot water temperature at the end of each supply branch, the Circuit Solver continuously senses water temperature and allows more flow if needed, but also reduces flow if water temperature is satisfied. The Circuit Solver TRV constantly modulates the amount of hot water flowing in each branch in order to maintain exactly the desired hot water temperature. This allows use of perfectly sized recirculation pumps that circulate just enough hot water to offset the heat losses. The challenges associated with trying to manually balance a DHW system are eliminated along with the time consuming labor and all too common recalls to readjust the system. Flow induced pipe erosion can be completely eliminated as long as the pipe sizes are within good design practice guidelines.

The thermal actuator [11] inside the Circuit Solver modulates the valve between an open and closed position in response to changing water temperature caused by heat loss, water demand, or any other reason. This constant, automatic response to water temperature enables each hot water branch to quickly and consistently deliver the right temperature of hot water to each connected fixture. The valve is constructed entirely of stainless steel and is certified to NSF/ANSI 61 and California AB1953 [12]. For recirculation pump sizing, Circuit Solver allows the pump(s) to be sized exactly without any need to oversize to account for typical manual balancing problems. Therm-Omega-Tech recommends using established industry standard pump sizing procedures. For example, the ASPE Design Handbook [13] and ASHRAE Handbook [14] both have established methods for recirculation pump sizing.

Figure 1 shows the circuit solver TRV device. The manufacturer identifies problems with the current hot water delivery systems: (a) water flows to the path of least resistance; (b) many buildings require multiple branches off the how water supply line; (c) hot water use is hyper-dynamic, so the path of least resistance constantly changes; (d) manual flow control valves cannot efficiently resolve these issues [15]. The manufacturer's solution that to install a circuit solver on each hot water supply branch line immediately downstream of the last run-out to a hot top. Figure 2 shows the potential installation of circuit solvers.

Figure 1. Circuit Solver TRV [15]

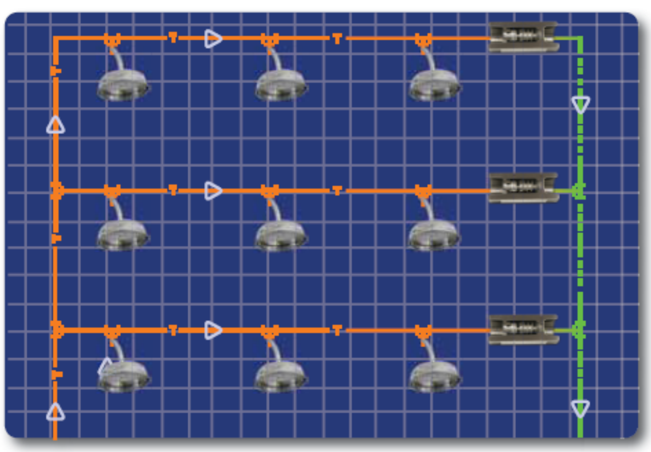

Figure 2. Illustration of the potential installation of circuit solvers [15]

The unique idea behind the Circuit Solver is that to overcome great difficulties in balancing domestic hot water systems that use conventional manual balancing valves (especially with complicated, large systems), the Circuit Solver (thermostatic balancing valve) does it automatically since it senses the water temperature; and the point of having the recirculation is to maintain the correct water temperature at the end of every supply branch. Manual balancing valves are all fixed flow devices so they do not respond to changing water temperature or flow requirements.

Preliminary Study and Design Work

A project team consisting of four engineering technology (ET) students, two ET faculty, university residence life technicians, Therm-Omega-Tech, and engineering firm engineers had preliminary design studies to install the circuit solver TRV. Based on the design work, it was decided that three circuit solvers should be installed at the Bearkat Village apartment complex. Each circuit solver handles18 apartments. There are three mechanical rooms for the apartment complex serving about 18 apartments each. Each mechanical room had a circuit solver installed to service 18 apartments. Figure 3 shows the Bearkat Village apartment layout, and selected apartments had circuit solver components installed in addition to temperature probes in the tubs and lavatories, temperature transmitters and receivers, and circuit solvers in mechanical rooms. In the layout, three selected apartments are shown to display the places where circuit solver project components were installed. Apartments were named K, J, L sections. Each section had a mechanical room for the plumbing connections. K section of the apartment complex had a main mechanical room and a data room near the mechanical room. All the water tanks, circulation pumps, and meters were in the mechanical room. A new computer and receivers were placed in the data room for data acquisition purposes. Transmitters and receivers were named as K, J, and L for the software package came with transceivers.

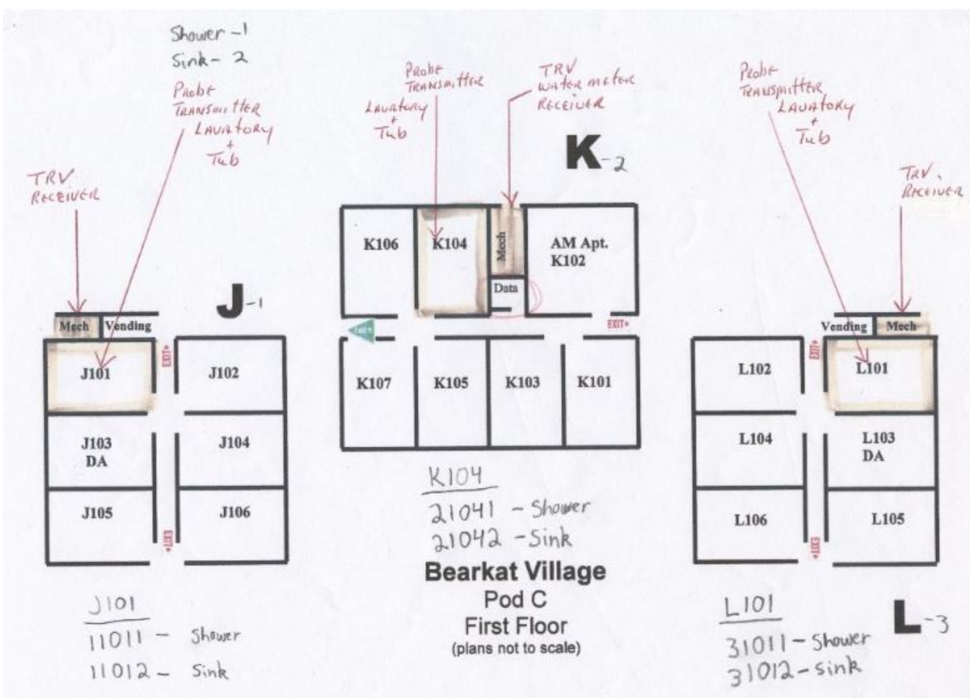

Figure 3. Bearkat Village first floor layout

Figure 4 shows the concept design graph of the overall data acquisition system for the temperature measurements. There were three buildings in the complex (J, K, L). Three apartments from the three buildings were selected. One is in the first floor and second one is in the third floor. All the wireless capable thermocouples were installed to lavatories and bath tubs. A specific place was reserved for a laptop for data storage and computer interface.

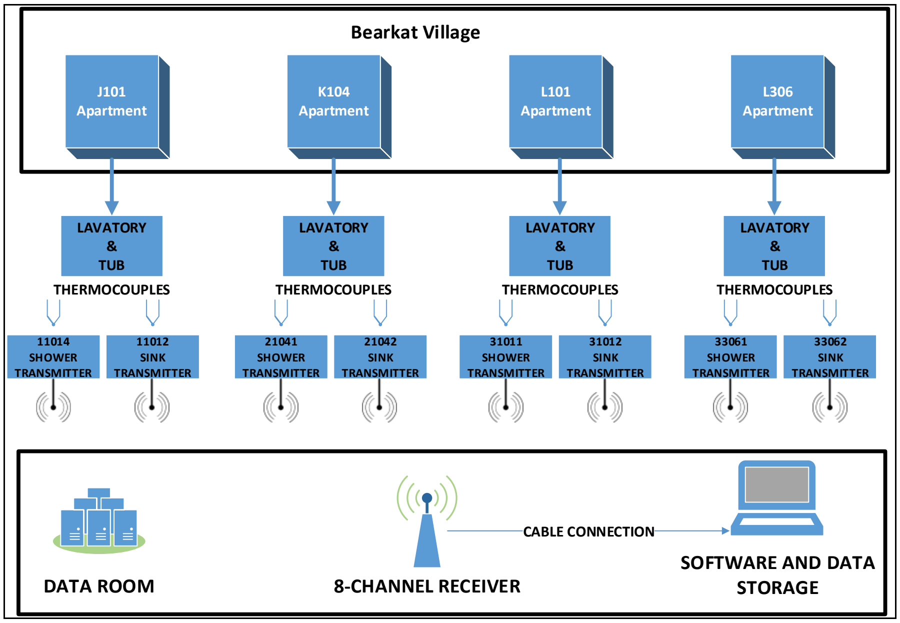

Figure 4. Concept design graph of the data acquisition system

Installation

An engineering firm was hired for the design work and preliminary studies for potential plumbing. The existing plumbing system was revised and potential locations for the circuit solvers, temperature probes, and water meter (to measure overall water consumption) were identified. After extensive meetings all the components were installed for testing and data acquisition. Figure 5 (a, b, c, d) shows the installed circuit solver devices in three mechanical rooms serving K, J, and L sections of the apartment complex, as well as the new water meter.

1: Mechanical Room

2: Circuit Solver TRV

3: By-pass valves

4: Main valve for existing circulating system

Figure 5a. Circuit Solver TRV and pay-pass valves

Figure 5b. Wireless thermocouple probes connected to the bath tub and lavatory pipes [16-18]

Figure 5c. Wireless transmitters and 8-Channel receiver [19-20]

Figure 5d. New water meter to measure consumption with/without circuit solver TRVs [21]

Due to limited access to the student apartment, and because the data had to be collected over a long time period, the project team decided to use a wireless data acquisition (DA) system that collected data on the water flow from the cold inlet to the hot water heater, the water temperature, and elapsed time at the test fixtures. One point we discussed was the possible use of wireless data acquisition to avoid intruding on resident students. For the measurements of water consumption, only one flow meter was required on the cold line into the hot water heater (to measure the made up water which should be equivalent to the hot water used). After searching various options, it was concluded that a wireless transmitter (Figure 5b) would was best as far as monitoring water temperatures at the faucets/showers in each room for this project. Initially, the temperature transmitter was located nearby the thermocouple probes under the sinks and bath tubs. However, there was a very weak or no signal between the temperature transmitters and receivers due to walls. After researching the specifications of the transceivers, it was concluded that the devices only worked based on line of sight. After several tests, the temperature transmitters were moved outside of the apartments in hallways closer to the data room where receivers were located (Figure 5c). Basically, the thermocouple leads were run into the transmitter located outside the apartments. Thermocouple sensors were mounted in tees below the water outlet fixtures. This increased the signal strength and transmission quality effectively. A receiver was installed above a desktop computer and a network connection was established in the data room (Figure 5c). An Omega engineering flow meter for the cold inlet to the hot water heater with data acquisition capability was connected to the water tank to measure water consumption (Figure 5d).

Testing of Transceivers and Software

The project team had several meetings for installation and the programming of the transmitters and receivers used for temperature readings. After the meetings, the team met and activated several transmitters to test the system. Unfortunately, the signal strength was lost very quickly as students walked down the first floor breezeway of building K in either direction and within eye sight of the receiver room; at approximately 60 feet, the strength dropped to about 40% (software interface on the laptop). As soon as students with the transmitters stepped into the breezeway of building J and L, all signals were lost. This test were repeated several times by the students. Basically, they moved the laptop with an attached receiver to various locations to investigate where the signal got weaker or was lost. Then students moved the transmitters around the building, and others followed them with the laptop/receiver. Outside of the building, the signal was moderate, but when students entered the apartments, the signal got very week and then disappeared. However, transmitters for apartment in K building worked adequately because of the short distance to data room.

The project team came up with several solutions to overcome signal strength issues:

- Implement a repeater/amplifier to boost the signal strength for the apartments in L and J building.
    - *Due to cost and complexity, this idea was not implemented*.

- Extending the thermocouple wires outside of the apartment so the transmitters can be located outside the dorm room. The transmitters are suitable for outdoor exposure.

However, the location of the transmitter should be in the sight line to the data room to get signal [22].

  - *The project team decided to extend thermocouple wires by drilling very small holes on the walls to outside the apartment to overcome the signal strength. This method improved the signal strength to almost 90%.*

- The third idea was to use another type of transmitter from the same company that had a higher signal strength. A test transmitter and receiver was ordered and received. It was a high power IEEE 802.15.4 compliant transmitter operating at 2.4 GHz designed to transmit over greater distances and through more obstructions than the standard transmitter. These wireless sensors transmit up to 1000m (3280`).
  - *The test transmitter did not work. Students tried various ways to get the new transmitters to transmit from point A to point B, and the results was the same as when using the original transmitters. It only worked within an approximated 60 feet and in sight of the data closet. Residence life staff came up with the conclusion that hardie wall paneling could be a factor because it is fiber cement siding; such paneling would basically be like concrete blocks between the walls. After talking to the transceiver manufacturer, it was concluded that their devices were designed for line of sight use. It was not recommended for use in a non-line of sight application.*

Data Acquisition and Evaluations

All the transceivers are programmed and named in order to track down the temperature readings for the specific apartments and locations in the apartments. An 8-channel receiver was plugged to the laptop computer for data storage and evaluations (Figure 6). Software interface was capable of showing all 6 thermocouple readings in real time. Additionally, based on programming, temperature readings were stored in a text file in 30 seconds intervals. The software generated .txt file with the all collected information. It also had the capability of generating charts. The software could collect the data for only 11.5 days based on 30 second time intervals for temperature reading transmissions. It could be set up for one minute intervals to increase the number of days to almost a month; this would be more consistent for water usage measurements. Figure 7 shows the text file with the collected data with 30 seconds intervals.

Figure 6. Laptop computer with receiver connection in the data room

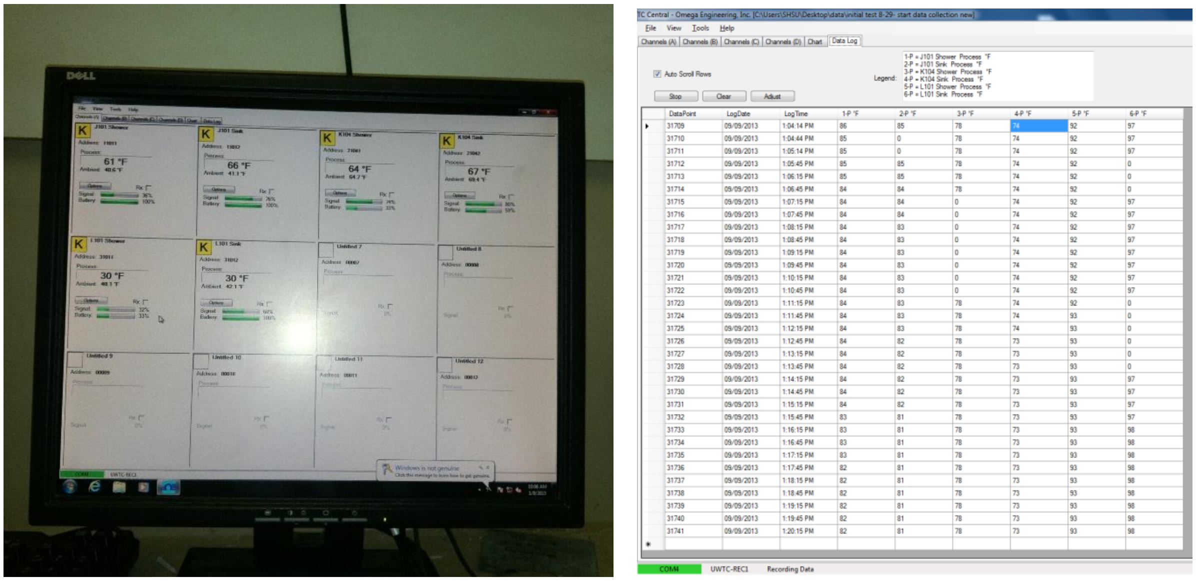

Figure 7. Software interface for generated text file of the temperature readings

The data collected were based on having a circuit solver TRV in line and bypassing the circuit solver TRV devices in the recirculation system. For example, during first 12 days, the circuit solver TRV devices were turned on using two valves connected each side of the device (Figure 5a). After 12 days, the circuit solver TRV devices were deactivated via the valves by activating the traditional water circulation system. In this phase, the circuit solvers are bypassed. The data collection for the traditional recirculation continued for about 12 days in order to compare water consumptions. All the data collected were entered in an excel workbook to be evaluated (Figure 8). In this file, both 12-day periods were compared in terms of water consumption and temperature readings at the lavatories and bath tubs. Using the circuit solver TRV, the temperature readings were constantly high. However, the water consumption reading did not show any improvement due to hot climate in Huntsville, TX during the test period. Another reason was the proximity of the apartments in the building to the water boilers. If the apartments and boilers are in close proximity, the hot water temperature was not affected much compared to locations with longer distances and cold climates. All the findings were shared with the Therm-Omega-Tech. for further evaluations.

	Water Meter Reading and Evaluation										
2	Device	Start Date	Start Time	End Date	End Time	Time Intervals	# of Days and Time	Water Meter Reading START	Water Meter Reading STOP	Water Consumption TOTAL (Gallon)	Average Water Consumption PER DAY
3	Circuit Solver TRV **NOT ACTIVE**	8/29/2013	12:30pm	9/9/2013	1:33pm	30 sec	11 days 1 hour 3 min	600300	627500	27200	**2472.73**
4	Circuit Solver TRV **ACTIVE**	9/9/2013	1:57pm	9/20/2013	9:15am	30 sec	11 days 4 hours 42	627500	654800	27300	**2481.82**
5	Circuit Solver TRV **NOT ACTIVE**	12/9/2013	1:18pm	12/20/2013	4:07pm	30 sec	11 days 2 hours 49	849300	878000	28700	**2609.09**
6	Circuit Solver TRV **ACTIVE**	1/22/2014	1:27pm	2/2/2014	4:14pm	30 sec	11 days 2 hours 47	890000	936000	46000	**4181.82**
7	Circuit Solver TRV **NOT ACTIVE**	2/5/2014	11:13am	2/27/2014	4:41pm	1 minute	22 days 5 hours 28	936000	1019300	83300	**3786.36**
8	Circuit Solver TRV **ACTIVE**	3/6/214	9:03am	3/25/2014	3:19pm	1 minute	18 days 6 hours 16	1019300	1050300	31000	**1722.22**
9	Circuit Solver TRV **NOT ACTIVE**	3/25/2014	3:22pm	4/15/2014	3:26pm	1 minute	21 days 0 hours 4 minutes	1050300	1108100	57800	**3211.11**
10	Circuit Solver TRV **ACTIVE**	4/15/2014	3:28pm	5/9/2014	1:30pm	1 minute	23 days 22 hours 2 minutes	1108100	1169600	61500	**3416.67**

Figure 8. Excel file with the water consumption comparison

Educational Outcomes

Four electronics and design & development major students were involved in this project; all were graduating seniors. The most common feedback from the students centered on skillsets gained by team work and their increased knowledge of building systems and instrumentation. Two of the electronics major and design minor students showed an interest in extending the project to overcome some of the issues they faced during the study. Two students are enrolled in an independent study course to work on this project during the spring 2015 semester. For demonstration purposes, this project is being demonstrated in instrumentation & interfacing, industrial electronics, and renewable-energy related classes offered in the program as examples. This type project produces hands-on activities and demonstration modules for the students enrolled in the classes. For example, the outcomes of this study created several lab activities for the students. During their research, students get to see firsthand the relative merits of the project and get to use some of the new technologies one-on-one.

Instrumentation and energy knowledge and projects are important to prepare students to be competitive for careers in the growing fields of instrumentation, automation & control, energy-related engineering, science, and technology. Preliminary projections from the Bureau of Labor Statistics state that the number of expected energy related green jobs is expected to increase by 11% by 2016, and most of it in environmental or energy-related sectors [23-24] . Edgar Dale's cone of learning shows that participating in discussions or other active experiences may increase retention of material by up to 90% [25]. Richard Felder and Linda Silverman recommend several teaching techniques to address all learning styles, one of which is to provide demonstrations for students with sensing and visual learning styles and hands-on experiments for students with active learning styles [26]. According to Moore, there is a direct correlation between in-class performance, laboratory attendance, and performance [27]. In capstone related project, active learning can be achieved through a variety of activities that include lab and project experiments with hands-on projects and hands-on laboratory experiments [28-31].

Conclusion

This study lasted about three years. Approximately twelve people are involved in this study including an engineering firm, the Sam Houston State University Residence Life Office, Therm-Omega-Tech., and SHSU students and faculty from the Engineering Technology program. Student feedback was very positive in terms of the learning curve and team work involved. This study will continue to be used as part of energy, instrumentation, and interfacing courses in the engineering technology program. It is a very interesting and challenging demonstration unit for the students as they learn how to save energy and water and learn more about data acquisition and interfacing methods. The study will continue in spring 2015. A team of students will work with Residence Life to examine the installed circuit solver TRV to determine if there are minerals and dirt or debris that build up in the devices.

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