SIMULATION-BASED APPROACH TO IMPACT ANALYSIS OF ELECTRIC WATER HEATER DEMAND MANAGEMENT BASED ON CONSUMER COST AND COMFORT

A Thesis by

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The following faculty members have examined the final copy of this thesis for form and content, and recommend that it be accepted in partial fulfillment of the requirement for the degree of Master of Science, with a major in Electrical Engineering

Visvakumar Aravinthan, Committee Chair

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DEDICATION

To my wife and my parents

ACKNOWLEDGMENTS

I would like to thank my advisor Dr.Visvakumar Aravinthan for all his guidance, patience and support. I would also like to thank my wife Nazila Massoudian for her help and support during my research, Furthermore I would like to show my gratitude to Mohammad Heidari, Amin Mohsen zadeh and Mojtaba Sepehry for their thought provoking inputs. Lastly, I would like to thank all who have ever helped in completing this work.

ABSTRACT

A demand side management (DSM) strategy is proposed in this work to schedule Electric Water Heater in order to maintain or elevate consumer’s thermal comfort while reducing demand cost at the end use. The motivation is to analyze the impact of Electric Water Heater on HVAC energy consumption, consumer comfort and health. The analysis parameters are total reduction in EWH heating cost, HVAC demand, and total room temperature deviations in comparing periods of spring, summer, fall and winter.

In an attempt to model a real system and test the strategy, Gridlab-D software core is used. The modeling system utilizes a residential unit model, including HVAC and EWH dynamic models developed by PNNL. The algorithm then utilizes climate information for outdoor temperature data, heat gain through the building exterior and solar radiation for scheduling and model inputs. The model also includes heat gains from body heat of residents.

Iterations of an apartment complex with a random parameters including HVAC set points, Hot Water consumption patterns, and different number of residents are used to imitate a realistic residential apartment complex. The Hot water draw pattern has been randomly generated for each apartment in the complex based on standard ASHRAE 90.2-2004. The duration of simulation is 1096 days.

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CHAPTER 1

INTRODUCTION

The smart grid technologies are facilitators to handle loads at the consumer level in order to save energy, cut expense, support grid operations, and sustainability. Load side management in organized way may help in saving more energy and therefore move towards more sustainability. Advanced metering infrastructures (AMI) and bidirectional communication between the grid and Demand side, novel technologies and designs are essential to achieve full potential of smart grid investments in infrastructure. Innovative analysis means and more complex control strategies are needed for distribution systems to utilize these investments [1]. While Demand side management was a more a utility driven from the beginning, it is changing to be a more demand side driven [2]. However, it is not possible to request a consumer, who is not a skillful grid operator, to make an ideal schedule from the grid status and parameters to control over its own loads. Consequently, an automatic load scheduling technique is needed to achieve consumer approval on consumer-level Demand response plans. This such technique must require little consumer attention to set up and support and allows consumers to compare costs and benefits with different load plans, moreover it is desirable to persuade consumers' active contribution in shaping their energy consumption for the benefit of themselves as well as for the efficient, reliable, and economical operation of the power grid. A growth in the comfort zone could offer more flexibility in scheduling [3]

1.1 Background

Household appliances have been categorized into three different groups: controllable thermostatically controlled appliances (C-TCAs), controllable non-thermostatically controlled appliances (non-TCAs), and non-controllable appliances [4] [5]. As Non-controllable appliance could not be scheduled, they are usually modeled by a load profile that is predict with recorded historical data. Controllable non-TCAs are normally discontinuous loads that are easy schedulable such as dishwashers, washer/dryers or even electric vehicles charging process. The Controllable Thermostatically Appliances loads have thermal storage capabilities, such as HVACs and water heaters. They are usually appropriate choices for consumer-level DR programs. C-TCA loads scheduling has to account for thermal dynamics, random consumption, and consumer comfort [1] [3]. HVAC and water heater from C-TCAs are in the center of attention and Electric vehicles from Controllable non-TCA as they are good candidates for scheduling and energy storage. There are a lot of researches on scheduling of HVAC, water heater and EVs. But each of mentioned has a role in user comfort violations when not properly scheduled. Usually the scheduling of these loads are for the purpose of load shifting or peak reduction in demand side management and they inherently come with some levels of user discomfort.

In this work main focus is on scheduling of water heater. Heating of residential water by over 40 million electric water heaters in the United States out of 107 million total residential water heaters is responsible for 8.7% to 18% of residential electricity use [6] [7]. The mean household water consumption has been found to be around 64 gallons per day per household [7], hot water consumption is 32 gallons with a 95% confidence interval of ± 4.3 Gallons per day [8]. Water heating is the second main load in households and more than 27 million water heaters in the U.S. are older than 10 years old [7] which means the efficiency of most these water heaters has been dramatically been reduced.

Hot water is consumed in different applications, which the most part of it is temperature sensitive consumption, this means when the temperature of the hot water is higher, the amount of hot water draw will be less as the consumer will mix the cold and hot water to draw a specific amount of water at a certain temperature. There are only a few applications such as dishwasher or clothes washer which will consume hot water only or in some cases mixture of hot water and cold water regardless of the water temperature. Figure 1 shows the participation of each part of hot water consumption in a typical apartment. It is obvious that the hot water consumption in bathroom i.e. Bath, Shower and Basin has more than 80% of hot water on a daily basis [7] [8] [9]. These types of consumptions are the most critical temperature based consumptions meaning if the hot water gets hotter the resident will use less hot water in the mixture of hot and cold water at tap.

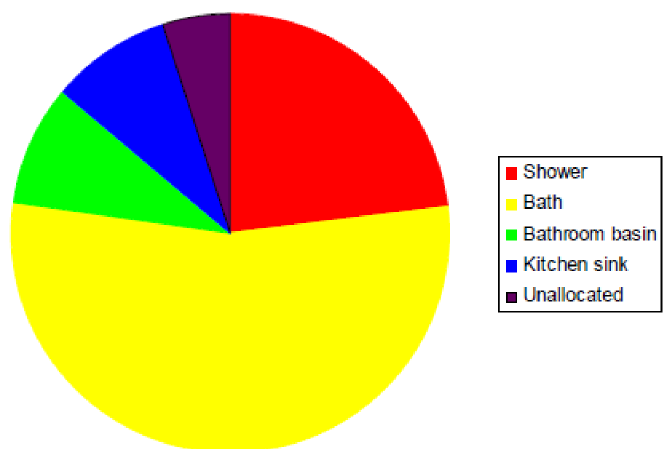

Figure 1. Residential hot water consumption types [8]

Periods of peak use of water occur in the morning and early evening. A similar profile measured over a 4-month period by [10] , and the 15,000-home data of [11] and also in [8] [12] [13] [14].

Figure 2 shows that the focus of temperature sensitive consumptions are around 8am to 12pm with the focus of showers at 9am.

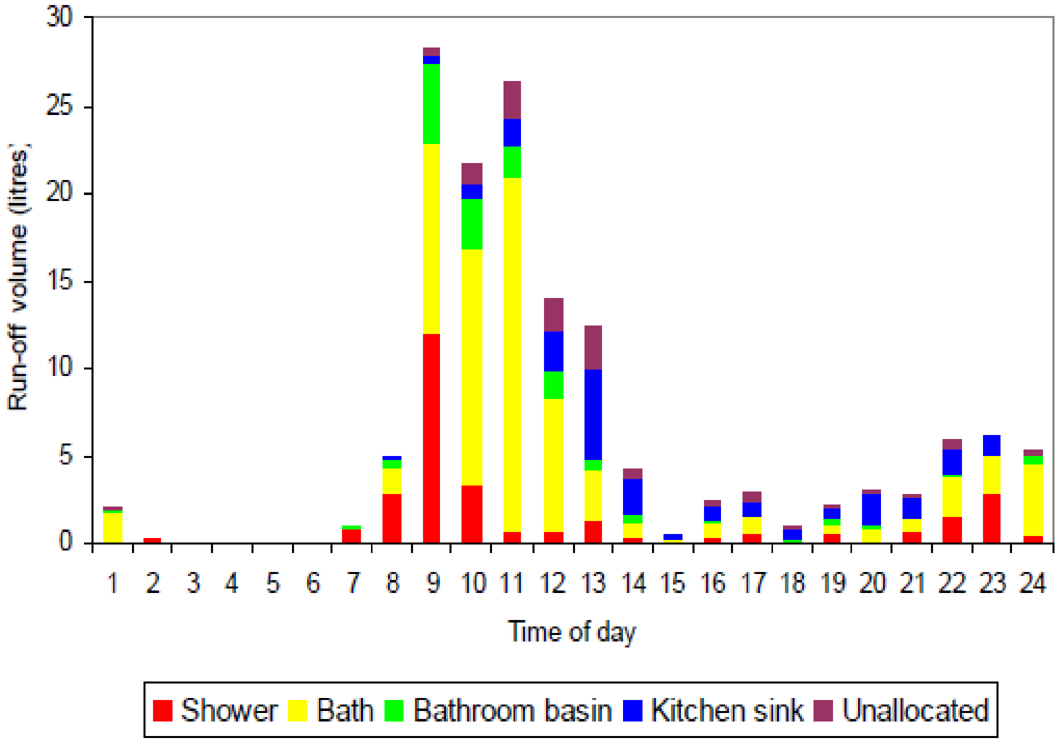

Figure 2. Hourly Hot Water Usage Profile [8]

1.2 Contribution

Outdoor temperature has direct effect on cold water entering residential unit, and will have effects on EWH working time and energy; also the effects of EWH scheduling on thermal parameters of the residential unit has not been studied, in this thesis an innovative and simple strategy for scheduling electric water heaters is proposed which not only violates or brings discomfort to consumers, it can elevates the comfort and health, and reduces the total energy consumption. In this work the effect of EWH scheduling on HVAC working time and energy consumption, and the role of Outdoor temperature parameter are studied. To be able to evaluate such a strategy, a new method is also developed to utilize Gridlab-D as simulator core and have more degrees of randomness. In this method a high level language software can run Gridlab-D core and feeds the core by pre-set values and preferences with some degree of randomness to create a much genuine test system. This link can elevate Gridlab-D ability to solve and evaluate random and complex strategies.

1.3 Organization

The rest of this thesis is organized as follows. Chapter 2 provides a literature review of the related work. In Chapter 3, the used models and parameters is described. The proposed Strategy is presented in Chapter 4. Simulation process is described in Chapter 5, and in Chapter 6 results are presented. Finally in Chapter 7 conclusion of research and suggests future works are introduced.

CHAPTER 2

LITERATURE REVIEW

This chapter provides detailed literature reviews that are related to the work done in this thesis. There are many available sources on using Direct Load Control of appliances as a demand side management strategy [3] [15] [16].

2.1 Energy Price Reduction vs Comfort level

In [3] [17] strategies have been implemented to reduce the total energy cost of consumers by reduce energy consumption during peak time for non-flat rate customers. In order to decrease the energy costs with dynamic pricing, customers could assume strategies and approaches for their water heaters. Therefore by using low-cost times for heating water even with usual maintenance of the fully storage water heater, taking advantage of storage capability in order to have enough hot water at high-cost times could be really possible. Though, it seems inevitable to trouble the consumer in order to cut the energy bill. This trouble includes low temperature of the water during the demanded interval or long delay before reaching the desired temperature. Even the reduction of cost has been studied extensively, in most cases the consumer comfort level has been hardly studied [3]. Even if they do study the consumer comfort level, the strategies used in those studies are to reduce consumer comfort or it’s a balance between comfort and savings.

According to [18] Load shaping is constrained by “energy payback” which means all of the energy not supplied when EWH is switched off will be required when they are switched on and contributing to generating potential load peaks. But this work shows it is not always true with load shaping.

2.2 TCL and Non-TCL

Some of the researches focus mainly on Non-TCLs [19] [20] and some other on TCLs [3] [17]. For Non-TCLs such as [19] and [20], the main focus is to reduce the demand of a residential unit during peak time by implementing power scheduling techniques. Although the main goal can be reached perfectly by cutting the power to the appliances and Non-TCL loads, these methods will result in termination of some customer preferred actions and results in customer discomfort at large.

In [3] Water heater has been studied and the aim has been to reduce the peak load. The result is to have balance between the customer preferences or reduction in expenses.

TCLs can be controlled by thermostatic parameters, although they can be implemented more like non-TCLs, but strategies which lower the thermostat set points are as economical as power interruption strategies i.e. On/Off strategy. And they will also result in higher minimum water/air temperatures [17].

In [17] authors have studied some strategies to control the cost of running a Water heater depending on a dynamic pricing signal. The strategies include both the Non-TCL and TCL aspects of water heater, which are Turing the water heater off at some times in one strategy, and also lowering the thermostat set point in another. But no analysis has be done on user comfort.

2.3 HVAC and EWH

Many papers pick HVAC as case study [1] [21]. HVAC has a huge capacity for storing energy and is a good candidate to be used for TCL control. But comparing to Water Heaters, any violation of user preferences will instantly and adversely affect customer comfort as HVAC is the main source of Heating or Cooling of living area. Furthermore any loss of room heat from the wall or windows are useless and a waste of energy.

Some other papers prefer Electric Water Heaters because it is believed the EWHs are sometimes better candidates to pick rather than HVAC for TCL case studies [15] [22]. The reasons which makes the EWH good candidates are:

a) They are continuously in operation, but violations from user preferences does not exactly mean the discomfort for the customer as there are time intervals that no hot water draw happens. Even violations happening during a hot water draw may be easily controlled and fixed by means of a Cold-Hot-Water mixer [23] [24].
b) When the heating element is off, the heat energy remains stored for long times, therefore the heating of water does not need to be overlapped with the consumption of hot water.
c) The Heat loss of the water heater may be used for other purposes, which will be discussed later in this thesis.
d) There is a high capacity when EWH's are aggregated across so many different consumers [9].
e) The load profile of EWH's closely follows average day-to-day profile of a household, consequently contributing significantly to peak load [11] [25] [26].
f) EWH's are easily available to access for control.

But the main challenges are more likely the same as other TCLs. Challenges are:

a) consumer approval and the effect on consumer satisfaction [27] [18] ,

b) the communications infrastructure,

c) ambiguity in the time and volume of water usage [15],

d) prediction accuracy and approximation errors over long time horizons [15],

e) The influence on aggregated load shaping of the Power System [18] [28].

2.4 Health

In almost every study of load shaping of water heaters [3] [15] [17] [22], cutting the electricity of the water heater or the reduction of water heater set point is suggested to save energy or reduce cost. In those studies pre-set value for water heater is 120 °F so the water temperature will be 120°F or less during the load shaping. According to the LEGIONELLA 2003 report [29] this temperature range is usually an optimal temperature band for growth and amplification of Legionella bacteria resulting Legionnaires' disease (LD). The report states LD is not a rare disease and very serious. The CDC has estimated that the disease infects 10,000 - 15,000 persons annually in the US. OSHA estimates that over 25,000 cases of the illness occur each year, causing more than 4,000 deaths [29]. The growth of bacteria happens in temperatures of 68°F to 122°F with optimal growth temperature of 95°F to 115°F. The bacteria exist in hot water system with colonization frequency of 12.03% in water heaters. It can be inferred that temperatures below 122 °F should be avoided or at least frequent disinfection of plumbing system in required. Higher temperatures kills the bacteria at different speeds, 90% bacteria kills can be achieved at 140°F and 100% kill at 158°F [29]. This shows that most of load shaping strategies will help the growth of Legionella bacteria in water system as a result of lower hot water temperatures.

2.5 Models

Modelling of water heaters can be categorized into:

a) Those that describe the aggregated load of so many EWHs [26] [30] [31].
b) Physical models of separate EWHs [25] [32] [33].

Each item offers a different perception of the outcome of Direct Load Control (DLC) on the Power System and individual consumers. Models based on aggregated load are used for power management and improving the stability and security of the Power System and could not promise individual consumer fulfillment and comfort [34]. Single zone models for single element heaters [15] [31] [32] [35] [36] and two zone models for dual element heaters [18] [30] have been developed and combined into DLC algorithms [37] [25] [31] [34].

The benefit of physical models is the capability of anticipating the effect of present and future control actions on water temperature in individual EWH's and therefore establish the effect on satisfaction of client [15].

2.6 Water Consumption Patterns

Measuring water usage patterns could not be obtained directly and are governed by the behavior of individual consumers [3] [15]. In [3] field data has been used with some degree of randomness to create random consumer behavior of hot water consumption, while in [8] hot water draw patterns has been used from famous standards.

CHAPTER 3

USED MODELS AND PARAMETERS

3.1 Water Heater

Typical residential EWHs have different sizes but usually they are in the range of 40 to 80 gallons [7] [38]. Figure 3 shows a simple schematic of a water heater. To feed the home hot water pipes, hot water is drawn from the top of the tank a and cold water fills the space by layers of cold water at the bottom of the tank.

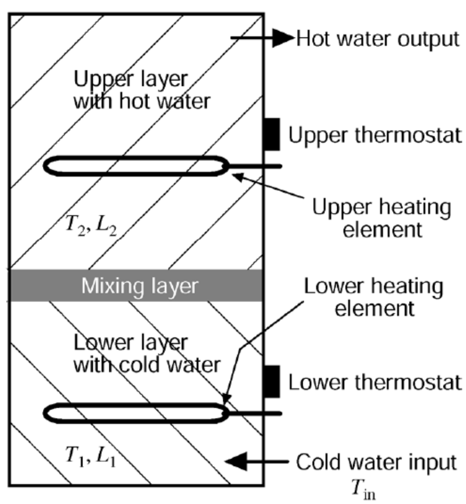

Figure 3. Electric Water heater [9]

In many commercial EWHs water is usually heated by two sets of elements like in Figure 3 [39], one of them is located near the cold water intel at bottom of the tank and the other one is located upper half of the tank. The lower element takes on most of the heating load as it confronts the inlet cold water, and the upper element participates on occasions when the colder layers of water reaches it [40] [9]. The two top and bottom elements are controlled by independent thermostats, but only one is permitted to be on at a time, with the upper element having the first priority [39]. Water heater element power are from about 1500 W to 6000 W, with 4500 W being the most common [40].

For the sake of simplicity, temperature inside the water heater is assumed to be uniform through the tank. After each draw, new temperature inside the water heater will tend to have a lumped temperature of:

$$Temp_{t+1} = \frac{Temp_t Mass_{Hot} + T_{cold} Mass_{cold}}{Mass_{total}} \tag{1}$$

Where,

t	is the time when hot water draw has happened.
$Temp_{t+1}$	is new temperature level of water in the tank after the temperature has stabilized in the tank.
$Temp_t$	is temperature of hot water at the time draw start time.
$Temp_{Cold}$	is the temperature of cold water entered into the tank, and directly influenced by outside temperature of the residential unit.
$Mass_{Hot}$	is the mass of hot water left at tank after draw has finished.
$Mass_{Cold}$	is the mass of cold water entered into the tank at the draw start time.
$Mass_{total}$	is the mass of total water in the tank at any time.

The equation (1) is true with assumption of perfectly mixed water in the tank.

Thermostatic controls have a “dead band” associated with the set point, which prevents rapid cycling of power to the elements. The dead band is typically a few degrees above and below the nominal set point. Figure 4 shows a hot water temperature profile inside the water heater tank over time when water heater set point is set at 130°F. The rising curves designate that the EWH is “on,” and the falling curves represent the standby periods when the heater is “off.” As the EWH cycles, the water temperature in the tank rises and falls accordingly [3]. In Figure 4 no hot water consumption is shown and falling curve are thanks to the thermal losses from the water heater body to area around it.

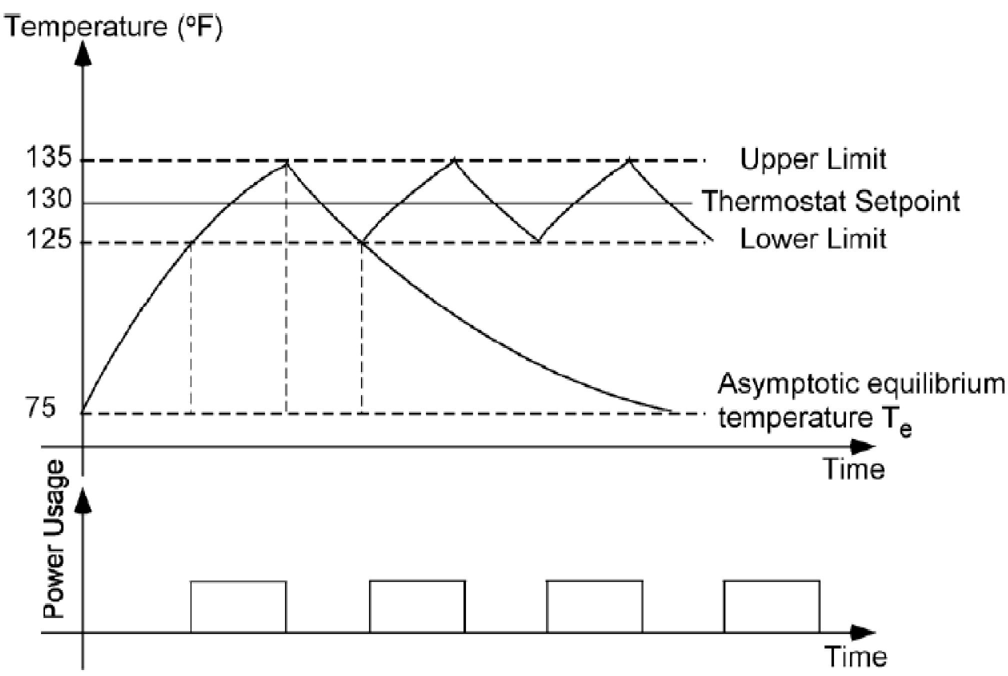

Figure 4. Hot water temperature profile with no hot water consumption [3]

Most heaters are shipped with both the upper and lower thermostats set to the same temperature set point at 120°F [3] [17].

3.1.1 The Thermal Dynamic Modes of the EWH

The modeling of a EWH operation requires a thermal dynamic model that describes its heat exchange with the environment and with cold water inflows [41]. The thermal model is based on an equivalent thermal parameter (ETP) approach [21].

The EWH thermal model is categorized by thermal resistance and thermal capacitance. The Gridlab-D approach to modeling EWH is designed to be computationally fast, yet reasonably accurate. It accommodates the common two-element design and the possibility for inverted thermostat settings, wherein the upper element maintains a higher temperature than the lower element [38].

There are two assumptions for the model:

1: Depending on the situation, the water will be considered to be either of uniform temperature throughout the tank or "lumped" into two temperature regions i.e. the hot and cold layers.

2. The injection of cold inlet water at the bottom of the tank results in either complete mixing with the hot water in the tank or no mixing at all, depending on the volumetric flow rate of cold water inlet.

Figure 5 shows a schematic representation of the water heater model in which T_{avg} is the average water temperature throughout the tank and T_{amb} is the ambient temperature. The thermal capacitance of the water C_w is a function of the tank volume V:

$$C_W = V(gal) * \frac{1ft^3}{7.48gal} * 62.4\frac{lb_m}{ft^3} * 1\frac{Btu}{lb_m.F} \qquad [38]\ (2)$$

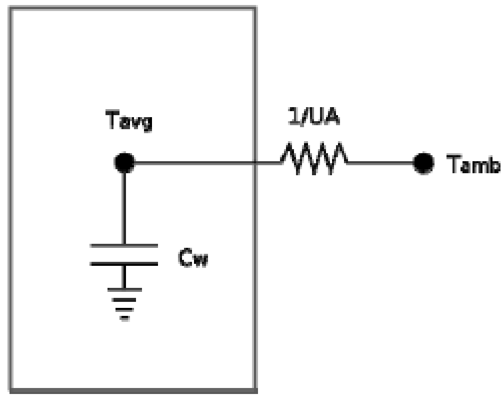

Figure 5. Simple water heater model [40]

The temperature change of the water is governed by [42] [39]:

$$M_w\,.S_w\,.\frac{dT}{dt} = UA.(T_{amb} - T) + Q_{electric} \qquad (3)$$

where

M_w Mass of water in the tank (lb)

S_w Specific heat of water (BTU/lb/°F)

T Temperature of the water in the tank (°F)

t Time (hr)

UA Standby heat loss coefficient • area of the storage tank (BTU/°F/hr)

$Tamb$ Ambient temperature (°F)

$Q_{electric}$ Rate of heat input to tank from the heater (BTU/hr); zero when the heater is off.

The modeled heater has insulation which affects the standby heat loss coefficient (UA) of the heater. The UA factor governs the rate at which the water cools when EWH is in off state and no hot water draw happens. Commercially available heaters with 2 inch insulation have an approximate UA factor of 4, and heaters with 3 inch insulation have an approximate UA factor of 2.5. The UA values are not directly proportional to the inverse of the insulation thickness due to end effects and penetrations [40] [39].

The water heater simulator module is based on two very models, and depending on the state of the tank one is used by simulator. The two models are:

3.1.1.1 One-Node Temperature Model

This is a simple, lumped-parameter electric analogue model that considers the entire tank to be a single body of water at a uniform temperature. This model considers the temperature of the water at any given time or the time required for the temperature to move between two specified points. Considering Figure 5 and treating the water heater as a single node with thermal capacitance *Cw*, a conductance *UA* to ambient conditions, with mass flow rate *m* and heat input rate of *Qelec*, a heat balance on the water node is as follows:

$$Q_{elec} - \dot{m}C_p(T_W - T_{inlet}) + UA(T_{amb} - T_W) = C_W\frac{dT_W}{dt} \qquad [38]\ (4)$$

3.1.1.2 Two-Node Temperature Model

This model, which applies when the heater is in a state of partial depletion, considers the heater to consist of two body of water but each of them are at a uniform temperature. The upper "hot" node is near the heater's set point temperature, while the lower "cold" node is near the inlet water temperature. This model considers the location of the boundary between the hot and cold nodes, calculating the movement of that boundary as hot water is drawn from the tank and/or heat is added to the tank. The time required to change the tank's hot water column from an initial height of $h_{initial}$ to a final height of h_{final} is given by the following equation:

$$t_1 - t_0 = \frac{1}{b} * log\left(\frac{dh_w}{d_t}\right)\Bigg|_{h_{initial}}^{h_{final}} \qquad [38]\ (5)$$

where

dh/dt is the temperature gradient along the height of the water column.

This is calculated as a function of mass flow rate and the temperature difference between the upper and lower interface layers of the water column.

3.1.2 Simulation Sequence of water heater

There are four steps in Gridlab-D for water heater synchronization:

1. Energy calculations, in which water heater module records its consumed energy.

2. Based on previous state of water heater the temperatures and the boundary between cold and hot water updates.

3. The heater module decides whether to start heating or remain unchanged depending on the calculated temperatures, if the temperatures are still within the thermostat dead band around set point the heater remains off.

4. The module calculates the next time stamp for checking the status and calculations. Depending on the tank temperature states the heater nest time to check the new states, for example if the heater is off and coasting, what is the next time to check whether the losses has reduced the internal temperature.

3.2 Climate Data

The Weather data is provided from Gridlab-D Climate module. The climate module provides an interface that other objects may use to include weather data in their calculations.

Objects such as houses and buildings rely on this data to factor outdoor weather into their calculations for internal temperature. The climate data includes temperature, humidity, and solar radiation, which is used to calculate temperature gain that is the result of heat gained from direct exposure of a surface to sunlight. The Climate Module retrieves climate data from TMY2 files, created and maintained by the National Renewable Energy Laboratory (NREL) [40].

3.3 Hot Water Usage

There is a significant variation in hot water draw patterns among households. Hot water usage had a large variance even within a single home [43]. But there are some standards and test procedures for hourly hot water consumptions of a residential unit. The study in [13] compared different sources of hot water consumption patterns, in which the conclusion shows the ASHRAE standard 90.2 provides the most reliable hot water consumption pattern. Even though the field data show more, Shorter and smaller draws at lower flow rates clustered closer together in time than the current ASHRAE test procedure [17].

As the result ASHRAE 90.2 hot water consumption data has been used in this study, But for the matter of randomness in this study some random variations have been used to generate a unique behavior of hot water usage for any individual residential unit.

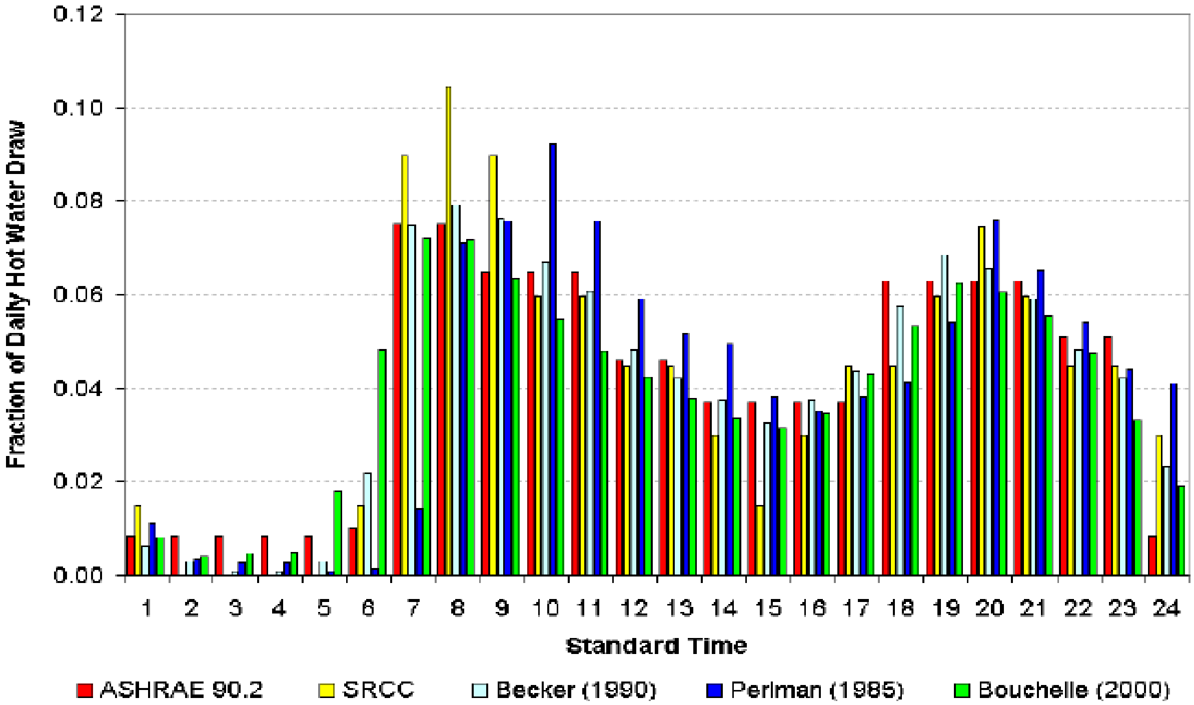

Figure 6. Normalized famous hot water draw patterns [13]

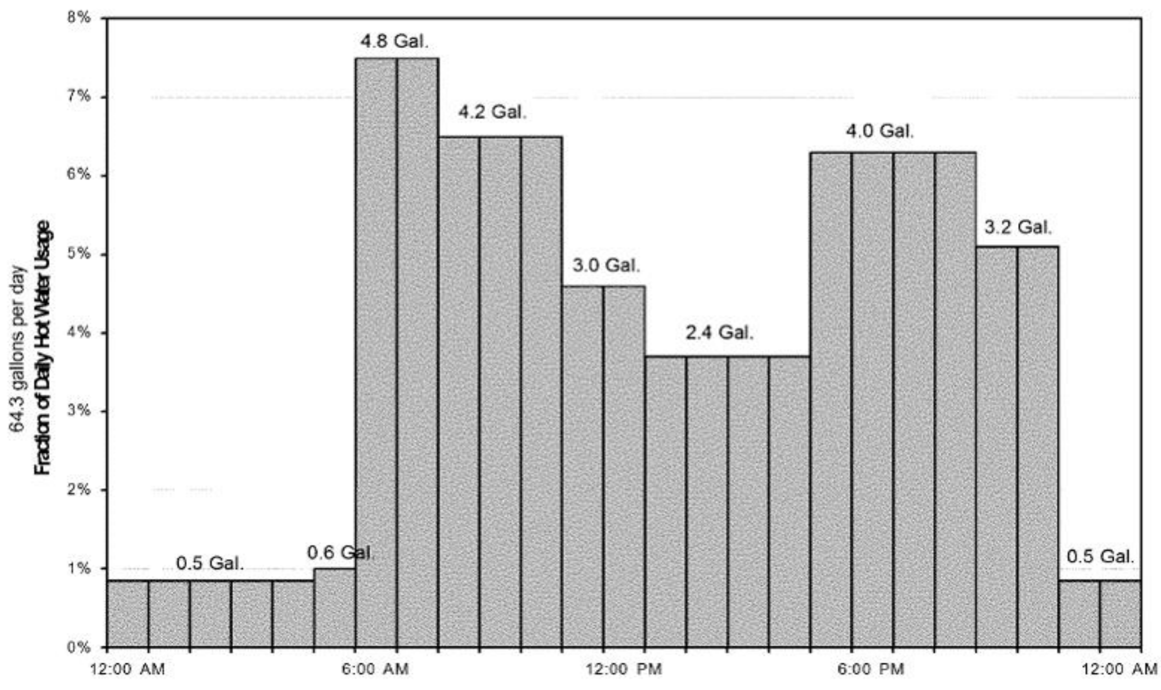

Figure 7. ASHRAE 90.2 Hot Water Draw Pattern [14]

Figure 7 is ASHRAE 90.2 hot water consumption pattern in a residential unit. Provided by [14], this shows the maximum draw is around 6am to 8am. According to Figure 6 peak draw is between 6:30 am to 9:30 am. Overlapping of these two incidents have a great potential to be studied.

CHAPTER 4

STRATEGY INTRODUCTION

This chapter proposes a new strategy for scheduling EWHs. Later in this chapter a new method for linking Gridlab-D core and a high level language programming software (MATLAB in this thesis) is described which is used to make the simulation more random, accurate and realistic.

4.1 Strategy

The outdoor temperature has a direct effect on the cold water inlet of any building including residential units. When a draw of hot water from water heater happens, cold water replaces in water heater at the same amount. Colder the water gets into the water heater it takes more energy and even time to heat up to set point temperature. Furthermore very cold outdoor temperatures will result in increase of thermal losses of the walls as the temperature differences of inside and outside increases. This will result to have more deviated indoor temperature [38].

It is obvious that average coldest outdoor temperature is before sunrise in the mornings when it usually coincides with peak of temperature-sensitive hot water consumption, this will result in extended water heater running time to heat up coldest possible water replacing the hot water in the tank which dramatically reduces average temperature of water in the tank and/or the consumer may run out of hot water sooner than expected. The situation will get worse if a controller cuts the power to the EWH or lower the set-point due to high price signal. The strategy proposed in this work simply suggest to shift the energy consumption to an earlier time in a higher magnitude based on input cold water temperature, to reduce the effects on the average temperature inside the tank. This strategy will result in saving energy cost, healthier hot water system and usually stabling living area temperature.

The key to control over the average temperature inside water heater tank when the outdoor ambient temperature is around minimum during a day is to reduce amount of cold water into the water heater, so that the water heater will consume less energy by heating up a smaller amount of cold water during that time.

To achieve this goal a smart control system should set the set point of water heater at higher temperature during the control active period (ACP) i.e. around the midnight and up to the time the minimum outdoor temperature (minimum cold water inlet) passes. ACP can be inferred from Weather data of the location where the strategy is being tested. During ACP water heater will start to heat up the water inside to a set point bigger than non-ACP set point, In other words water heater will shift the cold water input to a warmer outdoor temperature time and store the energy inside as thermal energy then release it at time when outdoor temperature is around the minimum.

To bring the water to preferred standard temperature for consumer, the control system should mix the hot water with cold water outside the water heater. This system is currently being used in many residential or commercial buildings [29] [23] [24]. The mixture will have exactly the same temperature when only hot water is consumed. The standard of hot water at tap is 120 °F.

While the first goal is achieved the inside tank water temperature will at much higher temperature after midnight during ACP compared to other times, and the water heater will have more losses. In cases where the water heater resides inside the HVAC thermally controlled area, these losses will have positive or adverse effects on room temperatures.

4.2 Method

In order to develop a testing scenario, Gridlab-D core simulator with residential and/or commercial modules along with Climate modules is used to generate an instance of testing model. Although Gridlab-D core uses precise algorithms and models, but the user interface is not a friendly environment to have variability, also Gridlab-D model file (GLM-file) cannot be manipulated during the simulation and randomizing the input parameters is very limited, even making the loops are sometimes not feasible. Consequently the need of a supplementary software gets inevitable when a repetitive and random test system is studied. Thus a new tool consisting of a MATLAB code is developed to implement the task, this high-level language code autonomously manipulate GLM-file with random parameters (e.g. hot water draw patterns, cooling and heating set points, different size of EWHs, etc.). Then it feeds Gridlab-D core with the new GLM-file to run different random instances of the model for a wide range of control parameter. The tools also organize the data and produce meaningful information or plot the data.

The flow chart of interactions between the Gridlab-D core and MATLAB code is represented in Figure 8.

The MATLAB code is available as Appendix at the end of this thesis.

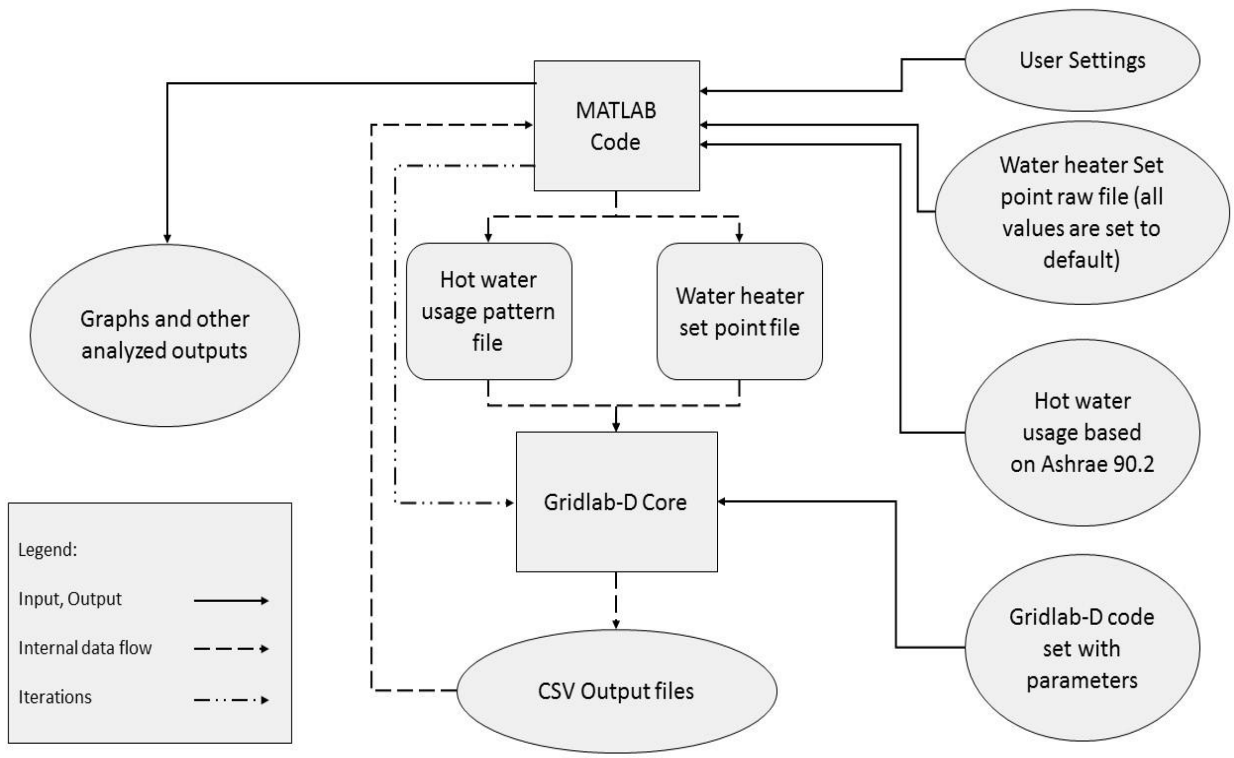

Figure 8. Simulation procedure flow chart.

CHAPTER 5

SIMULATION

In this chapter a detailed overview of simulation process steps is presented.

Simulation Procedure

A comprehensive simulation is implemented to test the strategy. The simulation is implemented for a virtual apartment complex consisting of 300 randomly specified apartments in Chicago area.

Figure 9 shows the daily average of outdoor temperature of Chicago, IL, during each four season. By looking at the outdoor temperature in this Figure this can be grasped that the minimum outdoor temperature is between 3am to 8am. Minimum temperature in the winter is less than any other season and specifically it is between 5am to 6am. With regards to Hot water consumption patterns Figure 7, ACP is defined from 10:30 pm when the hot water consumption reaches to its minimum, and ACP ends at 6am the next day when maximum hot water consumption overlapped with minimum outdoor temperature. It is expected that the strategy will have bigger effect in winters because outdoor temperatures are less than any other seasons compared to EWH pre-set set point value.

To demonstrate the differences of possible outcomes, the simulation has ran for a range of different set point temperatures from 80°F to 160°F during ACP, this will generate a new dimension of outcomes which is only feasible autonomously with this tool. The result will show which set point is the better option to choose.

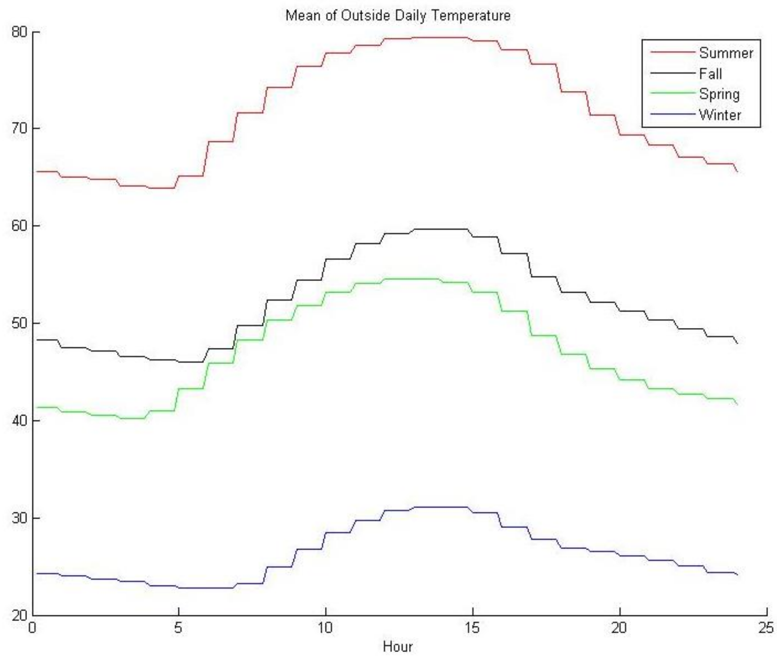

Figure 9. Average outdoor temperatures.

When the simulation runs, these steps will be followed:

a) Apartment size: MATLAB will randomly assigns floor area of the first apartment by using normal distribution. Apartments are chosen between 750 sq. ft. to 1200 sq. ft.

b) Number of Occupants: Depending on the size of the apartment, different random number of occupants will be assigned. According to [44] there are average of 2.59 residents. There are usually one to two bedrooms in apartment which are selected in a step a so the residents will be maximum of 4 people.

c) Water Heater size: The size of water heater will be chosen from two options of 50 gallon water heater or 80 gallon water heater for the apartment (according to [40] [7] most common water heater sizes are ranging from 40 gallons to 80 gallons with the most common at 50 gallon) based on apartment size or number of occupants.

d) Hot water consumption Pattern: Then the MATLAB code generates deviations of hot water consumption patterns from ASHRAE 90.2 by implementing uniform and normal distributions. This way every apartment will have its own random and unique hot water consumption pattern. The variations of hot water consumption pattern are in amplitude i.e. the amount of hot water consumed at a specific time or the time of consumption of hot water.

e) HVAC Thermostat Set Point: A unique heater and air conditioner set point will be assigned by MATLAB random functions, which are within a predefine range.

f) A Gridlab-D input file consisting of all the input settings from part a to part e feeds through the Gridlab-D simulator core by MATLAB. The Gridlab-D code i.e. GLM file includes a multi recorder to records all output variables such as room temperature, water temperature, energy used by Water heater and HVAC to an output CSV file for that specific apartment and water heater set point.

g) A loop starts in MATLAB to feed the GLM file to the Gridlab-D core starting with 80 °F for the water heater set point and runs the Gridlab-D simulator, after the first run finishes, every parameter within the apartment remains the same but only the water heater set point changes to 90 °F and the simulation starts again. The water heater set point changes 10 °F every time in the loop. This loop will be repeated for water heater set points up to 160°F which it is the maximum set point available on most commercial Water heaters.

h) When the simulation for first apartment finished, the second apartment simulation starts with the new set of random parameters starting with water heater set point from 80°F. The simulation continues until all 300 apartments' simulations finishes.

i) The output data from each simulation is recorded into an individual CSV file. These files are read into mat lab variables for future processing. At this moment there are 2700 CSV files.

j) The processing in MATLAB includes the variations in different parameters of apartment e.g. room temperatures, or specifically the energy consumption of Water heater and HVAC.

k) Plots and Graphs: The mean and variance of parameters versus the pre-set water heater set point i.e. 80°F to 160°F are plotted By MATLAB.

The results of the simulation are divided into four separate sets of which each set is representing of a season i.e. spring, summer, fall and winter. The data for each season has been studied and analyzed within the corresponding season to demonstrate the effects of the strategy for individual season.

CHAPTER 6

RESULTS

In this chapter experimental evaluations of the proposed strategy framework are provided and processed outputs are visualized in graphs for each season individually.

6.1 Hot Water Temperature

The hot water in water heater will fluctuate around its set point within the dead band gap for every selected set point. Figure 10 demonstrates changes of hot water inside water heater tank for every pre-defined set point in a day. For all scenarios water heater set point is set to 120 °F between 6am to 10:30 pm, but the set point between 10:30pm to the day after 6am.

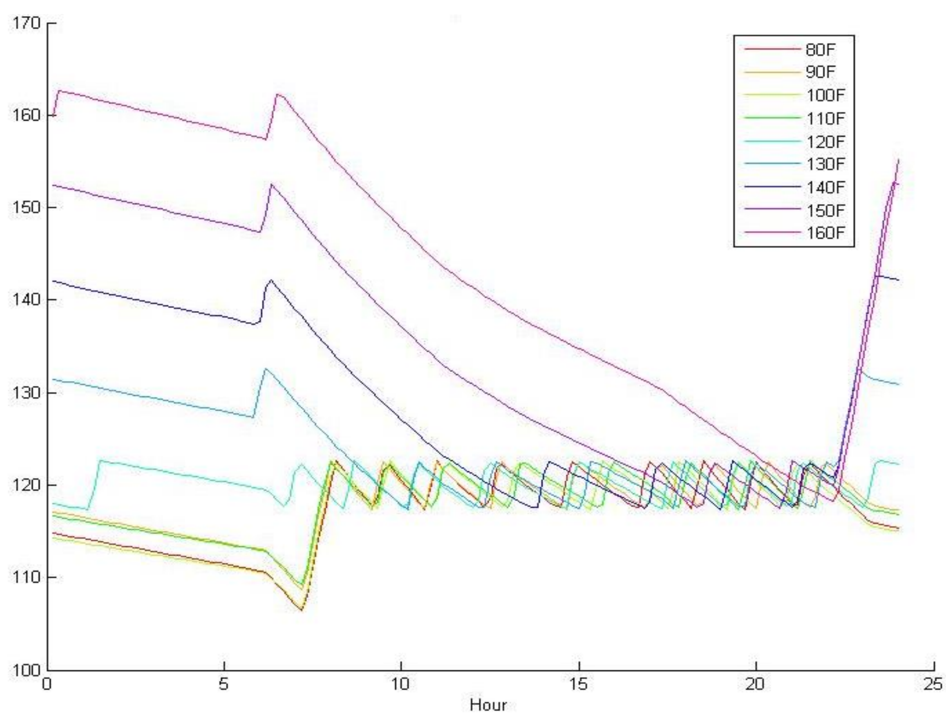

Figure 10: Water temperature inside water heater for a typical day

6.2 Changes in Energy Consumption Cost and Room Temperature

7.2.1 Energy Consumption Cost

This section presents the results of simulation done to evaluate the proposed strategy effects on energy consumption. Figure 11 presents the effect on water heater energy consumption for different seasons based on WH set point. It can be inferred that the energy consumption will be reduced when WH set point is set higher during control period for all the seasons. Exact values are presented in Table 1.

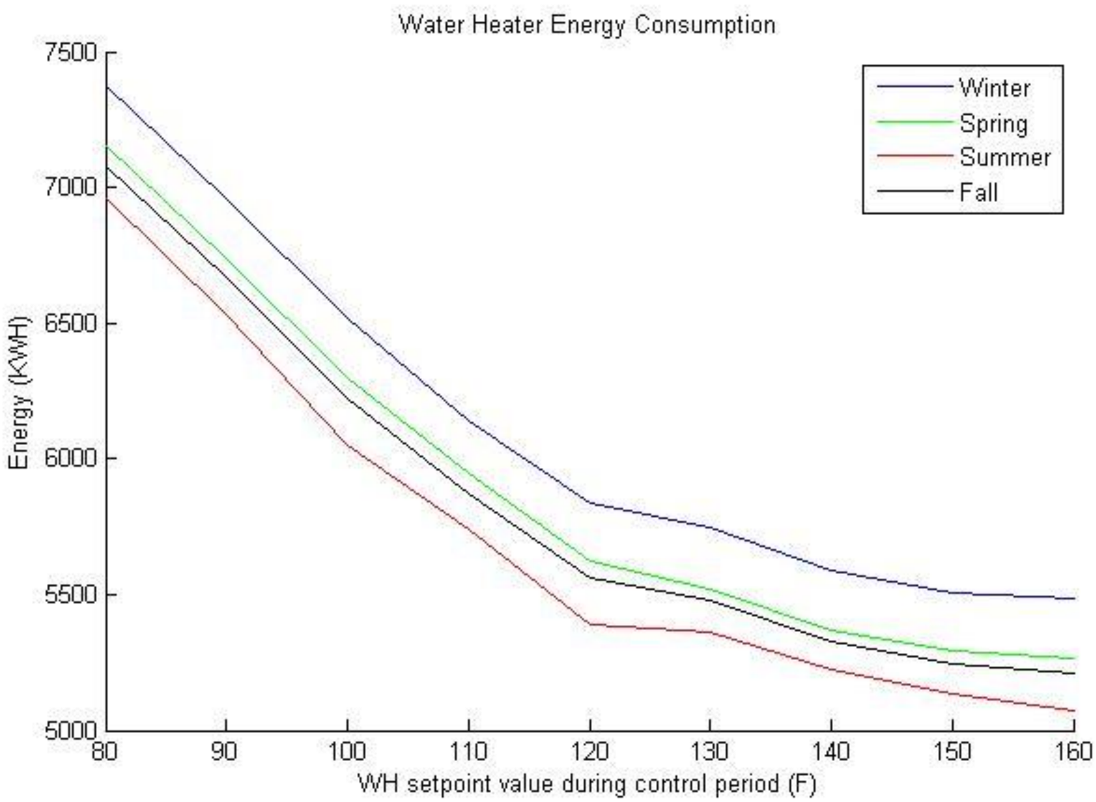

Figure 11. Water Heater energy consumption

To better differentiate the effects of strategy, only two sets of results are compared, one is when set point during control period is set to 120°F which is considered as no control, and, when the set point is set to 160°F during control period which is the maximum set point available and all other results are in between.

Table 1. Energy consumption for water heater

	Set point: 120°F (KWH)	Set point: 160°F (KWH)	Changes (%)	Changes (KWH)
Spring	5626	5268	6.4	358
Summer	5388	5070	5.9	318
Fall	5559	5212	6.2	347
Winter	5833	5485	6.0	348

According to Table 1 the strategy will reduce the energy consumption of water heater near 6% for all seasons.

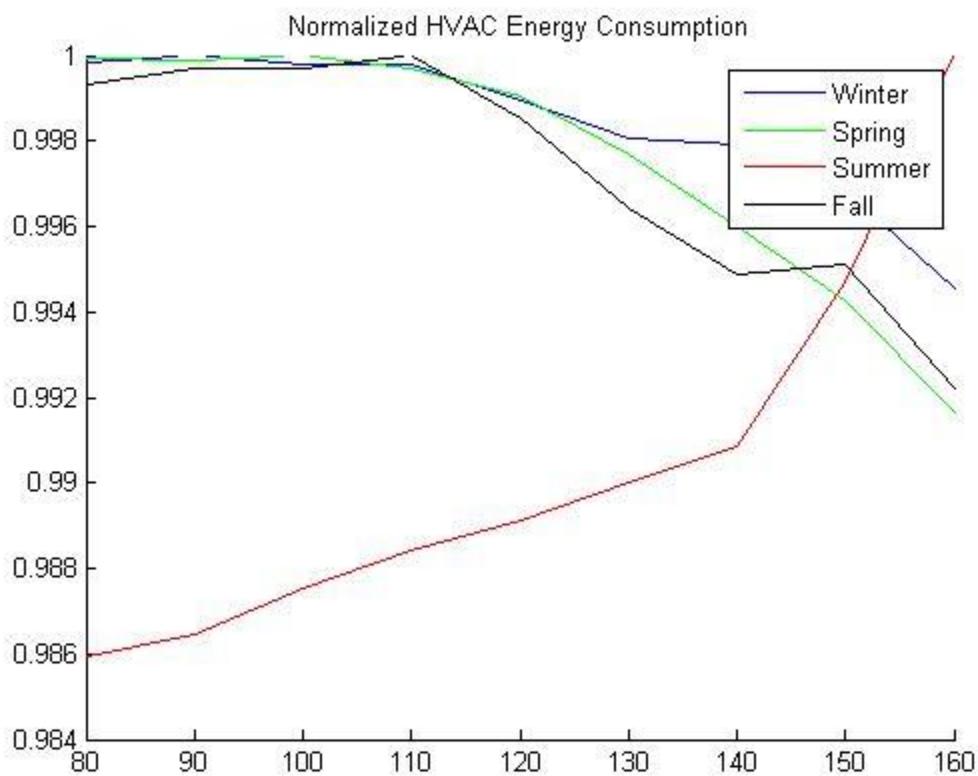

Figure 12. HVAC energy consumption

The effects of the strategy on HVAC is shown in Figure 12, For better ability to compare the effects of the strategy on HVAC normalized values are used in Figure 12, and Table 2 has actual values of HVAC energy consumption changes.

Table 2. Energy consumption for HVAC

	Set point: 120°F (KWH)	Set point: 160°F (KWH)	Changes (%)	Changes (KWH)
Spring	13369	13270	0.74	99
Summer	5288	5346	-1.10	-58
Fall	10339	10274	0.63	65
Winter	39658	39483	0.44	175

In Table 2 winter season has the highest change in terms of KWH for HVAC because mostly all the winter days are cold so the WH losses will warm the inside apartments and so that it reduces the working time of HVAC system, but oppositely for summer time, WH losses are contrary of working of the Air conditioning system and will result in more working time of the HVAC system. In our experiment HVAC consumes 524KWH less energy when there is control in winter time and 175KWH more energy during summer. Spring and fall seasons have warm and cold days which Air conditioning and Air heater will work respectively. In cold days control system helps the Air heating by heating up the inside air and in warm days it will put more load on Air conditioning.

For price analyzing, the Real-Time pricing of Chicago ComEd [45] is used. The Figure 13 shows total energy consumption changes, and Table 3 shows actual values and total savings by controlling at 160°F for set point during control period.

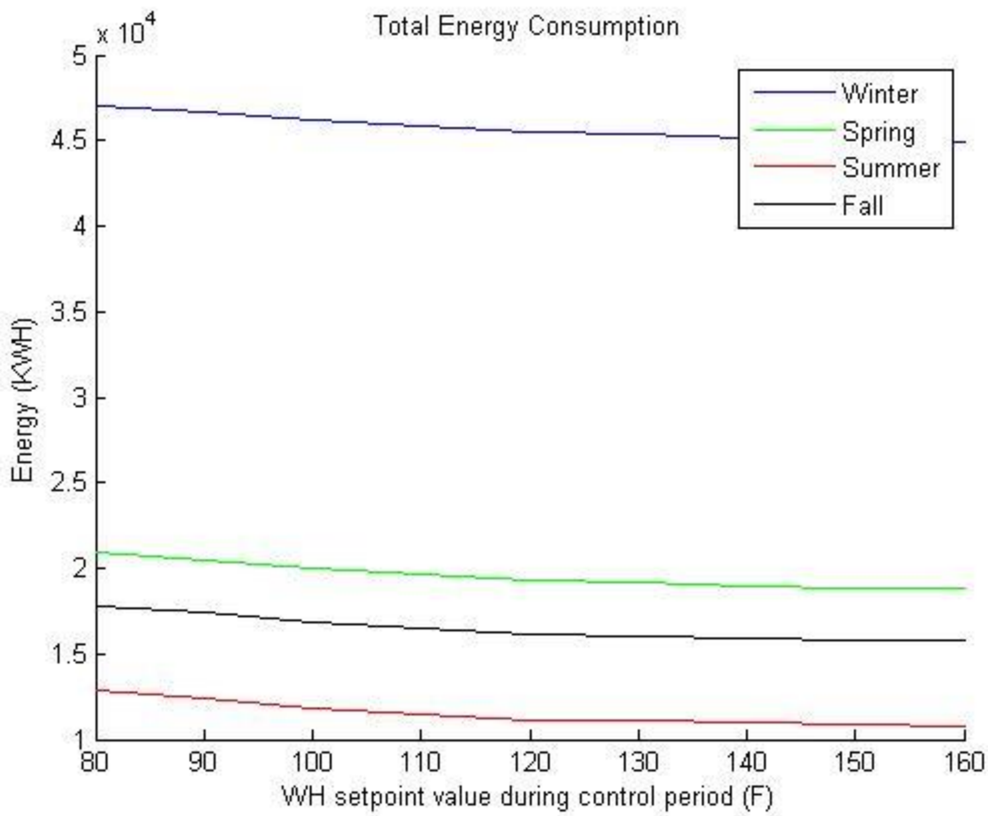

Figure 13. Total energy consumption changes

According to Table 3 savings for winter time is more than any other season, which is about 175$ for an average apartment.

Table 3. Total Energy consumption and cost change

	Set point: 120°F (KWH)	Set point: 160°F (KWH)	Changes (KWH)	Changes ($)
Spring	18994.67	18537.33	457.33	48.66
Summer	10676.00	10416.33	259.67	27.63
Fall	15897.67	15485.67	412.00	43.84
Winter	45491.00	44968.00	523.00	55.65

7.2.2 Room Temperature

As it has been discussed in this study, heating up the Water heater during night time will rise the WH thermal losses. Water heater heat dissipation will affect inside apartment room temperatures. When water heater has been set at higher set points during control time this effect should be more [3] [39] [40] [42]. Figure 14 shows how the Water heater setpoint changes will affect mean of Room temeprature during each season. Mean of Room temperatures have been higher when WH set point is set higher during control active period due to more heat dissipation. Normalized temperature values are plotted in Figure 14 for clarity. Actural values are presented in Table 4 .

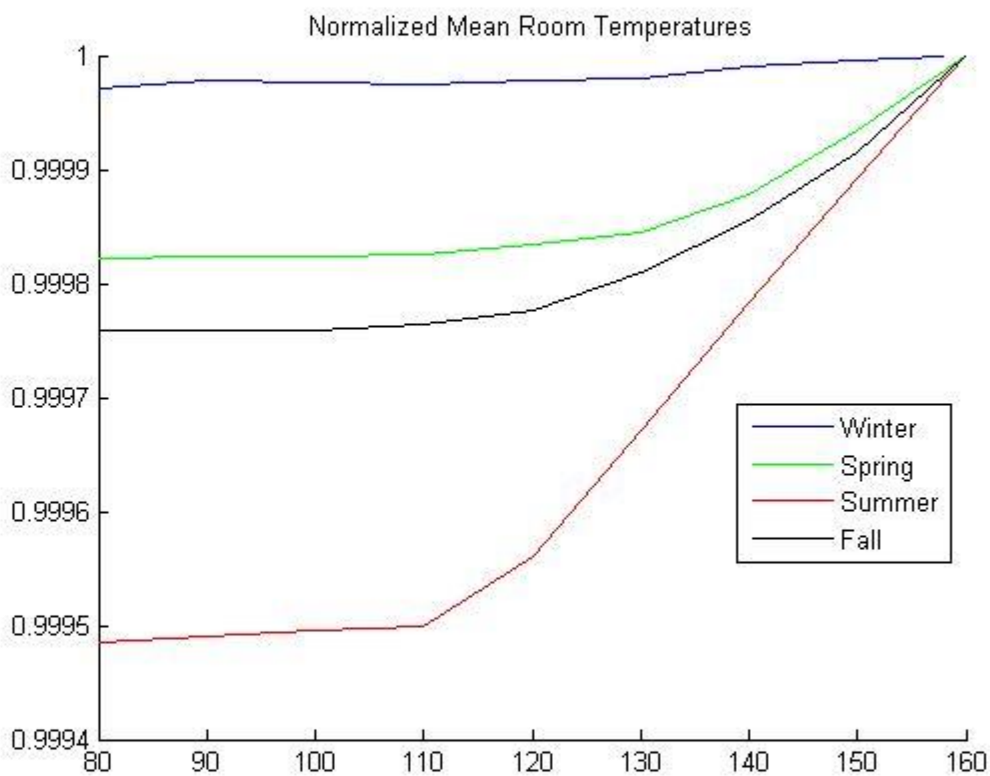

Figure 14. Normalized Mean room temperature for a single apartment.

Table 4. Mean Room temperatures

	Set point: 120°F (F)	Set point: 160°F (F)	Changes (F)
Spring	70.059	70.071	0.01
Summer	74.252	74.285	0.03
Fall	69.749	69.765	0.02
Winter	67.057	67.059	0.002

Table 4 shows that, although the changes are positive, but the effect on mean room temperature is negligible. The more important change of Room temperature is the reduction in temperature variations, Figure 15 shows that deviations in winter and summer season has been less with higher water heater setpoints during control period. The trend is a little differrent in other two seasons. Figure 15 is also plotted of normalized values for clarity. Actual valuse are presented in Table 5. From Table 5 it can be infered that the reduction in variance of room temperature will be more for Summer and Winter seasons while the reduction for Summer season has to pay the price of higher Room temperatures which will lead to less customer confort in summer time.

Table 5. Room temperature variance

	Set point: 120°F (F)	Set point: 160°F (F)	Changes (F)
Spring	123.245	122.841	-0.40
Summer	179.2059	177.8273	-1.38
Fall	124.49	123.8537	-0.64
Winter	238.57	237.59	-0.98

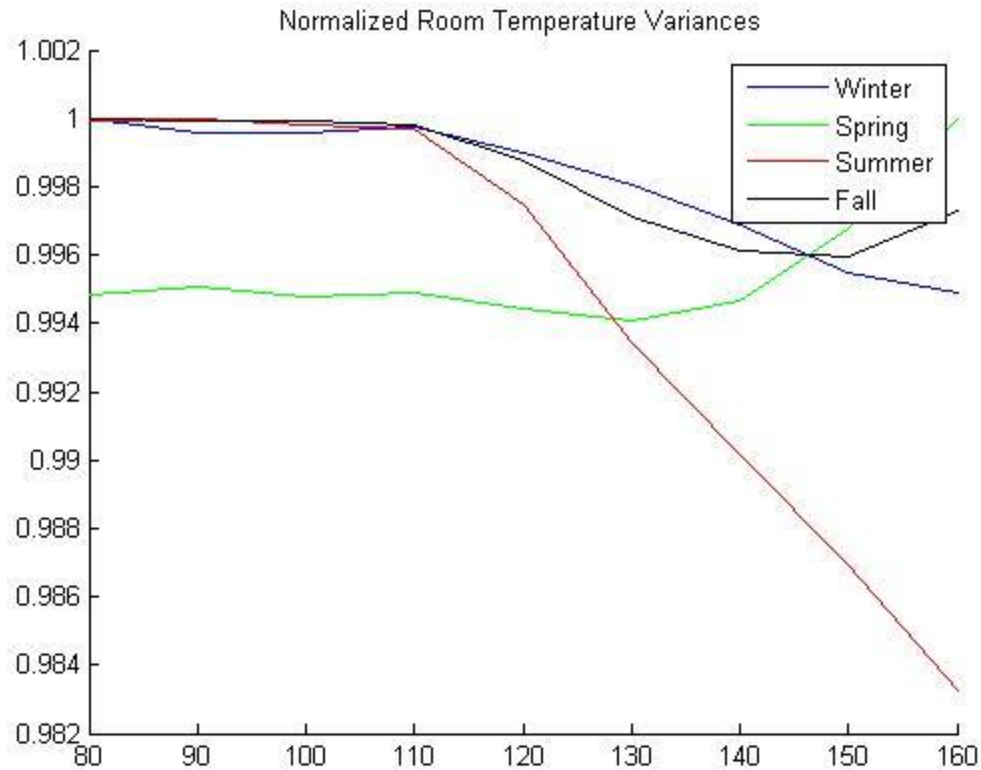

Figure 15. Room temperature variance

CHAPTER 7

CONCLUSION AND FUTURE WORK

7.1 Conclusion

This thesis proposes a strategy to reduce energy consumption and cost of the customer, while it can elevate the consumers comfort level to some degree by lowering the air temperature deviations, providing more hot water at demand peak, and it is also can be considered as an effective way to deal with Legionella bacteria when hot water temperature reaches 160°F in the water heater and water delivery system.

The results shows this is a more benefit in winter time than other seasons from consumers' comfort-level perspectives. According to the result of the tested scenario, this strategy has saved the consumer total of around 59$ per year for an average apartment is Chicago IL., so the development of a physical controller will be more feasible and reasonable. Also the algorithm of the strategy can also be developed as a supplement to the current Smart Home energy controllers.

Based on the simulation processes of proposed strategy it can be conclude that the method introduces in this thesis enhances the abilities of Gridlab-D simulator core to simulate more complex scenarios with more degrees of randomness and preferences. The method extends rang and dimension of input and out variables. The simulation process has less hassle and finishes in much less time, also the automated change of code and run of core has eliminated the human error in iterations.

7.2 Future work

The effect of the strategy on Power System is sugessted to be studied in future works, because as the more consumers strart to adapt this strategy, the impact on power system will be more severe and may create a new peak if the strategy does not implemented accordingly.

Although cutomer benefits are discussed in this study but it is also recommended to study utility benefits, or by taking power system constrains into account the distribution system also be studied as a future work.

Uncertainty has been modeled to some degree in this model, for future work uncertainty quantifing and uncertainty propagation to distribution system is also recommended.

REFERENCES

REFERENCES

[1] F. Shariatzadeh and A. K. Srivastava, *Look-ahead Control Approach for Thermostatic Electric Load in Distribution System,* Pullman, WA: IEEE, 2013.

[2] P. Palensky and D. Dietrich, *Demand Side Managment: Demand Response,Intelligent Energy Systems, and Smart Loads,* vol. 7 No.3, IEEE Transactions on Industrial Informatics, 2011, pp. 381-388.

[3] D. Pengwei and L. Ning, "Appliance Commitment for Household Load Scheduling," *IEEE TRANSACTIONS ON SMART GRID,* vol. 2, no. 2, pp. 411-419, June 2011.

[4] K. Schneider, J. Fuller and D. Chassin, *Multi-State Load Models for Distribution System Analysis,* vol. 21, IEEE, 2011, pp. 2425-2433.

[5] Z. Wei, K. Kalsi, J. Fuller, M. Elizondo and D. Chassin, *Aggregate model for heterogeneous thermostatically controlled loads with demand response,* San Diego, CA: IEEE, 2012, pp. 1-8.

[6] Energy Information Administration, U.S. Department of Energy, *Residential Energy Consumption Survey, Consumption and Expenditures Tables - Water-Heating Consumption Tables, Table CE4-9c,* 2001.

[7] *Energy.gov Energy Saver.*

[8] Energy Monitoring Company,, "Measurement of Domestic Hot Water Consumption in Dwellings," DEFRA, 2008.

[9] J. Kondoh, L. Ning and D. J. Hammerstrom, *An Evaluation of the Water Heater Load Potential for Providing Regulation Service,* vol. 28, IEEE, 2011, pp. 1309-1316.

[10] J. Reed, J. Thompson, R. Broadwater and A. Chandrasekaran, *Analysis of water heater data from Athens load control experiment,* vol. 4, IEEE Journals & Magazines, 1989, pp. 1232-1238.

[11] M. Gustafson, J. Baylor and G. Epstein, *Direct water heater load control-estimating program effectiveness using an engineering model,* vol. 8, IEEE, 1993, pp. 137-143.

[12] J. Lutz, "Typical Hot Water Draw Patterns Based on," ASHRAE, 2014.

[13] P. Fairey and D. Parker, "A review of Hot Water draw profiles used in performance analysisof residential domestic hot water system," Florida Solar Energy Center, Florida, 2004.

[14] *ASHRAE standard 90.2-2004,* ASHRAE, 2004.

[15] M. Shaad, A. Momeni, C. P. Diduch, M. Kaye and L. Chang, *Parameter identification of thermal models for domestic electric water heaters in a direct load control program,* Montreal, QC: IEEE, 2012, pp. 1-5.

[16] L. Yao and H. R. Lu, *A two-way direct control of central air-conditionening load via the internet,* vol. 24, IEEE, 2009, pp. 240-248.

[17] C. H. K. Goh and J. Apt, "Consumer strategies for controlling electric water heaters under dynamic pricing," *Carnegie Mellon Electricity Industry Center Wirking Paper m CEIC-04-02.URL: https://wpweb2.tepper.cmu.edu/ceic/pdfs/CEIC_04_02.pdf* [cited Feb 20, 2016].

[18] K. Y. Huang and Y. C. Huang, *Intergratingdirect load control with interruptible load managment to provide instantanous reserve for ancillary services,* vol. 19, IEEE, 2004, pp. 1626-1634.

[19] G. Xiong, C. Chen, S. Kishore and A. Yener, *Smart (in-home) power scheduling for demand response on the smart grid,* Hilton Anaheim, CA: IEEE, 2011, pp. 1-7.

[20] A. Di Giorgio, L. Pimpinella, A. Quaresima and S. Curti, *An event driven Smart Home Controller enabling cost effective use of electric energy and automated Demand Side Management,* Corfu: IEEE, 2011, pp. 358-364.

[21] L. Ning and D. Chassin, *A state queueing model of thermostatically controlled appliances,* vol. 19, IEEE, 2004, pp. 1666-1673.

[22] California Energuy Commision Demand Response Committee, *Feasibility if implementing dynamic pricing in california,* 2003.

[23] Honeywell, [Online]. Available: http://www.forwardthinking.honeywell.com/related_links/water/mixing_valve/sell/63_9876.pdf. [cited Feb 20, 2016].

[24] W. (. H. E. C. L. Reid, "Thermostatic mixing value". United States Patent 6820816, 2004.

[25] M. Nehrir, R. Jia, D. Pierre and D. Hammerstorm, *Power management of aggregate electric water heater loads by voltage control,* IEEE, 2007, pp. 1-6.

[26] I. Lane and N. Beute, *A model of domestic hot water load,* vol. 11, IEEE, 1996, pp. 1850-1855.

[27] H. Saele and O. Grande, *Demand response from houshold customers: experiences from a pilot study in norway,* vol. 2, IEEE, 2011, pp. 10-109.

[28] J. E. McDonald, A. M. Bruning and W. R. Mahieu, *Cold Load Pickup,* Vols. PAS-98, 1979, pp. 1384-1386.

[29] T. C. o. AWT, "Legionella 2003, An updated and statement," the Association of Water Technologies, Rockville, 2003.

[30] M. Orphelin and J. Adnot, *Improvement of methodes for reconstructing water heating aggregated load curves and evaluating demand-side contol benefits,* vol. 14, IEEE, 1999, pp. 1549-1555.

[31] R. Jia and M. Nehrir, *Voltage contorl of aggregate electric water heater load for distribution system peak load shaving using field data,* Las Cruces, NM: IEEE, 2007, pp. 492-497.

[32] L. Paull, H. Li and L. Chang, *A novel domestic electric water heater model for a multi-objective demand side management program,* vol. 80, 2010, pp. 1446-1451.

[33] B. Rautenbach and I. Lane, *The multi-objective contoller: a novel approach to domestic hot water load control,* vol. 11, IEEE, 1996, pp. 1832-1837.

[34] K. Elgazzar, H. Li and L. Chang, *A centralized fuzzy contorller for aggregated control of domestic water heaters,* 2009, pp. 1141-1146.

[35] P. Dolan, M. Nehrir and V. Gerez, *Development of a monte carlo based aggregate model for residnetal electric water heater loads,* vol. 36, 1996.

[36] L. Paull, D. MacKay, H. . Li and L. Chang, *A water heater model for increased power system efficiency,* 2009, pp. 731-734.

[37] J. Laurent and R. Malhame, *A Physically-based comupter model of aggregate electric water heating loads,* vol. 9, IEEE, 1994, pp. 1209-1217.

[38] Z. Taylor, K. Gowri and S. Katipamula, "GridLAB-D Technical Support Document Residential End-Use Module Version 1.0," PNNL, 2008.

[39] D. Kern, Process Heat Transfer, McGraw-Hill, 1990.

[40] PNNL, "Online Help on Gridlab-D Climate Module" [cited Feb 20, 2016].

[41] J. Van Tonder and I. Lane, "A load model to support demand management decisions on domestic storage water heater control strategy," IEEE, 1996.

[42] N. Chopey, Handbook of chemical Engineering Calculations, McGraw-Hill, 1994.

[43] B. Schoenbauer, D. Bohac and M. Hewett, *Measured Residential Hot Water End Use,* ASHRAE, 2012.

[44] *U.S. Census Bureau, Year 2000 Census.,* 2002.

[45] ComEd, [Online]. Available: https://www.comed.com [cited Feb 20, 2016].

APPENDIX

APPENDIX

SIMULATION MATLAB M-FILE

This Appendix is the MATLAB code which is used to run the simulation:

```
clc;
clear all;
close all
pause on;
pause(1);

disp(['Run started @',datestr(now,'yyyymmdd_HHMMSS')])

%global kstart kend kstep;
%START OF USER INPUTS

%Name of input file (no matter with or without extention)
input_file_raw = 'WHDTest04_IL_3y';
glm_file = 'WHDTest04_IL.glm';%%%%
input_schedule = 'WHSetpoint_Raw.glm';
input_price= 'Price_Chicago';
input_waterusage='HotWater_Ashrae_raw.glm';
tstart=80;
tend=160;
tstep=10;

hno=((tend-tstart)/tstep)+1;

Hstart=1;
Hend=300;

%END OF USER INPUTS

%CODE BODY
%CSVOut=FileProcess(input_file,input_schedule,kstart,kend,kstep);

House_Config(Hend,7)=0;
% CSVOut{1:Hend,tstart:tend}(1:26304,1:7)=0;
CSVOutSizeSet='SizeSet.csv';
CSVOut{Hend,tend}=csvread(CSVOutSizeSet,8,1);

%%%%%%%%%%
% Input file processing
%%%%%%%%%%
 if(strfind(input_file,'.glm')>0)
     input_file = strsplit(input_file,'.');
     input_file=input_file{1};
 end
if(strfind(input_file_raw,'.glm')>0)
    input_file_raw = strsplit(input_file_raw,'.');
    input_file_raw=input_file_raw{1};
```

```
end
extraction_input_raw=[input_file_raw,'.glm'];
fileIDr01 = fopen(extraction_input_raw,'r');
Fileinput = textscan(fileIDr01,'%s %s %s %s %s %s %s %s %s %s %s %s %s %s %s
%s %s %s %s %s %s %s %s');
fclose(fileIDr01);
[cin,din] = size(Fileinput);
[ain,bin] = size(Fileinput{1});



%%%find desired X in GLM
X1i=0;X1j=0;
X2i=0;X2j=0;
X3i=0;X3j=0;
X4i=0;X4j=0;
X7i=0;X7j=0;
X5i=0;X5j=0;
X6i=0;X6j=0;
for j=1:ain
  %d is number of coloumns
  for i=1:din
    if (strfind(Fileinput{1,i}{j,1},'X1')==1)
    X1i=i;
    X1j=j;
    end
    if (strfind(Fileinput{1,i}{j,1},'X2')==1)
    X2i=i;
    X2j=j;
    end
    if (strfind(Fileinput{1,i}{j,1},'X3')==1)
    X3i=i;
    X3j=j;
    end
    if (strfind(Fileinput{1,i}{j,1},'X4')==1)
    X4i=i;
    X4j=j;
    end
    if (strfind(Fileinput{1,i}{j,1},'X5')==1)
    X5i=i;
    X5j=j;
    end
    if (strfind(Fileinput{1,i}{j,1},'X6')==1)
    X6i=i;
    X6j=j;
    end
    if (strfind(Fileinput{1,i}{j,1},'X7')==1)
    X7i=i;
    X7j=j;
    end
  end
end

if (X1i==0)
    disp('Err!!! No X1 Found')
end
if (X2i==0)
```

```
    disp('Err!!! No X2 Found')
end
if (X3i==0)
    disp('Err!!! No X3 Found')
end
if (X4i==0)
    disp('Err!!! No X4 Found')
end
if (X7i==0)
    disp('Err!!! No X7 Found')
end
if (X5i==0)
    disp('Err!!! No X5 Found')
end
if (X6i==0)
    disp('Err!!! No X6 Found')
end


%%%%%%%%%%
%SCHEDULE PROCESS
%%%%%%%%%%
if(strfind(input_schedule,'.glm')>0)
    input_schedule = strsplit(input_schedule,'.');
    input_schedule=input_schedule{1};
end
extraction_schedule=[input_schedule,'.glm'];
fileIDr02 = fopen(extraction_schedule,'r');
S = textscan(fileIDr02,'%s %s %s %s %s %s %s %s %s %s %s %s %s %s %s');
fclose(fileIDr02);
if(strfind(input_schedule,'_Raw')>0)
    input_schedule = strsplit(input_schedule,'_');
    input_schedule=input_schedule{1};
end
Output_schedule=[input_schedule,'.glm'];
%Output_file=[input_file,'_TempOutput.glm'];
%determining the size of schedule to be used in writing the file
[c,d] = size(S);
[a,b] = size(S{1});
% END OF SCHEDULE PROCESS

RunStartTime=datestr(now,'yyyymmdd_HHMMSS');
DirName=['WHDTest_',RunStartTime];
mkdir(DirName)

%%%%%%%%%%%
%%%% water usage
%%%%%%%%%%%

fileIDr03 = fopen(input_waterusage,'r');
WUSE = textscan(fileIDr03,'%s %s %s %s %s %s %s');
fclose(fileIDr03);
Output_waterusage='HotWater_Ashrae_w.glm';
%determining the size of schedule to be used in writing the file
[cw,dw] = size(WUSE);
[aw,bw] = size(WUSE{1});
%%%%%%%%%%%%%
```

```
%%% Main LOOP
%%%%%%%%%%%%%%



for H1=Hstart:Hend
    %floor area
    floor_area=0;
    while floor_area<750 || floor_area>1200
%   floor_area=random('uniform',750,1200);
    floor_area=random('normal',950,100);
    end

    Fileinput{1,X1i}{X1j,1}=num2str(floor_area);
    House_Config(H1,1)=floor_area;
    if floor_area>950
        Fileinput{1,X5i}{X5j,1}=num2str(4); %%% Number of occupants
        Fileinput{1,X6i}{X6j,1}=num2str(80);%%% water heater size
        House_Config(H1,5)=4;
        House_Config(H1,6)=80;
        AshraeAmp=random('uniform',0.95,1.1);
%         AshraeAmp=1;

    end
    if floor_area<=950
        Fileinput{1,X5i}{X5j,1}=num2str(2);
        Fileinput{1,X6i}{X6j,1}=num2str(50);
        House_Config(H1,5)=2;
        House_Config(H1,6)=50;
        AshraeAmp=random('uniform',0.9,1.05);
%         AshraeAmp=1;
    end
    Cooling_setpoint=random('uniform',72,78);
    House_Config(H1,2)=Cooling_setpoint;
    Fileinput{1,X2i}{X2j,1}=num2str(Cooling_setpoint); %%% cooling set point
    Heating_setpoint=random('uniform',65,71);
    House_Config(H1,3)=Heating_setpoint;
    Fileinput{1,X3i}{X3j,1}=num2str(Heating_setpoint); %%% heating set point

    Fileinput{1,X4i}{X4j,1}=['waterw*',num2str(AshraeAmp)];
    House_Config(H1,4)=AshraeAmp;

    skew=random('uniform',-500,500);
    Fileinput{1,X7i}{X7j,1}=num2str(skew);  %%% skew
    House_Config(H1,7)=skew;


    fileIDw01 = fopen(glm_file,'w');

    for j=1:ain
        fprintf(fileIDw01,'\n');
        for i=1:din %d is number of coloumns
            fwrite(fileIDw01,Fileinput{1,i}{j,1});
            fprintf(fileIDw01,' ');
        end
    end
    fclose(fileIDw01);
```

```
%%%%%%%%%%%%%
%%% Schedule Editing
%%%%%%%%%%%%%

%for h=hstart:hend;
for sp=tstart:tstep:tend; %different setpoint to test


for rh=2:49; %reset all to 120
S{1,6}{rh,1}='120'; %%%%%%%%%% IL 120 AZ:160
end

for rh=2:15;  %set setpoint to sp from 30=14:00 32=15:00 to 37=18:00// 2:15=
12am to 7am
S{1,6}{rh,1}=num2str(sp);
end
for rh=46:49;  %set setpoint to sp from 46:49= 10pm to 11:59pm
S{1,6}{rh,1}=num2str(sp);
end

for j=2:10
WUSE{1,6}{j,1}=str2num(WUSE{1,6}{j+11,1});
end

fileIDW02 = fopen(Output_waterusage,'w');

 for j=1:aw
 fprintf(fileIDW02,'\n');
 %d is number of coloumns
  for i=1:dw
    fwrite(fileIDW02,num2str(WUSE{1,i}{j,1}));
    fprintf(fileIDW02,' ');
  end
 end
fclose(fileIDW02);

fileIDw01 = fopen(Output_schedule,'w');

 for j=1:a
 fprintf(fileIDw01,'\n');
 %d is number of coloumns
  for i=1:d
    fwrite(fileIDw01,S{1,i}{j,1});
    fprintf(fileIDw01,' ');
  end
 end
fclose(fileIDw01);

command=['Gridlab-D ',glm_file];
ok=dos(command);
%Rename Output CSV file
CSVName=['House1_MultiRecorder_',num2str(H1),'_',num2str(sp),'.csv'];
movefile('House1_MultiRecorder.csv',CSVName);
CSVOut{H1,sp}=csvread(CSVName,8,1);

%Move CSV file to folder
```

```
disp(['Moving ',CSVName,'...'])
pause(1); %Adding Delay to all remanes take place
movefile(CSVName,[DirName,'/']);


if(ok==0)
disp(['Gridlab-D file ',CSVName,': Done!'])

 else
disp(['Err!!! Gridlab-D file ',CSVName,' !'])
end %end of IF
disp(' ')

end %End of For
% fclose all;
end  %End for main LOOP
vfilename=['MainRun_',RunStartTime,'_Houses-1-',num2str(Hend),'_tstep-
',num2str(tstep),'.mat'];
save(vfilename,'-v7.3');
disp(' ')
disp(['Run Finished @',datestr(now,'yyyymmdd_HHMMSS')])
%End of CODE BODY
```