DOMESTIC HOT WATER SYSTEMS USING ELECTRIC HEAT TRACING CONTRIBUTE TO BUILDING LEED STATUS

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Abstract – Water heating for residential use consumes over 18% of all energy used for residential purposes and is the second largest energy use after space heating and cooling[1]. Similarly water heating in commercial buildings represents over 7% of all energy used for commercial purposes[2]. There are several different technologies for delivering domestic hot water from the heat generating sources to the various usage points scattered throughout buildings. Since the distance between sources and usage points can vary dramatically, designers attempt to minimize water consumption, heat loss, and subsequent energy consumption by various means. Over a third of the energy use associated with hot water delivery is wasted in distribution losses[3]. The three most common ways to minimize the wait time for hot water to appear at points of use while subsequently reducing wasted water going down the drain are recirculation systems, electric hot water temperature maintenance systems, and point of use heaters. All three methods can be implemented and optimized in various ways to minimize wait times and energy consumed. This paper will compare and contrast system types and their respective costs and benefits. In addition, the method of calculating energy savings of hot water temperature maintenance systems will be presented. Such calculations can result in valuable extra credits for Leadership in Energy and Environmental Design (LEED) certifications.

Index Terms – Hot Water Distribution, Domestic Hot Water (DHW), heat tracing, Hot Water Ambient Temperature (HWAT), recirculation systems, Leadership in Energy and Environmental Design (LEED), International Plumbing Code (IPC), International Energy Conservation Code (IECC), American Society of Plumbing Engineers (ASPE), ENERGY STAR®, Environmental Protection Agency (EPA), Savewatt®, Raychem®

I. INTRODUCTION

Today's architecturally complex buildings and residences make ever increasing demands on HVAC, mechanical piping, electrical and communication wiring. Energy and water conservation requirements further challenge architects and engineers to provide cost effective energy efficient domestic hot water systems. The efficiency of hot water delivery systems depends on the efficiency of the hot water heat generation devices, the distribution system, and the wide variety of fixtures and appliances at the points of use. Product improvements of hot water heat generators such as gas and electric boilers, condensing boilers, storage tanks, solar thermal panels, and point of use heaters have resulted in significant efficiency improvements over the past decade. Likewise, most modern fixtures and appliances (faucets, showerheads, clothes washers, and dishwashers) have dramatically reduced the amount of water used over the past 20 years with a resultant reduction in the amount of energy needed to heat the water. This paper is focused on efficiency improvements of domestic hot water (DHW) distribution systems which deliver the hot water from the heat generators to various points of use located throughout a building. Such distribution systems typically lose 10 to 15% of the generated hot water energy before it gets to the points of use. Techniques are now available to greatly reduce wasted distribution energy while simultaneously reducing wasted water and wait times for hot water to appear at points of use. These energy savings can be easily calculated and provide building architects and designers a valuable source of LEED credits.

A. Typical Hot Water Distribution Systems

Domestic hot water systems include a hot water source such as a boiler, a piping distribution system and plumbing fixtures and appliances attached at points throughout the building. When considering the distribution piping between the boiler and points of use, the three most prevalent DHW systems are:

1) A one-way piping network to the points of use, often using pipe insulation to reduce heat loss.

2) A piping network that recirculates the hot water via pumps, valves and piping out near the points of use and back to the boiler.

3) A one-way piping network that uses a specialized self-regulating pipe heat tracing system with digital controls to replace heat loss along the pipes to the points of use.

All three systems attempt to minimize the time it takes for hot water to appear at points of use and simultaneously minimize the amount of cool water that is dumped down the drain while waiting for the hot water. Federal standards were put in place in the 1990s for water fixture flow rates to conserve water.

Some states such as California, have flow rate standards more restrictive than federal standards. In many cases these standards make it especially challenging to minimize wait times since pipe sizing rules have not been revised to match flow rate standards resulting in an increased volume of water in the piping. In all cases, designers typically attempt to keep warm piping as close as possible to the point of use.

In applications where the distances between uses are large, and the needs for hot water are intermittent, point of use heaters may be utilized. One example is remote or isolated building locations such as lavatories that are far from building hot water sources. This paper, however, will focus on the other DHW systems.

B. Hot Water Recirculating Distribution Systems

In their simplest form, recirculating systems utilize additional piping and a series of pumps and valves to circulate hot water from the source to locations close to the points of use then back to the source. Figure 1 illustrates one diagram of such a system. Alternate configurations can also be used to minimize the amount and complexity of the return piping, balance valves, riser vents and related equipment.

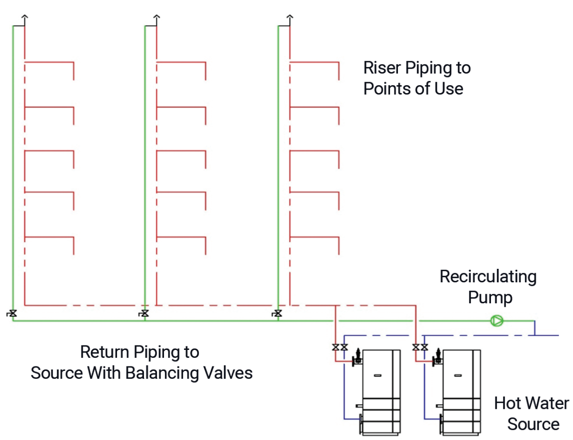

Figure 1. Typical Hot Water Recirculating System Diagram

In high rise buildings, multiple recirculating zones and pressure reducing valves (PRVs) may be required to assure proper pressure at all points of use. Balancing valves are incorporated to regulate recirculation flow of each individual riser and assure that points of use furthest from the hot water source are maintained at an adequate temperature. To reduce piping and energy losses, risers and/or the return piping are sometimes grouped. To further reduce energy consumption, timers control the recirculation so that flow is optimized for off peak and on peak demand periods. Of course, any such control systems must be designed to comply with ASHRAE 188 regarding the minimization of Legionella disease risk.

C. Hot Water Self-Regulating Temperature Maintenance Systems

The second type of DHW system uses self-regulating heat tracing to maintain the piping at a constant temperature. The heat tracing is attached directly to the DHW piping so there is no need for recirculating piping, balance valves or pumps. When the heating cable is attached to the risers, the hot water delivery performance is essentially the same as a recirculating system without the need for the return piping. The time it takes to get hot water to the points of use is then dependent on the volume of water in the branch piping. However, unlike recirculating systems, heating cable can easily be attached to the branch piping which greatly reduces or virtually eliminates the wait times.

Heating cable controls can enable additional energy savings by turning the system on or off according to demand and in some cases also include a cycle to help reduce Legionella disease risk. Figure 2 is a diagram of a typical self-regulating heat tracing DHW system.

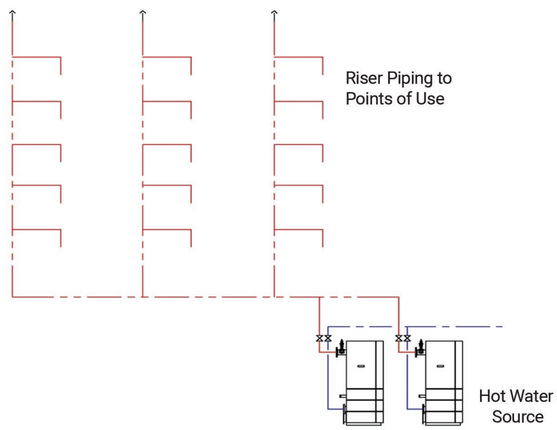

Figure 2. Typical Self-Regulating Hot Water Temperature Maintenance System Diagram

Self-regulating heating cables vary their heat output according to the pipe temperature everywhere along the run. This allows them to maintain a uniform water temperature by replacing only the heat lost through the insulation at each point along the cable. Because heating cable systems are not dependent on flow they can easily be applied from the source to the farthest points of the system regardless of the piping layout.

D. Codes and Standards

Many factors affect the time it takes for hot water to get to a point of use:

1) The distance from a heated pipe (recirculated or heat traced)

2) Pipe size

3) Point of use fixture flow rate

In 2007, Plumbing Systems & Design[4] published recommendations for hot water delivery times. Table 1 lists the delivery times as a function of pipe length, pipe size and flow rates.

Delivery Time in Seconds

Fixture flow rate		0.5 GPM		1.5 GPM		2.5 GPM		4.0 GPM	
Piping Length	Pipe Size	10 Feet	25 Feet	10 Feet	25 Feet	10 Feet	25 Feet	10 Feet	25 Feet
Copper	1/2”	25	63	8	21	5	13	3	8
Copper	3/4”	48	119	16	40	10	24	6	15
Steel Pipe Schd 40	1/2”	63	157	21	52	13	31	8	20
Steel Pipe Schd 40	3/4”	91	228	30	76	18	46	11	28
CPVC Schd 40	1/2”	64	159	21	53	13	32	8	20
CPVC Schd 40	3/4”	95	238	32	79	19	48	12	30

Acceptable Performance	1 – 10 seconds
Marginal Performance	11 – 30 seconds
Unacceptable Performance	31+ seconds

Source: Plumbing Systems & Design – December 2007 “Domestic Hot Water Systems”

Table 1. Hot Water Delivery Times and Performance

The report recommended 1-10 seconds for acceptable performance, 11-30 seconds for marginal performance and 31+ seconds as unacceptable performance. As expected, the combination of low flow rate fixtures, large diameter piping and long lengths produced the worst performance.

Starting in 2015, the International Energy Conservation Code (IECC[5]) includes many requirements for domestic hot water distribution systems including recirculating systems and heat trace systems. Table 2 taken from section C404.5.1 of the IECC code provides the recommended maximum piping length from the nearest heated water source to the point of use fixture. The heated water source can be the recirculation loop or heat traced pipe header.

Piping Volume and Maximum Piping Lengths

Nominal Pipe Size (Inches)	Volume (Liquid ounces per foot length)	Maximum Piping Length (Feet)	
		Public Lavatory Faucets	Other Fixtures and Appliances
1/4	0.33	6	50
5/16	0.5	4	50
3/8	0.75	3	50
1/2	1.5	2	43
5/8	2	1	32
3/4	3	0.5	21
7/8	4	0.5	16
1	5	0.5	13
1 ¼	8	0.5	8
1 ½	11	0.5	6
2 or larger	18	0.5	4

For SI: 1 inch = 25.4 mm, 1 foot = 304.8 mm, 1 liquid ounce = 0.030 L, 1 gallon = 128 ounces.

Table 2. Piping Volume and Maximum Piping Lengths

Table 2 is based on the calculated maximum volume of water in the pipe between the heated water source to the fixture. For public lavatory faucets, not more than 2 ounces (0.06 L) of water is acceptable. For other plumbing fixtures or plumbing appliances, not more than 0.5 gallon (1.89 L) is acceptable.

The difficulty of implementing this requirement in real-world piping installations, is that recirculation or heat tracing systems would be required within 1.5 ft of the fixture (using ½" copper piping).

Since 2015, the International Plumbing Code[6] likewise has recommendations for domestic hot water systems and references the IECC tables for maximum piping volume and lengths.

II. SELF-REGULATING HEATING CABLES FOR HOT WATER TEMPERATURE MAINTENANCE

Self-regulating heating cables were invented by Raychem Corporation in 1974. Since then, these cables have become industry standard for most pipe heating applications, with well over a billion feet of similar cables installed.

The cables feature parallel bus wires separated by a semi-conductive polymer which acts as the heating element. Such cables have the unique feature that their heat output is inversely related to the surrounding temperature. When attached to a pipe, for example, the heater gets hotter when the pipe is cold and regulates back when the pipe gets hot. This not only saves energy, but produces a uniform temperature everywhere along the pipe. Figure 3 is an infrared image of a self-regulating heating cable installed on a pipe with the heater crossed over itself. Note the uniform heater temperature, indicated by the color, even at the point of crossover.

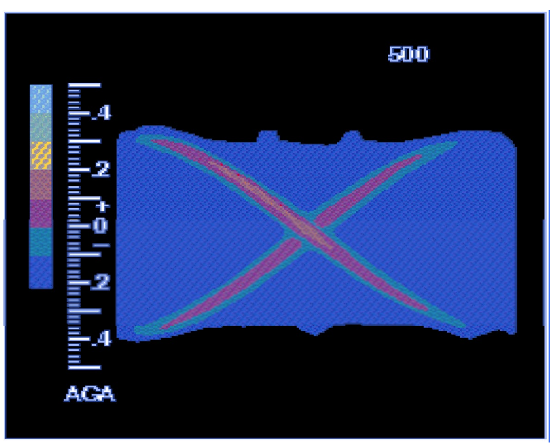

Figure 3. Self-regulating Heater Installed on a Pipe Infrared Image

Self-regulating heaters are rugged, flexible, flat, and can be crossed over without fear of burning out. Furthermore, they can be cut-to length in the field, are easy to tee, splice, install and repair. All of these features and benefits lead to cost effective designs and installations especially for DHW systems, where the heaters can be easily installed all the way to the point of use.

A. Domestic Hot Water Maintenance Heating Cable Construction

There are many different types of self-regulating heaters. Self-regulating cables are designed for water freeze protection, industrial applications, snow melting and other applications. Self-regulating cables for domestic hot water maintenance are custom designed to continuously maintain higher temperatures while minimizing water overheating.

It is critical in this application for the cable to include an internal vapor barrier. Whether aluminized or another film, this vapor barrier will protect the heater from chemicals that off-gas from pipe thermal insulations and other building materials that potentially degrade the polymer heating element. For additional mechanical protection, some brands also include more robust braids and outer heater jackets than freeze protection cables.

B. Self-Regulating DHW Heater System Components

A self-regulating DHW Heater System consists of the heating cable, in-line splice and tee connections, power connections and end seals. Quick-connect heater cable components have kept pace with other industry labor-saving pipe connection technologies, ensuring efficient and reliable cable connections.

The ease of design and installation make self-regulating systems suitable for even the most complex piping configurations. Figure 4 illustrates the various self-regulating DHW system components.

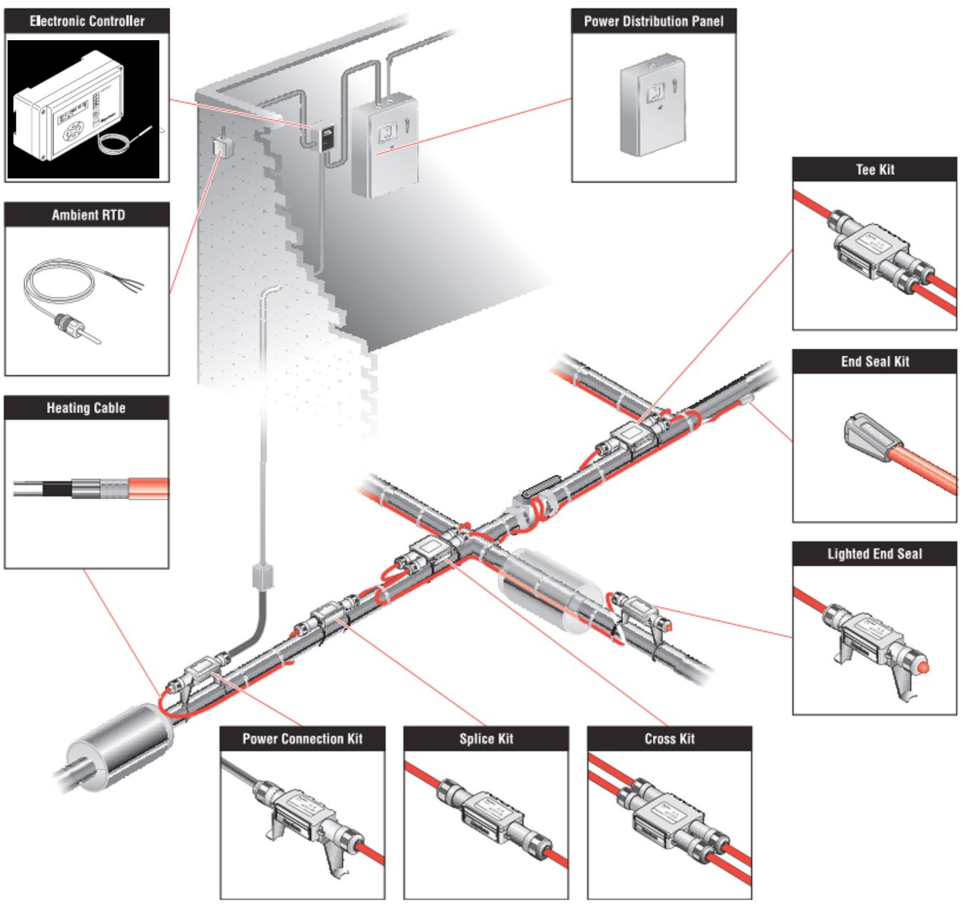

Figure 4. Self-regulating DHW System Components

Once attached to the pipe, thermal insulation is applied over the cables. The cables are typically connected to standard electrical panels for powering. Controllers provide 24/7 system monitoring as well as the capability for scheduled operation to comply with codes and minimize energy consumption during off-peak hours. Temperature settings are also adjustable for different applications such as hospitals, schools, hotels, kitchens, or residential needs.

Tight temperature control is provided using carefully designed semi-conductive polymers and digital controls coupled with proper insulation type and thickness. Temperature sensors on the pipe, common for freeze protection, are not typically recommended as the control process variable for heat tracing DHW systems.

III. RECIRCULATING VERSUS HEAT TRACING

A. System Design Complexity

The need for recirculating systems to return water to the source makes them distinctly different from heat traced temperature maintenance systems. The additional recirculating return piping, pumps, valves, and sensors can sometimes be complex, especially in high rise buildings where numerous pressure zones, supply and return risers and balancing devices are required. For most building layouts the capital outlay for proper recirculating and heat tracing systems are comparable. However, heat tracing systems offer opportunities for optimization which recirculating systems do not. For example, in buildings with multiple pressure zones, separate heaters and recirculating systems are typically required.

By comparison, a single heat tracing system can be used across multiple pressure zones which may facilitate the consolidation of multiple DHW plants to a larger, central DHW plant with a reduced maximum DHW load. Further, heat tracing may reduce the amount of piping, mechanical equipment, and reduce or even eliminate the need for some mechanical electrical rooms in large buildings, all of which reclaim valuable floor space.

Water scarcity is driving plumbing code changes even as DHW piping systems get more complex to keep up with architectural requirements. Compliance is simplified, since a heat tracing system can be run direct to the point of use regardless of how many branches there are or how long they are. With no need for return piping, there are no balancing issues due to piping complexity or length. In theory a pipe run could be 20 feet or 20 miles. As long as power is available along the route a heat tracing system would keep the run hot all along its length.

B. System Reliability

Heat tracing systems have fewer operational issues as they are static in nature with no moving parts. System controllers provide continual 24/7 monitoring and can communicate directly with building management systems (BMS) for easy alarm monitoring. Controllers conform to International Energy Conservation Code demand-based usage requirements. They are fully programmable and can run a multitude of time or use based operating programs to optimize and minimize energy usage.

Heat tracing systems can improve the performance of the hot water generating source by reducing cycling which leads to less boiler maintenance and longer life. In larger building applications, the increased volume of water needed for recirculating systems may even require larger boilers than for heat tracing systems which have no return piping. For condensing water heaters, self-regulating heater DHW systems help to optimize their performance by minimizing the inlet water temperatures. Recirculating systems by design mix the hot water return with the condensing water heater cold water inlet which reduces operational efficiency. Figures 5 illustrates what happens when condensing water heaters are used with recirculating and self-regulating heater DHW systems. Self-regulating heater systems increase the operational efficiency of condensing water heaters by as much as 9% over recirculating systems due to the lower inlet water temperatures of heat traced systems.

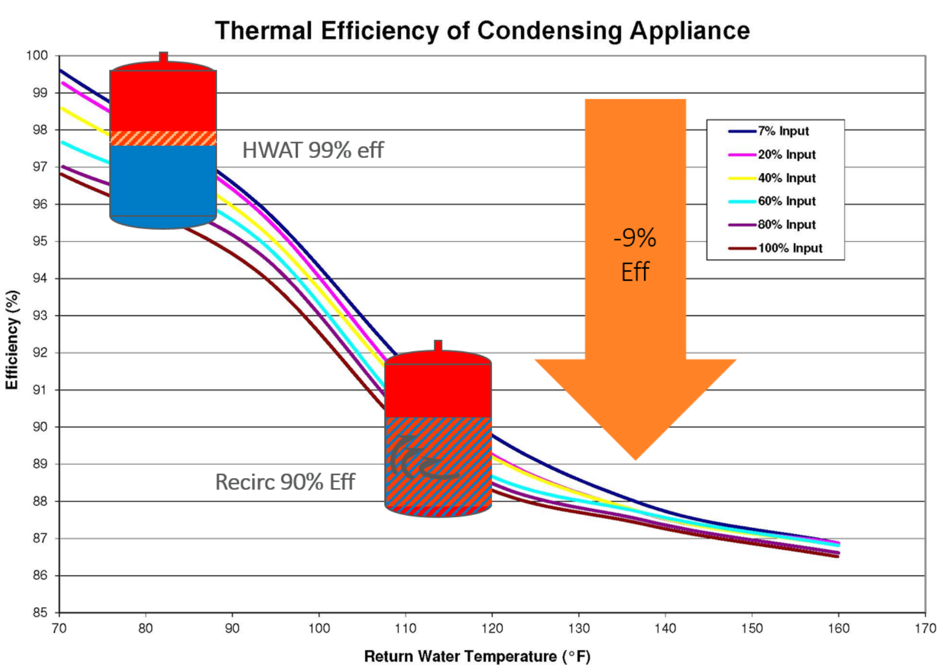

Figure 5. Condensing Water Heater Efficiency

IV. LEED, COST, AND ENERGY SAVINGS

A. Leadership in Energy and Environmental Design (LEED)

Leadership in Energy and Environmental Design (LEED) is the most widely used green building rating system in the world. LEED provides a point system to score green building design and construction. Buildings are awarded points based on the extent various sustainable strategies are achieved. More points lead to higher levels of certification. The goal is to improve building performance by maximizing energy savings, water efficiency, CO2 emissions reduction, improved indoor environmental quality, and resource stewardship.

B. LEED Credits

Recirculating systems and self-regulating temperature maintenance systems both save water, increase performance and help to reduce building energy consumption. However, only self-regulating temperature maintenance systems are eligible for LEED points due to their greater potential to reduce energy consumption and/or greenhouse gas. For example, in the LEED Alternative Energy Performance category, whole building simulations are used to calculate the percentage reduction in energy of a given building design over a baseline design. A 12% reduction in energy in a new building translates to 1 point whereas a 48% reduction translates to 19 points. In version 4 of LEED, Alternate Compliance Path (ACP) methods were allowed in some categories such as Alternative Energy Performance which allow alternate calculation methods to determine LEED credits. Another category, Innovation in Design, was created which can earn Standard Pilot Credits (SPC), each worth 1 point, for ideas and strategies new to LEED. Pilot Alternate Compliance Path Credit (pACP) is a pilot credit used in place of a standard LEED credit which earns ACP points as well as 1 point in the Innovation in Design category. Self-regulating heater temperature maintenance is eligible to use pACP methods to earn LEED credits when used to calculate savings over recirculation technology. This alternative calculation process translates to extra credits earned when using self-regulating heater DHW systems.

C. Self-regulating Heater LEED Credit Calculation

Software is available to compare and calculate the installation and operating costs of recirculating and self-regulating heater temperature maintenance systems. The software, called Savewatt®, compares the material and installation labor costs, operating costs and energy consumption over the life of the systems.

For LEED point calculations, the key parameter of interest is the energy consumption category. Estimates of the potential energy savings of a self-regulating heater DHW system must be compared to traditional hot water recirculation systems. To do so the following calculations must be performed:

1. Baseline energy performance calculation
   a. Traditional recirculation hot water system

2. Self-regulating heater DHW energy performance calculation
   a. Self-regulating heater DHW alternative to recirculation system

3. Comparisons
   a. Energy costs
   b. Source energy usage
   c. Greenhouse gas emission

A calculating tool is available to perform self-regulating heater DHW energy savings over recirculating systems which can then be exported to the LEED credit submission forms. Figure 6 lists the tool overview along with the input requirements and outputs.

Tool Overview

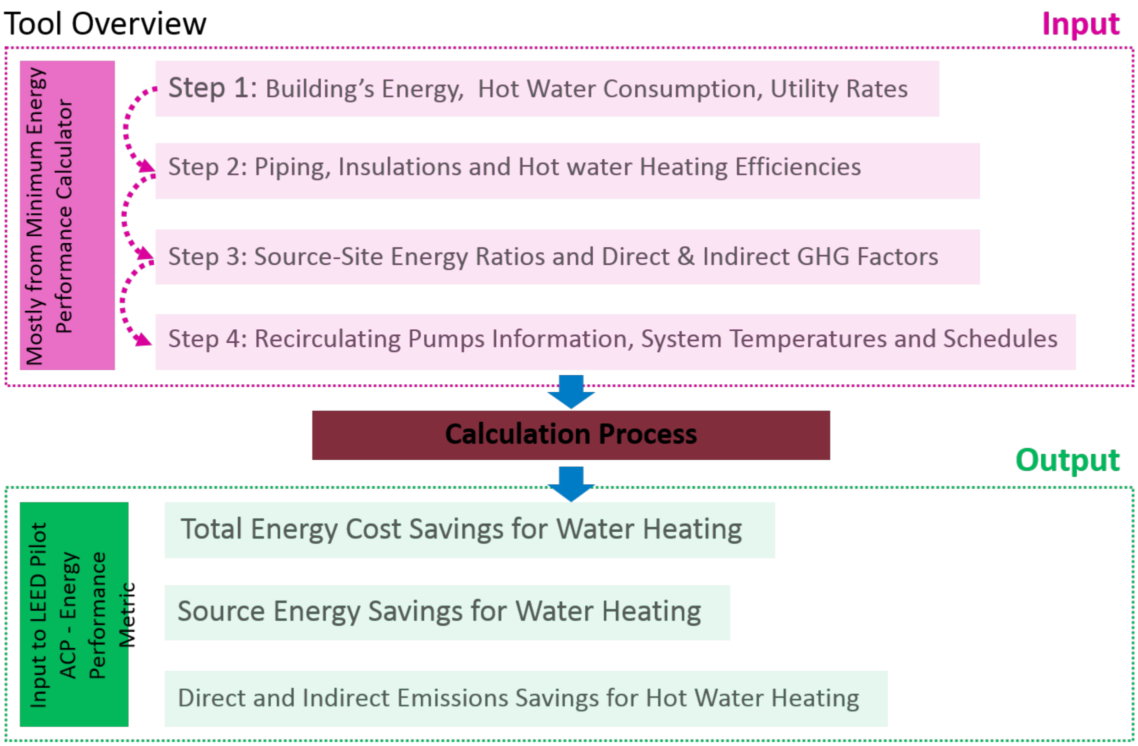

Figure 6. Self-regulating Heater DHW Energy Saving Calculator

Step 1 requires inputting the local utility rates for electricity and natural gas, the building energy consumption (electricity and natural gas) and hot water information such as entering water temperature, exiting water temperature, and water demand. The resulting calculation provides the baseline energy consumption.

Step 2 requires piping information such as pipe diameter, pipe length, and insulation thickness. These are needed for both the base case recirculation case as well as the self-regulating heater case. As noted previously, boiler efficiency is improved with self-regulating heater DHW so efficiencies for both the recirculating case and self-regulating heater case are required.

Step 3 requires that source site energy ratios and direct and indirect greenhouse gas factors be taken from the EPA ENERGY STAR® listed tables[7].

Step 4 requires the pump flow rates, pressure, efficiency, and power along with supply water temperature, return water flow rate and setpoint for pump activation. Lastly, the weekly operation schedule needs to be input.

Using the data collected in steps 1-4, the tool calculates the total energy cost savings, the source energy savings for water heating, and the direct and indirect emissions savings for hot water heating as compared to recirculating hot water systems.

The output data from the tool can then be transferred to the LEED EAp2 documentation spreadsheet which will determine the LEED points granted. In addition to the energy performance credit, one bonus point will also be granted in the innovation in design category by using self-regulating heater DHW systems.

V. CONCLUSIONS

Domestic hot water heating and distribution are major energy consumers in both residential and commercial buildings. Furthermore, waiting for hot water at faucets and other points of use often wastes significant amounts of water, particularly in large buildings with complex piping. Over one third of the energy use associated with hot water delivery is wasted in distribution losses. Typically, two major ways to minimize the wait for hot water are recirculation systems and electric hot water temperature maintenance systems using heat tracing. Both methods can be implemented and optimized in various ways. Hot water temperature maintenance systems using self-regulating heaters have been used for nearly 40 years and have proven to be viable alternatives to more complex hot water recirculating systems. With increased interest in faster time to the tap, green building designs and LEED building certifications, architects and engineers are constantly looking for methods to reduce building energy and water consumption. Self-regulating heater DHW systems have been proven to do both and can do so using simple calculation tools. More importantly, the calculated energy savings of self-regulating heater DHW systems as compared to recirculating systems can result in valuable LEED credits.

VI. REFERENCES

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VII. VITA

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