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Modeling of GE Appliances: Cost Benefit Study of Smart Appliances in Wholesale Energy, Frequency Regulation, and Spinning Reserve Markets

JC Fuller
GB Parker

December 2012

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Richland, Washington 99352

Summary

The widespread adoption of demand response (DR) enabled appliances and thermostats can result in significant reduction to peak electrical demand and provide potential grid stabilization benefits. GE has developed a line of appliances that will have the capability of offering several levels of demand reduction actions based on information received from the utility grid, often in the form of price or grid status. However due to a number of factors, including the number of DR-enabled appliances available at any given time, the reduction of diversity factor due to the synchronizing control signal, and the percentage of consumers who may override the utility signal, it can be difficult to predict the aggregate response of a large number of residences.

This report is the second in a series of three reports describing the potential of GE's DR-enabled appliances to provide benefits to the utility grid. The first report described the modeling methodology used to represent the GE appliances in the GridLAB-D simulation environment and the estimated potential for peak demand reduction at various deployment levels. The third report will explore the technical capability of aggregated group actions to positively impact grid stability, including frequency and voltage regulation and spinning reserves, and the impacts on distribution feeder voltage regulation, including mitigation of fluctuations caused by high penetration of photovoltaic distributed generation.

In this report, a series of analytical methods were presented to estimate the potential cost benefit of smart appliances while utilizing demand response. Previous work estimated the potential technical benefit (i.e., peak reduction) of smart appliances, while this report focuses on the monetary value of that participation. The effects on wholesale energy cost and possible additional revenue available by participating in frequency regulation and spinning reserve markets were explored. Specifically, historical market data from NYISO and PJM in 2006 were used to estimate the savings available to consumers and/or utilities by engaging demand response capabilities in HVAC systems, water heaters, clothes dryers and washers, dishwashers, refrigerators, freezers, miscellaneous light and plug loads, and cooktop range and ovens. While prices were marginally higher in 2006 than current prices, these were openly available, complete data sets and are used to provide a general indication of the value of smart appliances within a structured market.

Historical data from the End-Use Load and Consumer Assessment Program (ELCAP) and current U.S. energy usage by appliance was used to create seasonal, hourly load shapes for an average single family household. The appliance load shapes are available in Appendix B. These were applied against the 2006 NYISO and PJM wholesale energy markets. Estimates were made on the peak shifting capability of each appliance to respond to a TOU/CPP signal designed to significantly shift peak load for six hours on the 15 highest energy cost days within those markets and slightly shift peak load on all other days. A series of "optimism levels" were created to represent consumer willingness to participate in the demand response program ranging

from “unresponsive” to “very responsive”. Optimism levels 3-4 were designed to represent an “average” consumer, while optimism level 5 was designed using GE Appliance survey data and was considered an “early adopter” for the purposes of this study. The estimated load shifting capabilities for each optimism level for each appliance are available in Appendix A. The net annual savings (in dollars and kWh) on a per household basis (i.e., an average household’s response at that optimism level) are shown in Figure S-1. It should be noted that this value represents the wholesale *cost* savings not the retail savings, and does not include adders, tariffs, or additional retail markups applied at the distribution level. Effectively, this represents the amount of money the utility would save on wholesale energy costs, on a per household basis, by consumers shifting their load to a different time of day. The distribution of this money, i.e., what portion is returned to the customer versus the utility, is not discussed in this study.

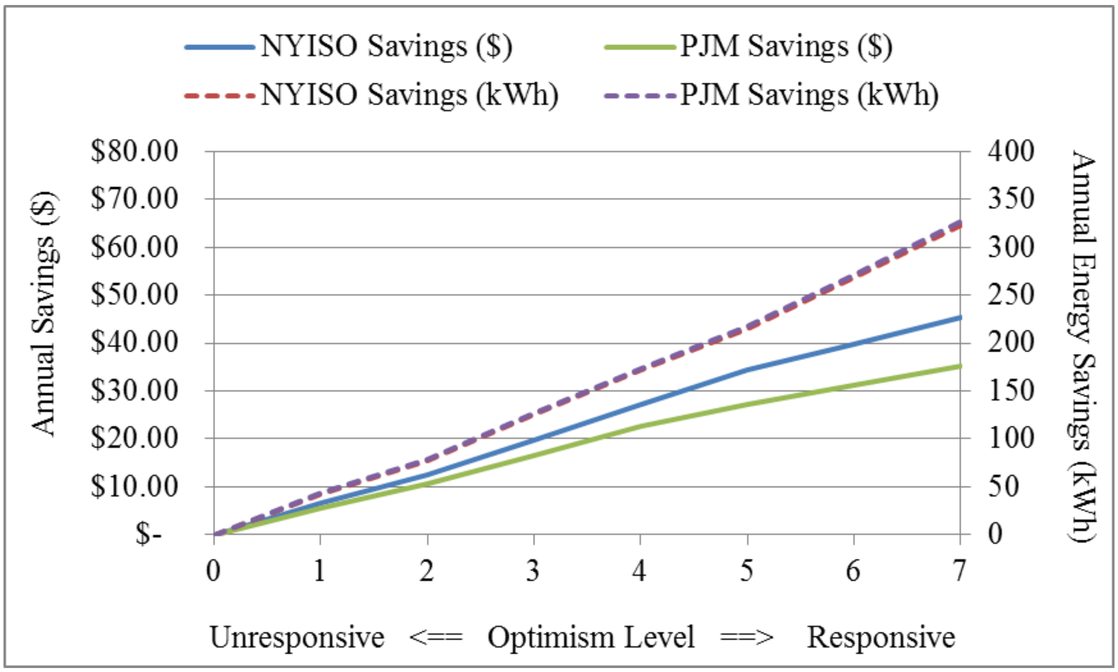

Figure S-1: Annual utility wholesale savings ($ and kWh) on a per household basis using a TOU/CPP rate.

This process was repeated for frequency regulation and spinning reserve markets utilizing one hour average markets from NYISO and PJM. On the 15 CPP days, frequency regulation and spinning reserve participation was not allowed. The next 30 highest price days in the frequency regulation market were then chosen for the appliances to participate, allowing up to three hours of market participation on each of those days. Only three hours were allowed per day to limit customer fatigue. Finally, excluding the 15 CPP days and 30 frequency regulation days, 150 spinning reserve days with three hours each day were chosen for appliance participation. This gave a total of 630 DR participation hours out of 8760 in a year. While it is expected that load resources can provide multiple benefits on a single day (e.g., mixing frequency regulation and spinning reserves), for the purpose of simplifying this analysis, single-day multi-objective controls were not considered.

As certain appliances are more amenable to short term load shifting than others, estimates on the load shifting capabilities of each appliance were made for frequency regulation and spinning reserves at each optimism level. These estimates can also be found in Appendix A. The net effects of wholesale energy cost reductions and additional revenue due to participation in frequency regulation and spinning reserve markets are shown in Figure S-2 and Figure S-3, again on a per household basis. For the purpose of this study, the additional revenue generated in the frequency regulation and spinning markets is considered a savings.

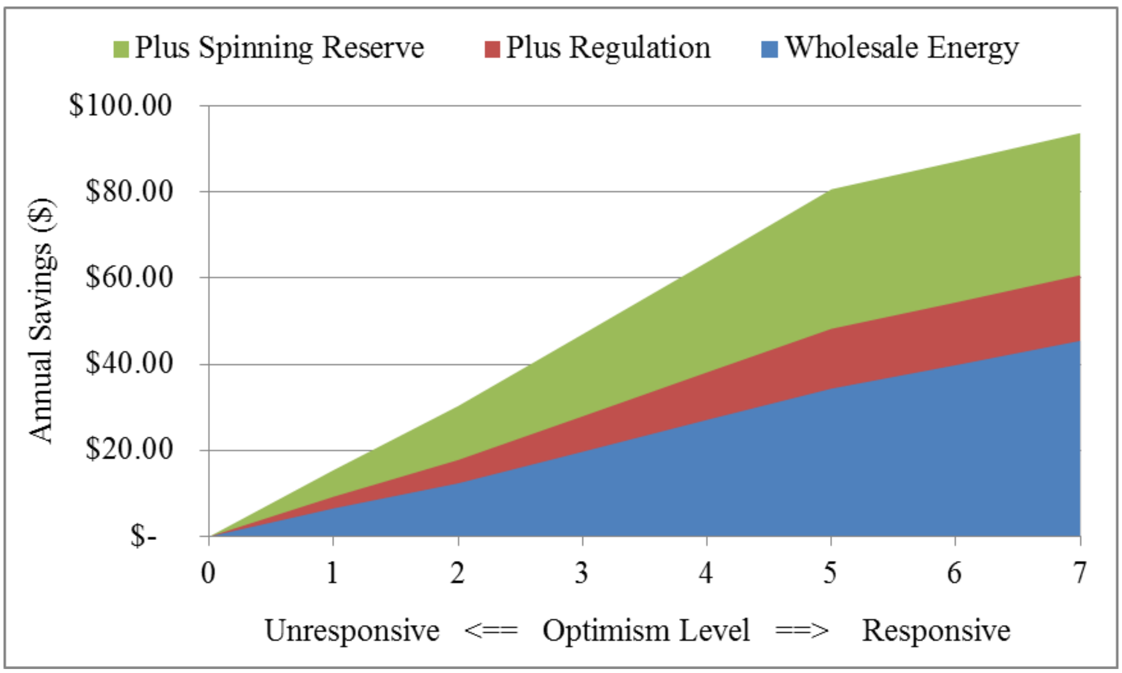

Figure S-2: Annual utility cost savings ($) on a per household basis when applying TOU/CPP rates, frequency response, and spinning reserve in NYISO.

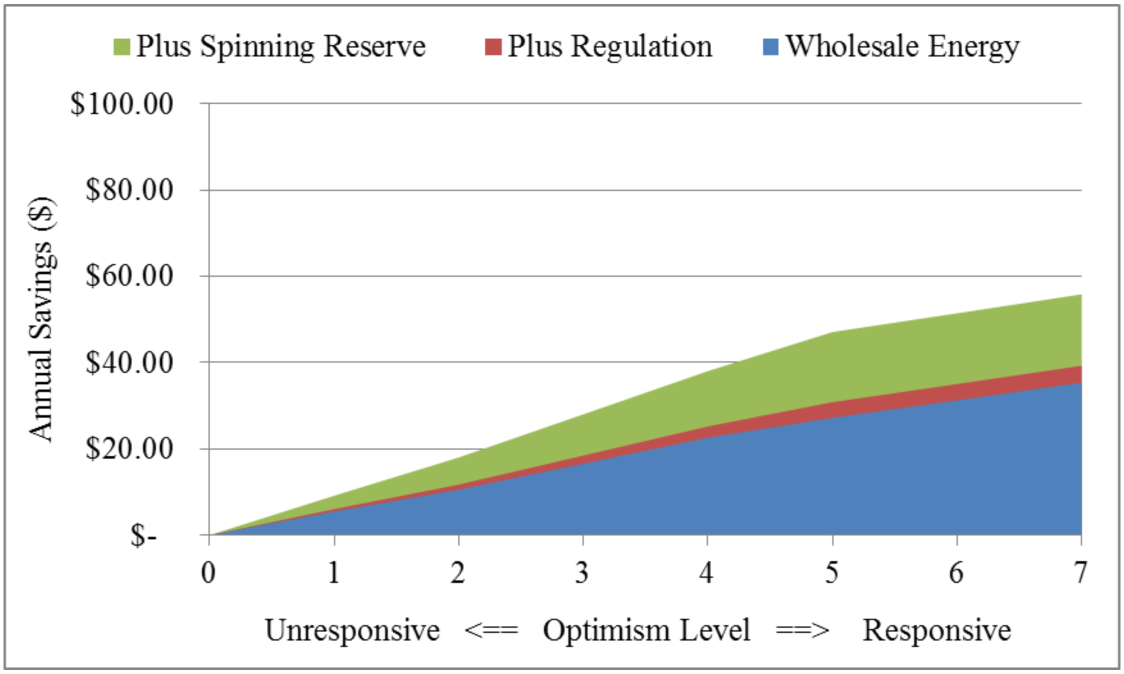

Figure S-3: Annual utility cost savings ($) on a per household basis when applying TOU/CPP rates, frequency response, and spinning reserve in PJM.

While much of this value is derived from the HVAC system and water heaters, significant lifetime benefits can be seen from other appliances. Standard appliances continue operation for 10-20 years, so the initial capital investment of a smart appliance is offset by not only a single year of usage, but over its lifetime. Using average appliance lifetime data, Table S-1 and Table S-2 show the potential reduced cost over the lifetime of the appliance, assuming 30% of the water heater benefits come from the dishwasher and clothes washer, at optimism level 4, or an "average" consumer. This represents the amount of savings a single household would generate over the lifetime of a suite of smart appliances. From these tables, it is clear that devices such as HVAC, water heaters, clothes dryers, clothes washers, and dishwashers can provide significant savings over and above the increased energy efficiency that comes with new, energy efficient appliances. Refrigerators and freezers provide some additional benefits. Considering these devices respond to signals with nearly no input from the consumer in an automated fashion, this may be considered significant. Food preparation (mainly ovens and ranges), however, does not appear to provide a significant benefits.

Table S-1: Lifetime savings for an average household by appliance in NYISO.

	Average Lifetime of Appliance (years)	Lifetime Savings ($)
Clothes Dryer	14	$ 71.50
Clothes Washer	12	$ 46.82
Dishwasher	12	$ 65.01
Food Preparation	15	$ 9.12
Freezer	16	$ 23.36
HVAC	14	$ 324.59
Lights and Plugs	-	-
Refrigerator	14	$ 20.83
Water Heater	14	$ 226.84
Total	-	$ 788.07

Table S-2: Lifetime savings for an average household by appliance in PJM.

	Average Lifetime of Appliance (years)	Lifetime Savings ($)
Clothes Dryer	14	$ 37.62
Clothes Washer	12	$ 27.88
Dishwasher	12	$ 39.61
Food Preparation	15	$ 3.72
Freezer	16	$ 13.08
HVAC	14	$ 201.07
Lights and Plugs	-	-
Refrigerator	14	$ 12.12
Water Heater	14	$ 137.31
Total	-	$ 472.41

While this report should not be considered comprehensive, it does give some valuable insights into the potential use of smart appliances for demand response. A few key conclusions can be drawn from this study:

1) A significant fraction (over 50%) of the total monetary benefits available to smart appliances are in the form of spinning reserve and frequency regulation markets, providing as much additional revenue in spinning reserve and frequency regulation markets as savings in wholesale energy markets. It was not determined how this revenue should be distributed between the utility and the consumer, but is left for individual deployments.

2) In addition to traditional demand response appliances (HVACs and water heaters), clothes dryers, clothes washers and dishwashers provide a significant amount of savings when accounting for the indirect effects on the water heater load. In areas where gas water heaters are prevalent, clothes washers and dishwashers participating in demand response do not provide significant savings or revenue in electricity markets.
3) Refrigerators and freezers are capable of providing some monetary benefits, but less so than the previous appliances. However, since these devices are nearly 100% automated with little to no effect on the consumer experience, this may increase their intrinsic value to demand response programs.
4) Food preparation devices (cooktops and ovens) do not provide significant monetary benefits.

This study did not focus on the mechanism by which smart appliances engage in spinning reserve or frequency regulation services or how the utility and consumer might split the cost and benefits associated with such a program. Further work is needed to understand how these devices might engage in these markets, the reliability of such participation, and what the capital and continuing costs of such engagement might be.

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Acronyms and Abbreviations

BPA	Bonneville Power Administration
CPP	Critical Peak Pricing
CRADA	Cooperative Research and Development Agreement
DOE	U.S. Department of Energy
DOE-OE	Office of Electricity and Energy Reliability
DR	Demand Response
EIA	Energy Information Agency
ELCAP	End-Use Load and Consumer Assessment Program
EPCA	Energy Policy and Conservation Act
ERCOT	Electric Reliability Council of Texas
ES	Energy Savings
FERC	Federal Energy Regulatory Commission
GE	General Electric
HVAC	Heating, Ventilation, and Air Conditioning
HWH	Hybrid Water Heater
ISO	Independent System Operator
LMP	Locational Marginal Price
LSE	Load Serving Entity
NYISO	New York Independent System Operator
PJM	Pennsylvania-New Jersey-Maryland Interconnection
PNNL	Pacific Northwest National Laboratory
RTO	Regional Transmission Operators
SR	Spinning Reserve
TOU	Time-of-Use

1 Introduction

The Energy Information Administration (EIA) estimates that electricity use will increase by more than 30 percent by 2035, and that residential electricity usage will increase by 23 percent [1]. During this time, peak electricity demand is expected grow at an even greater rate, requiring significant investment in system capacity. In addition, increased penetration of intermittent renewable resources will increase system variability, requiring additional resources to mitigate the variability associated with generator output [2]. Widespread adoption of demand response (DR) enabled appliances, thermostats, and other demand-side resources can result in significant reduction to peak electrical demand and provide potential grid stabilization benefits. The key to adoption is to provide this resource at a cost commensurate with traditional grid capabilities, and to appropriately share both the costs and the benefits between the consumer and the service provider (i.e., the utility). However, the business model for investing in demand-side resources cannot be determined without an estimation of the possible technical benefits and how those benefits translate to monetary value in current electrical market structures.

GE Appliances' has developed a line of appliances that will have the capability of offering several levels of demand reduction actions based on information received from the utility grid, often in the form of price or grid status. However due to a number of factors, including the number of DR-enabled appliances available at any given time, the reduction of diversity factor due to the synchronizing control signal, and the percentage of consumers who may override the utility signal, it can be difficult to predict the aggregate response of a large number of residences. The effects of these behaviors have been modeled and simulated in the PNNL-developed open-source software, GridLAB-D™ [3], including evaluation of appliance controls, improvement to current algorithms, and development of aggregate control methodologies. The results of these simulations provide an estimation of the possible technical benefits (e.g., peak load reduction) attributable to smart appliances, but do not describe the monetary value of these services.

This report is the second in a series of three reports funded by U.S. Department of Energy Office of Electricity Delivery and Energy Reliability (DOE-OE) in collaboration with GE Appliances' through a Cooperative Research and Development Agreement (CRADA) to describe the potential of GE Appliances' DR-enabled appliances to provide benefits to the utility grid. The first report described the modeling methodology used to represent the GE appliances in the GridLAB-D simulation environment and the estimated potential for peak demand reduction at various deployment levels [4].

The second report explores the monetary value of potential grid services (e.g., peak reduction or frequency regulation) provided by DR-enabled appliances in various U.S. energy markets. This report is not intended to be an all-inclusive analysis, but rather explore some of the possibilities of the potential cost savings that could be seen by utilizing smart appliances to reduce wholesale energy costs, while also participating in frequency regulation and spinning reserve markets. There are too many possibilities to attempt an all-inclusive analysis. Consumers in different areas of the country respond differently to demand response signals.

Climate and weather will significantly affect how consumers allow demand response programs to interact with their devices. Electric market structures are structured in some parts of the country with wholesale demand response markets, while others use only bilateral agreements for wholesale purchasing of energy and ancillary services. Electrical rates vary widely across the country. These are just a few examples. Rather, this report will lay out a number of "optimism levels" which regard consumers from "unresponsive" to "very responsive" and make estimates on how much appliance loads may be shifted at each of these levels. The load shifting behavior will be applied to historical data (2006) from NYISO and PJM wholesale energy, frequency regulation, and spinning reserve markets. The potential monetary value of these services will be estimated on an annual basis and over the lifetime of the appliance.

The third report will explore the technical capability of aggregated group actions to positively impact grid stability, including frequency and voltage regulation and spinning reserves, and the impacts on distribution feeder voltage regulation, including mitigation of fluctuations caused by high penetration of photovoltaic distributed generation.

This report will be presented as follows. Section 2 will briefly describe the power system requirements for operational balancing and reserves. Section 3 will describe the ability of smart appliances to meet those needs. Section 4 will provide a limited benefit analysis for smart appliance participation in energy and ancillary markets. Section 5 will provide overall observations and conclusions. Appendix A will provide more detailed information about the operational and model characteristics of GE Appliances' DR-enabled appliances and the models used in this work.

2 Power System Balancing and Reserve Requirements

The American power system is a large, complex machine, requiring near-perfect balance of generation resources and load demand to continue operation. Minute-to-minute load and generation variability caused by cycling on and off of millions of individual loads, requires constant adjustments to this balance. Significant variations can also occur within the generation resource with increased penetrations of intermittent resources (mainly wind and solar), increasing system-wide variability and increasing requirements for securing balancing resources. Traditionally, these balancing resources have been obtained on the supply side (generators), but in aggregate, demand-side resources may represent an equal potential for providing balancing services if the resource can be controlled in an equivalent manner to the generation resource.

Balancing services are acquired by Transmission Providers, e.g., Bonneville Power Administration (BPA) or New York Independent Service Operator (NYISO), to maintain the balance between supply and demand at all times. These balancing services are often referred to as ancillary services. The Federal Energy Regulatory Commission's (FERC) Order 888 [5] defines ancillary services as "*Those services that are necessary to support the transmission of capacity and energy from resources to loads while maintaining reliable operation of the Transmission Provider's Transmission System in accordance with Good Utility Practice*." and defines six forms of ancillary service:

(1) Scheduling, System Control and Dispatch Service: schedule the movement of power through, out of, within or into the control area;
(2) Reactive Supply and Voltage Control from Generation Sources Service: to maintain transmission voltages within acceptable limits, facilities are operated to produce reactive power;
(3) Regulation and Frequency Response Service: provides for continuous balancing (generation and interchange) with load to maintain frequency at 60 Hz;
(4) Energy Imbalance Service: reduces the deviation between the scheduled and actual delivery of energy to a load within a local control area;
(5) Operating Reserve – Spinning Reserve Service: provided by generating units that are online but not at full capacity to immediately serve changes in load, typically during a system contingency;
(6) Operation Reserve – Supplemental Reserve Service: serves load during a system contingency and is not available immediately, but rather after a short time interval.

Transmission providers may have different definitions of service, or may group them in a different manner. For the purpose of this study, the FERC classifications will be used. Actual requirements and proportions of the resources to the total load vary from region to region. Engagement of the resource also varies from provider to provider. Some providers employ a double-auction market system (both real-time and day-ahead) to determine the lowest cost resource, while others establish long-term settlement contracts dispatching the resources as needed. Again, the structure of the engagement varies throughout the United States. In some markets, capacity markets have been developed to encourage long-term capacity growth. Responsive loads are well-positioned for participating in this type of market. Capacity markets were not considered in this study. For the purpose of this study, the penetration level of the DR-enabled appliances will be considered low enough that their behavior has no effect on the price of the services acquired (i.e., open loop response or a “price-taking” scenario), but rather respond to variations in the price providing the required service at current market price.

3 Smart Appliance Capabilities

Energy efficiency has long been a focus of residential appliance research and development. The Energy Policy and Conservation Act (EPCA) of 1975 established energy conservation programs for major household appliances [6], with additional amendments and requirements established as necessary to encourage appliance manufacturers to increase energy efficiency [7]-[11]. Combined with voluntary industry energy efficiency efforts, residential appliance consumption has saved nearly 1.5 quads of energy since 1990 [12]. However, load management capabilities have not had as high a priority in research and development. These resources are crucial, along with the energy efficiency standards, in managing increasing electricity demand, especially during on-peak or critical event periods on the electrical grid.

Smart appliances have the capability to provide not only energy reduction but load shifting resources. The GE Appliances are designed to automatically respond to a control signal (analogous to price), while engaging the customer through a visual interface and various override actions. This is a key to acceptability with customers, operating under the principle of automating as many response actions as possible without circumventing the customer's freedom to choose to override the response strategy and operate normally when necessary. In general, when the price of electricity increases, the customer is presented with three choices: delay operation to a later time when prices are cheaper; enter an Energy Savings mode (ES-mode), but continue operation; or override the load reduction and operate normally. When the customer is not present, the appliance defaults to either energy savings or delay of operation, depending upon the control signal and particular appliance settings. The different control actions of the appliances, and how consumers can interact with them, are more thoroughly described in [4].

The combination of consumer choices and visual feedback with automated controls creates a number of opportunities for the GE Appliances to participate in various demand response markets, from short term, automated responses to longer term, consumer driven responses. This report will focus on three such services, wholesale energy costs, spinning reserve requirements, and frequency regulation, which are well-suited for use with appliance operation. Some appliances are more effective at supplying certain resources than others, and consumers may be more inclined to provide short term services that long term services, again depending upon the type of appliance. For example, an automated short term reduction (such as 5 minutes) in the demand of a clothes dryer produced by turning off the heating element will not adversely affect the consumer experience as drying time will only be extended by a few minutes, but may provide significant resources (up to 4 kW) towards a frequency regulation signal. However, a long term delay, as can be requested during a critical peak pricing period, may adversely affect consumer experience, needs advanced planning, and requires the participation of the consumer, but also provides significant benefits towards reduction of wholesale costs. Most customers will not be aware of a short term reduction in the compressor load of their refrigerator, nor a 6 hour shift in the defrost cycle, making the refrigerator ideal for a number of services. Each of the services, and how effectively they can be used to shift demand, will be further discussed in the next sections.

3.1 Wholesale Energy Costs

All loads incur a cost for the wholesale production and delivery of energy. Costs are typically far greater during peak demand periods than off-peak periods; however, consumers are most commonly exposed to a flat rate charge for electricity that does not necessarily reflect the current cost of energy production. For example, in the 2008 Energy Reliability Council of Texas (ERCOT) the average on-peak price was 105.36 $/MWh, while the off-peak price was 66.99 $/MWh (a ratio of 1.57 on-peak to off-peak) [13]. Note that the actual ratio is very dependent upon which hours are specified as on-peak versus off-peak. This ratio can be much greater during "extreme" market periods, such as seen during very hot summer days when air conditioning load is at a maximum. Commonly used methods for encouraging customers to shift their loads from on-peak to off-peak periods are Time-of-Use (TOU) and Critical Peak Pricing (CPP) programs. These programs encourage consumers to change their load consumption patterns by raising the price of electricity during on-peak periods, while correspondingly reducing the price during off-peak periods. The goal is to reduce utility demand during on-peak periods and therefore reduce overall costs. While there are more complex methods for reducing demand during on-peak periods (Real Time Pricing, Peak Time Rebates, etc.), this method is relatively simple and has been used since the 1970s to effectively reduce demand [14]. Numerous studies, mostly focused on air conditioning systems and hot water heaters, have shown that a combination of automation and providing consumers with feedback makes these mechanism far more effective [15]-[19].

GE Appliances' have been designed to work in conjunction with TOU/CPP price signals to reduce demand, building the automation and consumer feedback directly into the appliance interface. This eases the use for consumers, utilizing an interface they may already be familiar with rather than introducing a new "widget". The consumer is able to access settings through a set of pre-configured automated responses, translating the TOU/CPP prices into control signals: Low, Normal, High, and Critical, or modify the pre-configured settings as needed, including overriding the utility price signal and continuing normal operation. Ideally, this makes it easy-to-use and transparent enough for consumers to actively engage in the process, reducing energy bills and increasing system efficiency.

Of course, the big unknown with these types of systems is how actively the consumer will engage in the process, both initially and over time. To evaluate the effects of consumer interaction, a number of consumer response scenarios were created, ranging from "none" (given an optimism level of 0) to "very optimistic" (optimism level 7). These scenarios try to reflect the consumers' willingness to 1) participate in a demand response program and shift their load for the given amount of time, 2) shift a given percentage of that load, and 3) reduce the consumption versus shift the consumption to a different time period.

To describe the load shifting capabilities of the clothes dryer (and other appliances), three settings were used. The first, *Percentage of Customers Allowing (PCA)*, describes the percentage of customers who are willing to engage in load shifting. This could also be thought of as the penetration level of responsive appliances, or what percentage of customers within a service area have smart appliances connected to a utility signal, given by

$$PCA = \frac{Number\ of\ Customers\ Willing\ to\ Participate}{All\ Customers} \tag{1}$$

The second setting, *Percentage of Available Load (PAL)*, describes the percent of load reduction during the given time frame, or how much load is available for shifting as a combination of controls and consumer interaction, described by

$$PAL = \frac{Appl.Load\ Avail.for\ Reduction\ per\ Willing\ Customer\ (kW)}{Total\ Appl.Load\ per\ Willing\ Customer\ (kW)} \tag{2}$$

Where possible, this information was extracted from previous work [4], which estimated the load shifting capabilities of the appliances using consumer survey data from GE Appliances' while using various TOU and CPP test cases. For reference, optimism level 5 represents the "best guess" as extracted from the survey data, and likely represents an early adopter scenario. The third setting, *Percentage of Load Shifted (PLS)*, represents the percent of load that was available for shifting from an on-peak period to an off-peak period.

$$PLS = \frac{Reduced\ Appl.Load\ Consumed\ at\ a\ Later\ Period\ (kW)}{Appl.Load\ Avail.for\ Reduction\ per\ Willing\ Customer\ (kW)} \tag{3}$$

The reverse, 1 - *Percentage of Load Shifted*, represents the percentage of energy reduced. In some economic models, this concept is referred to as substitution elasticity versus daily elasticity [17], where a change in the price of electricity encourages consumers to either shift or reduce energy consumption. This resulted in three time periods of load shapes: low price, high price, and recovery. For the normal period, the total load at each hour is simply defined as

$$E_{WS} = \sum_{n=1}^{\#\ of\ appl.} E_{base_n} \tag{4}$$

where E_{WS} is the amount of energy consumed at the wholesale level during a given hour by all of the appliances within a demand response scenario and E_{base} is the amount of energy consumed by each appliance during a given hour using base conditions, or the load shape prior to modifying the load with a demand response signal.

During a high price period, the load is reduced by the percentage of customers willing to engage in the demand response request and the amount of load that is available for shifting. The energy consumed during a high price hour is defined as

$$E_{WS} = \sum_{n=1}^{\# \, of \, appl.} E_{base_n} - E_{base_n} * PCA_n * PAL_n \tag{5}$$

The energy reduction by a given appliance during a high price hour can be stated as

$$\Delta E_{WS_n} = E_{base_n} - E_{WS_n} \tag{6}$$

and the amount of energy reduction by appliance (ΔE_{red}) during a high price event lasting *h* hours can be stated as

$$\Delta E_{red_n} = \sum_{h=1}^{hours} \Delta E_{WS_{n_h}} \tag{7}$$

This energy reduction (ΔE_{red}) represents the amount of load deferred during the high price event. Some of that load will be shifted to a later period as consumers recover their deferred processes, i.e., a delayed load of laundry. For the purpose of this study, it was assumed that the number of hours of recovery was equal to the number of hours spent in a high price event, and the deferred load was evenly spread across those hours. So, for a given hour within the recovery period, an individual appliance would consume

$$E_{WS_n} = E_{base_n} + \frac{\Delta E_{red_n}}{h} * PLS_n \tag{8}$$

A good example of this is the operation of a clothes washer versus a range oven during a high price event. Consumers will delay the operation of the clothes washer, but will still eventually wash those clothes at a later period. However, if the consumer makes the choice to not cook dinner in the oven, using the microwave instead, that load is not replaced at a later time. Table 3-1 and Table 3-2 list the assumptions at various "optimism levels" for the clothes dryer for both CPP and TOU. Assumptions for all other appliances are listed in Appendix A. Note that as the optimism level increases, the expected reduction in load also increases. The data in these tables represent an amalgamation of survey and testing data determined from [4].

Table 3-1: Clothes Dryer response assumptions for CPP.

Optimism Level	*Percentage of Customers Allowing*	*Percentage of Available Load*	*Percentage of Load Shifted*
0	0%	0%	0%
1	15%	45%	90%
2	35%	45%	90%
3	55%	45%	90%
4	75%	45%	90%
5	95%	45%	90%
6	100%	45%	90%
7	100%	45%	90%

Table 3-2: Clothes Dryer response assumptions for TOU.

Optimism Level	*Percentage of Customers Allowing*	*Percentage of Available Load*	*Percentage of Load Shifted*
0	0%	0%	0%
1	15%	20%	90%
2	35%	20%	90%
3	55%	20%	90%
4	75%	20%	90%
5	95%	20%	90%
6	95%	20%	90%
7	95%	20%	90%

As an example, assume that the values for CPP and optimism level 4 in Table 3-1 are used with a representative dryer load shape and a price signal, as defined in Table 3-3. When applying these values in conjunction with a 4-hour CPP signal to the daily load shape, the daily energy consumption is reduced by 0.9%, and the daily load shape is adjusted as shown in Figure 3-1. The filled areas represent the energy reduced due to the CPP signal (Reduced Energy) and the amount of energy that is shifted to a later period (Recovered Energy). Note that the Recovered Energy is 10% less than the Reduced Energy, indicating that customers not only shifted their loads due to the CPP signal, but also reduced their overall energy consumption.

Table 3-3: Example calculation of new dryer load shape when applying a 4-hour CPP period, where PCA is 75%, PAL is 45%, and PLS is 90%.

Hour	Period	E_{base}	E_{WS}	Calculation
14	Low	0.916	0.916	E_{base}
15	High	0.868	0.575	E_{base} - E_{base} * 0.75 * 0.45
16	High	0.836	0.554	E_{base} - E_{base} * 0.75 * 0.45
17	High	0.788	0.522	E_{base} - E_{base} * 0.75 * 0.45
18	High	0.707	0.469	E_{base} - E_{base} * 0.75 * 0.45
19	Recovery	0.637	0.880	E_{base} + 1.08 / 4 * 0.9
20	Recovery	0.605	0.848	E_{base} + 1.08 / 4 * 0.9
21	Recovery	0.576	0.819	E_{base} + 1.08 / 4 * 0.9
22	Recovery	0.476	0.719	E_{base} + 1.08 / 4 * 0.9
23	Low	0.299	0.299	E_{base}

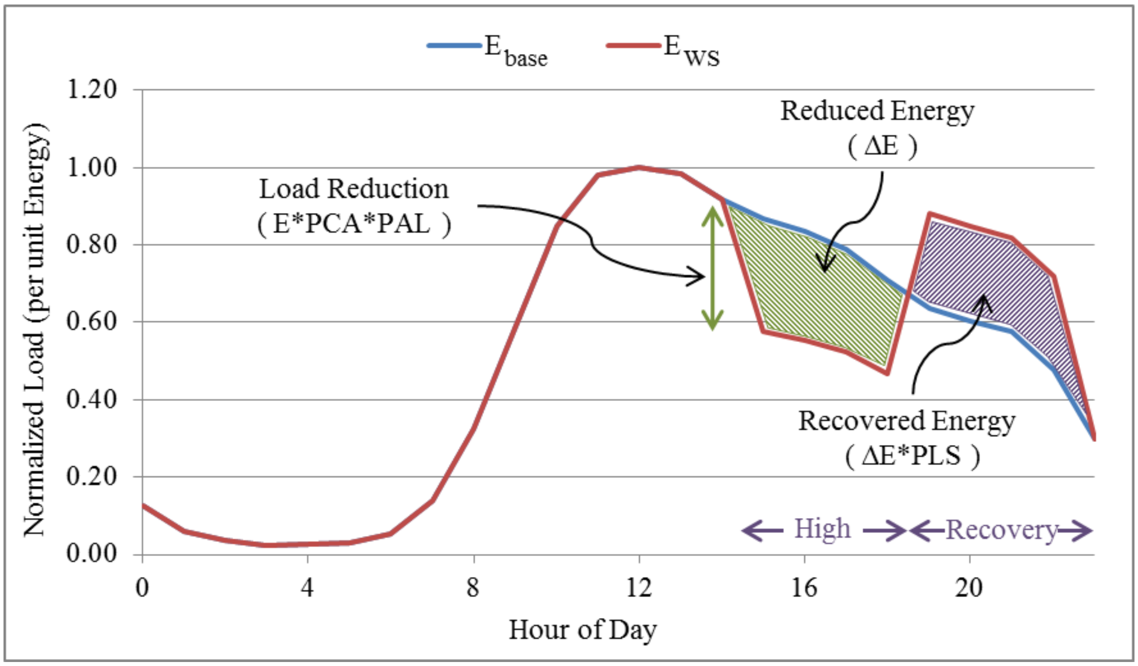

Figure 3-1: Base and modified load shape for the clothes dryer using a CPP signal.

3.2 Frequency regulation

In addition to adjusting basic energy consumption patterns, a number of appliances have a significant capability to provide regulation service. Frequency regulation is required to balance load and generation moment-to-moment, utilizing nearly instantaneous control to maintain a grid frequency of 60 Hz. An imbalance can cause a shift in system frequency, reducing overall system stability. If extreme frequency deviations (~0.5 Hz) cannot be corrected in a timely manner, load shedding and generation tripping mechanisms operate to restore system frequency.

Conceptually, frequency regulation could be provided by either generation or load, maintaining the balance between the two. Traditionally, only generation resources have been engaged, utilizing a centralized control signal referred to as Automatic Generation Control (AGC) in combination with instantaneous local controls to adjust generator output on a second-by-second basis. Typically, Independent System Operators (ISOs) purchase blocks of up- and down-frequency regulation in 15- to 60-minute intervals, commanding the set point of the generator via the AGC signal at intervals on the order of seconds. Historically, generators have only participated in this operation as they are considered deterministic and controllable, while loads are stochastic in nature and less controllable. With increasing penetration of renewable energy resources, particularly wind and solar resources that are also stochastic in nature, generation can no longer be considered deterministic and controllable, adding a level of uncertainty to frequency control. For example, a report from Navigant Consulting Inc. indicated that for California to meet its 33% Renewable Portfolio Standard (RPS) goals, an additional 4,600 MW of frequency regulation would be required by 2020, mainly in regulation-up services [2]. This could in part be supported by current resources, but it was also concluded that during extreme events, additional resources were needed. Traditionally, this would have been met by investing new capital and building additional power plant resources. However, new 'smart' load devices and increasing communication infrastructure are capable of providing the same resource to the grid, adjusting the load behavior as a function of frequency.

Again, not all loads are capable of meeting these requirements; some appliances are far more capable of shifting their behavior in a short time interval than others. Modifying energy consumption through a CPP or TOU signal requires a shift in behavior by the user (automation can expand this resource), moving entire cycles from one time period to another, but without fundamentally affecting the overall behavior of the appliance. However, to respond on very short timeframes (~seconds), individual processes within the appliance must be interrupted, requiring careful design and additions to the internal control logic. And, not all processes are interruptible on these shorter timeframes. For example, turning the heat element(s) on and off within a short interval (~minutes) in a clothes dryer will not adversely affect the operation; however, this same operation on the compressor of a refrigerator may severely shorten the lifetime of the compressor. The advantage of this short timeframe is that once the controls are added to the appliance and the consumer gives consent for the response to occur, the behavior is automated and non-intrusive to the consumer. The disadvantage is that it may require more robust communication systems. There are a number of proposed methods for controlling residential load devices for frequency response, including purely autonomous Grid Friendly Appliances™ [20], direct load control (DLC) using either a centralized signal or local measurements [21], or in a hybrid cooperative control system using both centralized signals and local information [22][23] (Note, this is not a comprehensive list). The goal of this paper will not be to focus on the type of control used, but rather assume that some form of control is available and assess the load behavior changes created by it and the subsequent economic impact of the "ideal" control.

Similar to the wholesale energy costs, three settings were used to describe the aggregate behavior of the appliances when receiving a regulation signal: *Percentage of Customers Allowing, Percentage of Available Load,* and *Percentage of Load Shifted.* Table 3-4 lists an example of the settings used for the clothes dryer. Notice that the percentage of available load is greater than that seen in TOU/CPP due to the fact that the heating element can be turned off for a greater percentage of the shorter time period, and that the percent shifted is greater as the short response period will not affect the overall energy consumption as greatly. Note that for each appliance, these assumptions are different depending upon the capability of the appliance. The assumptions for each appliance are listed in Appendix A and were estimated from previous work [4].

Table 3-4: Clothes Dryer response assumptions for frequency regulation.

Optimism Level	*Percentage of Customers Allowing*	*Percentage of Available Load*	*Percentage of Load Shifted*
0	0%	0%	0%
1	15%	80%	97%
2	35%	80%	97%
3	55%	80%	97%
4	75%	80%	97%
5	95%	80%	97%
6	95%	80%	97%
7	95%	80%	97%

3.3 Spinning Reserve

Spinning reserves (SR) operate in the timeframe between frequency regulation and wholesale energy, typically on a 10-minute period. These reserves act to maintain system balance in the event of a catastrophic failure, such as a loss of the largest generation plant in the system, for a short period of time (10 – 30 minutes) until non-spinning reserves can be activated, such as a cold start of a thermal plant. Spinning reserve resources must be deployable within 10 minutes of being called. Once the non-spinning reserves are deployed, spinning reserve resources return to their normal operation (less than 30 minutes of disturbance). Typically, this is reserve capacity at an already operating power plant, but can be delivered by any grid-connect and synchronized device. The amount of spinning reserve required at any given time is very dependent upon the system. For example, NYISO requires that the 10-mimute (non-spinning) reserve be greater than or equal to the greatest contingency in the system and 10-minute spinning reserve equal to one-half the largest contingency [24]. This is typically on the order of 100s-1000s of MW. The price for spinning reserve resource is usually determined an hour to 75 minutes ahead of time through an ISO market.

Historical data shows that most spinning reserve resources are deployed for ten minutes or less [25]. Again, this resource is typically provided by generation resources. However, most appliances are capable of shifting behavior for ten minutes without noticeable effect on the consumer interaction. In a Lawrence Berkeley National Laboratory demonstration, it was found that load response for spinning reserve could occur within 20 seconds with zero customer complaints over a three-month trial period [25]. Clothes dryers and water heaters are capable of turning off the heating element and refrigerators can delay the defrost cycle by ten minutes without adverse effects. This would eliminate wear and tear on generators that currently have to ramp up and down very quickly within a 10-minute period. It would also eliminate the need to have fossil fuel supplied thermal plants sitting on idle, burning fuel, but producing negligible energy. It is also assumed that non-spinning reserves would return the system to pre-contingency conditions within a 30-minute window, allowing the appliances to return to normal operation. As described in the previous two sections, three settings were used to determine the availability of each appliance as a spinning reserve resource. Table 3-5 lists the settings for the clothes dryer for each of the optimism levels. Appendix A gives similar settings for each of the appliances, estimated from previous work [4].

Table 3-5: Clothes Dryer response assumptions for spinning reserves.

Optimism Level	*Percentage of Customers Allowing*	*Percentage of Available Load*	*Percentage of Load Shifted*
0	0%	0%	0%
1	15%	80%	95%
2	35%	80%	95%
3	55%	80%	95%
4	75%	80%	95%
5	95%	80%	95%
6	95%	80%	95%
7	95%	80%	95%

4 Benefit Analyses

In the previous report [4], the potential technical benefits of smart appliances were evaluated. Highly detailed models of GE Appliances' devices were created and the devices were tested under a variety of conditions to determine the potential for longer term peak reduction (2-6 hours) and shorter term load reduction (less than an hour). This section focuses on the resulting revenue streams that could be generated by applying load shifting behaviors in three demand response markets: wholesale energy, frequency regulation, and spinning reserve. Two ISO/RTO markets, NYISO and PJM in 2006, that contain publicly available data on historical prices for all three markets were used to determine the potential return on investment in using demand response capable appliances [26][27]. For this analysis, wholesale hourly averages for Locational Marginal Price (LMP), frequency regulation, and spinning reserves were used to estimate the potential revenue that consumers and/or utilities might see by using responsive appliances. Nine appliances were considered. The assumptions for annual energy consumption for each appliance are shown in Table 4-1. Note that the appliances with asterisks are not GE Appliances, but were modeled for completeness. Hourly and seasonal load shapes from the End-Use Load and Consumer Assessment Program (ELCAP) were applied to each device to represent daily and seasonal consumption patterns [28]. These load shapes are typical for the Pacific Northwest, with large electric heating loads but relatively small cooling loads. An example of the clothes dryer load shape is shown in Figure 4-1, while all of the load shapes can be found in Appendix B. Where appropriate, the load shapes were adjusted from the original ELCAP data to account for advances in energy efficiency to meet the annual energy consumption data listed in Table 4-1, which is intended to represent an average U.S. single family home with all electric appliances.

Table 4-1: Annual energy consumption for an average household of studied appliances.

	Annual Energy Consumption per Household (kWh)	Percent of Total Consumption (%)
Clothes Dryer	1,037	5.3%
Clothes Washer	108	0.6%
Dishwasher	121	0.6%
Food Preparation	516	2.7%
Freezer	716	3.7%
HVAC	6,712	34.5%
Lights and Plugs	5,344	27.5%
Refrigerator	699	3.6%
Water Heater	4,196	21.6%
Total	19,449	

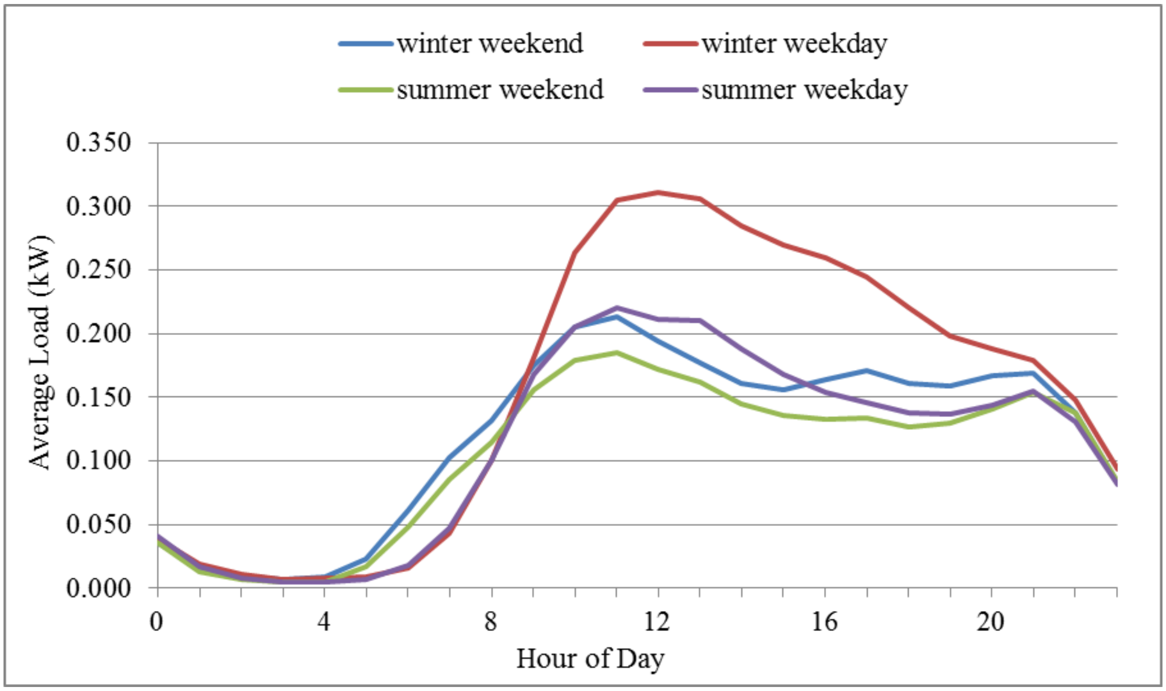

Figure 4-1: Load shape used for the clothes dryer simulation.

A model was created in MATLAB® that applies the ELCAP load shapes to the hourly wholesale energy prices for one year. For example, Table 4-2 shows the total cost of wholesale energy purchased to serve the energy needs of one household using the PJM and NYISO 2006 data and the ELCAP load shapes. It should be noted that this is the *cost* of the wholesale energy, and does not include adders, mark-ups, or additional tariffs. If a system were to be deployed, this is effectively the reduced wholesale energy cost that would be deferred for the utility or Load Serving Entity (LSE), and the reduced cost would have to be appropriately divided between the utility and the customer, depending upon what type of system is created (i.e., the utility own the control devices and communications while the consumer owns the appliances).

Table 4-2: Annual energy costs and consumption for an average household in PJM and NYISO using an average single family all electric appliance household.

	PJM 2006	NYISO 2006
Total Annual Cost ($)	$ 861.39	$ 1,457.33
Total Annual Energy (kWh)	19,449	19,449
Average Energy Rate ($/kWh)	0.0443	0.0749

To estimate the change in wholesale energy costs that may be achieved by utilizing smart appliances, TOU rates were applied to each weekday, while the 15 highest wholesale price weekdays were chosen to apply CPP. Weekends were left unaffected. It should be noted that the "rates" were not actually applied, but rather the load was shifted during those periods as if the higher rate were applied to the consumer using the load shifting patterns described in Section 3.1. It should also be noted that the highest price days represent the perfect choice for CPP application and represent results that would be seen if operators had perfect information and forecasting, and represents the best that can be done. For the purpose of this study, two-tier, 6-hour CPP and two-tier TOU rates were applied as shown in Table 4-3, with different hours chosen for winter versus summer to capture the maximum benefit of the seasonality of the wholesale energy prices.

Table 4-3: TOU and CPP rate hours used in analysis.

	High	Low
TOU - Winter	5-12	0-5 12-24
TOU - Summer	14-22	0-14 22-24
CPP - Winter	6-12	0-5 12-24
CPP - Summer	17-23	0-17 23-24

Each of the optimism levels, including the base "unresponsive" (optimism level 0), was applied to each of the markets for an entire year. Figure 4-2 shows the annual savings in dollars and the annual savings in kilowatt-hours for each market at each optimism level. For the "average customer" (considered levels 3 and 4 for the purpose of this study) this equates to a 0.6-0.9% reduction in energy consumption and a 1.4-2.6% reduction in energy costs.

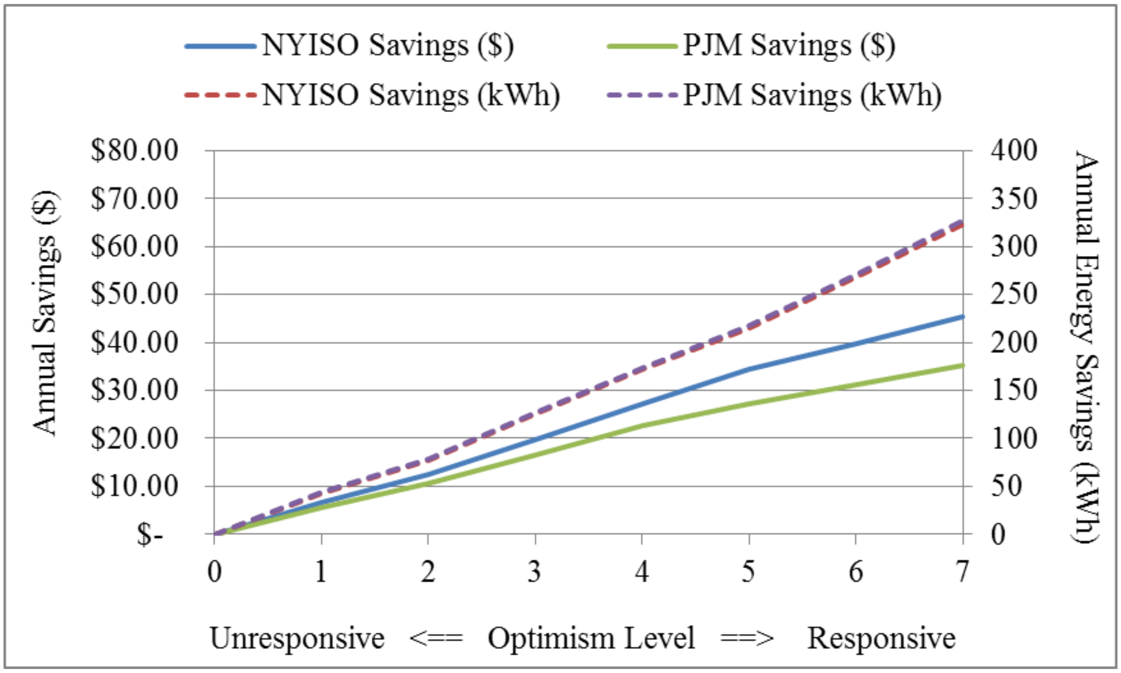

Figure 4-2: Annual cost savings for an average household ($ and kWh) when applying TOU/CPP rates.

Of course, the goal is to participate in multiple revenue streams to capture as many benefits as possible from the use of the demand response enabled appliances. After modifying the load shape behavior using TOU and CPP signals, the benefit of responding to frequency prices was studied. Appliances were assumed to respond to the 30 highest frequency regulation price days out of the year, on days other than CPP high price days. Appliances were also allowed to respond on weekends. On any day that was chosen to for frequency regulation response, appliances were able to respond up to three market periods (1 hour) within the day. It should be noted that any number of days or hours for response could be chosen (and is allowed within the analytic model), however 90 hours per year was chosen to limit the number of events to reduce appliance wear and tear and limit the number of times consumer behavior was affected. It should also be noted that it is assumed that the response of the appliances in not large enough to affect the price of the frequency regulation market. With large penetrations of DR enabled appliances, the value of such markets may decrease.

Figure 4-3 and Figure 4-4 show the result of both wholesale energy savings and additional revenue from frequency response applied to each of the markets. For the purpose of this study, additional revenue generated by participating in frequency response and spinning reserve markets will be considered a “savings”, as the net effect would be to reduce the consumer costs. Notice that the value of regulation is much lower in the PJM market. Much of this due to the fact that the overall PJM frequency response market is lower than the NYISO market, but is also due to the fact that a number of the highest price regulation days coincided with the highest price wholesale energy days. More advanced optimization and forecasting algorithms could potentially increase the value seen by utilizing multi-objective control functionality.

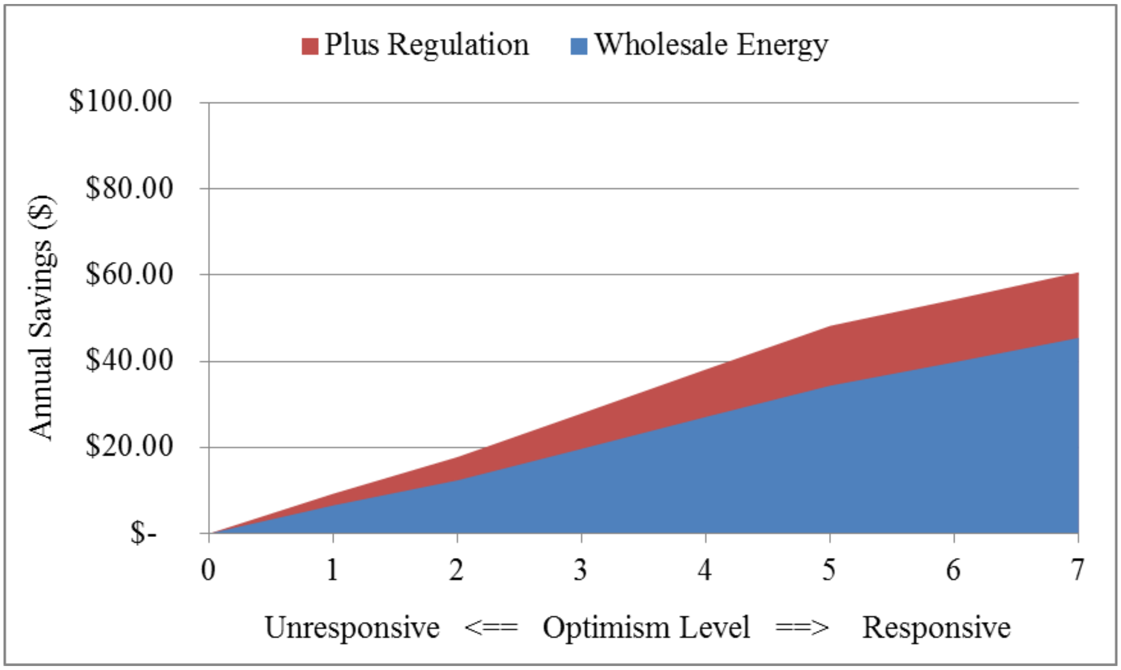

Figure 4-3: Annual cost savings ($) for an average household when applying TOU/CPP rates and frequency response in NYISO.

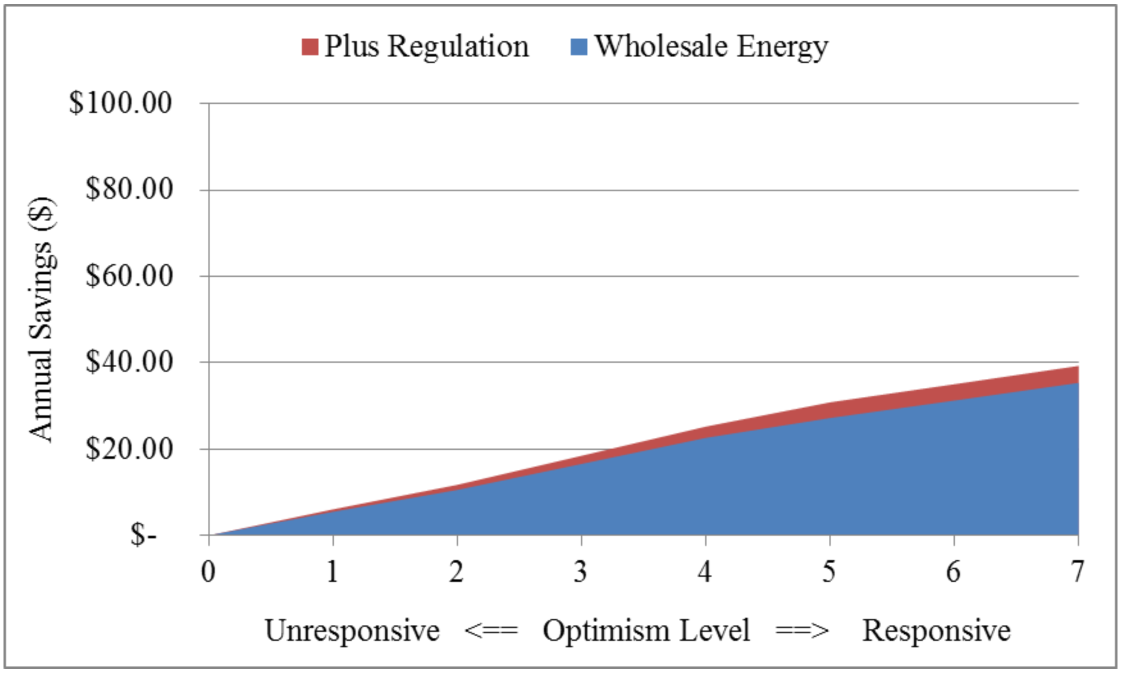

Figure 4-4: Annual cost savings ($) for an average household when applying TOU/CPP rates and frequency response in PJM.

Finally, to capture as many benefits as possible, spinning reserve markets were also applied. Appliances were assumed to respond to the 150 highest price days, excluding CPP and frequency regulation days. During those days, which included weekends, three hours per day were allowed for response. While 150 days (or 450 hours per year) seems like an excessive number of days to allow response, in a real system, the devices are not necessarily called upon to perform response during each of those periods. The devices are contracted to perform the service, but are only required to reduce load if the system requires it due to an unplanned outage or catastrophic event. Including CPP and frequency regulation hours a total of 630 DR participation hours out of 8760 in a year were assumed, or approximately 7%. Again, it is assumed that the penetration levels of the appliances are low enough that it does not affect the current market value of the spinning reserve resources.

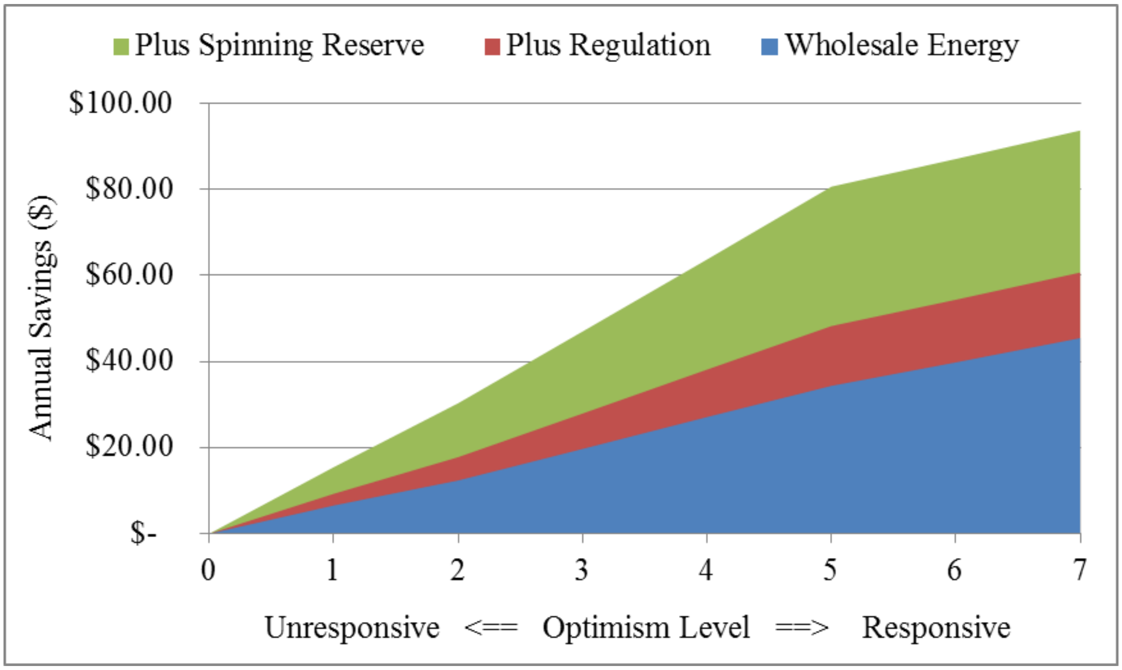

Figure 4-5: Annual cost savings ($) for an average household when applying TOU/CPP rates, frequency response, and spinning reserve in NYISO.

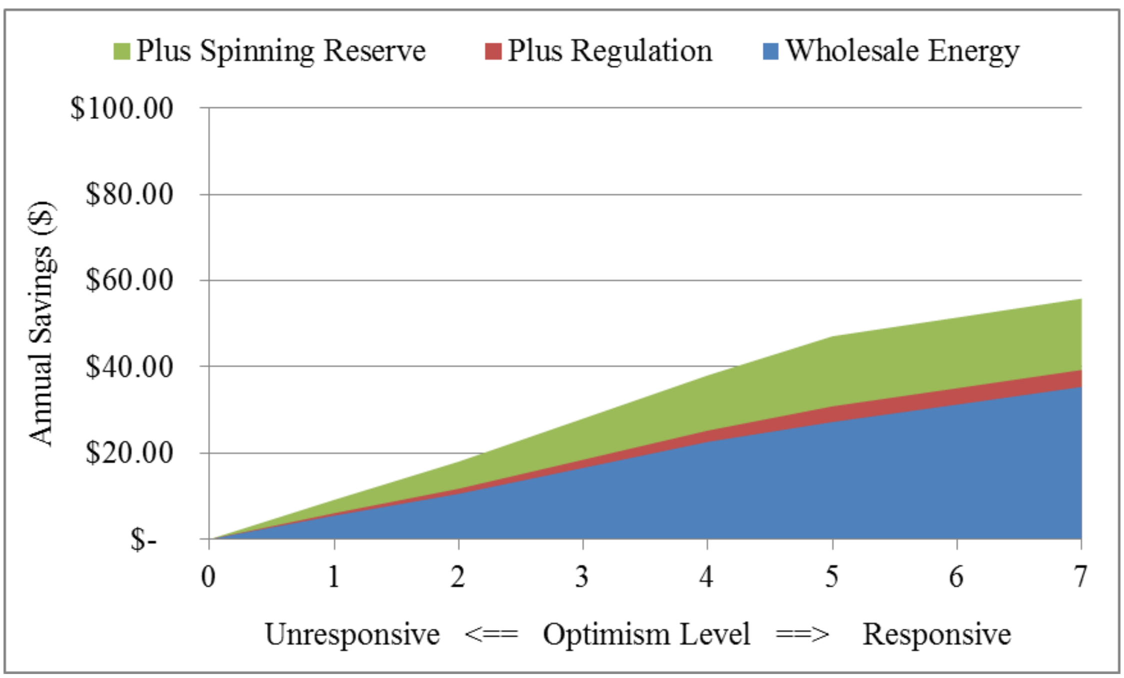

Figure 4-6: Annual cost savings ($) for an average household when applying TOU/CPP rates, frequency response, and spinning reserve in PJM.

Notice that the revenue generated in the spinning reserve and frequency regulation markets is nearly equal to the amount of savings in the wholesale energy market. In general the rate (in

$/kWh) for spinning reserve and frequency regulation markets are far less than wholesale energy. But, because of the relatively short amount of time that load is shifted in spinning reserve and frequency regulation markets it is assumed that consumers will be willing to engage in this market more often that the 15 days of CPP. Additionally, looking at the two graphics, it appears there is more value in the NYISO market; however, in terms of customer savings as a percentage of the total cost, they are far more similar. Figure 4-7 and Figure 4-8 show the same graphics in percent of total cost rather than in absolute dollars. Notice that in both markets, the maximum achievable savings is about 6.5% while the average consumer in both would see a 3-4% reduction in their overall cost.

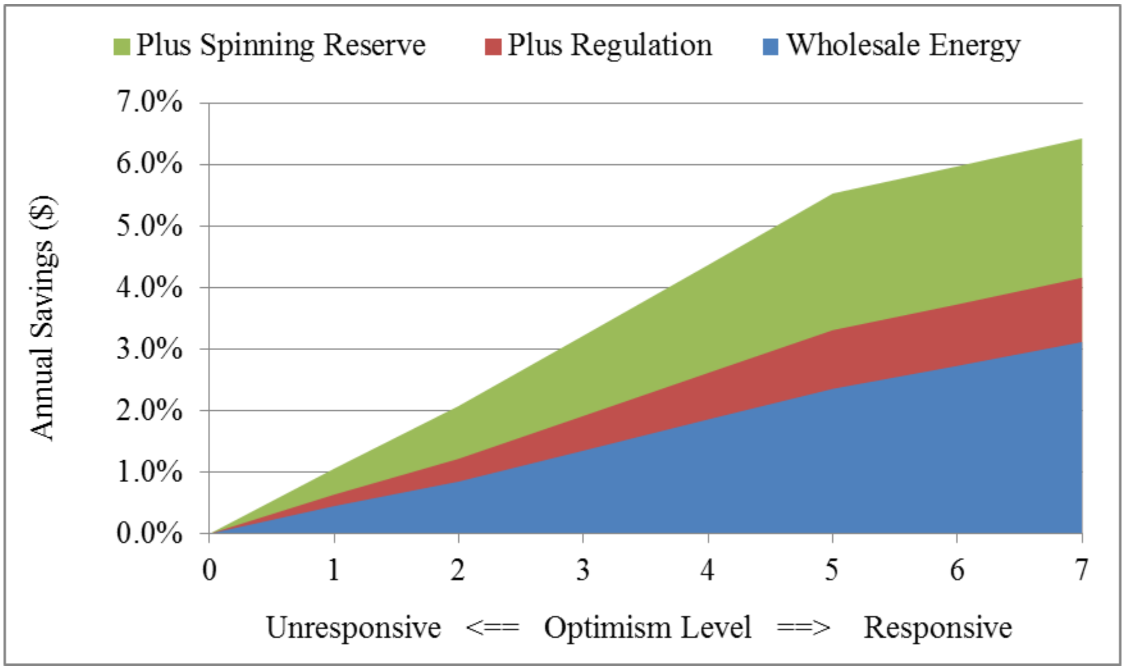

Figure 4-7: Annual cost savings (%) for an average household when applying TOU/CPP rates, frequency response, and spinning reserve in NYISO.

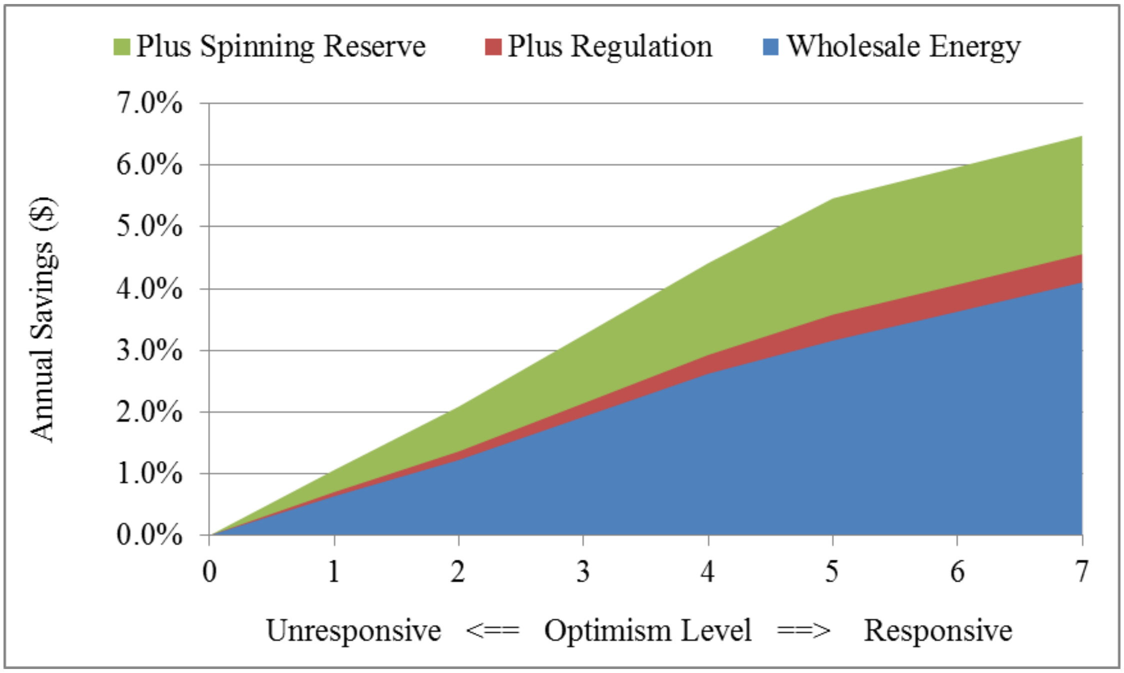

Figure 4-8: Annual cost savings (%) for an average household when applying TOU/CPP rates, frequency response, and spinning reserve in PJM.

The value streams can also be broken down by appliance to understand the effectiveness of each appliance in reducing cost. Figure 4-9 and Figure 4-10 show the savings seen by each appliance in each market. As expected, HVAC systems and water heaters provide the greatest amount of benefit. However, much of the water heater reduction is in response to devices like the clothes washer and dishwasher deferring hot water usage. Figure 4-11 and Figure 4-12 show the other appliances (clothes dryer, clothes washer, dishwasher, food preparation, freezer, and refrigerator) lumped together. Using water temperature and volume of water use by appliance from [29], these figures also assume that approximately 30% of the hot water in the home is consumed by the dishwasher and clothes washer and therefore 30% of the cost reduction comes indirectly from the other appliances by reducing the hot water demand rather than directly from the water heater. Using this assumption, it shows that the appliances provide a near equivalent level of resource as the HVAC and water heater, resulting in $13-$23 savings per year.

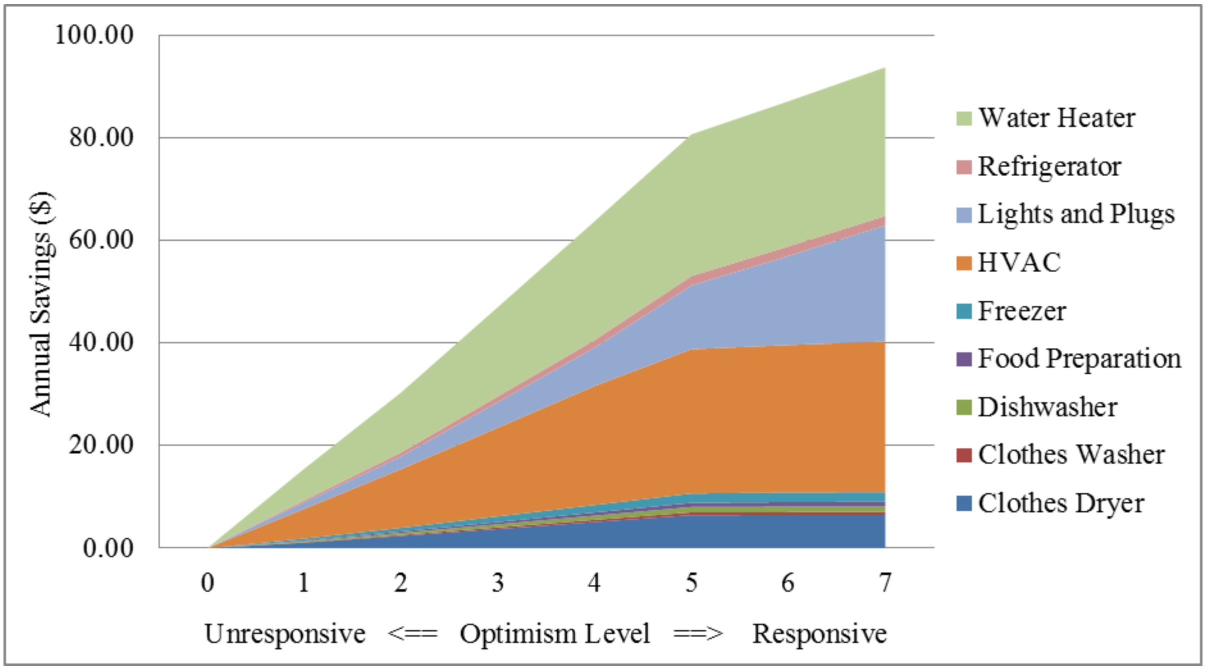

Figure 4-9: Annual cost savings ($) for an average household by appliance in NYISO.

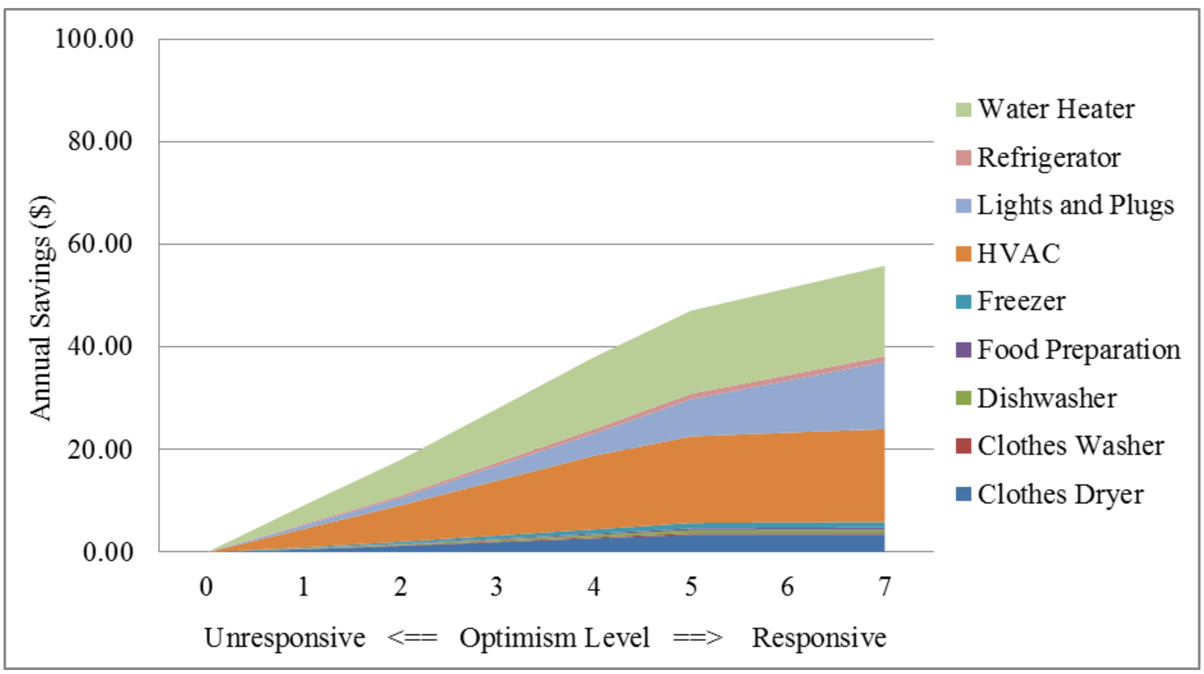

Figure 4-10: Annual cost savings ($) for an average household by appliance in PJM.

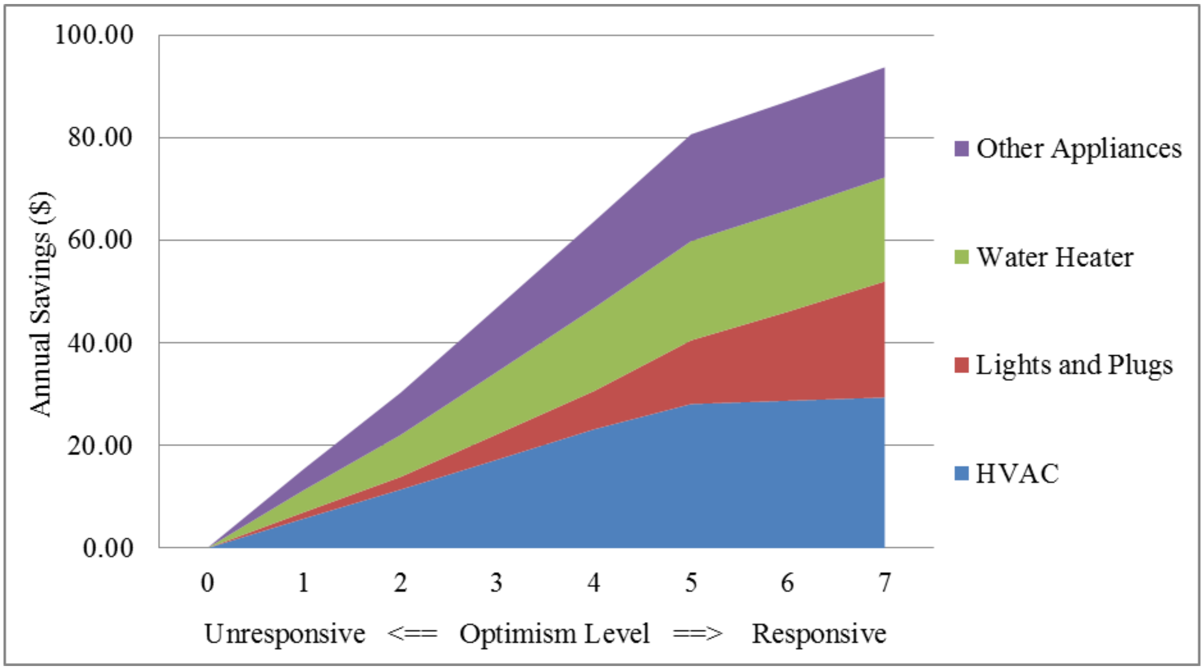

Figure 4-11: Annual cost savings ($) for an average household by appliance in NYISO assuming water heater indirect reduction.

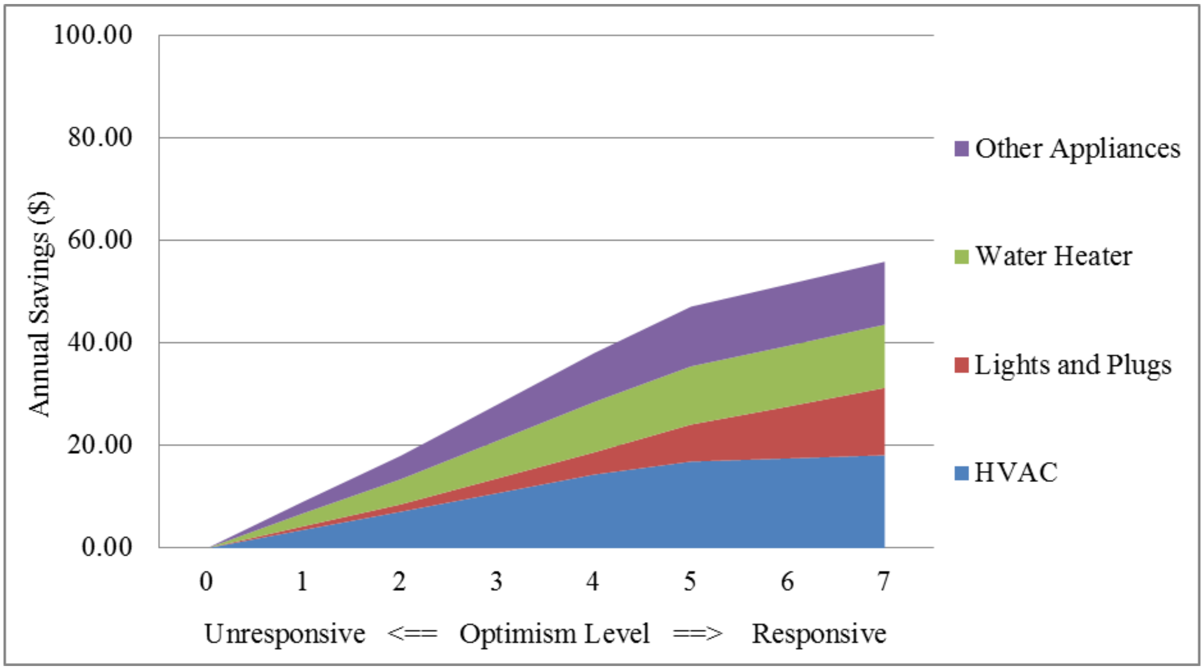

Figure 4-12: Annual cost savings ($) for an average household by appliance in PJM assuming water heater indirect reduction.

While $13-$23 per year does not appear to be a significant amount of value considering the expense of program plus the initial expense of the smart appliance, the lifetime benefits must also be considered. Standard appliances continue operation anywhere from 10-20 years, so the initial capital investment of a smart appliance is offset by not only a single year of usage, but over its lifetime. Using average appliance lifetime data [30][31], Table 4-4 and Table 4-5 show the potential reduced cost over the lifetime of the appliance, assuming 30% of the water heater benefits come from the dishwasher and clothes washer at optimism level 4, or an "average" consumer. From these tables, it is clear that devices such as HVAC, water heaters, clothes dryers, clothes washers, and dishwashers can provide significant savings over and above the increased energy efficiency that comes with new, energy efficient appliances. Refrigerators and freezers provide some additional benefits. Considering these devices respond to signals with nearly no input from the consumer in an automated fashion, this may be considered significant. Food preparation (mainly ovens and ranges), however, does not appear to provide a significant benefits.

Table 4-4: Lifetime savings for an average household by appliance in NYISO.

	Average Lifetime of Appliance (years)	Lifetime Savings ($)
Clothes Dryer	14	$ 71.50
Clothes Washer	12	$ 46.82
Dishwasher	12	$ 65.01
Food Preparation	15	$ 9.12
Freezer	16	$ 23.36
HVAC	14	$ 324.59
Lights and Plugs	-	-
Refrigerator	14	$ 20.83
Water Heater	14	$ 226.84
Total	-	$ 788.07

[1]Value estimated from range ovens; microwave lifetimes tend to be shorter.
[2]Lights and plug lifetimes were not estimated, as these are composed of a number of small devices.

Table 4-5: Lifetime savings for an average household by appliance in PJM.

	Average Lifetime of Appliance (years)	Lifetime Savings ($)
Clothes Dryer	14	$ 37.62
Clothes Washer	12	$ 27.88
Dishwasher	12	$ 39.61
Food Preparation	15	$ 3.72
Freezer	16	$ 13.08
HVAC	14	$ 201.07
Lights and Plugs	-	-
Refrigerator	14	$ 12.12
Water Heater	14	$ 137.31
Total	-	$ 472.41

[1]Value estimated from range ovens; microwave lifetimes tend to be shorter.
[2]Lights and plug lifetimes were not estimated, as these are composed of a number of small devices.

5 Conclusions and Future Work

In this report, a series of analytical methods were presented to estimate the potential cost benefit of smart appliances while utilizing demand response. The effects on wholesale energy cost and possible additional revenue available by participating in frequency regulation and spinning reserve markets were explored. Specifically, historical market data from NYISO and PJM in 2006 was used to estimate the savings available to consumers and/or utilities by engaging demand response capabilities in HVAC systems, water heaters, clothes dryers and washers, dishwashers, refrigerators, freezers, miscellaneous light and plug loads, and cooktop range and ovens. Historical load shapes for each of the appliances and estimates for potential load shifting behavior were used to estimate the potential monetary benefits in a wholesale energy market, a frequency response market, and a spinning reserve market. These were then equated to annual and lifetime savings generated by each appliance in each energy market.

While this report should not be considered comprehensive, it does give some valuable insights into the potential use of smart appliances for demand response. A few key conclusions can be drawn from this study:

1) A significant fraction (over 50%) of the total monetary benefits available to smart appliances are in the form of spinning reserve and frequency regulation markets, providing as much additional revenue in spinning reserve and frequency regulation markets as savings in wholesale energy markets. It was not determined how this revenue should be distributed between the utility and the consumer, but is left for individual deployments.
2) In addition to traditional demand response appliances (HVACs and water heaters), clothes dryers, clothes washers and dishwashers provide a significant amount of savings when accounting for the indirect effects on the water heater load. In areas where gas water heaters are prevalent, clothes washers and dishwashers participating in demand response do not provide significant savings or revenue in electricity markets.
3) Refrigerators and freezers are capable of providing some monetary benefits, but less so than the previous appliances. However, since these devices are nearly 100% automated with little to no effect on the consumer experience, this may increase their intrinsic value to demand response programs.
4) Food preparation devices (cooktops and ovens) do not provide significant monetary benefits.

This study did not focus on the mechanism by which smart appliances engage in spinning reserve or frequency regulation services or how the utility and consumer might split the cost and benefits associated with such a program. Further work is needed to understand how these devices might engage in these markets, the reliability of such participation, and what the capital and continuing costs of such engagement might be.

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Appendix A: Appliance Response Assumptions

Clothes Dryer

Table A-1: Clothes dryer response assumptions for CPP.

Optimism Level	*Percentage of Customers Allowing*	*Percentage of Available Load*	*Percentage of Load Shifted*
0	0%	0%	0%
1	15%	45%	90%
2	35%	45%	90%
3	55%	45%	90%
4	75%	45%	90%
5	95%	45%	90%
6	100%	45%	90%
7	100%	45%	90%

Table A-2: Clothes dryer response assumptions for TOU.

Optimism Level	*Percentage of Customers Allowing*	*Percentage of Available Load*	*Percentage of Load Shifted*
0	0%	0%	0%
1	15%	20%	90%
2	35%	20%	90%
3	55%	20%	90%
4	75%	20%	90%
5	95%	20%	90%
6	95%	20%	90%
7	95%	20%	90%

Table A-3: Clothes dryer response assumptions for frequency regulation.

Optimism Level	*Percentage of Customers Allowing*	*Percentage of Available Load*	*Percentage of Load Shifted*
0	0%	0%	0%
1	15%	80%	97%
2	35%	80%	97%
3	55%	80%	97%
4	75%	80%	97%
5	95%	80%	97%
6	95%	80%	97%
7	95%	80%	97%

Table A-4: Clothes dryer response assumptions for spinning reserve.

Optimism Level	*Percentage of Customers Allowing*	*Percentage of Available Load*	*Percentage of Load Shifted*
0	0%	0%	0%
1	15%	80%	95%
2	35%	80%	95%
3	55%	80%	95%
4	75%	80%	95%
5	95%	80%	95%
6	95%	80%	95%
7	95%	80%	95%

Clothes Washer

Table A-5: Clothes washer response assumptions for CPP.

Optimism Level	*Percentage of Customers Allowing*	*Percentage of Available Load*	*Percentage of Load Shifted*
0	0%	0%	0%
1	15%	70%	100%
2	35%	70%	100%
3	55%	70%	100%
4	75%	70%	100%
5	95%	70%	100%
6	100%	70%	100%
7	100%	70%	100%

Table A-6: Clothes washer response assumptions for TOU.

Optimism Level	*Percentage of Customers Allowing*	*Percentage of Available Load*	*Percentage of Load Shifted*
0	0%	0%	0%
1	15%	20%	100%
2	35%	20%	100%
3	55%	20%	100%
4	75%	20%	100%
5	95%	20%	100%
6	95%	20%	100%
7	95%	20%	100%

Table A-7: Clothes washer response assumptions for frequency regulation.

Optimism Level	*Percentage of Customers Allowing*	*Percentage of Available Load*	*Percentage of Load Shifted*
0	0%	0%	0%
1	15%	70%	100%
2	35%	70%	100%
3	55%	70%	100%
4	75%	70%	100%
5	95%	70%	100%
6	95%	70%	100%
7	95%	70%	100%

Table A-8: Clothes washer response assumptions for spinning reserve.

Optimism Level	*Percentage of Customers Allowing*	*Percentage of Available Load*	*Percentage of Load Shifted*
0	0%	0%	0%
1	15%	70%	100%
2	35%	70%	100%
3	55%	70%	100%
4	75%	70%	100%
5	95%	70%	100%
6	95%	70%	100%
7	95%	70%	100%

Dishwasher

Table A-9: Dishwasher response assumptions for CPP.

Optimism Level	*Percentage of Customers Allowing*	*Percentage of Available Load*	*Percentage of Load Shifted*
0	0%	0%	0%
1	20%	82%	100%
2	40%	82%	100%
3	60%	82%	100%
4	80%	82%	100%
5	100%	82%	100%
6	100%	82%	100%
7	100%	82%	100%

Table A-10: Dishwasher response assumptions for TOU.

Optimism Level	*Percentage of Customers Allowing*	*Percentage of Available Load*	*Percentage of Load Shifted*
0	0%	0%	0%
1	10%	82%	100%
2	20%	82%	100%
3	40%	82%	100%
4	60%	82%	100%
5	80%	82%	100%
6	90%	82%	100%
7	90%	82%	100%

Table A-11: Dishwasher response assumptions for frequency regulation.

Optimism Level	*Percentage of Customers Allowing*	*Percentage of Available Load*	*Percentage of Load Shifted*
0	0%	0%	0%
1	20%	50%	100%
2	40%	50%	100%
3	60%	50%	100%
4	80%	50%	100%
5	100%	50%	100%
6	100%	50%	100%
7	100%	50%	100%

Table A-12: Dishwasher response assumptions for spinning reserve.

Optimism Level	*Percentage of Customers Allowing*	*Percentage of Available Load*	*Percentage of Load Shifted*
0	0%	0%	0%
1	20%	50%	100%
2	40%	50%	100%
3	60%	50%	100%
4	80%	50%	100%
5	100%	50%	100%
6	100%	50%	100%
7	100%	50%	100%

Food Preparation

Table A-13: Food Preparation response assumptions for CPP.

Optimism Level	*Percentage of Customers Allowing*	*Percentage of Available Load*	*Percentage of Load Shifted*
0	0%	0%	0%
1	15%	20%	80%
2	30%	20%	80%
3	50%	20%	80%
4	70%	20%	80%
5	90%	20%	80%
6	100%	20%	80%
7	100%	20%	80%

Table A-14: Food Preparation response assumptions for TOU.

Optimism Level	*Percentage of Customers Allowing*	*Percentage of Available Load*	*Percentage of Load Shifted*
0	0%	0%	0%
1	5%	10%	90%
2	10%	10%	90%
3	20%	10%	90%
4	30%	10%	90%
5	50%	10%	90%
6	70%	10%	90%
7	90%	10%	90%

Table A-15: Food Preparation response assumptions for frequency regulation.

Optimism Level	*Percentage of Customers Allowing*	*Percentage of Available Load*	*Percentage of Load Shifted*
0	0%	0%	0%
1	20%	80%	100%
2	40%	80%	100%
3	60%	80%	100%
4	80%	80%	100%
5	100%	80%	100%
6	100%	80%	100%
7	100%	80%	100%

Table A-16: Food Preparation response assumptions for spinning reserve.

Optimism Level	*Percentage of Customers Allowing*	*Percentage of Available Load*	*Percentage of Load Shifted*
0	0%	0%	0%
1	20%	10%	100%
2	40%	10%	100%
3	60%	10%	100%
4	80%	10%	100%
5	100%	10%	100%
6	100%	10%	100%
7	100%	10%	100%

Freezer

Table A-17: Freezer response assumptions for CPP.

Optimism Level	*Percentage of Customers Allowing*	*Percentage of Available Load*	*Percentage of Load Shifted*
0	0%	0%	0%
1	20%	30%	100%
2	40%	30%	100%
3	60%	30%	100%
4	80%	30%	100%
5	100%	30%	100%
6	100%	30%	100%
7	100%	30%	100%

Table A-18: Freezer response assumptions for TOU.

Optimism Level	*Percentage of Customers Allowing*	*Percentage of Available Load*	*Percentage of Load Shifted*
0	0%	0%	0%
1	10%	15%	100%
2	20%	15%	100%
3	40%	15%	100%
4	60%	15%	100%
5	80%	15%	100%
6	90%	15%	100%
7	90%	15%	100%

Table A-19: Freezer response assumptions for frequency regulation.

Optimism Level	*Percentage of Customers Allowing*	*Percentage of Available Load*	*Percentage of Load Shifted*
0	0%	0%	0%
1	20%	30%	100%
2	40%	30%	100%
3	60%	30%	100%
4	80%	30%	100%
5	100%	30%	100%
6	100%	30%	100%
7	100%	30%	100%

Table A-20: Freezer response assumptions for spinning reserve.

Optimism Level	*Percentage of Customers Allowing*	*Percentage of Available Load*	*Percentage of Load Shifted*
0	0%	0%	0%
1	20%	40%	100%
2	40%	40%	100%
3	60%	40%	100%
4	80%	40%	100%
5	100%	40%	100%
6	100%	40%	100%
7	100%	40%	100%

Heating Ventilation and Air Conditioning

Table A-21: HVAC response assumptions for CPP.

Optimism Level	*Percentage of Customers Allowing*	*Percentage of Available Load*	*Percentage of Load Shifted*
0	0%	0%	0%
1	15%	40%	80%
2	30%	40%	80%
3	50%	40%	80%
4	70%	40%	80%
5	80%	40%	80%
6	90%	40%	80%
7	100%	40%	80%

Table A-22: HVAC response assumptions for TOU.

Optimism Level	*Percentage of Customers Allowing*	*Percentage of Available Load*	*Percentage of Load Shifted*
0	0%	0%	0%
1	20%	20%	80%
2	40%	20%	80%
3	60%	20%	80%
4	80%	20%	80%
5	80%	20%	80%
6	90%	20%	80%
7	100%	20%	80%

Table A-23: HVAC response assumptions for frequency regulation.

Optimism Level	*Percentage of Customers Allowing*	*Percentage of Available Load*	*Percentage of Load Shifted*
0	0%	0%	0%
1	20%	50%	100%
2	40%	50%	100%
3	60%	50%	100%
4	80%	50%	100%
5	100%	50%	100%
6	100%	50%	100%
7	100%	50%	100%

Table A-24: HVAC response assumptions for spinning reserve.

Optimism Level	*Percentage of Customers Allowing*	*Percentage of Available Load*	*Percentage of Load Shifted*
0	0%	0%	0%
1	20%	60%	100%
2	40%	60%	100%
3	60%	60%	100%
4	80%	60%	100%
5	100%	60%	100%
6	100%	60%	100%
7	100%	60%	100%

Lights and Plugs

Table A-25: Lights and Plugs response assumptions for CPP.

Optimism Level	*Percentage of Customers Allowing*	*Percentage of Available Load*	*Percentage of Load Shifted*
0	0%	0%	0%
1	5%	25%	0%
2	10%	25%	0%
3	20%	25%	0%
4	30%	25%	0%
5	50%	25%	0%
6	70%	25%	0%
7	100%	25%	0%

Table A-26: Lights and Plugs response assumptions for TOU.

Optimism Level	*Percentage of Customers Allowing*	*Percentage of Available Load*	*Percentage of Load Shifted*
0	0%	0%	0%
1	5%	15%	0%
2	10%	15%	0%
3	20%	15%	0%
4	30%	15%	0%
5	50%	15%	0%
6	70%	15%	0%
7	90%	15%	0%

Table A-27: Lights and Plugs response assumptions for frequency regulation.

Optimism Level	*Percentage of Customers Allowing*	*Percentage of Available Load*	*Percentage of Load Shifted*
0	0%	0%	0%
1	5%	5%	0%
2	10%	5%	0%
3	20%	5%	0%
4	30%	5%	0%
5	50%	5%	0%
6	70%	5%	0%
7	90%	5%	0%

Table A-28: Lights and Plugs response assumptions for spinning reserve.

Optimism Level	*Percentage of Customers Allowing*	*Percentage of Available Load*	*Percentage of Load Shifted*
0	0%	0%	0%
1	5%	5%	0%
2	10%	5%	0%
3	20%	5%	0%
4	30%	5%	0%
5	50%	5%	0%
6	70%	5%	0%
7	90%	5%	0%

Refrigerator

Table A-29: Refrigerator response assumptions for CPP.

Optimism Level	*Percentage of Customers Allowing*	*Percentage of Available Load*	*Percentage of Load Shifted*
0	0%	0%	0%
1	20%	30%	100%
2	40%	30%	100%
3	60%	30%	100%
4	80%	30%	100%
5	100%	30%	100%
6	100%	30%	100%
7	100%	30%	100%

Table A-30: Refrigerator response assumptions for TOU.

Optimism Level	*Percentage of Customers Allowing*	*Percentage of Available Load*	*Percentage of Load Shifted*
0	0%	0%	0%
1	20%	15%	100%
2	40%	15%	100%
3	60%	15%	100%
4	80%	15%	100%
5	100%	15%	100%
6	100%	15%	100%
7	100%	15%	100%

Table A-31: Refrigerator response assumptions for frequency regulation.

Optimism Level	*Percentage of Customers Allowing*	*Percentage of Available Load*	*Percentage of Load Shifted*
0	0%	0%	0%
1	20%	30%	100%
2	40%	30%	100%
3	60%	30%	100%
4	80%	30%	100%
5	100%	30%	100%
6	100%	30%	100%
7	100%	30%	100%

Table A-32: Refrigerator response assumptions for spinning reserve.

Optimism Level	*Percentage of Customers Allowing*	*Percentage of Available Load*	*Percentage of Load Shifted*
0	0%	0%	0%
1	20%	40%	100%
2	40%	40%	100%
3	60%	40%	100%
4	80%	40%	100%
5	100%	40%	100%
6	100%	40%	100%
7	100%	40%	100%

Water Heater

Table A-33: Water Heater response assumptions for CPP.

Optimism Level	*Percentage of Customers Allowing*	*Percentage of Available Load*	*Percentage of Load Shifted*
0	0%	0%	0%
1	20%	70%	90%
2	40%	70%	90%
3	60%	70%	90%
4	80%	70%	90%
5	100%	70%	90%
6	100%	70%	90%
7	100%	70%	90%

Table A-34: Water Heater response assumptions for TOU.

Optimism Level	*Percentage of Customers Allowing*	*Percentage of Available Load*	*Percentage of Load Shifted*
0	0%	0%	0%
1	20%	40%	90%
2	40%	40%	90%
3	60%	40%	90%
4	80%	40%	90%
5	80%	40%	90%
6	90%	40%	90%
7	100%	40%	90%

Table A-35: Water Heater response assumptions for frequency regulation.

Optimism Level	*Percentage of Customers Allowing*	*Percentage of Available Load*	*Percentage of Load Shifted*
0	0%	0%	0%
1	20%	90%	100%
2	40%	90%	100%
3	60%	90%	100%
4	80%	90%	100%
5	100%	90%	100%
6	100%	90%	100%
7	100%	90%	100%

Table A-36: Water Heater response assumptions for spinning reserve.

Optimism Level	*Percentage of Customers Allowing*	*Percentage of Available Load*	*Percentage of Load Shifted*
0	0%	0%	0%
1	20%	40%	90%
2	40%	40%	90%
3	60%	40%	90%
4	80%	40%	90%
5	80%	40%	90%
6	90%	40%	90%
7	100%	40%	90%

Appendix B: ELCAP Load Shapes

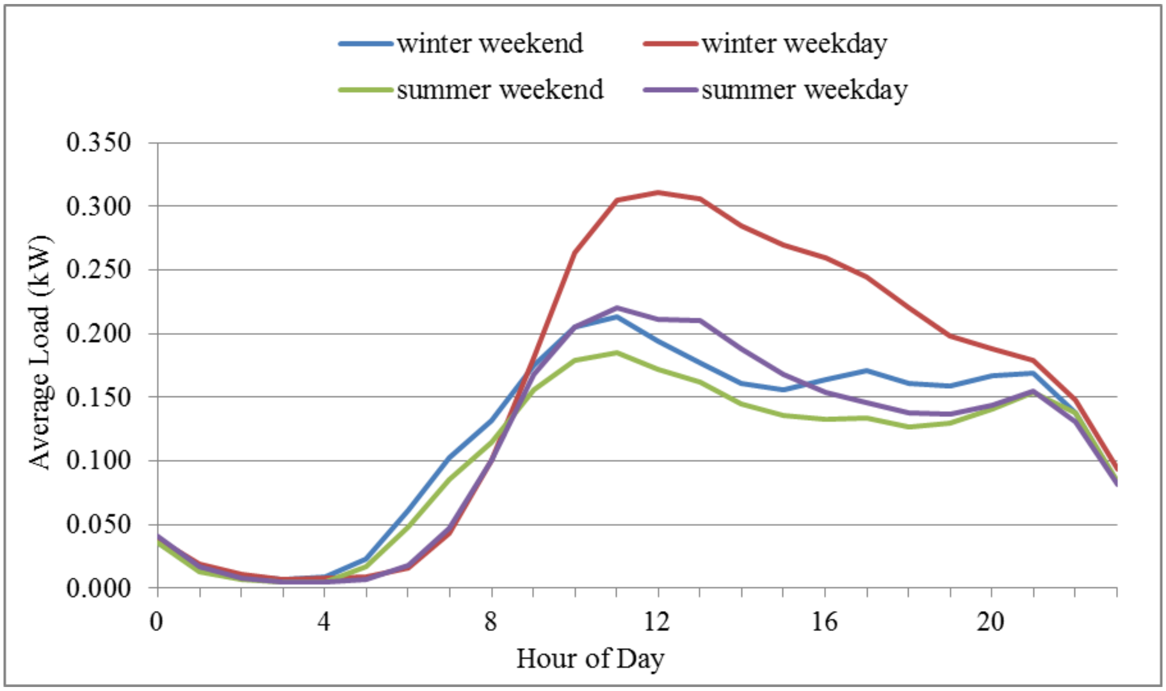

Figure B-1: ELCAP load shapes for clothes dryers.

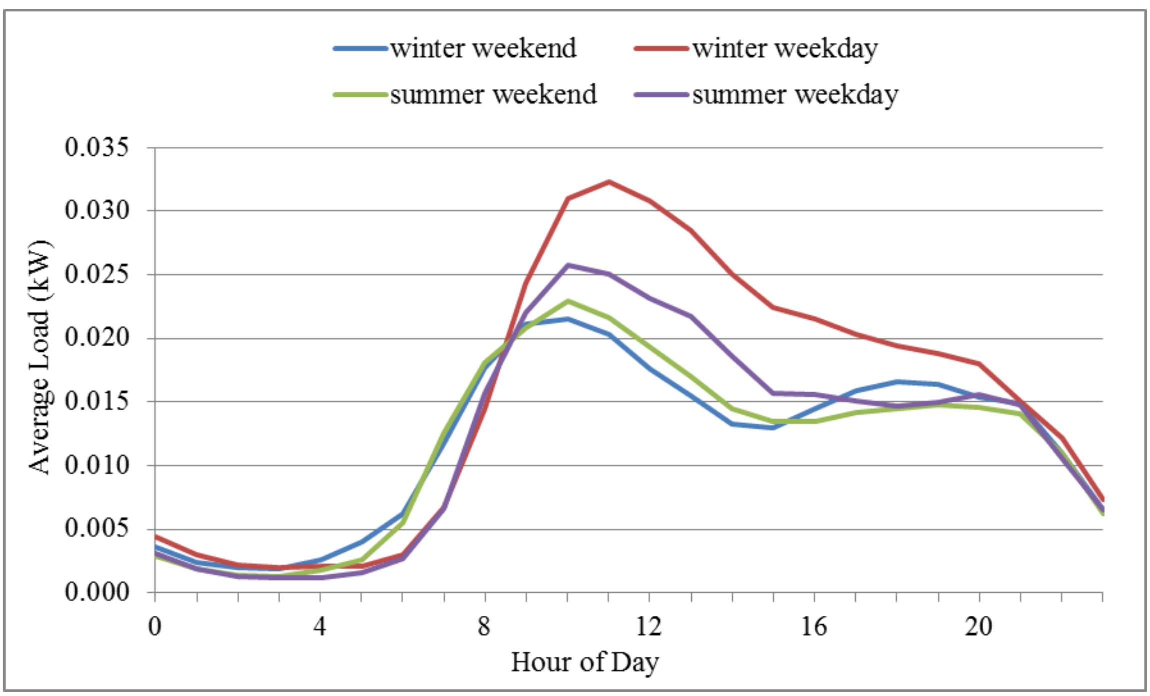

Figure B-2: ELCAP load shapes for clothes washers.

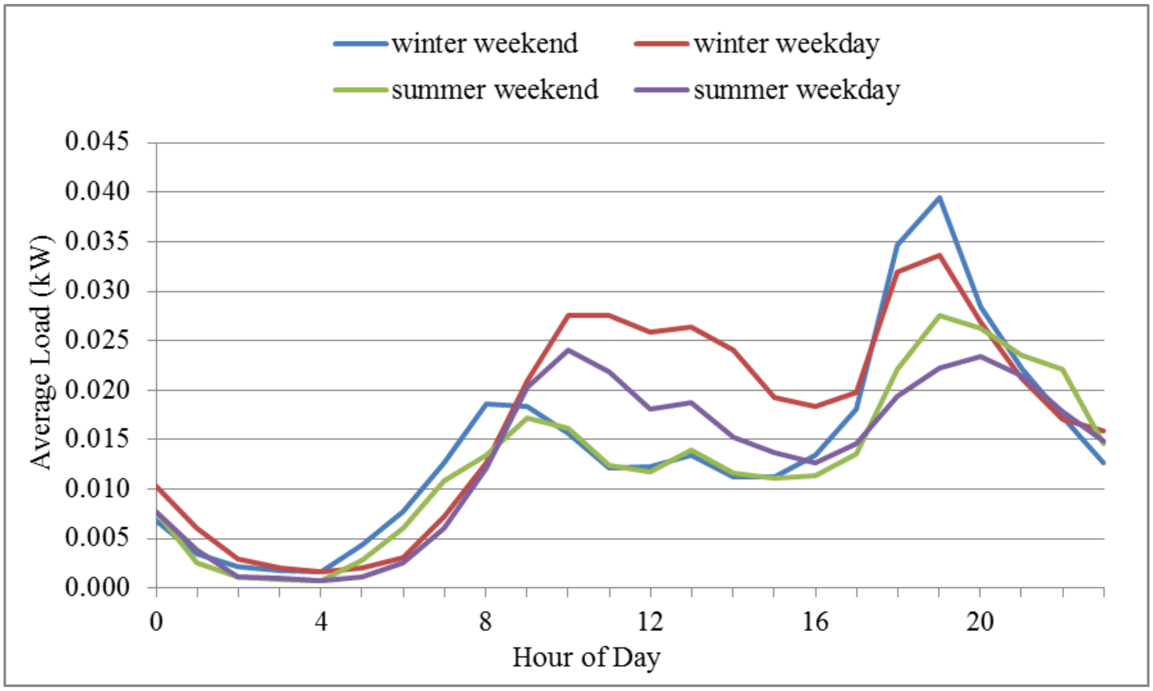

Figure B-3: ELCAP load shapes for dishwashers.

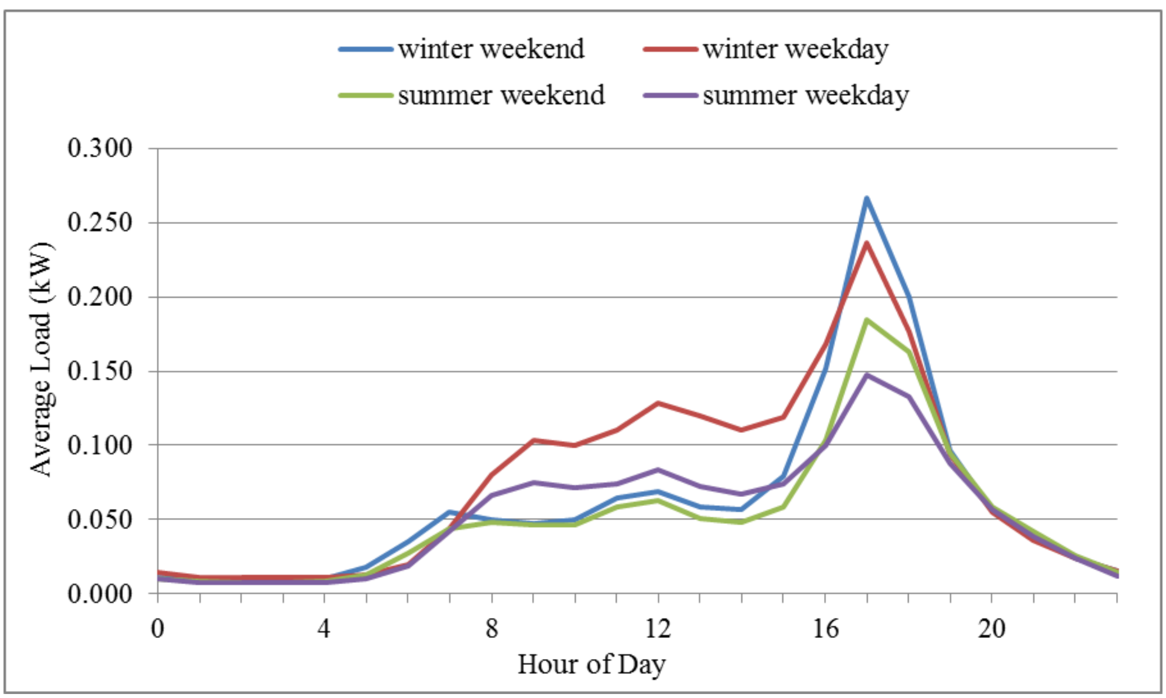

Figure B-4: ELCAP load shapes for food preparation.

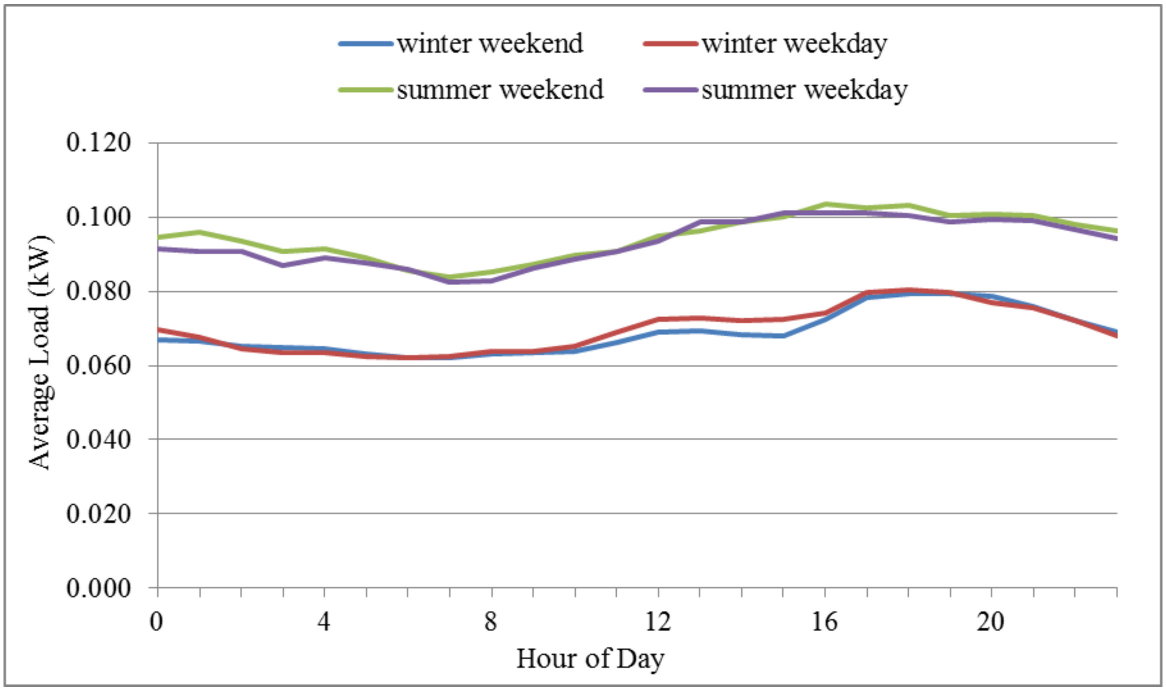

Figure B-5: ELCAP load shapes for freezers.

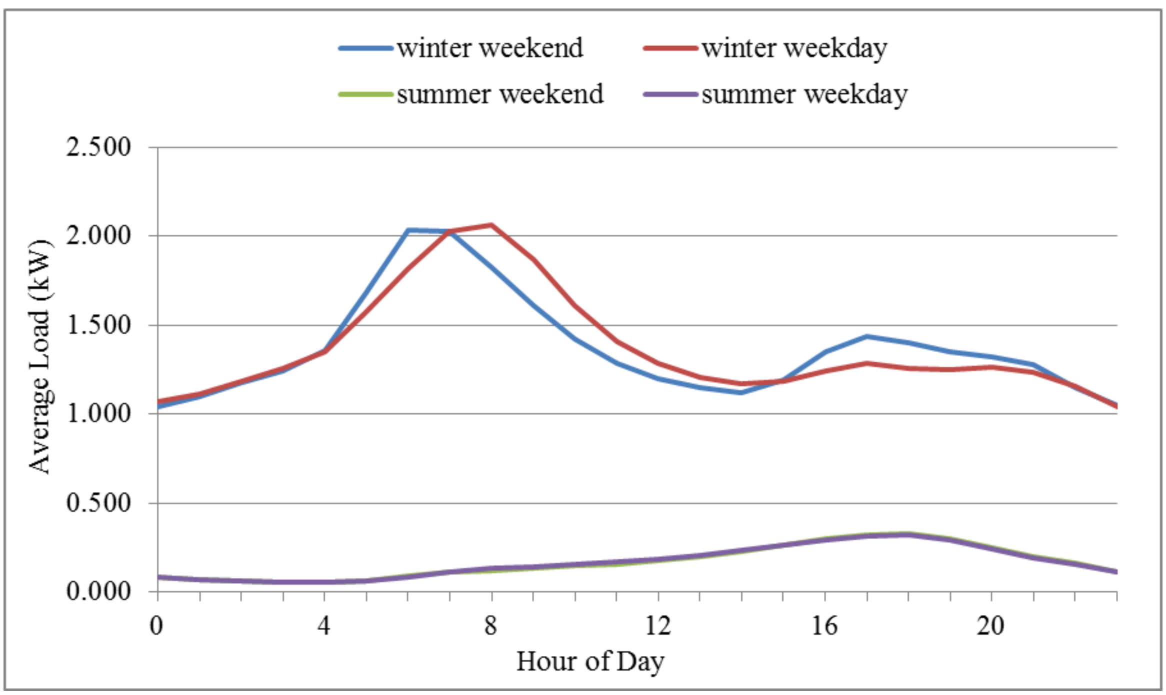

Figure B-6: ELCAP load shapes for HVACs.

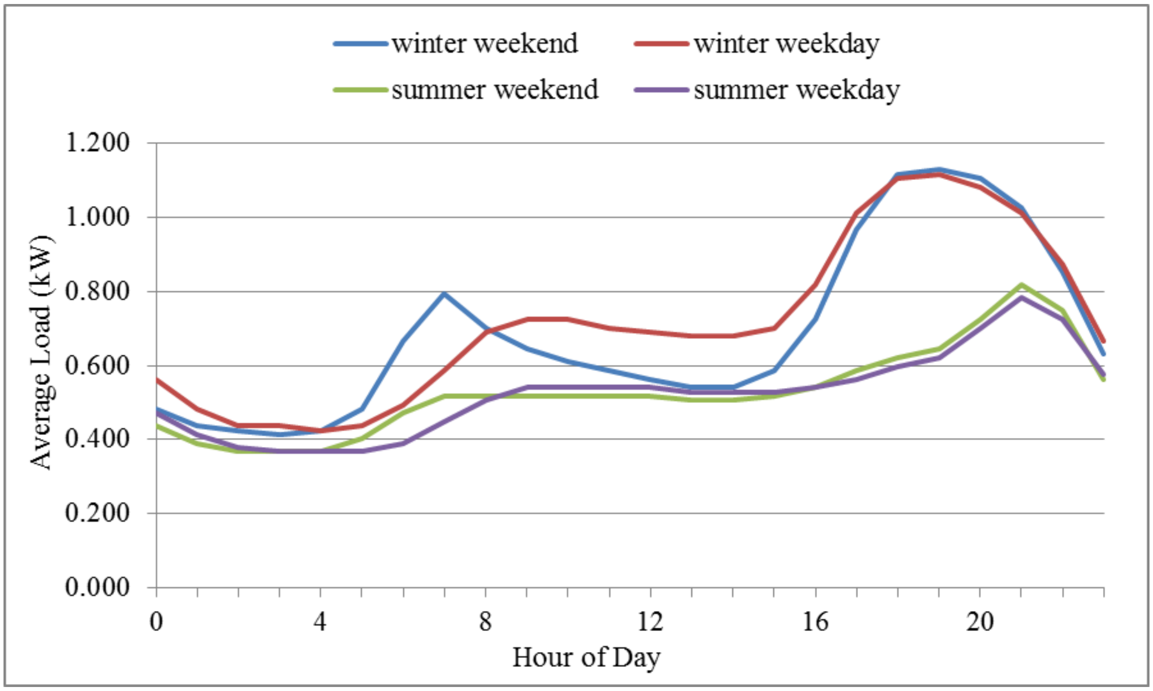

Figure B-7: ELCAP load shapes for lights and other miscellaneous devices.

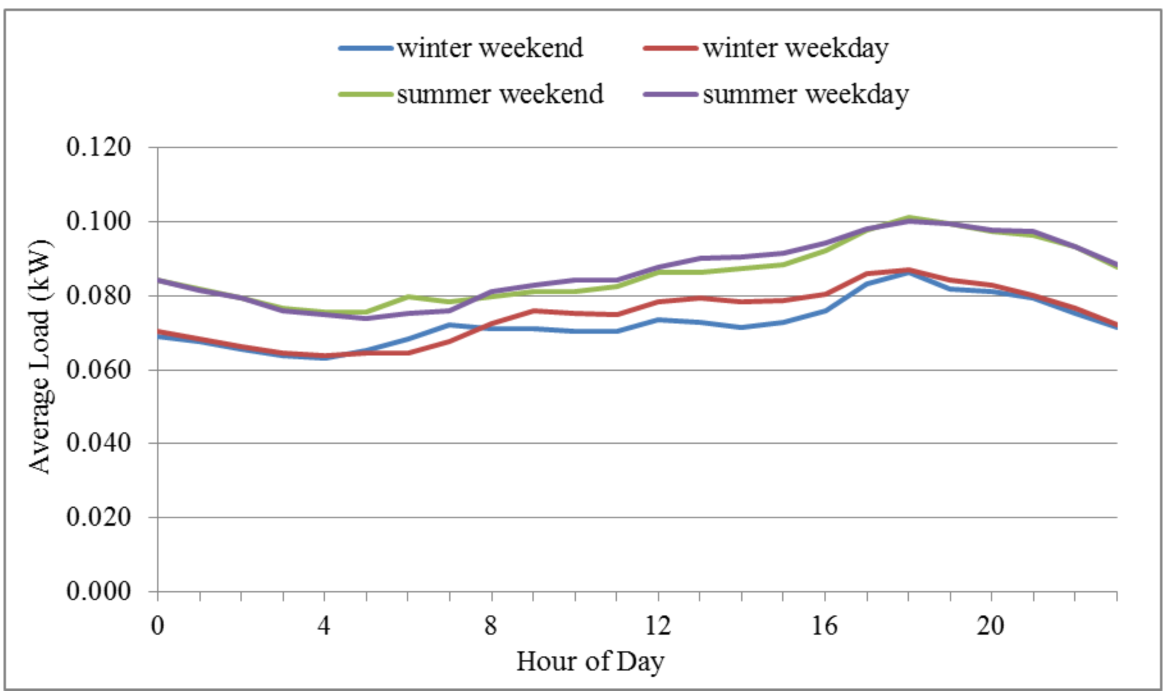

Figure B-8: ELCAP load shapes for refrigerators.

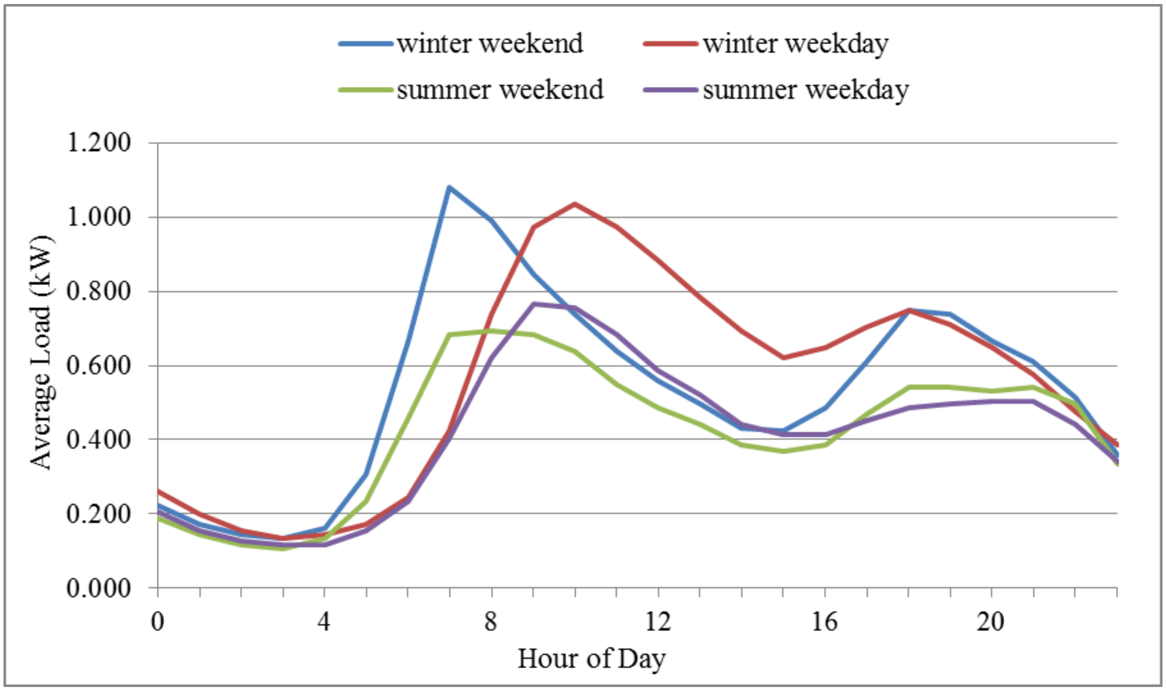

Figure B-9: ELCAP load shapes for water heaters.

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