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"DRAMATIC DEMAND REDUCTION IN THE DESERT SOUTHWEST"

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University of Nevada, Las Vegas
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FINAL REPORT

Prepared for:

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NOTICE

Executive Summary

This report summarizes a project that was funded to the University of Nevada Las Vegas (UNLV), with subcontractors Pulte Homes and NV Energy. The project was motivated by the fact that locations in the Desert Southwest portion of the US demonstrate very high peak electrical demands, typically in the late afternoons in the summer. These high demands often require high priced power to supply the needs, and the large loads can cause grid supply problems. An approach was proposed through this contact that would reduce the peak electrical demands to an anticipated 65% of what code-built houses of the similar size would have.

It was proposed to achieve energy reduction through four approaches applied to a development of 185 homes in northwest part of Las Vegas named Villa Trieste. First, the homes would all be highly energy efficient. Secondly, each house would have a PV array installed on it. Third, an advanced demand response technique would be developed to allow the resident to have some control over the energy used. Finally, some type of battery storage would be used in the project.

Pulte Homes designed the houses. The company considered initial cost vs. long-term savings and chose options that had relatively short paybacks. HERS (Home Energy Rating Service) ratings for the homes are approximately 43 on this scale. On this scale, code-built homes rate at 100, zero energy homes rate a 0, and Energy Star homes are 85.

In addition a 1.764 Wp (peak Watt) rated PV array was used on each house. This was made up of solar shakes that were in visual harmony with the roofing material used.

A demand response tool was developed to control the amount of electricity used during times of peak demand. While demand response techniques have been used in the utility industry for some time, this particular approach is designed to allow the customer to decide the degree of participation in the response activity. The temperature change in the residence can be decided by the residents by adjusting settings. In a sense the customer can choose between greater comfort and greater money savings during demand response circumstances.

Finally a battery application was to be considered. Initially it was thought that a large battery (probably a sodium-sulfur type) would be installed. However, after the contract was awarded, it was determined that a single, centrally-located battery system would not be appropriate for many reasons, including that with the build out plan there would not be any location to put it. The price had risen substantially since the budget for the project was put together. Also, that type of battery has to be kept hot all the time, but its use was only

sought for summer operation. Hence, individual house batteries would be used, and these are discussed at the end of this report.

Many aspects of the energy use for climate control in selected houses were monitored before residents moved in. This was done both to understand the magnitude of the energy flows but also to have data that could be compared to the computer simulations. The latter would be used to evaluate various aspects of our plan. It was found that good agreement existed between actual energy use and computed energy use. Hence, various studies were performed via simulations.

Performance simulations showed the impact on peak energy usage between a code built house of same size and shape compared to the Villa Trieste homes with and without the PV arrays on the latter. Computations were also used to understand the effect of varying orientations of the houses in this typical housing development, including the effect of PV electrical generation.

Energy conservation features of the Villa Trieste homes decreased the energy use during peak times (as well as all others), but the resulting decreased peak occurred at about the same time as the code-built houses. Consideration of the PV generation decreases the grid energy use further during daylight hours, but did not extend long enough many days to decrease the peak. Hence, a demand response approach, as planned, was needed.

With participation of the residents in the demand response program developed does enable the houses to reduce the peak demand between 66% and 72%, depending on the built years. This was addressed fully in the latter part the study and is described in the latter part of this report.

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List of Acronyms

Acronym	Definition of the Acronym
ACH	Air Changes per Hour
ADR	Autonomous Demand Response
APR	Annual Percentage Rate
BECP	Building Energy Codes Program
BSP	Battery Storage Project
CER	Center for Energy Research (UNLV)
CFL	Compact Fluorescent Light
CT	Current Transformer
DHI	Diffuse Horizontal Irradiance
DNI	Direct Normal Irradiance
DOE	United States Department of Energy
DR	Demand Response
DRMS	Demand Response Management System
DSM	Demand Side Management
EA	Energy and Atmosphere (One of the LEED consideration categories)
EE	Energy Efficient
EIA	US Energy Information Administration
EPA	US Environmental Protection Agency
EPS	Expanded Polystyrene
FOA	Financial Opportunity Announcement (Public notice of research funds available from the US government)
GHI	Global Horizontal Irradiance

HERS	Home Energy Rating Service
HVAC	Heating, Ventilating and Air Conditioning
IA	Intelligent Agent
IBC	International Building Code
IEQ	Indoor Environmental Quality
IECC	International Energy Conversion Code
kW	Kilowatt
kWp	Kilowatt at Peak Output
LEED	Leadership in Energy and Environmental Design
MEC	Model Electrical Code
MERV	Minimum Efficiency Reporting Value
MPG	Miles Per Gallon
MR	Materials & Resources
NAPDR	National Assessment and Action Plan on Demand Response
NREL	National Renewable Energy Laboratory
ODEA	On Demand Energy Appliance
PV	Photovoltaic
R-value	Resistance to Heat Flow
RECS	Residential Energy Consumption Survey
SCE	Southern California Edison
SEER	Seasonal Energy Efficiency Ratio
SHGC	Solar Heat Gain Coefficient
SIPs	Structurally-insulated Panels
TOU	Time of Use

UBC	Uniform Building Code
U-factor	Heat Transmission Coefficient (Related to the inverse of R-value)
UNLV	The University of Nevada Las Vegas
USGBC	US Green Building Council
VT	Villa Trieste

1 Introduction

1.1 Background

The Southwest region of the United States is a particularly hot and arid corner of the world. Vast swaths of Nevada, Arizona, New Mexico, Utah, and portions of California are covered by deserts that, according to the National Oceanic and Atmospheric Administration, are characterized as being both the warmest and most solar irradiated areas of the country. Despite these conditions, some of the United States' largest metropolitan areas are located within this region. The greater Las Vegas, Nevada area boasts nearly two million persons, and Phoenix, Arizona more than doubles this mark with over four million residents. Trends identified by the 2010 Census suggest that both of these populations continue to increase.

These heavily populated areas currently pose increasingly significant problems for electric utility companies, particularly during the summer months when residents stave off sweltering heat by running air conditioning systems in their homes nearly constantly. The U.S. Energy Information Administration (EIA) 2009 Residential Energy Consumption Survey (RECS) indicates that 25% of the energy consumed by homes in Arizona is used strictly for air conditioning, or 4 times the national average. These numbers indicate that air conditioning alone accounts for nearly 30% of the total electrical load for residences in Arizona. The aggregate effect of large portions of the population simultaneously demanding electricity creates an undesirable strain on the electric utilities' generators. This effect, often called 'peak demand', commonly occurs during the late summer afternoons when the business day overlaps with people returning home from work.

Such short-term peak demands derived from cooling loads during late afternoon summer hours have been an issue in Las Vegas for a number of years. A consortium was formed between the University of Nevada Las Vegas's Center for Energy Research (CER), Pulte Homes (a production homebuilder), and NV Energy (the local utility) to demonstrate community-level peak reduction in a purpose-built housing development. The community, Villa Trieste, is a 185-unit housing development located near the western edge of Las Vegas, Nevada (Figure 1) that was constructed specifically to research various peak shifting/reduction strategies in a cooling-dominated climate.

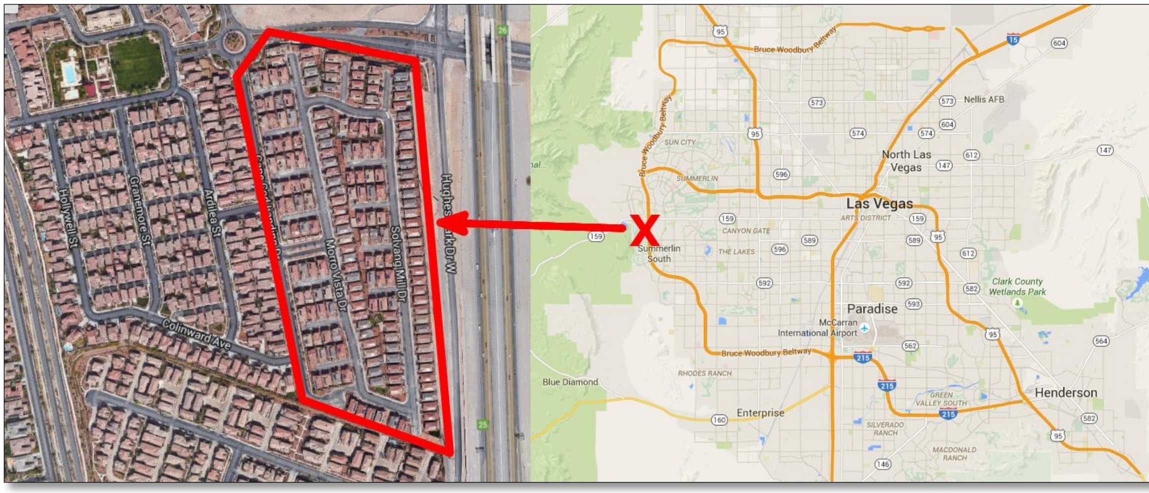


Figure 1 – Location of the Villa Trieste Community

Each home within the community is LEED Platinum certified, and built to a higher standard of energy efficiency than the IECC-2006 energy code that was in effect when the homes were built. In addition, each home includes a roof-mounted 1.8 kW PV array and grid-interactive inverter. The community is comprised of homes constructed from four different floor plans ranging in size from 1,487-1960 ft^2, with each floor plan consisting of two finished stories (**Figure 2Error! Reference source not found.**). Shortly after the completion of the construction phase of the project, 100% of the homes were occupied.

Figure 2 – Aerial View of Four Villa Trieste Floor Plans

2 Motivation

As members of the greater Las Vegas community, UNLV's Center for Energy Research, NV Energy, and Pulte Homes share a vested interest in understanding the unique challenges facing the residential building sector in the modern-day American Desert Southwest.

This region of the country is unlike any other in the United States, and recently, people have valued this uniqueness to the point that they have moved to the region in vast numbers. A major impetus has been the movement of retirees from colder portions of the US, to this area, in search of favorable weather. Correspondingly, there has been considerable residential development in many of the region's major metropolitan areas. As summarized by the Southern Nevada Home Builders Association in Figure 3, the annual number of new home sales in just Southern Nevada has been quite large for the past nearly three decades. When this project was conceived in 2007, new homes were being sold at a historically-high rate. Less than a year later, the housing bubble crashed across the country, and construction in the Las Vegas area took a nosedive. Only recently has this construction activity begun to increase again.

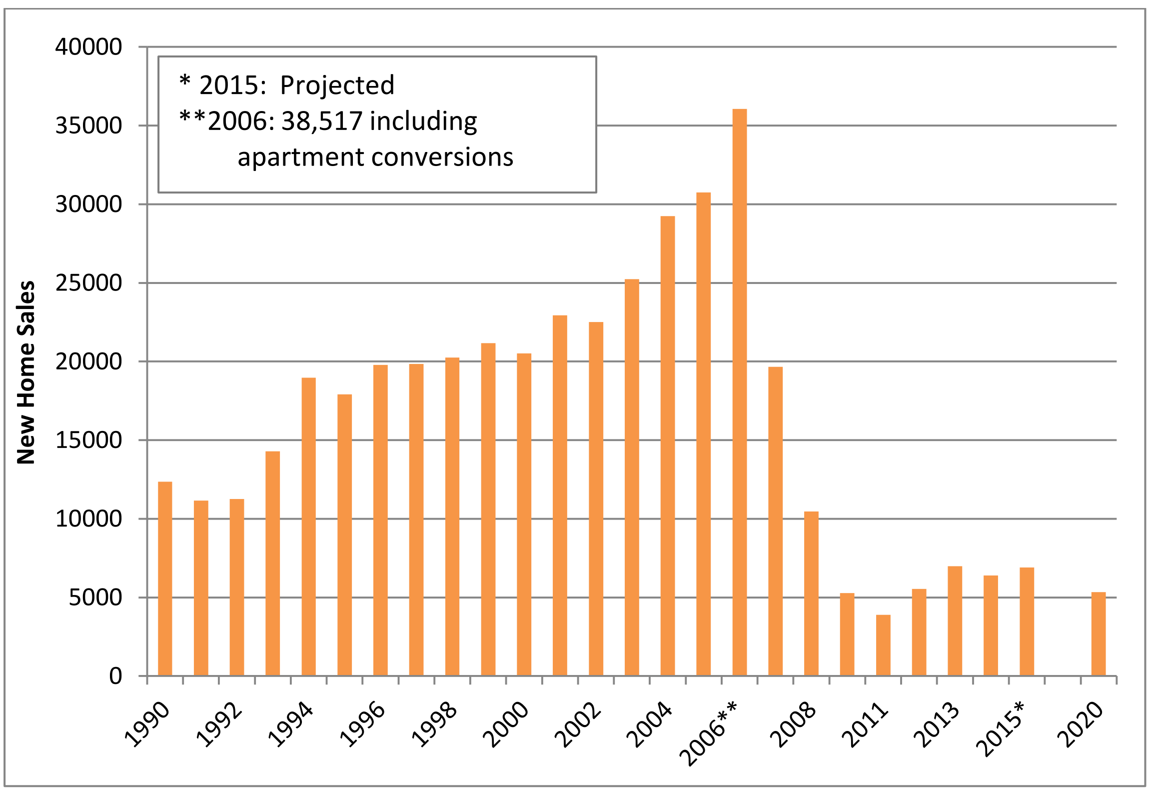


Figure 3 – Variation in Annual New Residential Sales in Southern Nevada (http://snhba.com/economic_indicators.asp)

When this level of housing growth is coupled with the very-warm-to-hot temperatures experienced within this region (Las Vegas is quite typical), there is a corresponding increase in the amount of energy the residential sector requires to air condition these homes. This demand mostly manifests itself toward the latter parts of the afternoon and earlier parts of the evening, as seen in Figure 4. At almost any given time during a typical summer day, the utility system load is higher than during any other season's peak demand. The summer's peak is approximately twice that of the winter's.

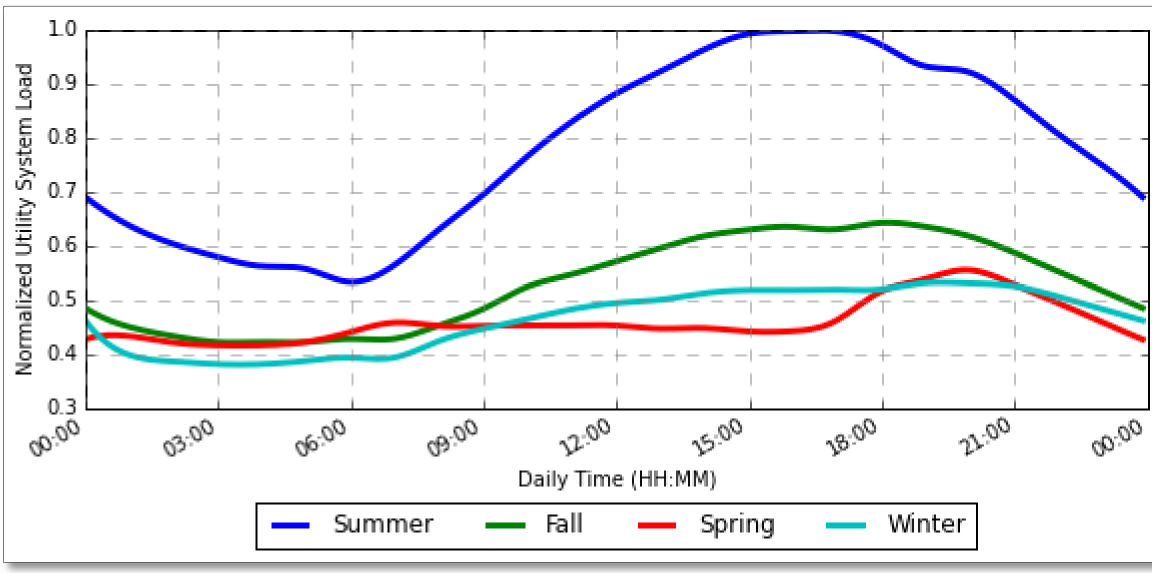


Figure 4 – Normalized Seasonal Utility System Load for Southern Nevada

One of the causes of the peak demand is the high amount of solar energy incident upon this region. The Desert Southwest boasts the highest levels of solar flux in the entire country, as seen in **Figure 5**. The abundance of this natural resource offers the unique opportunity to make use of solar energy for electrical generation. The cost of photovoltaic (PV) cells has recently been decreasing substantially, making PV generation an economically feasible addition to most structures, including residences. While the daily timeframe for measurable PV generation does not cover the total peak period (this will be shown later in the report), it does manage to offset a great deal of it.

For these reasons, it appeared that the circumstances were favorable for UNLV to propose the project described in this report to a DOE Smart Grid related FOA. A partnership was formed between Pulte Homes, NV Energy, and the CER to draft a proposal that would allow the partnership to build a test-community that could quantifiably lower the aforementioned summer peak electrical demand. It was proposed that, in addition to utilizing an energy-conserving building design, each home would incorporate roof-mounted PV panels. It was also proposed that the partnership would explore the use of advanced demand response techniques, as well as storage batteries that would assist in controlling demand peaks. The proposal staff was sufficiently sure that they would be able to deliver a proposed peak reduction of 65% compared to code-built homes.

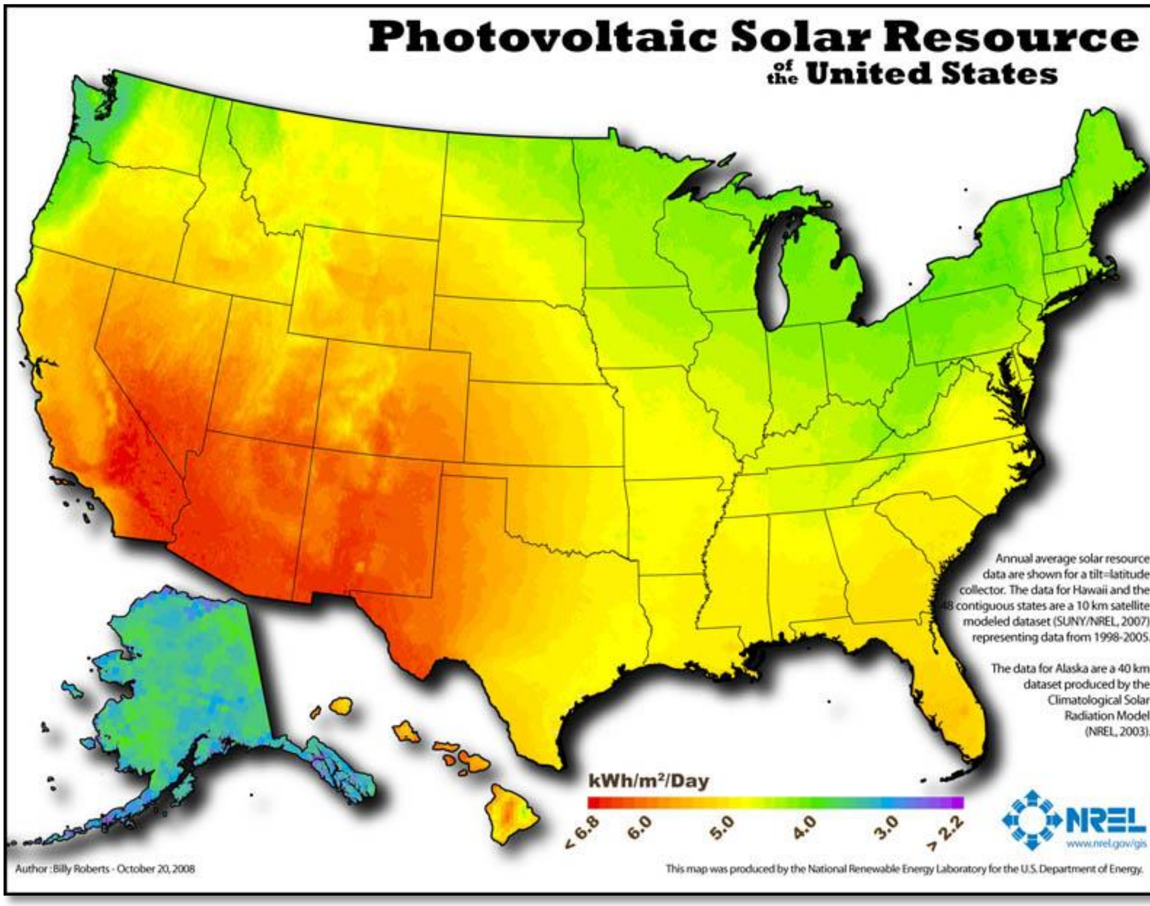


Figure 5 –Average Annual Total Solar Flux (Beam and Diffuse) in the US (Source: National Renewable Energy Laboratory (NREL), "Photovoltaic Solar Resource of the United States" From Dynamic Maps, GIS data, and Analysis Tools, accessed August 3, 2012. http://www.nrel.gov/gis/solar.html)

2.1 Objective

The primary objective of this project is to demonstrate dramatic peak demand reduction of a minimum of 65% in residential new construction via distributed generation, distributed energy storage, energy efficiency, intelligent load control, and possible price-responsive load control over a standard production homebuilder development. This objective will be satisfied in addition to the following:

- Advanced technology shall be deployed into a new housing development, which will contain state-of-the-art energy efficient homes developed by a production homebuilder.
- The project will require a substantial research component to optimize capital layout and electric system control methodologies.
- A rigorous measurement and verification methodology shall be used to validate project results.

3 Villa Trieste Energy Reduction

The Villa Trieste community was originally conceived by Pulte Homes prior to their involvement with this DOE-funded project. As home-builders that have long had a reputation for constructing energy efficient housing, even compared to minimum code requirements, Pulte began their preliminary work on Villa Trieste during the latter parts of 2008. Drawing on their experience with construction of houses ranging from code-built to more efficient types of building (more typically the case for Pulte), Pulte personnel considered a reasonable goal for peak reduction. After several discussions, it was thought that 65% reduction should be possible and would represent good new frontier for production homes. 65% appeared to be a good choice. That number was ultimately chosen. Pulte focused on designing four models of energy-efficient, two-story, single-family houses, and initially did so exclusively without any involvement from CER or NV Energy. After DOE-grant NT02873 grant was awarded during the summer of 2009, and the research consortium began working together, the design for Villa Trieste was iterated and transformed into an inspiring community that would aim to reduce summer peak production by 65% compared to code-built homes.

3.1 Residential Code Standards

To understand what Villa Trieste's 65% peak reduction would be in reference to, it is important to establish the applicable codes and discuss their implications. In terms of strictly residential energy codes, the relevant literature is known as the International Energy Conservation Code ®, or IECC. The International Code Council has been publishing this standard roughly every three years since 1998. Adoption of this standard occurs at the state level, though their effective dates differ by jurisdiction. Table 1**Error! Reference source not found.** shows the energy codes that have been in effect for the Las Vegas valley during the duration of this project. When the building plans for Villa Trieste were approved in early 2010, the community was subject to IECC-2006.

Table 1 – Energy Code Effective Dates for Clark County, NV

Code	Effective Date
IECC-2006	May 1, 2007
IECC-2009	Jul 5, 2011
IECC-2012	Jul 1, 2015

The IECC's requirements for mechanical equipment are largely regulated by Federal law through the National Appliance Energy Conservation Act as amended by the Energy Policy

Act of 2005, which regulates the efficiency requirements of most residential equipment. For example, these requirements mandate that the minimum allowable rating for air conditioning efficiency be SEER 13.

Energy standards are important in the building sciences world, but they're only just a subset of standards when it comes to residential building construction. Before energy standards were adopted, building codes were the primary reference for point for residential material usage and construction practices. The City of Las Vegas has only been issuing residential-specific building permits since 2003 but has issued permits since 1915. This will be discussed further in Section 4.3.

3.2 Design Considerations

All of the design decisions that went into these homes were heavily influenced by both energy conservation considerations as well as sustainability aspects. The first iteration's design changes involved "upgrading" materials and structural component so that they exceeded the requirements of IECC-2006. When all was said and done, the first iteration resulted in comparable-or-higher-rated insulation in the floors, roofs, walls, and doors. The second design iteration focused on energy-conserving components that, in general, had longer payback periods. An additional design aspect that was included was the infrastructure to support each home with five-years of cost-free internet, guaranteeing that internet-based communications could later be utilized for demand-side energy management systems and advanced metering research. Some of the thought processes that were considered during the design phases are included below.

3.2.1 Exterior Wall Insulation

According to IECC-2006, external walls were required to be, at a minimum, constructed with 2"x4" wood studs, glass fiber batts rated at R-13, 5/8" interior drywall, and 0.2" plaster. This combination results in an average R-value of approximately 9.85 when the sections of the wall without insulation (due to studs) are considered. As part of the larger effort to increase the exterior walls' insulating capabilities, expanded polystyrene (EPS) foam rated at R-4 was added between the exterior wall studs and the stucco finish. The additional EPS increased the average R-value of the 2"x4" walls to approximately 14.49. The incremental cost for this upgrade was estimated to be $750. Additionally, the walls' studs were upgraded to 2"x6" with R-19 cellulose insulation at an estimated incremental expense of $2,679 for the 1758 ft^2 home being examined.

3.2.2 Slab and Floor Insulation

Insulation along the perimeter of a home's slab foundation effectively reduces heat transfer between the interior and the ambient. Slab insulation also results in an increased amount of thermal mass, which is better suited for maintaining indoor temperatures. Due to installation difficulties stemming from the use of post-tension slabs, builders are sometimes unable to offer slab edge insulation. Because of the post tension aspect of Villa Trieste design, slab insulation was not used.

In terms of second level floors located above unconditioned areas, such as garages and outdoor patios, the minimum requirements of the 2006-IECC are that the floors be insulated with cellulose to at least R-19. Upgrading this insulation to R-30 cellulose was relatively inexpensive and easy to implement.

3.2.3 Windows

According to 2006-IECC, the windows for buildings in Las Vegas were required to have a U-factor of 0.650 and a solar heat gain coefficient (SHGC) of 0.40. However, these windows could still be upgraded to double-pane with low-emissivity coatings and vinyl frames, making them more insulated and more resistant to solar heat gains. This modification reduced both the windows' U-factor and their SHGC values to approximately 0.40 and 0.35, respectively. The incremental cost for this upgrade was estimated to be $300.

Furthering energy conservation was considered by examining windows with triple glazing and those filled with low-conductivity argon and krypton gas, but the incremental energy savings did not justify the additional expense of these extremely high-performance windows. Instead, more moderately priced windows, manufactured by Milgard, were installed. They still managed to improve performance over the first design iteration, with average U-factors of 0.280 and average SHGCs of 0.23. These windows carried an incremental cost of $156 per house.

3.2.4 Exterior Doors

The 2006-IECC stipulated that exterior doors be insulated to a minimum rating of R3. Similarly, interior garage doors that provided access between an unconditioned garage space and a conditioned interior space needed to be rated to just R-3, as well. Improved doors are often installed on upgraded homes, and Villa Trieste was no exception. Doors manufactured by Therma-Tru, rated at R-7, were included in the design. The incremental cost for this upgrade was estimated to be just $40/door.

3.2.5 Infiltration

According to ASHRAE Standard 62, the recommended minimum natural infiltration rate for a home is 0.35 air changes per hour (ACH) for residential buildings. In other words, the standard requires that at least 35% of a home's air volume be replaced by outside air every hour. Homes constructed tighter than 0.35 ACH require mechanical ventilation to allow for proper ventilation levels to maintain indoor air quality.

In order to cut down on building infiltration, a number of options were considered, including structurally-insulated panels (SIPs), but these were not taken further because of the lack of local installers. Spray foam insulations were also considered for the exterior walls, but the material properties of the various spray foams available at the time were not advantageous. Hence, blown-in cellulose insulation rated at R-13 was added to the walls. Infiltration was further reduced through the use of cellulose insulation attached to the roof deck.

3.2.6 Conditioned Attics

Unlike conventional homes with vented attic/roof assemblies, the Villa Trieste homes were constructed with unvented attics, which can be quite beneficial during the hot summers of the Southwest. Rather than laying insulation atop the second level ceiling, insulation was installed along the underside of the roof sheathing, accomplished by stapling fabric netting to the bottom face of the roof trusses. Unvented attics with blown-in cellulose insulation between the netting and the roof deck further reduced infiltration. Due to weight restrictions on the netting and potential settling issues, the insulation was limited to an R-22 thickness. The moderate zone temperatures in this semi-conditioned area allow the mechanical equipment located there to operate more efficiently, and nearly eliminates detrimental effects normally associated with duct leakage.

The minimum energy code level for attic insulation required for the Las Vegas Valley is R-30, or equivalent. Although the insulation itself doesn't adhere to the R-30 threshold, the entire configuration, including the unvented attic, satisfies this requirement in its net equivalency.

3.2.7 Roof Color

Applying low-absorptivity paints or highly reflective coatings to the homes' roofs could have reduced the level of solar radiation penetrating into the homes. Research has shown that such coatings can provide substantial benefits in cooling-dominant climates. However, this option was discarded in the case of Villa Trieste because these paints are currently not acceptable for production homes in Las Vegas.

3.2.8 Raised Roof Battens

Also known as a double roof, raised roof battens provide a wooden structure that supports a second roof layer that acts as part of the thermal envelope. This configuration allows the functional “interior” roof surface to be out of direct sunlight, and provides a passageway for natural convective cooling to occur between the roofs’ surfaces. Raised roof battens do have drawbacks, though, notably additional unwanted convective cooling during winter months. The increased cooling could increase a home’s heating load and potentially negate some of the energy saved during the summer months. Ultimately, raised roof battens were not included for these reasons in addition to a variety of structural issues.

3.2.9 Air Conditioners

The mechanical systems were a primary focal point when conducting building energy studies, because heating and cooling loads are typically responsible for half of the total energy demand in an average home. Clark County, where Villa Trieste resides, mandates that air conditioners be rated at seasonal energy efficiency ratio (SEER) 13. Installing air conditioners with higher efficiency ratings was determined to be appropriate in this case.

In most cases, and Villa Trieste was no exception, the added expense of the efficiency measures is often completely offset by the reduced cost of lower-capacity air conditioners. Two models with SEER ratings of 17.5 and 20 were considered, however a unit with a 15.82 SEER was ultimately chosen during the value-engineering phase of the design. For the 1758 ft^2, three-bedroom home under consideration, the requirement was a 4-ton air conditioner. The upgrade cost of the unit from a standard 13 SEER rated unit was estimated to be $700.

3.2.10 Lighting

All permanent lighting fixtures in energy efficiency homes are considered to be made up of compact fluorescent light bulbs (CFLs). CFLs have proven to be one of the most effective energy-saving building practices. As a secondary benefit, CFLs decrease a home’s overall cooling load because they emit roughly 75% less waste heat than similar incandescent bulbs.

3.2.11 Photovoltaic (PV) Systems

The Desert Southwest region of the US receives a large amount of solar radiation. Both because of this, and various incentive programs available, PV systems were added to the design without substantial increases in the homes’ prices. A range of prices were quoted, and they included installation and installer-furnished repair in the price. Roof-integrated PV tiles and 94% efficient grid-interactive inverters manufactured by SunPower were ultimately installed. Three sizes of the PV systems 1.764 (28 tiles), 2.28 and 3.192 kWp (42 tiles) of peak power were examined for this study, though the 1.764 kWp system was deemed adequate for offsetting peak energy consumption.

3.2.12 Leadership in Energy & Environmental Design

At the time of Villa Trieste's design, the US Green Building Council (USGBC) had only very recently launched their Leadership in Energy & Environmental Design (LEED) for Homes rating. Prior to 2007, LEED had been a building certification program that had exclusively serviced the commercial and industrial building sectors. With Villa Trieste's design mentality being as committed to energy conservation and sustainability as it was, it only made sense for the developers to use Villa Trieste as an opportunity to familiarize themselves with the newly-established certification process and pursue the highest LEED certification level available – LEED Platinum.

LEED certifications are ultimately awarded based on merit. This merit is objectively determined through the use of a "points system". Guidelines are published, and when followed to a given extent, the USGBC correspondingly awards the appropriate number of points to a design. The number of points required for each certification level can be seen in Table 2.

Table 2 – Point System for LEED for Homes Certification

LEED for Homes Certification Level	Number of Points Required
Certified	45-59
Silver	60-74
Gold	75-89
Platinum	90-136
Total Available Points	136

Design guidelines are grouped into eight broad categories, as seen in **Table 3**. A discussion of each of these aspects, and how they influenced Villa Trieste's design, follows.

Table 3 – Design Aspects Considered for LEED Evaluation

LEED-Considered Items
Innovation and Design
Location and Linkages
Sustainable Sites
Water Efficiency
Energy and Atmosphere
Materials and Resources
Indoor Environmental Quality
Awareness and Education

3.2.12.1 INNOVATION AND DESIGN

Points are earned in this category by following modern project planning techniques designing for durability and high performance, and by incorporating additional design and construction measures that aren't explicitly outlined within the LEED for Homes Rating System. To tackle these challenges, the developers drew inspiration from the Environments for Living® program, the US Bureau of Reclamation's WaterSMART program, and the DOE's Builders Challenge.

3.2.12.2 LOCATION AND LINKAGES

This category primarily focuses on site selection, infrastructure, and community resources. The only requite for site selection is that the development not be placed within any environmentally sensitive areas. The site that was chosen was located on the west side of Las Vegas, in the desirable Summerlin master-planned community. Pulte had experience developing in this general area, and Summerlin boasted a number of community resources, including hospitals, hotels, dining, and shopping districts. Since construction began on Villa Trieste, a significant number of community resources have been added in the vicinity. Downtown Summerlin, an outdoor business, entertainment, fashion and retail district, is now located directly across the major freeway from Villa Trieste.

3.2.12.3 SUSTAINABLE SITES

Included in the planning for this aspect, Pulte considered erosion controls (both best management practices and the Storm water Pollution Prevention Plan manual), Zero Turf artificial grass, drought-tolerant plants, and permeable lots for surface water management. These included 76% vegetative and 24% permeable paving.

3.2.12.4 WATER EFFICIENCY

Included in this general set of considerations is *Water Efficiency*, resulting in a high efficiency irrigation system being incorporated into the design. Since no lawn would be used for any of the houses, head-to-head coverage was not pertinent, but the system still included drip irrigation, separate zoning (timing zoning), and pressure regulators. Indoor features included dual flush toilets, highly efficient fixtures, and tankless water heaters.

3.2.12.5 ENERGY AND ATMOSPHERE

This category's objectives coincided quite well with the project's premise, so it was not an additional burden to meet the specified guidelines. The primary intent of this portion was to achieve higher levels of energy performance over existing standards, which is what the project entailed regardless. Still, developers borrowed elements from the US

Environmental Protection Agency's (EPA) ENERGY STAR® program when outfitting the homes with equipment.

The Home Energy Rating Service (HERS) Index was also examined during this part of the design process. After some calculations, it was determined that the HERS index for the Milano floorplan was 43 (**Figure 6**), the same rating shared by the other three floorplans. The HERS rating is particularly valued by home owners in that it gives some comparison of energy performance in a general sense – it is analogous to the EPA's gas mileage ratings that accompany new automobiles.

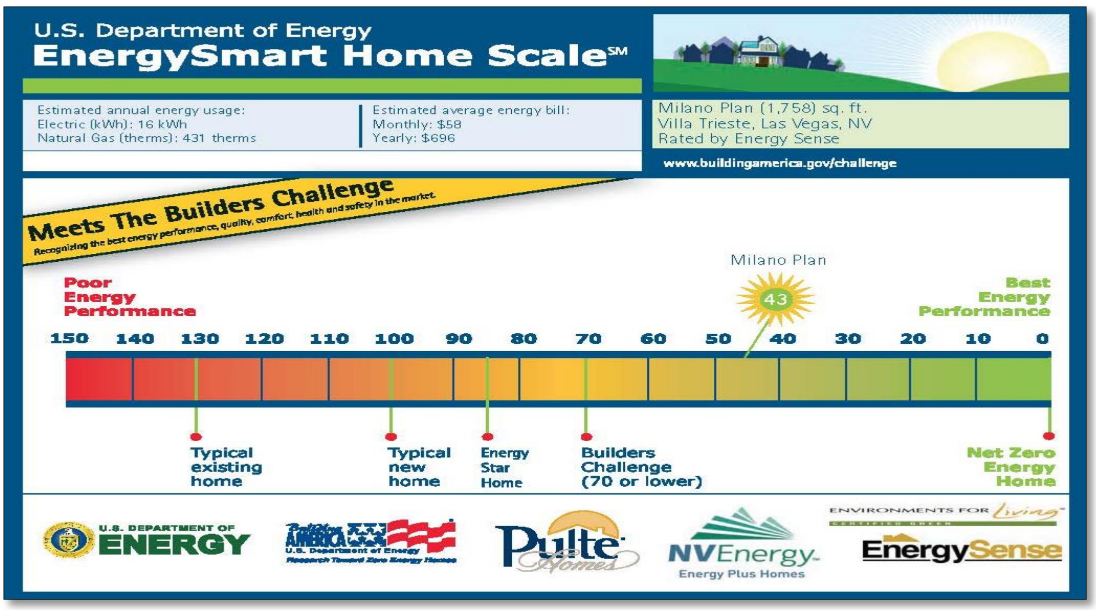


Figure 6 –The Energy Smart Home Scale for the Milano Floorplan

Examining **Figure 6** further, a HERS rating of 100 is what would be considered a "code-built" house. A rating of around 85 corresponds to baseline ENERGY STAR® households, and a HERS rating of no more than 70 can be achieved by following the prescribed measures outlined by the DOE's Builders Challenge. Considering the extremes, 0 would be achieved by a Net Zero energy home, and 130 is typical for existing homes. Exact values for Villa Trieste's parameters are shown in **Table 4** in comparison to the HERS 2006 Reference House.

Table 4 –Villa Trieste Compared to the HERS 2006 Reference House

Component	Detail	Units	HERS Ref '06	Villa Trieste
Floor	Slab-on-Grade Edge Insulation	-	No	No
	Floor Over Garage R-Value	$K\text{-}m^2/W$	2.9	3.3
	Raised Floor R-Value	$K\text{-}m^2/W$	3	3.3

Roof	Deck Insulation R-Value	K-m²/W	0	3.9
	Solar Absorptance	-	0.75	0.75
Ceiling	R-Value	K-m²/W	4.2	0.18
Walls	Exterior Walls R-Value	K-m²/W	1.7	3.3
	Solar Absorptance	-	0.75	0.75
Garage Walls	R-Value	K-m²/W	1.7	3.3
	Solar Absorptance		0.75	0.75
Doors	U-Value	W/m² k	3.7	0.7
Windows	U-Factor	W/m² k	3.7	2.3
	Coefficient Value	-	0.40	0.35
	Winter SHGC	-	0.34	0.31
	Summer SHGC	-	0.28	0.24
Infiltration	Effective Leakage area	cm²	1882.6	354.2
Air Conditioning	SEER	kJ/W-h	13.71	15.82
Heating (Nat. Gas)	Efficiency HSPF	-	78	92
Ducts	R-Value	K-m²/W	1.1	0.7
Hot Water (Nat. Gas)	Energy Factor	-	0.67	0.82

Construction techniques were a part of *EA* that assisted in achieving the low value of a HERS rating. Special framing techniques such as a continuous air barrier and air tightness reduce the potential for moisture to enter the building envelope and sealing of penetrations help reduce internal leaks and drafts. Another aspect of it was solar power. The SunTiles on the roof (initially furnished by Sun Power) produces clean energy year around and the systems are equipped with net-metering so extra power is sent to the utility for future credits. Both the panel supplier and the electrical utility monitor the amount of energy produced.

Another aspect to the *EA* was the monitoring of electrical consumption and production as well as controls for the HVAC and security systems. Pulte selected In2Networks to furnish this aspect of the houses. Pulte had prior experience with In2Networks for the security aspects in a development in the Denver area. A wall dashboard was used for the residents to keep track of various performance aspects if they wished.

Each house was designed to use 100% CFL lighting. This allowed the power used for lighting to be reduced as well as the amount of air conditioning to be reduced since it didn't have to remove the additional heat from the lighting fixtures. In addition, the houses used Energy Star appliances.

3.2.12.6 MATERIALS AND RESOURCES

The category of *Materials & Resources (MR)* was made up of Value Engineered Framing, Environmentally Preferable Products, and Construction Waste Reduction. Special framing techniques reduce lumber requirements and material use, while maintaining structural integrity. This is accomplished with detailed cut sheets and framing plans, pre-cut packages, open web floor trusses, and appropriate stud, truss, and joist spacing. Both low emissions and local products aided the effort to have environmentally preferable products. These included blown cellulose, low VOC paint, and locally supplied aggregate, cement, and gypsum board. To reduce construction waste, a clean up company was used that has its own materials recovery facility that uses several recycling stations. It has been shown that up to 80% of the construction waste is diverted from the landfill.

3.2.12.7 INDOOR ENVIRONMENTAL QUALITY

Indoor Environmental Quality (IEQ) is supported by several aspects: enhanced outdoor air ventilation, ENERGY STAR exhaust fans, MERV 11 air filtering, contaminant control during construction, insulated rafters, and room-to-room air balancing (jump ducts). Also included is indoor moisture management. All ductwork is sealed during construction.

3.2.12.8 AWARENESS AND EDUCATION

The final element in the LEED evaluation is *Awareness and Education (AE).* Included here are an Operations Training Manual, homeowner walk through, and publications. When the evaluation was performed, the VT development earned a LEED PLATINUM award. This is the highest award for sustainability and energy conservation possible.

3.3 Design Decisions

In reference to the many design upgrades discussed above, REM/Rate was utilized to assist in justifying cost/benefit decisions. When calculating payback periods, a fixed APR of 5% on principal cost, compounded annually, was used in addition to an energy cost inflation rate of 5%. REM/Rate was used because the output (HERS rating) is used regularly in local sales efforts.

The following energy efficiency upgrades were all calculated to have payback periods of less than 10 years for an energy-cost inflation rate of at least 1%. Though not initially under a 10-year payback period, when federal and state rebates were considered, the PV system payback period dropped below this threshold; the useful life of each of these upgrades-over-code far exceeds their respective payback periods.

Table 5 – Villa Trieste Design Upgrades

Upgrade	Upgrade Description
Exterior Walls	Both 2x4 and 2x6 walls are used with an additional 1” thick EPS insulation added to all the walls.

Windows	High efficiency low-e with U-factor and SHGC 0.40 and 0.35 respectively.
Exterior Doors	R-7
Infiltration	Blown-in cellulose insulation is used in walls and roof.
Attic/Roof Treatments	Conditioned attic with R-22 blown-in cellulose roof insulation.
Air Conditioners	SEER 15
Lighting	All permanent lighting fixtures are replaced with CFL lights
PV Panels	1.764 kWp Systems

3.4 Demand Response

One energy reduction strategy that was particular interest to researchers during the proposal stage of the project is referred to as 'demand response' (DR). This strategy is defined by the DOE as:

> "Changes in electric usage by demand-side resources from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized."

Although the feasibility and usefulness of such a system relies heavily on the utilities' ability to notify customers of the *dynamic pricing* changes that ultimately drive customer behavior modifications, the industry has not conclusively developed an effective method for conveying pricing changes to customers. Therefore, the industry generally refers to any load reduction strategy that is based on monetary incentives or compensation for electricity consumption reduction during peak times as a "demand response" effort.

By examining data from surveys and case studies across the country, the 2009 National Assessment & Action Plan on Demand Response (NAPDR) projected the potential impact of DR programs and extrapolated them to 2019, as shown in Figure 7. The primary lesson to be learned from this graph is that there exists an enormous opportunity for nation-wide peak energy reduction by adopting dynamic pricing policies and technology that can autonomously make use said dynamic prices. The NAPDR, analyzed potential DR benefits as a function of building type, rather than by DR program**Error! Reference source not found.** suggests that a substantial percentage of the potential peak demand reduction will be achieved by residential buildings as shown in Figure 8.

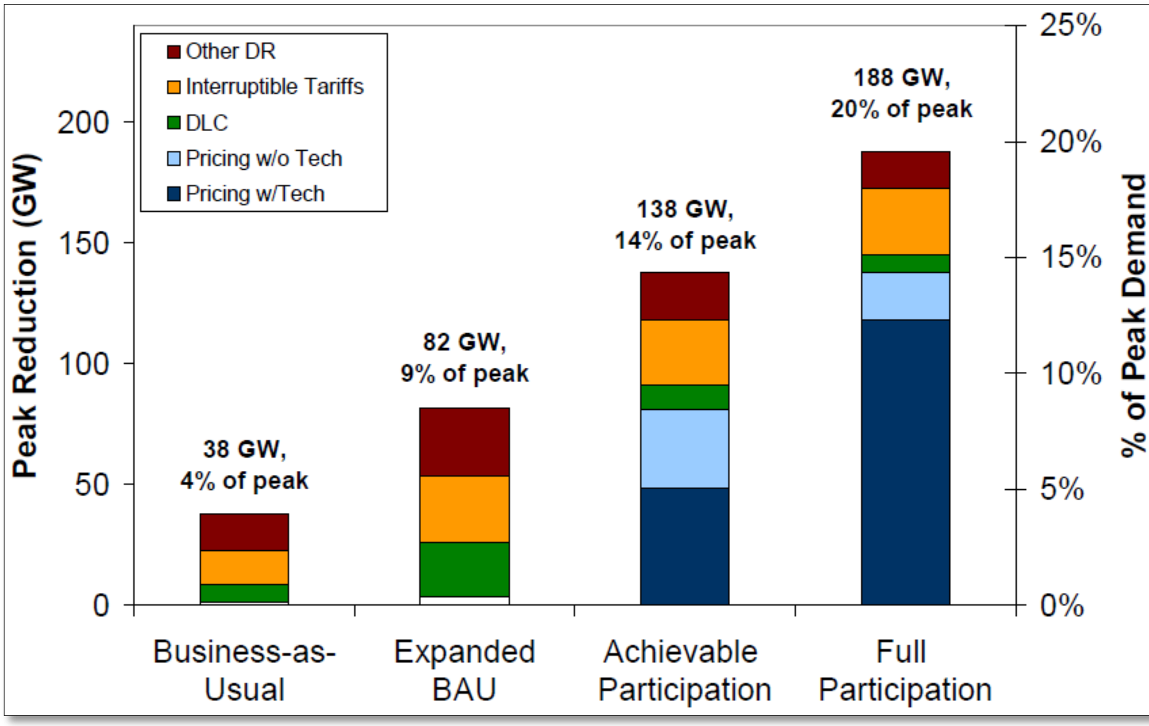


Figure 7 – U.S. Demand Response Potential by Program Type (2019)

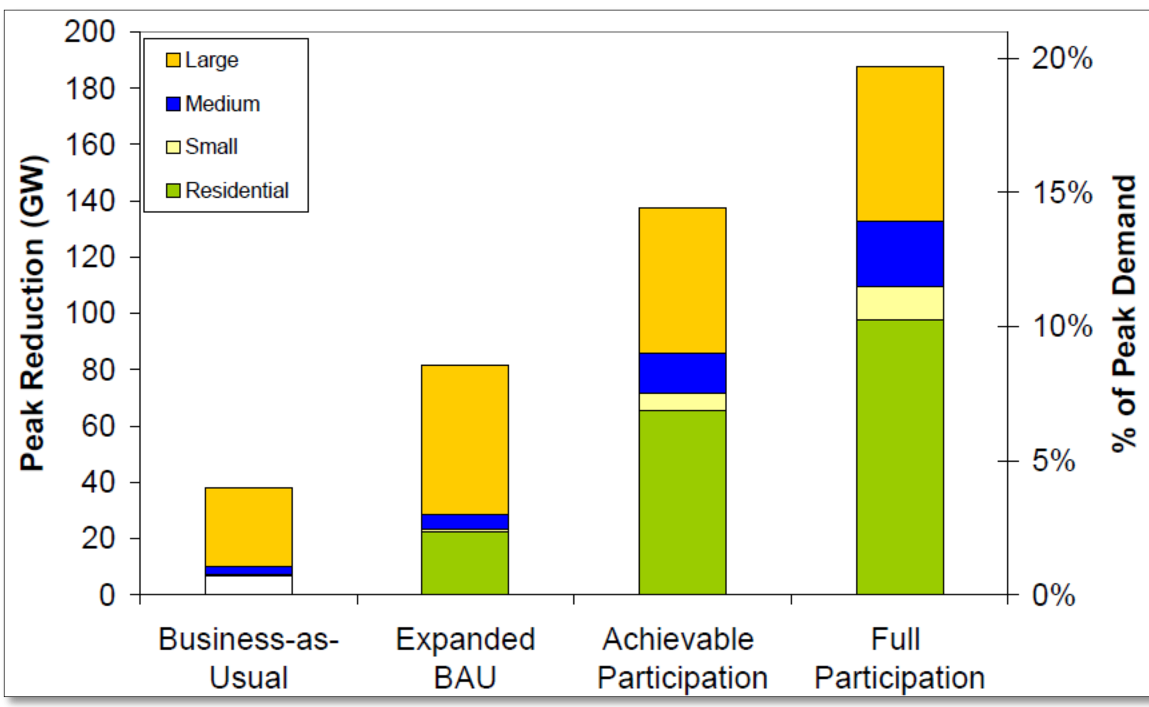


Figure 8 – U.S. Demand Response Potential by Class (2019)

3.5 "Intelligent" Demand Response

One significant takeaway from the NAPDR study referenced above was that although the majority of DR efforts in effect today come from large industrial and commercial consumers, it is the enabling technology and residential class of buildings that represent the largest potential for DR energy deferral. Those factors lay the foundation for majority of this research.

The "business-as-usual" residential DR efforts of today are relatively straightforward. When alerted by the utility, thermostats installed in participating homes adjust their setpoints by a fixed number of degrees. Typically, this offset is programmed to be either 3 or 4 °F. Since this offset is hard-coded into the thermostat, and set by the utility, home owners have no way of customizing this setting per their personal preference. This results in home owners "opting out" of DR efforts by manually adjusting their thermostats' setpoints, and drastically reducing the overall benefit (to both the home owner and the utility) of the DR effort. Additionally, today's systems are ill-equipped to deal with dynamic pricing initiatives.

3.5.1 Intelligent Agent Conceptualized

The Intelligent Agent (IA) was proposed in an attempt to mitigate the problems associated with home owner opt-out rates, and provide a platform for researching future advancements in dynamic pricing. Its objective was to engage home owners, and allow them tailor their level of autonomous participation in any DR event. Understanding that the two major factors that influence residents' decisions when adjusting their thermostats' setpoints are comfort and cost, it was proposed that the IA would be able to factor in both these considerations when implementing DR events. The IA would utilize homeowner preferences when determining the magnitude of thermostat setpoint increases as shown in **Figure 9**.

This was proposed to be accomplished using fuzzy logic, which would be built into the IA controller. From a home owner's standpoint, they would be responsible for establishing their level of interest in saving money on the operation cost of their air conditioner, as well as the generalized range of temperatures within their home they felt would be "acceptable". These preferences would apply to any and all DR events. Similarly, the utility would be responsible for characterizing the urgency of each deployed DR event on a scale of 1 to 3, with 1 being least critical and 3 being the most critical. This characterization would obviously change for each event. Figure 9 visualizes these inputs, and the corresponding output of the IA controller.

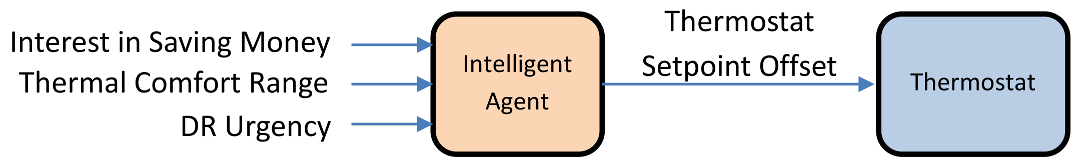


Figure 9 – Block diagram of Input and output of Intelligent Agent

Although residential dynamic pricing has yet to see wide adoption in the region, it is proposed that this utility input could one day be adjusted to act more like a "price signal" than an "urgency level." This would result in a greater benefit provided by the IA system.

3.5.2 Intelligent Agent System Development

Since Villa Trieste home owners were gifted 5 years of free internet upon the purchase of the homes, researchers were able to employ web-based technologies when developing the Intelligent Agent, as seen in Figure 10.

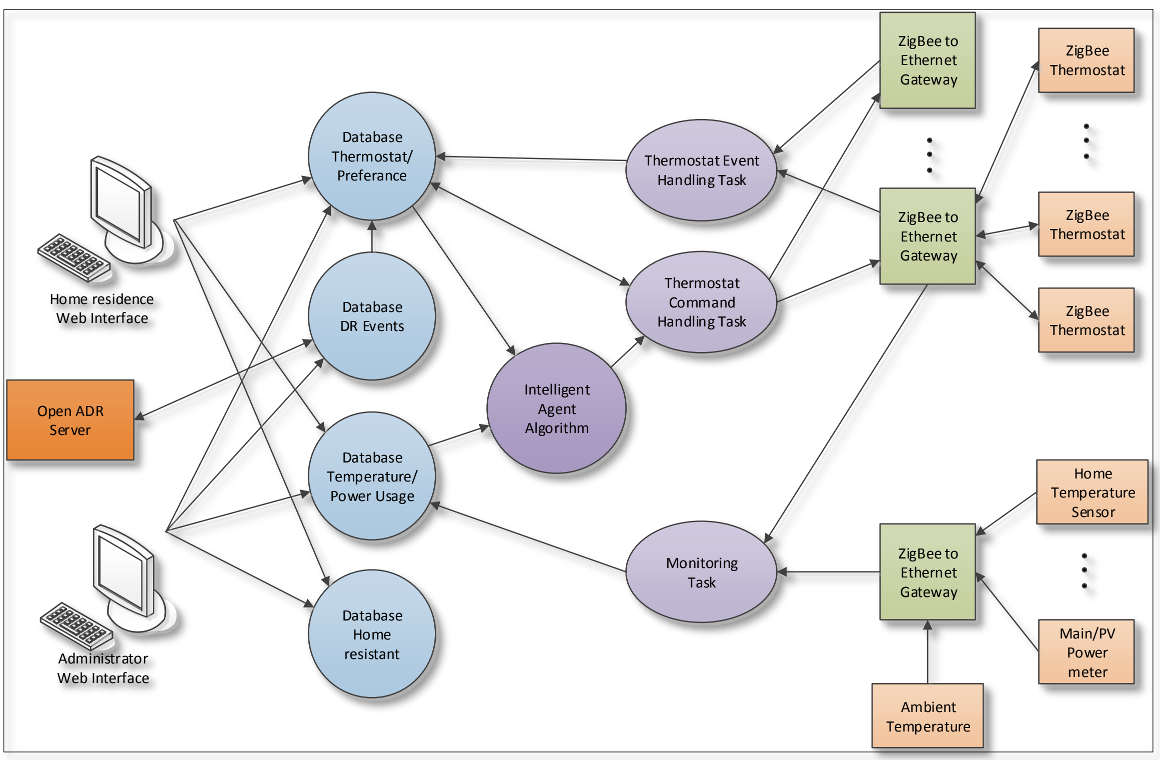


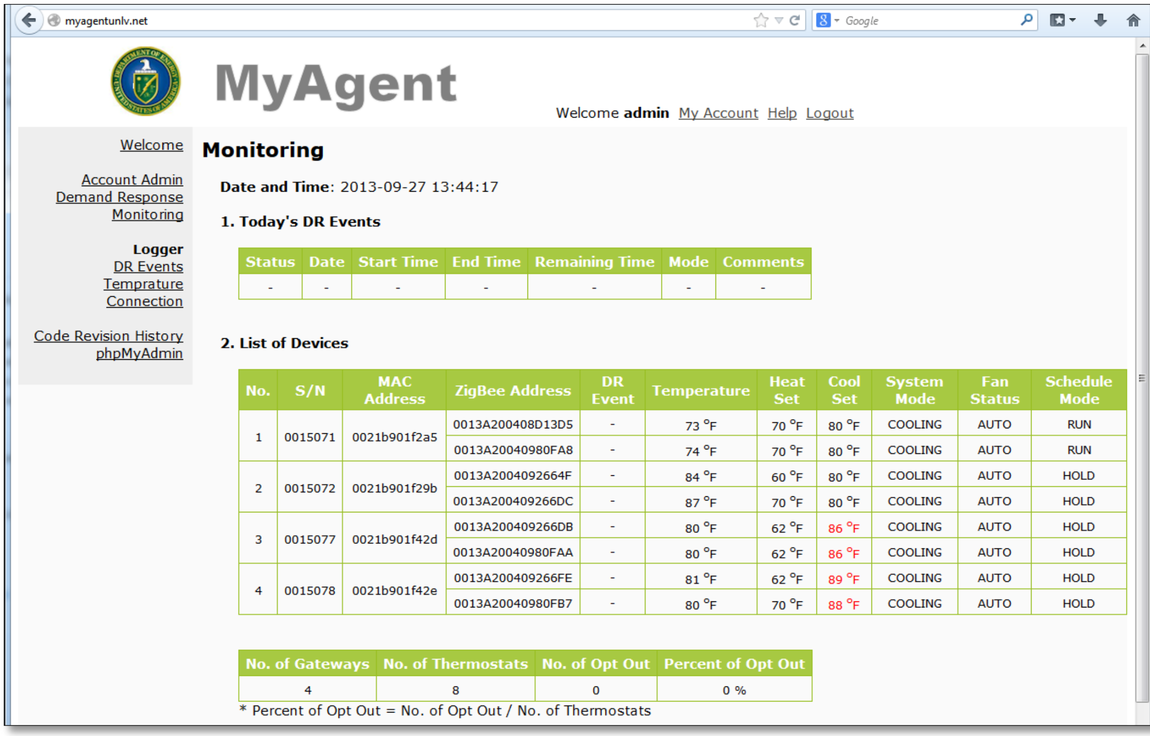
Figure 10 – Block Diagram of the Intelligent Agent System

Making sense of Figure 10 by reviewing the blocks right to left, two ZigBee-enabled wireless thermostats were installed at each participating Villa Trieste house–one on each floor of the residence. In order for these thermostats to communicate with the server at UNLV, gateways were also installed at each home that were able to translate ZigBee wireless signals to TCP/IP signals that would be relayed back to the server. These gateways facilitated communication between server and thermostat. By using this communication path, UNLV's server was able to send control signals to the thermostats, and act as a data logger that would record each thermostat's activity on an event-driven basis. For example, instead of constantly logging a given thermostat's temperature every minute, a record would only be added to the database when the thermostat's temperature changed. In this way, the following activities for each thermostat involved with the project were logged extremely efficiently:

- Temperature
- Heat/Cool Setpoints
- System Mode (Cool, Heat, Off, Auto)
- HVAC Status (Cooling, Heating)
- Fan Status (On, Off, Auto)
- Schedule Mode (Run, Hold)

For the IA to be successful, as previously discussed, it would need to be capable of considering each home owners' preferences as well as utility DR classifications. To accomplish this, a web interface was developed that allowed both entities to interact with the Intelligent Agent system. Users would login to the interface (http://www.myagentunlv.net or http://iecopower.unlv.edu), and be presented with content depending on their particular permissions. **Figure 11** is a screenshot of the interface served to administrators, which shows what a homeowner would see when logging on to the web interface in **Figure 12**.

By navigating to the 'Preferences' page, the homeowner is provided the opportunity the input their personal preferences that the IA controller considers when implementing DR thermostat offset temperatures. The interface for this preference-input task is shown in **Figure 13**. More details about the functionalities of the complete site can be found in Appendix A.



myagentunlv.net

MyAgent

Welcome **admin** My Account Help Logout

Welcome

Account Admin
Demand Response
Monitoring

Logger
DR Events
Temprature
Connection

Code Revision History
phpMyAdmin

Monitoring

Date and Time: 2013-09-27 13:44:17

1. Today's DR Events

Status	Date	Start Time	End Time	Remaining Time	Mode	Comments
-	-	-	-	-	-	-

2. List of Devices

No.	S/N	MAC Address	ZigBee Address	DR Event	Temperature	Heat Set	Cool Set	System Mode	Fan Status	Schedule Mode
1	0015071	0021b901f2a5	0013A200408D13D5	-	73 °F	70 °F	80 °F	COOLING	AUTO	RUN
			0013A20040980FA8	-	74 °F	70 °F	80 °F	COOLING	AUTO	RUN
2	0015072	0021b901f29b	0013A2004092664F	-	84 °F	60 °F	80 °F	COOLING	AUTO	HOLD
			0013A200409266DC	-	87 °F	70 °F	80 °F	COOLING	AUTO	HOLD
3	0015077	0021b901f42d	0013A200409266DB	-	80 °F	62 °F	86 °F	COOLING	AUTO	HOLD
			0013A20040980FAA	-	80 °F	62 °F	86 °F	COOLING	AUTO	HOLD
4	0015078	0021b901f42e	0013A200409266FE	-	81 °F	62 °F	89 °F	COOLING	AUTO	HOLD
			0013A20040980FB7	-	80 °F	70 °F	88 °F	COOLING	AUTO	HOLD

No. of Gateways	No. of Thermostats	No. of Opt Out	Percent of Opt Out
4	8	0	0 %

* Percent of Opt Out = No. of Opt Out / No. of Thermostats

Figure 11 – Administrator Interface

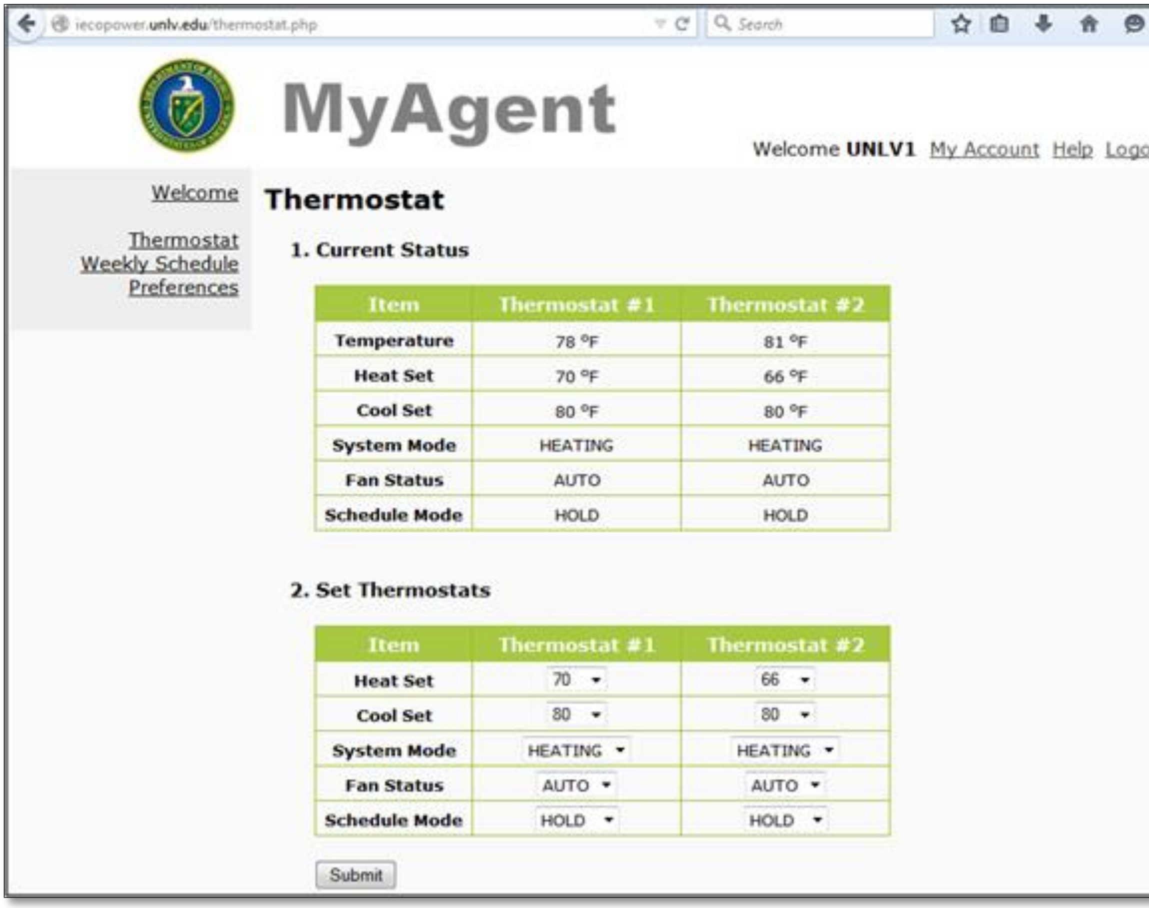


Figure 12 – Homeowner Interface

Figure 13 – Home Owner Preference Interface

3.5.3 Intelligent Agent Logic

With the mechanism for collecting controller inputs understood, it is time to discuss the controller's logic. Remembering that the IA controller ultimately determines each thermostat's customized thermostat offset amount through the use of fuzzy logic, a Gaussian shape function is used to establish each input parameter's membership function on a scale from 0 to 1 (Figure 14). A similar function is established for the controller's output, with the temperature offset ranging from 0 to 5 °F.

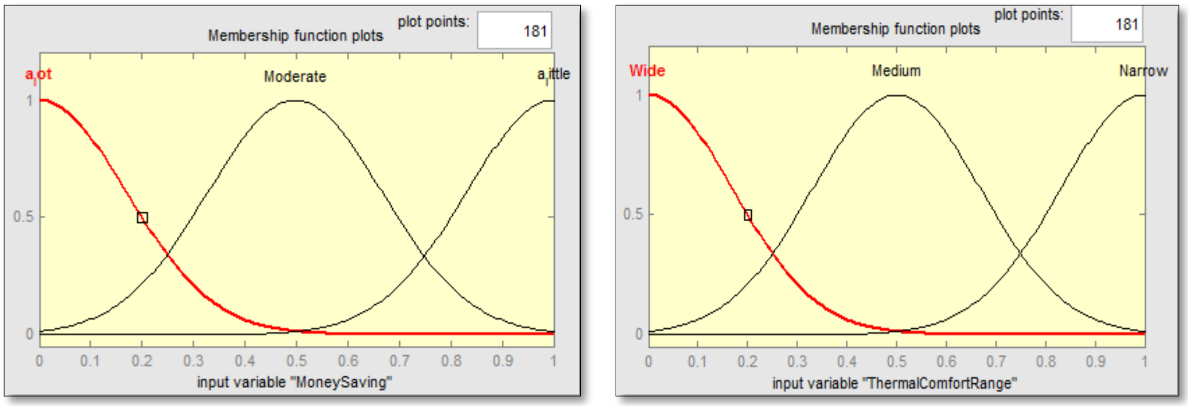


Figure 14 – Membership Function Plots for Money Savings and Thermal Comfort.

Next, fuzzy inference rules are established to map contours between system inputs and the single output. More details about these rules can be found in Appendix B. Figure 15**Error! Reference source not found.** illustrates how the home owner's preferences map to the thermostat offset for a DR event corresponding to lowest level of utility-determined urgency. By following this surface plot, the home owner's preferences, which range from 0 to 1, are ultimately mapped to a corresponding output between 0 and 4 °F. More controller surface plots can be found in Appendix B.

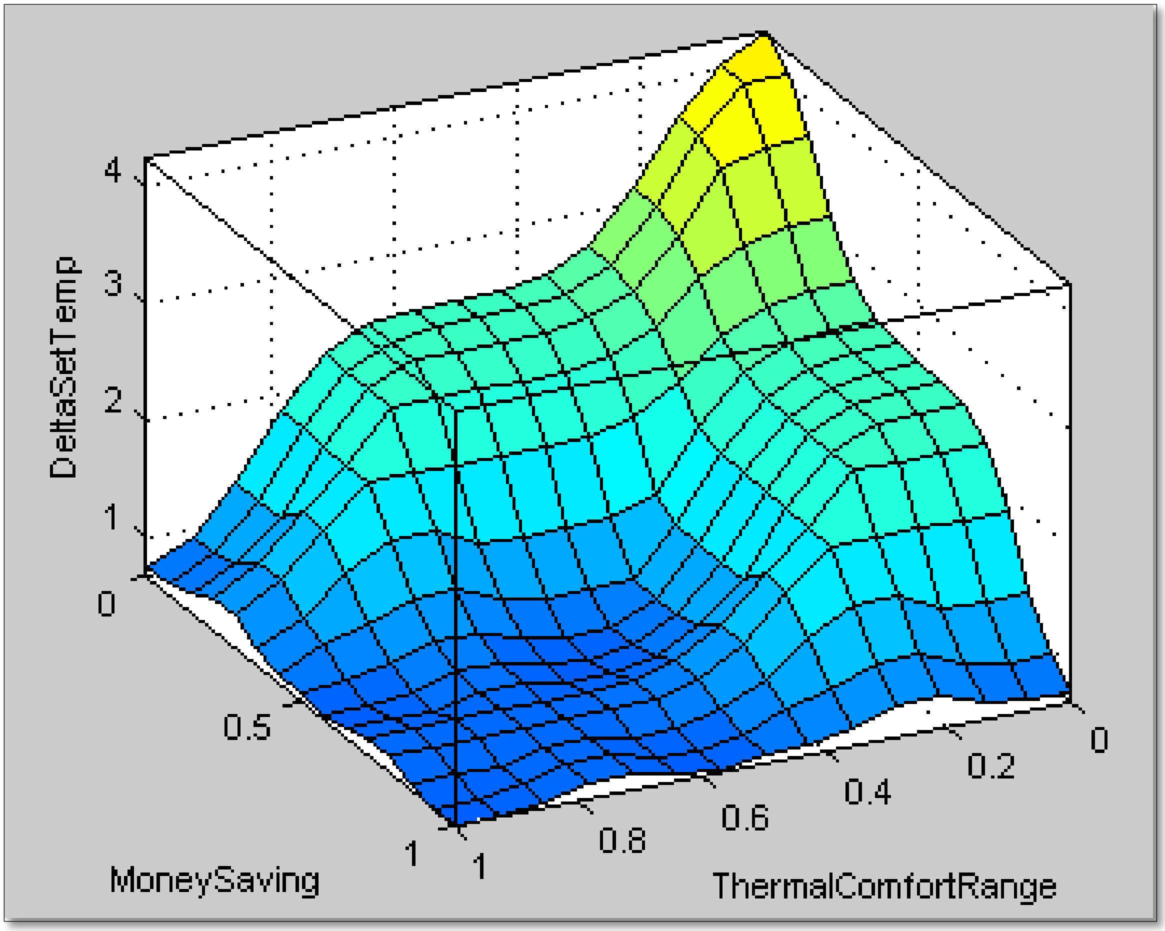


Figure 15 – Fuzzy Control Setpoint Offset Surface Plot for 'Normal' DR Urgency

3.6 Energy Storage Systems

Small distributed battery systems have seen an increase in (international) popularity recently as the technology matures and effective battery controllers are developed. It was important to everyone involved with the project that the potential domestic benefits of this type of distributed energy storage be investigated, particularly within the context of an entire community of homes that include electricity-generating sources.

Upon the launch of the battery storage project (BSP) pilot testing in 2011, it was one of only a handful of projects across the country that aimed to test the use distributed battery storage in a residential community. Though not part of the original proposal, after conducting some preliminary assessments, the project team decided to perform their distributed energy storage testing at Villa Trieste. Before installing battery storage equipment and launching the operation of pilot tests, a number of preparatory activities, including the following (not necessarily in the order listed) were required:

3.6.1 *Project Planning*

One of the first activities that the BSP team undertook was to document the project's objectives, structure, required processes, phases and use cases, metrics to be measured and corresponding data requirements, as well as technology and support needs. One of the elements that entered into the early planning function of the project was the type of battery to be incorporated. Initially it was thought that a large battery (probably a sodium-sulfur type) would be installed. However, after the contract was awarded, it was determined that a single centrally-located battery system would not be appropriate for many reasons, including that with the build out plan there would not be any location to put it. The price had risen substantially since the budget for the project was put together. Also, that type of battery has to be kept hot all the time, but its use was only sought for summer operation. Hence, individual house batteries would be used, and these are discussed in what follows.

3.6.2 *Identification of Battery Storage Vendors*

Given the novelty of battery storage technology, a substantial effort was made to identify and vet various offerings. The BSP team sought to find robust, integrated battery systems that were UL certified, were market-ready, and had a form factor that could accommodate easy installation in customers' garages. Unfortunately, the number of feasible options was found to be very limited.

3.6.3 *Acquiring the Battery Storage Technology*

Once a short-list of vendors had been developed, due diligence and negotiations were conducted to reach a mutually agreeable structure and ensure that vendors could deliver the required capabilities within the desired time and budget constraints, while committing to provision of adequate levels of product and customer support.

3.6.4 *Customer recruitment*

The BSP team undertook several activities to recruit homeowners at Villa Trieste to participate in the program. These efforts included development of an incentive plan, an email campaign, phone calls, as well as door-to-door engagement with customers.

3.6.5 *Permitting*

The novelty of this pilot resulted in relatively long permitting timeframes, since Clark County Planning Department staff did not have the benefit of any sort of local precedent. For example, permitting of the first installed unit took nearly seven months. In addition, each subsequent change in the project, such as use of a new type of battery, triggered a number of new data requests or possibly a restart of the entire process.

3.6.6 System installation

The BSP team engaged a local electrical services firm to oversee the installation of the battery storage system and perform any required re-wiring and installation of peripheral equipment such as additional meters and sensors.

3.6.7 Data Gathering/Analysis and Reporting

In close cooperation with the battery system vendors, the BSP team worked diligently to ensure that a wide range of data could be collected to enable the measurement and tracking of key metrics, data analysis, and production of regular quarterly system performance reports. This report presents the culmination of this process by providing a compilation of performance data from the entire duration of the pilot testing. See Appendices Appendix C, Appendix D, Appendix E and Appendix F for a summary of this information.

4 Data Collection and Supporting Hardware

To quantify Villa Trieste energy consumption, it was necessary to install hardware that would allow researchers to log various measurements and observations at high resolution. Some of these logged data include energy consumption, thermostat readings, and PV panel energy production, among others. Several of the systems were designed to passively collect data from a strictly monitoring standpoint, while others relied on active two-way communications to supplement data collection with control capabilities. Multiple data logging strategies were employed, including event-driven recording and standard sampling. Whereas standard sampling results in data being stored at regular intervals (ie, every minute), event-driven records are stored only when a measureable or observable change occurs to the relevant parameter.

Table 6 summarizes the data collection systems that were employed during the project period. Detailed system descriptions and data types are discussed in the following sub sections.

Table 6 – Summary of Data Collection Devices over Time

		2009				2010				2011				2012				2013				2014				2015			
Measurement Effort	Data Resolution	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Project Termination
Phase I – Indoor Temperature (°F)	15-minute																			■	■	■	■	■	■	■	■	■	
Phase I – Energy Consumption (Wh)	15-minute	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
Phase I – Indoor Temperature (°F)	Event-driven	■	■	■	■	■																							
Phase II – Indoor Temperature (°F)	1 minute									■	■	■	■	■	■	■								■	■	■	■	■	
Phase II – Energy Imported from Grid (Wh)	1 minute									■	■	■	■	■	■	■								■	■	■	■	■	
Phase II – Energy Exported to Grid (Wh)	1 minute									■	■	■	■	■	■	■								■	■	■	■	■	
Phase II – FCU Energy Consumption (Wh)	1 minute									■	■	■	■	■	■	■								■	■	■	■	■	
Phase II – AC Energy Consumption (Wh)	1 minute									■	■	■	■	■	■	■								■	■	■	■	■	
Phase II – PV Energy Consumption (Wh)	1 minute									■	■	■	■	■	■	■								■	■	■	■	■	
Phase III – Indoor Temperature (°F)	Event-driven																						■	■	■	■	■	■	
Phase III – Setpoint Temperature (°F)	Event-driven																						■	■	■	■	■	■	

Q1: January-March; Q2: April-June; Q3: July-September; Q4: October-December

4.1 Phase II – Passive Monitoring

Phase II was an initiative to gather data on a representative number (6) of Villa Trieste homes that could be used to preliminarily analyze energy consumption/generation and verify the energy models that had been developed during the design phase of the project. Additionally, interior temperature data were gathered in an attempt to gain insight that may have proved to be useful when developing the aforementioned Intelligent Agent system.

4.1.1 ZigBee Wireless System

Phase I was heavily reliant on ZigBee wireless technology. ZigBee is an open global standard built on IEEE 802.15.4, which is the basis for low-power personal area networks. ZigBee is another network layer built on top of 802.15.4 that supports advanced and robust mesh routing capabilities. Its low power output limits transmission distance to a maximum of 100 meters, but through its meshed framework, devices are capable of transmitting data over much longer distances by passing data through intermediate devices. A ZigBee "gateway" was installed in each participating home, effectively creating "nodes" for the mesh network. An early satellite picture of the unfinished Villa Trieste community with approximate node location can be seen in **Figure 16**.

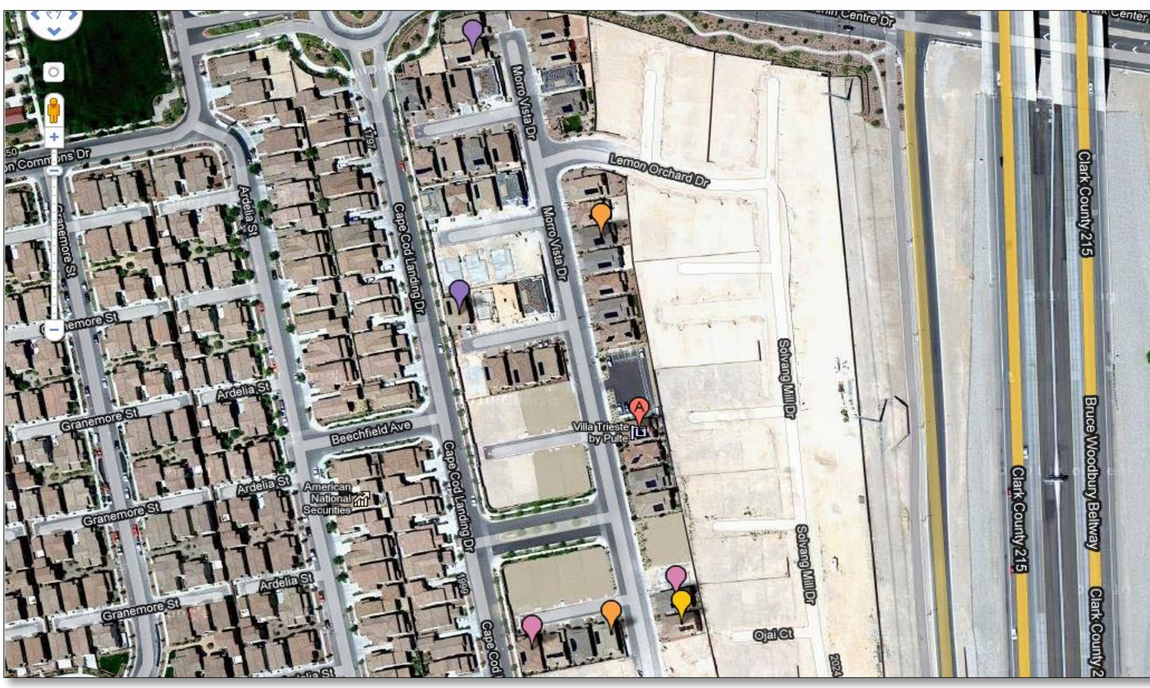


Figure 16 – ZigBee Mesh Network Nodes Locations

The ZigBee gateway designated by point A in **Figure 16** was located in the community's model home. It was connected to a GSM modem that was configured to relay data flowing through the mesh network straight to UNLV's data logging server. These data were recorded at a rate of once per minute for the duration of the experiment.

Even as each node was working within the context of the greater mesh network, they were also responsible for interfacing with locally-installed sensors. A block diagram that illustrates how temperature and energy sensors within these seven homes interfaced with the ZigBee can be seen in Figure 17.

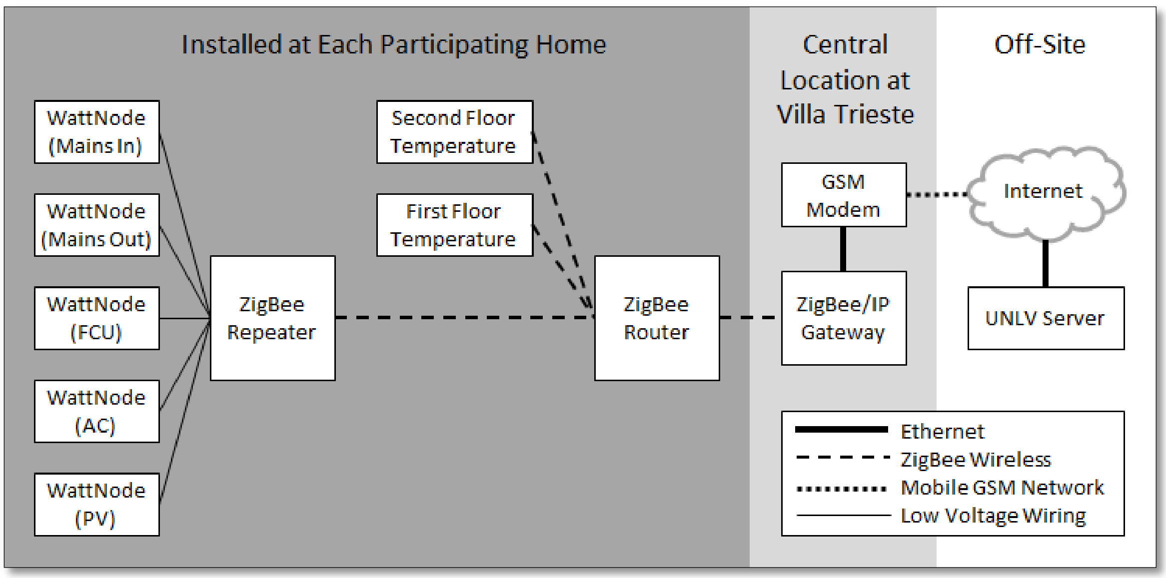


Figure 17 – ZigBee System Block Diagram

Due to undiagnosed issues with the ZigBee mesh network, not all homes monitored provided useful data, and those that did report consistently enough did so for only brief periods. Figure 18 contains a series of subplots for each of the 6 homes that participated in Phase II data collection. The value plotted indicates the number of records that were ultimately recorded by each set of monitoring hardware, keeping in mind that at a sampling rate of 1 minute, each day should represent 1440 discreet measurements. From February 2011 to the early part of July 2011, the entire mesh network experienced an extraordinarily high level of instability. Through the entire duration, the sensors labeled PWR2 only managed to record consistently for a brief period from July 2012 through the middle of August 2012. PWR3, PWR5, PWR6, and PWR7 all functioned comparably, from November 2011 through the middle of August 2012 with only one prolonged outage around March 2012. Over this same period, PWR8 had a little more difficulty communicating with the mesh network, but still had a large number of days with a sufficient number of records stored. More details can be found in Appendix G.

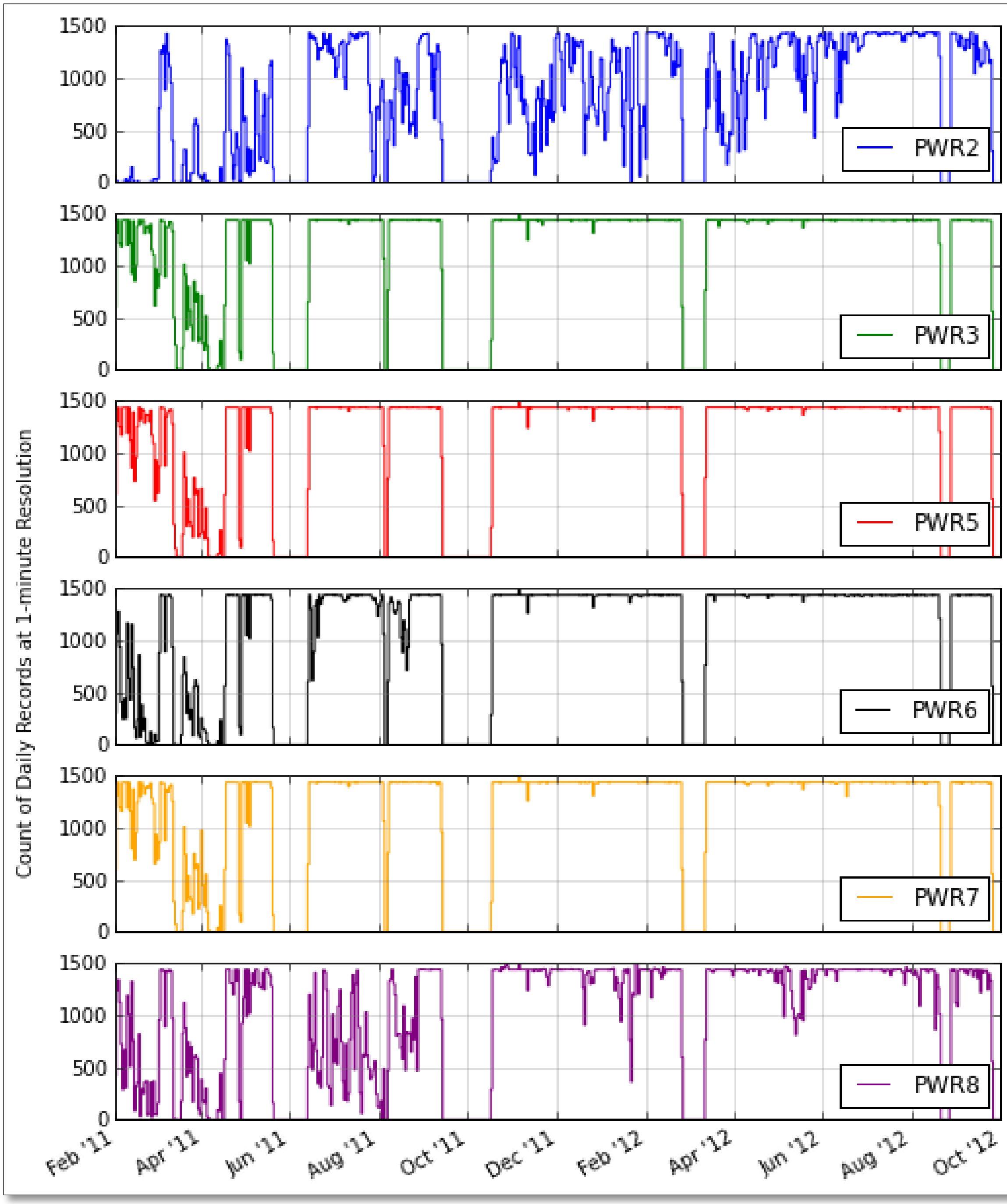


Figure 18 – ZigBee System Communication Consistency Quality

4.1.2 ZigBee Wireless Energy Sensors

At each of the seven participating homes, project boxes were installed next to each home's respective utility service panel, either within a garage or outside next to the panel. Each box was loaded with five WattNode Pulse watt-hour transducers and a wireless ZigBee Repeater as shown in **Figure 19Error! Reference source not found.**.

The current transducers (CT) attached to each WattNode device were wired so that they could measure the amount of current flowing through various wires. More details on this arrangement can be found in Appendix H. Coupled with a knowledge of what voltages each wire was subject to, these CTs allowed researchers to obtain the following energy measurements:

- Amount of energy the grid delivered to the home.
- Amount of energy the home returned to the grid.
- Amount of energy generated by the PV panels.
- Amount of energy consumed by the AC system.
- Amount of energy consumed by the fan coil unit (FCU).

4.1.3 ZigBee Wireless Temperature Sensors

Researchers wanted to obtain representative interior temperature measurements for both floors in each participating home. In an attempt to be an unobtrusive as possible, each temperature collection device (Figure 20) was packaged within a small project box that would plug directly into a wall outlet (Figure 21).

When placed in the homes, CER personnel worked with the homeowners to find acceptable placement locations that were on interior walls, away from registers, and as out-of-sight as possible. For reasons discussed later, this may not have resulted in the most "representative" temperature measurements for each zone.

Figure 19 – WattNode model WNB-3Y-208-P and Installed Project Box.

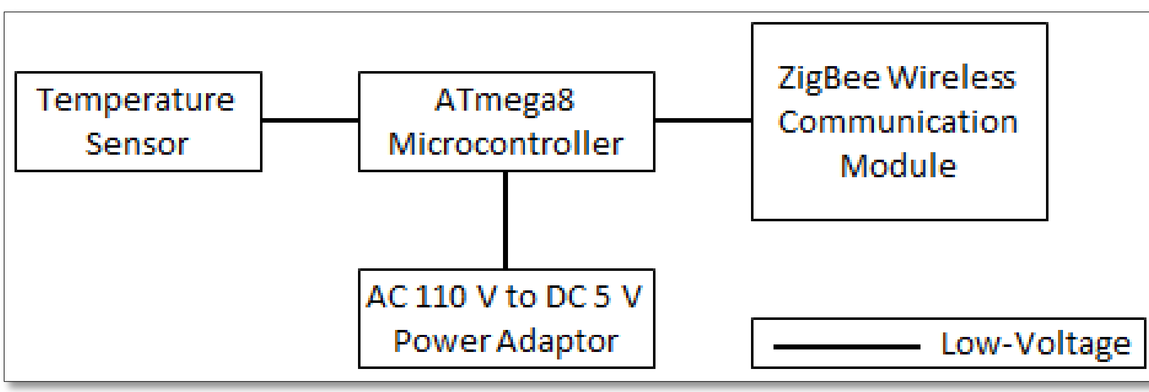


Figure 20 – Temperature Sensor Hardware Block Diagram

Figure 21 – Temperature Sensor Enclosure

4.1.4 Weather Data

It was assumed that later analysis could in some way involve weather data, so a temporary weather station capable of measuring dry-bulb temperature, humidity, and global horizontal radiation was installed at Villa Trieste, even prior to Phase I of the experiment. However, later analysis of its recorded information showed that large chunks of data were missing for reasons that were unclear to the researchers. Fortunately, extremely localized weather data was later deemed to be unnecessary. Ambient conditions, especially solar insolation, do not vary substantially over distances of several miles.

For the purposes of later analysis, instead of relying on the temporary weather station's sporadic data, researchers tapped into the data supplied by the weather station located at CER's lab on the University of Nevada, Las Vegas. This weather station records historical ambient conditions on a per-minute basis dating from the present back to March 16th, 2006, and makes this information publically accessible through an assisted database-querying interface.

A script was setup to extract three different solar measurements daily through this weather station's interface – global horizontal irradiance (GHI), direct normal irradiance (DNI), and a calculated diffuse horizontal irradiance (DHI) – in addition to the ambient dry bulb temperature. These data were then processed and added to the same database that was logging Villa Trieste energy and temperature measurements.

4.2 Phase III – Active Monitoring

Phase II of the data collection process was centered on the installation of the Intelligent Agent hardware. This equipment would allow researchers to monitor and log direct thermostat measurements and observations, while at the same allowing researchers to push signals to the same thermostats and enact DR events.

Notable differences between Phase I and Phase II include the fact that energy measurements were not included within the scope of Phase II's objectives, and standalone temperature sensors outside of the thermostats themselves were not involved. The only hardware required to supplement the thermostats was a single ZigBee gateway in each home that would act as an intermediary bridging communications between the thermostats and CER's server.

4.2.1 Hardware

The thermostat chosen to support this work was manufactured by RCS Technology, model number TZB45U (Figure 22). This particular thermostat was constructed with this sort of project's application in mind. It acted in every way like a "standard" programmable thermostat, except that it contained a ZigBee module similar to the modules utilized during Phase I of the data collection process. It was also designed and built to support the OpenADR protocol, a publically-available protocol specifically created to help utilities, manufacturers, and researchers implement DR programs. As such, it was a perfectly suited thermostat for the IA's purposes.

Figure 22 – RCS Technology's TZB45U Thermostat

In order to allow the thermostat to communicate with the UNLV server, it was necessary to install a "gateway" in the home that would be capable of communicating with the thermostat via the ZigBee protocol, but also be able to relay this information through the internet back to UNLV's server. In fact, the TZB45U is typically sold as a packaged deal with one of these pieces of equipment – an ISY994i-Z manufactured by Universal Devices (Figure 23).

Figure 23 – Universal Devices' ISY994i-Z

Prior to being installed in the Villa Trieste homes, each gateway was manually "paired" to two thermostats by CER researchers at UNLV. Some additional configuring of the ISY994i-Z was necessary so it would be capable of communicating with UNLV's server, but the system was then ready to be installed in a home. For the installation of this equipment, researchers relied on professional HVAC installers to replace the existing thermostats found in the homes. The result was a simple, secure, and streamlined infrastructure for implementing internet-based DR events and obtaining thermostat measurements and observations (Figure 24).

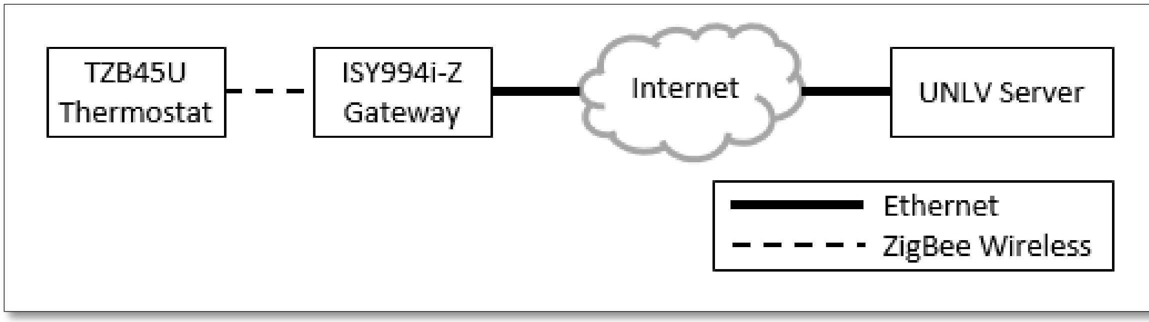
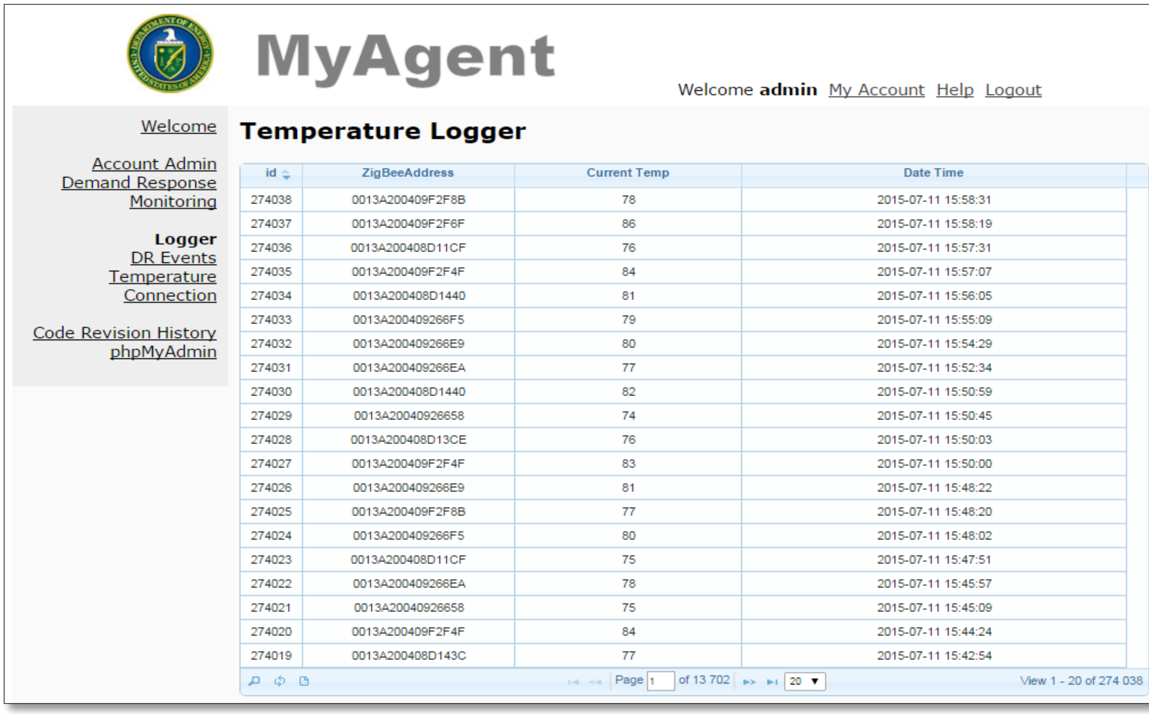


Figure 24 – Phase II's Active Monitoring System Block Diagram (installed at each participating home)

4.2.2 Data Logging

The equipment described in section 4.2.1 was designed to operate on an event-driven basis. This type of approach is well-suited for this application considering the relatively static nature of all of a thermostat's parameters. For example, a temperature setpoint may be changed as infrequently as once every two weeks, so it only makes sense to record the instances in time when those changes are made rather than logging the unchanging setpoint value of 76 every five minutes for two weeks straight. This advantageously reduces the size of the database needed to accurately represent thermostat activity within a home.

Event-based parameter change signals are initiated by the thermostat itself. Prompted by the change of any parameter on the thermostat, an entire "state of the thermostat" signal is transmitted to the gateway. The gateway then repackages this information and forwards it on to UNLV's server within a conveniently documented API where a daemon running on the server intercepts any and all incoming thermostat-status packages. The daemon then compares the received signal to the previously received signal, picks out any changes between the two states, and then writes the appropriate parameters' changes to their respective tables within the MySQL database. This data could be easily live-queried by the IA online portal to provide real-time statistics and metrics to home owners and IA administrators. A tabular visualization tool was even built into the IA administrators' webpage (**Figure 25**).



MyAgent

Welcome **admin** My Account Help Logout

Welcome

Account Admin
Demand Response
Monitoring

Logger
DR Events
Temperature
Connection

Code Revision History
phpMyAdmin

Temperature Logger

id	ZigBeeAddress	Current Temp	Date Time
274038	0013A200409F2F8B	78	2015-07-11 15:58:31
274037	0013A200409F2F6F	86	2015-07-11 15:58:19
274036	0013A200408D11CF	76	2015-07-11 15:57:31
274035	0013A200409F2F4F	84	2015-07-11 15:57:07
274034	0013A200408D1440	81	2015-07-11 15:56:05
274033	0013A200409266F5	79	2015-07-11 15:55:09
274032	0013A200409266E9	80	2015-07-11 15:54:29
274031	0013A200409266EA	77	2015-07-11 15:52:34
274030	0013A200408D1440	82	2015-07-11 15:50:59
274029	0013A20040926658	74	2015-07-11 15:50:45
274028	0013A200408D13CE	76	2015-07-11 15:50:03
274027	0013A200409F2F4F	83	2015-07-11 15:50:00
274026	0013A200409266E9	81	2015-07-11 15:48:22
274025	0013A200409F2F8B	77	2015-07-11 15:48:20
274024	0013A200409266F5	80	2015-07-11 15:48:02
274023	0013A200408D11CF	75	2015-07-11 15:47:51
274022	0013A200409266EA	78	2015-07-11 15:45:57
274021	0013A20040926658	75	2015-07-11 15:45:09
274020	0013A200409F2F4F	84	2015-07-11 15:44:24
274019	0013A200408D143C	77	2015-07-11 15:42:54

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Figure 25 – Tabular Tool for Examining Database Records

In terms of the information that was actually time-stamped and logged, incremental revisions to the server's daemon resulted in several logged parameters being added as the project continued. A timeline of these parameters' additions can be seen in Figure 26, followed by a short discussion of each.

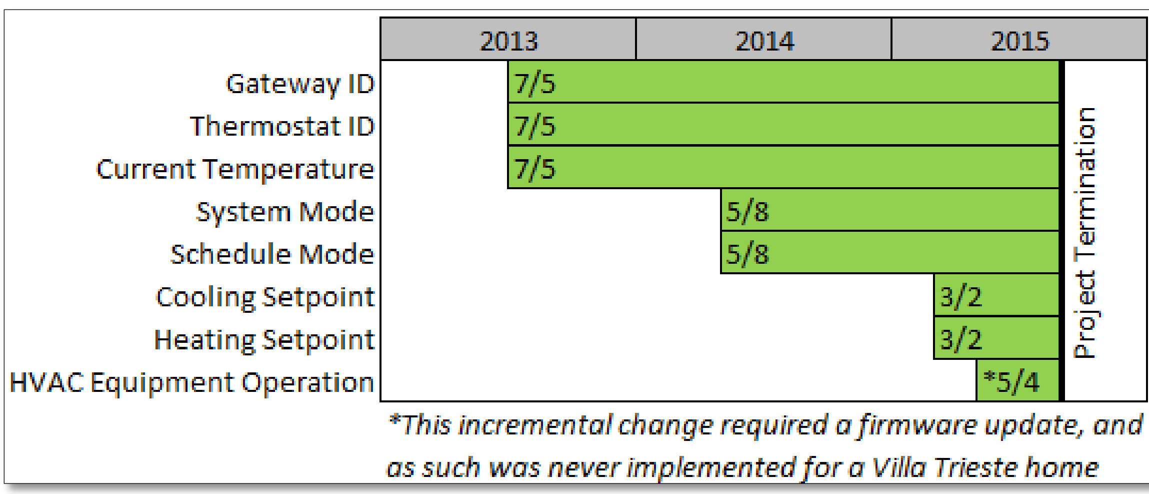

Figure 26 – Logged Thermostat Parameters

4.2.2.1 Gateway/Thermostat IDs

It was critical that researchers were able to identify exactly which thermostat parameter changes originated from. This allowed profiles to be generated on a per-thermostat basis, and allowed for comparisons to be made between even thermostats located within the same home.

4.2.2.2 Current Temperature

As Phase II aimed to emulate the temperature-sensing capabilities of the devices included within Phase I, it made sense to record historical temperature changes within the homes participating in the project. The hope was that this information would later prove to be useful during the analysis phase of the project or any subsequent IA improvement approaches.

4.2.2.3 System/Schedule Mode

A thermostat's system mode is restricted to HEATING, COOLING, or AUTO, and generally communicates the type of conditioning the thermostat is allowed to authorize. For example, while in HEATING mode, the thermostat observes the HEAT setpoint only, and cannot initiate any air conditioner usage. Similarly, while in COOLING mode, the COOL setpoint is the observed setpoint and no heater can be utilized to warm the home up. AUTO mode allows the thermostat to use either air conditioning or heating when necessary.

Schedule mode is a binary parameter that communicates whether or not the thermostat is adhering to a programmed schedule. When in RUN mode, the thermostat will make changes to the appropriate setpoint, corresponding to the schedule that has been programmed either through the thermostat or via the IA online portal. HOLD mode indicates that no schedule is being observed by the thermostat.

4.2.2.4 Cooling/Heating Setpoints

The heating and cooling setpoints are examples of parameters that had been temporarily stored within the database since the installation of the IA system to facilitate DR offsets and returns, but they weren't time-stamped and logged until the second summer of operation. These setpoints really define the essence of a thermostat – the homeowner uses these numbers to communicate to their equipment exactly the temperature they'd like their equipment to work to maintain in their homes.

4.2.2.5 HVAC Equipment Operation

The last parameter provided by the thermostats that was time-stamped and logged was the alert that communicated a thermostat's control signal to turn HVAC equipment either on or off. This parameter allowed researchers to historically document air conditioning (and heater) usage, and quantify duty cycle durations.

Unfortunately, the implementation of this recording feature required a firmware update be made to the ISY944i-Z gateway. This update could not be completed "over the air", and required direct access to the installed devices. Instead of intruding on the gracious volunteers at Villa Trieste, several more IA systems were installed in homes around the Las Vegas valley in an attempt to glean some utility from the parameter.

4.3 Comparative Data

Since the objective of the project was to reduce peak energy consumption *compared to code-built homes*, it was necessary to obtain data from homes that would serve as baseline comparators.

The process began by requesting data from the Clark County Assessor's Office that included information on 636,614 residences in the greater Las Vegas area. Each residence was associated with about 70 parameters including, year built, number of bedrooms, garage attached, fireplace included, among others. These residences were then filtered down based the year built (1989-2012), square footage (1500-1800), lack of pool presence, lack of basement, and immediate vicinity to Villa Trieste (located in zip codes 89135, 89138, 89144, 89145, 89117, 89147, 89148 and 89124). These criteria were chosen to theoretically find comparable homes with which to gauge Villa Trieste against. Ultimately, approximately 4,500 homes were selected for this purpose.

With their impressive network of smart meters, NV Energy was able to provide historical electrical consumption data for the majority of filtered homes at a resolution of 15 minutes. Data included records[1] from May-September for both 2013 and 2014. In order to contextualize Villa Trieste's performance in relation to various codes' standards, three broad classifications were set, as seen in **Table 7**. This range of dates considered included four total revisions from two separate energy codes – the Model Energy Code (MEC) and the International Energy Conservation Code (IECC), and seven total revisions from two separate building codes – the Uniform Building Code (UBC) and the International Building Code (IBC). With so many varying codes involved, the classifications were aimed at broadly capturing the differences between energy codes.

Table 7 – Comparative Data Groupings for Las-Vegas-area Homes

[1] For the protection of privacy, the dataset was intentionally obfuscated so that in no way could individual residences ever be correlated back to a specific address or homeowner.

Year Built	Sample Size	Applicable Energy Codes	Date Adopted	Applicable Building Codes	Date Adopted
1989-1999	1363	1992 MEC	4/19/95	1988 UBC	11/21/90
				1991 UBC	8/4/93
				1994 UBC	7/5/95
				1997 UBC	8/24/98
2000-2005	1934	1992 MEC	4/19/95	1997 UBC	8/24/98
		2003 IECC	5/4/05	2003 IBC	11/19/03
2006-2012	848	2003 IECC	5/4/05	2003 IBC	11/19/03
		2006 IECC	1/17/07	2006 IBC	1/17/07
		2009 IECC	7/5/11	2009 IBC	6/5/11

5 Analysis and Results

5.1 Defining "Peak Periods"

As has been broadly discussed, "peak periods" are the periods of time in which the grid's demand for electricity far exceeds the median demand. For the purposes of analysis, researchers examined three different daily periods, as seen in Table 8.

Table 8 – Peak Period Definitions

Time Period	Description
4-6 PM	Used by NVE for most DR events activated during 2013 and 2014
4-7 PM	Used when simulating variable thermostat setback temperatures
1-7 PM	Used by NVE for the purposes of Time of Use (TOU) pricing

Ambient dry-bulb temperature is the primary factor considered when gauging the necessity and urgency of a potential DR event. Since this determination is made, at a minimum, of 24 hours in advance, the utility is reliant on day-ahead weather projections. Of course, a certain margin of inherent error exists when using day-ahead projections, but DR events are typically only planned when the dry-bulb temperature looks to exceed 100 °F for the majority of the late afternoon.

5.2 Impact of Temperature on Energy Consumption

By all measures, 100 °F is as arbitrary as 101 °F in terms of a threshold for DR event planning, but it's not entirely without basis. Using data obtained from smart meters installed at Villa Trieste (refer to Section **Error! Reference source not found.** for more details), researchers were able to examine the relationship between ambient dry-bulb temperature and average household energy consumption. **Figures 27** and **28** show how the household energy consumption on a 15-minute basis was impacted by the ambient temperature for summers of 2013 and 2014, respectively.

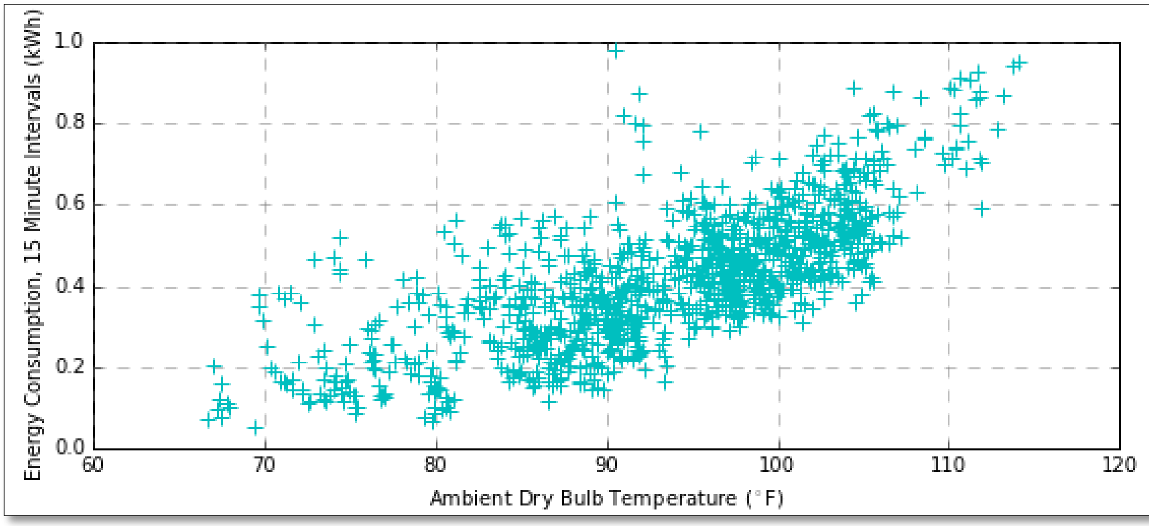

Figure 27 – Villa Trieste Average Household Energy Consumption for 4-8 PM from 5/1/13–9/31/13 during Periods Unaffected by DR Events

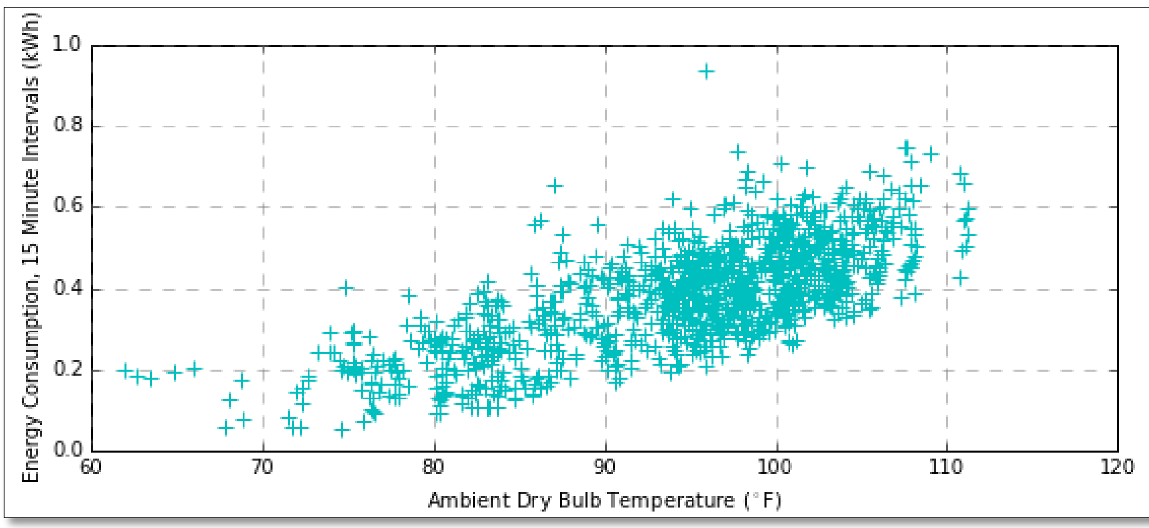

Figure 28 – Villa Trieste Average Household Energy Consumption for 4-8 PM from 5/1/14–9/31/14 during Periods Unaffected by DR Events

As has been alluded to previously, the reason for the increase in energy consumption during warmer periods of time is due to the influence of air conditioners. Using data gathered during Phase II of the monitoring efforts, Figure 29 was generated[2] to illustrate

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[2] The quality of data reporting (Figure 18) necessitated that only March through August of 2012 be taken into account. Additionally, the dataset was filtered to only include days in which no more than 15 minute-samples were missing.

the amount of energy, on average, a Villa Trieste home consumes just to meet its air conditioning requirements. Table 9 contains the figure's pertinent values, and it can be seen that during the warmer months of the year air conditioning accounts for a sizeable percentage of a home's overall energy demand.

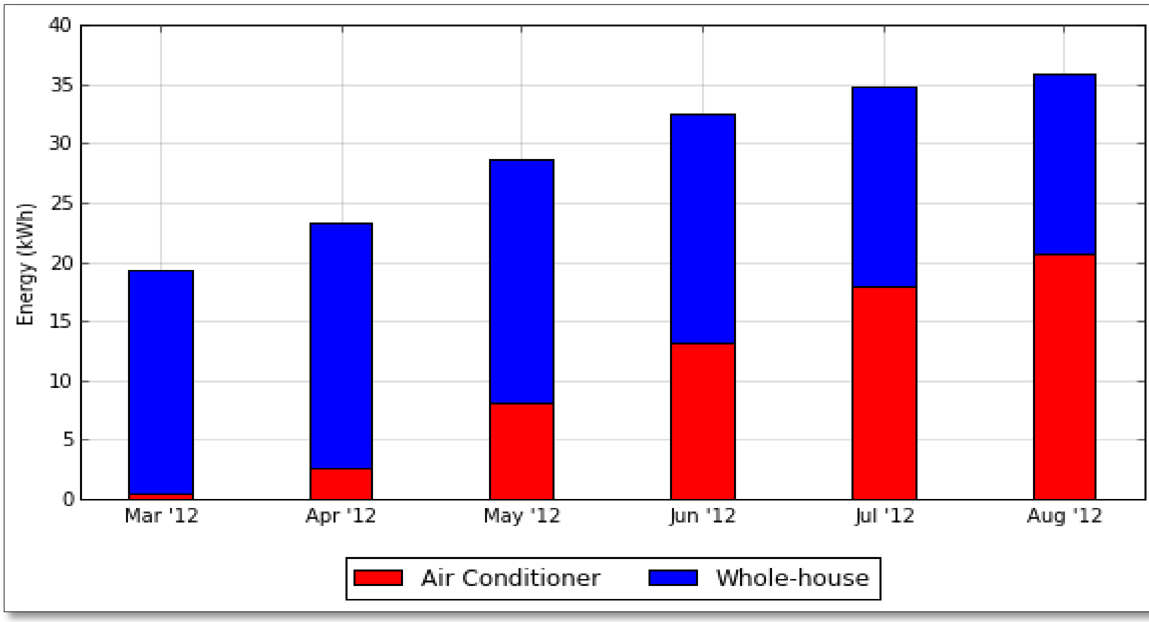


Figure 29 – Qualifying Five Villa Trieste Homes' Average Daily Energy Consumption by Destination per Month

Table 9 – Qualifying Five Villa Trieste Homes' Average Daily Energy Consumption by Destination per Month

Month	AC (kWh)	Net (kWh)	AC/Net (%)
Mar '12	0.5	19.3	2.8
April '12	2.6	23.3	11.1
May '12	8.1	28.7	28.2
June '12	13.3	32.6	40.7
July '12	17.9	34.8	51.5
Aug '12	20.7	35.8	57.9

5.3 Villa Trieste Energy Consumption Characterized

Using the same dataset that was utilized to produce Figure 29, researchers were able to further generalize summertime energy consumption tendencies for the Villa Trieste homes. Instead of breaking down energy consumption by end use, Figure 30 shows average whole-house consumption broken down by energy source. The same figure also visualizes the degree to which solar panel production supplemented utility-delivered energy during 2012, while Table 10 includes the values that pertain to the graph.

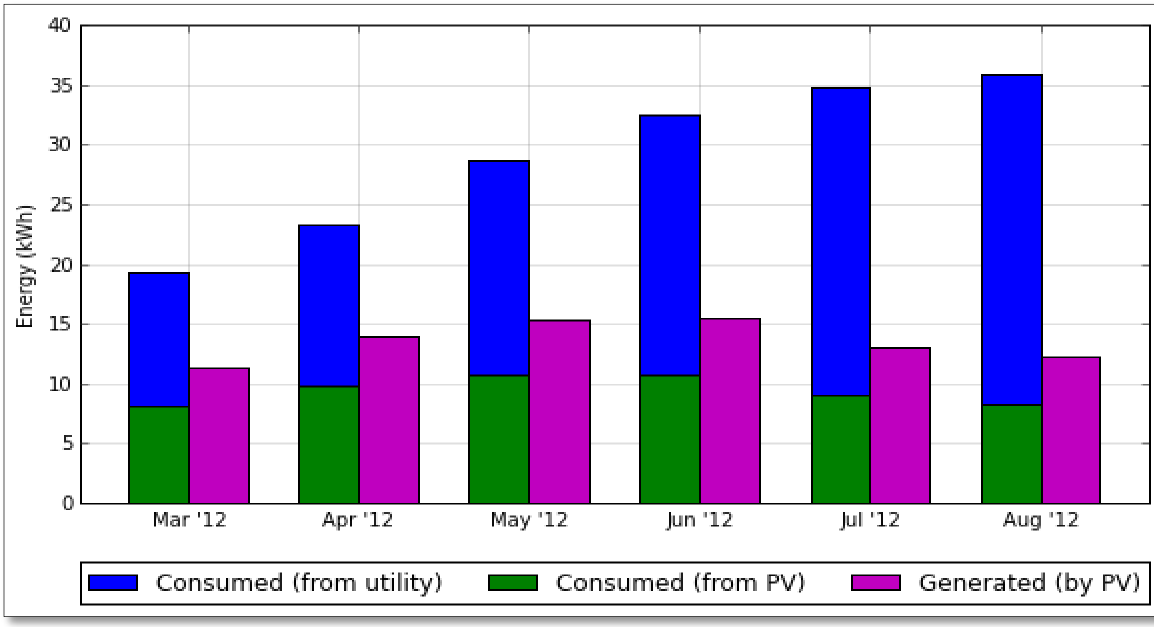


Figure 30 – Qualifying Villa Trieste Homes' (5) Average Daily Energy Consumption by Source and Net PV Generation

Table 10 – Qualifying Villa Trieste Homes' (5) Average Daily Energy Consumption by Source and Net PV Generation

Month	Mains In (kWh)	PV Consumed (kWh)	Net (kWh)	PV Consumed/ Net (%)	PV Generated (kWh)	PV Consumed /PV Generated (%)
Mar '12	11.3	8.1	19.3	41.7	11.4	70.8
April '12	13.5	9.8	23.3	42.0	14.0	70.0
May '12	17.9	10.7	28.7	37.4	15.3	70.0
June '12	21.8	10.8	32.6	33.0	15.4	69.7
July '12	25.7	9.1	34.8	26.2	13.0	70.2
Aug '12	27.5	8.3	35.8	23.3	12.2	68.2

Examining Figure 30, total consumption continued to increase from March through August, though the amount of consumed energy sourced from PV panels maxed out in May and June. For these reasons, the 'supplemented energy' percentage decreased nearly every month over the sampled time period. When the VT homes consumed the most energy during the month of August, and solar panel production was nearly minimized, over 20% of the homes' energy demands were still met by their PV systems. Regardless of the month, the examined VT homes consumed roughly 70% of the energy produced by their respective PV panels.

It is important to note that not all of the energy generated by PV is directly consumed. For example, Figure 31 shows several energy-related profiles during a day with uninterrupted solar irradiance. PV energy was generated steadily from about 6 AM to 6 PM, but the home's energy demands were such that sizable amounts of energy were exported to the grid instead of being directly utilized. In every instance in which the air conditioner cycled on, energy was no longer exported. Rather, it allocated to satisfying the demands of the air conditioner. Figure 32 is from the same dataset, but shows how even with air conditioning energy consumption remaining nearly constant throughout the daylight hours, the amount of energy required from the grid is lessened during the middle of the day due to the production of the PV.

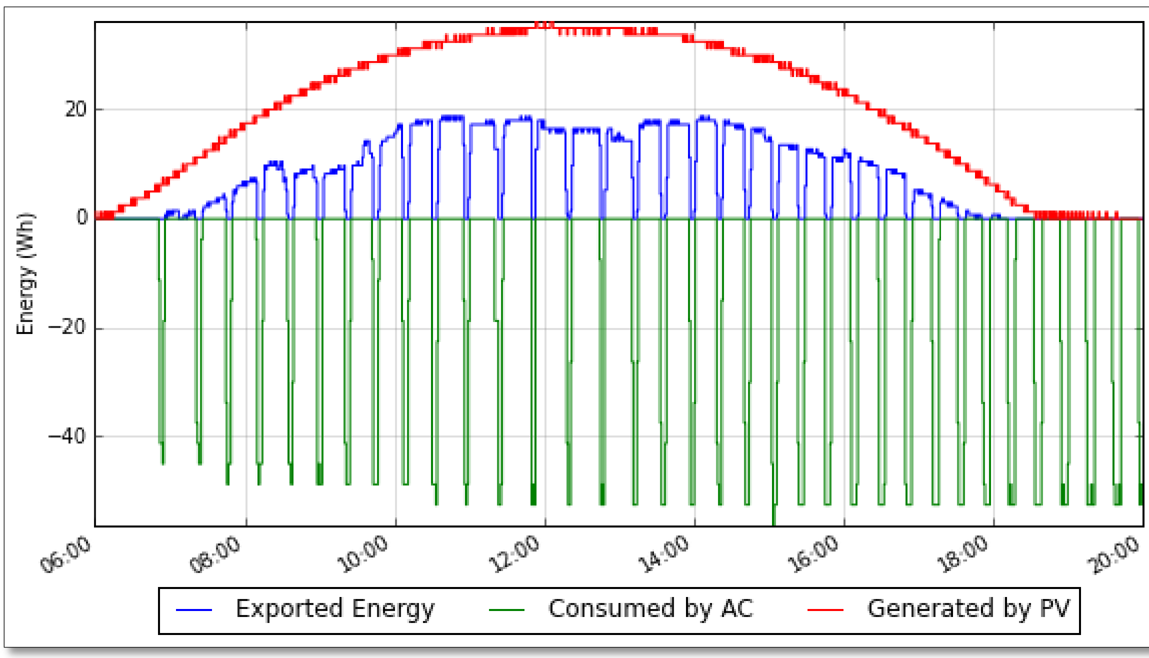


Figure 31 – Energy Consumption/Generation at 1-Minute Resolution during Daylight Hours for a Single Home on June 6, 2012

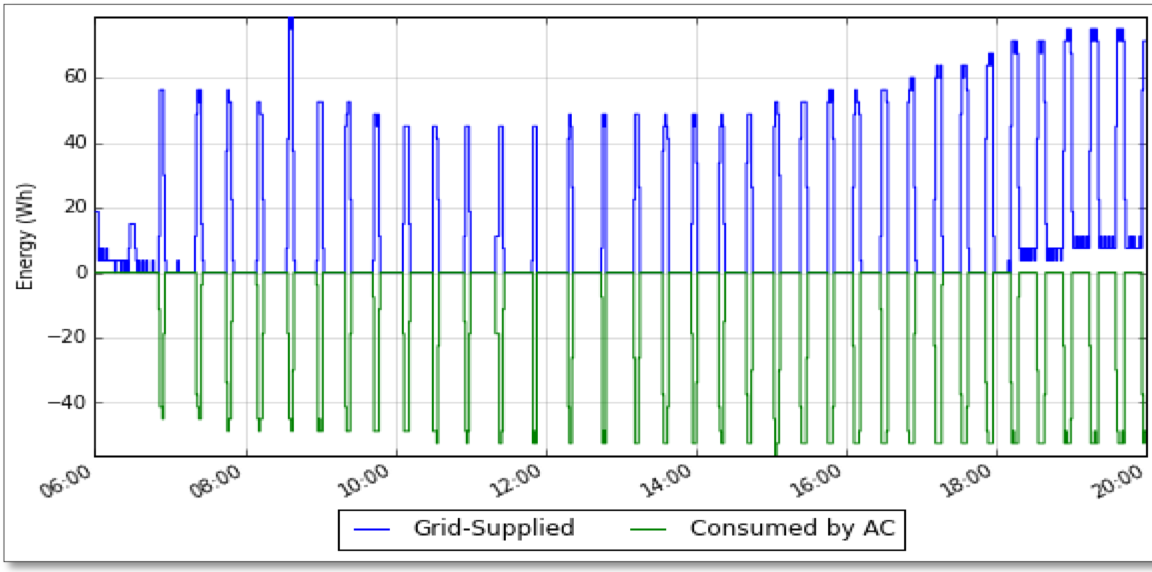


Figure 32 – Impact of PV on Amount of Grid-Supplied Energy Necessary to Satisfy Air Conditioning Demand

As discussed, since PV production is intrinsically tied to air conditioner usage, it is possible to examine how much of the air conditioners' energy demands were offset by PV-sourced energy. From a net metering standpoint, Figure 33 shows the average daily air conditioner load per month and the amount of energy generated by PV. Over this limited range from March through August, PV panels offset air conditioning demands by over 18 kWh.

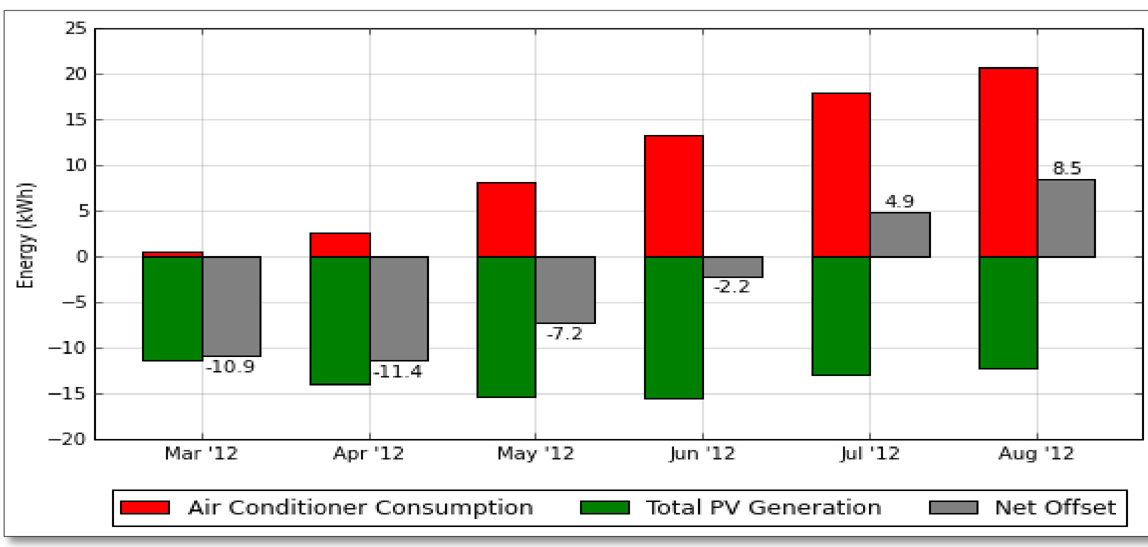


Figure 33 – PV Offsetting Air Conditioner Demands

5.4 Peak Reduction

Understanding that the project's main objective was for the VT community to achieve a substantial reduction in peak energy consumption when compared to code-built homes, it was necessary to first establish the baselines that would act as experimental controls.

5.4.1 Baseline Comparison Formulation

Tapping into the resources provided by NV Energy's extensive Trilliant smart meter network, a selection of 4500 homes in the Las Vegas area was made based on characteristics that that made the homes similar to Villa Trieste – things like similar square footage, number of stories, no swimming pool present, etc. With the dataset in place, researchers were able to draws some aggregate conclusions on how houses built during different building-code eras (**Table 7**) characteristically consumed energy.

When analyzing the data to form the baseline comparisons, it was critical to restrict the dataset such that it would only contains data from extremely warm days – the type of days in which peak demand was a legitimate concern. Taking a look at the average ambient temperature between 4-6 PM for the summer months of both 2013 (**Figure 34**) and 2014 (**Figure 35**), the vast majority of DR-employed-days occurred when the temperature exceeded 100 °F. There were also a large number of comparably warm days in which no DR events were run. With no external efforts to decrease consumption, these were the days that would be used to define the "baseline" comparators.

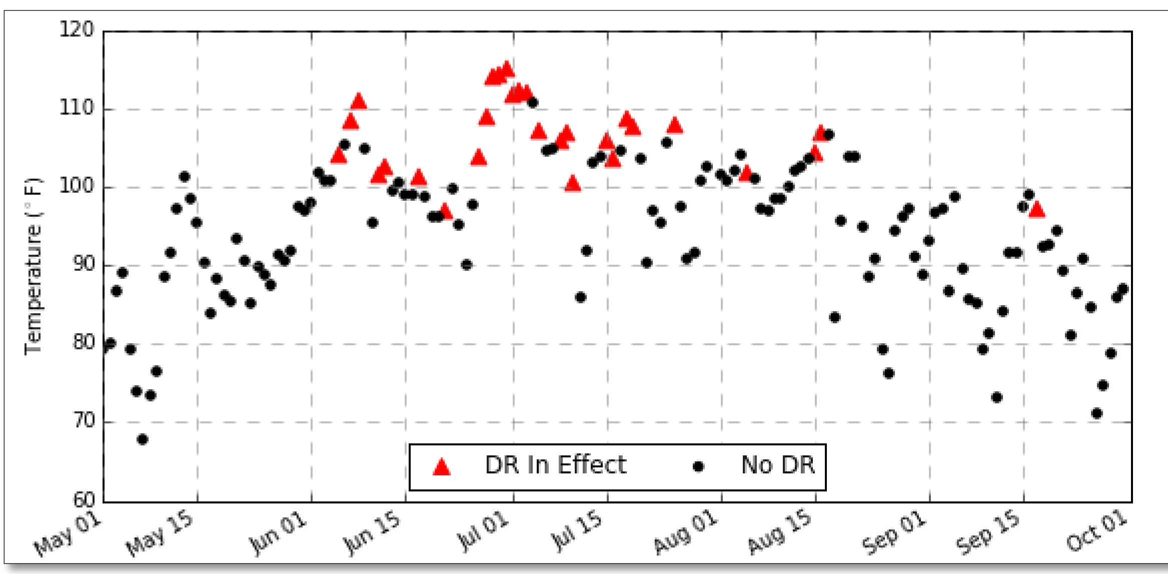


Figure 34 – Average Ambient Dry-Bulb Temperature from 4-6 PM for 2013 Summer

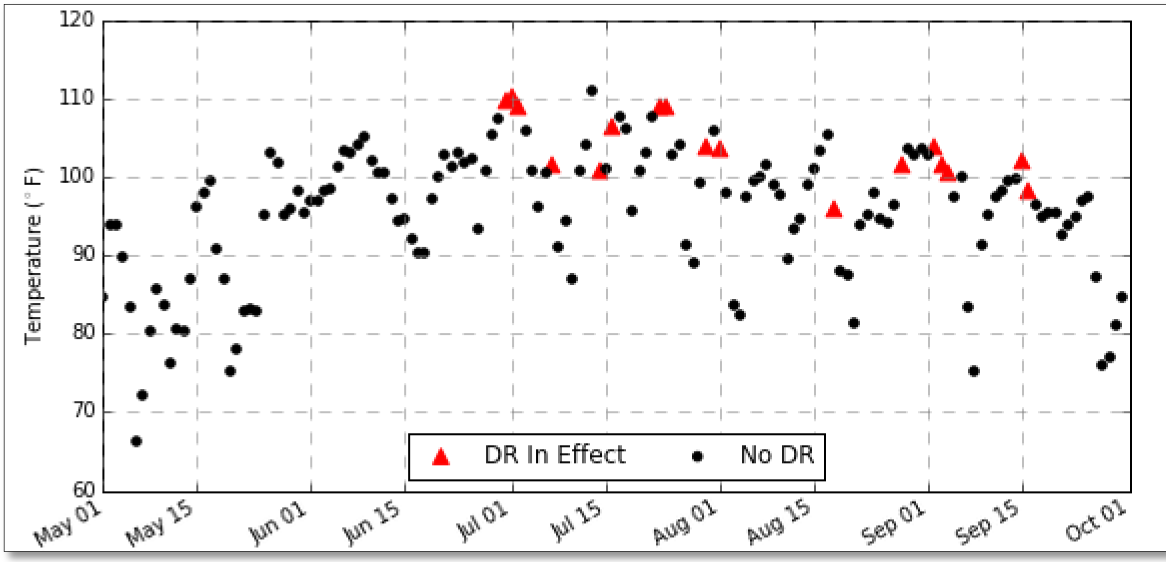


Figure 35 – Average Ambient Dry-Bulb Temperature from 4-6 PM for 2014 Summer

Considering summer days in 2013 in which NVE did not run any DR events and the average ambient temperature exceeded 100 °F during the 4-6 PM peak period, Figure 36 shows, at 15-minute resolution, how differently the homes constructed during the three eras consumed energy.

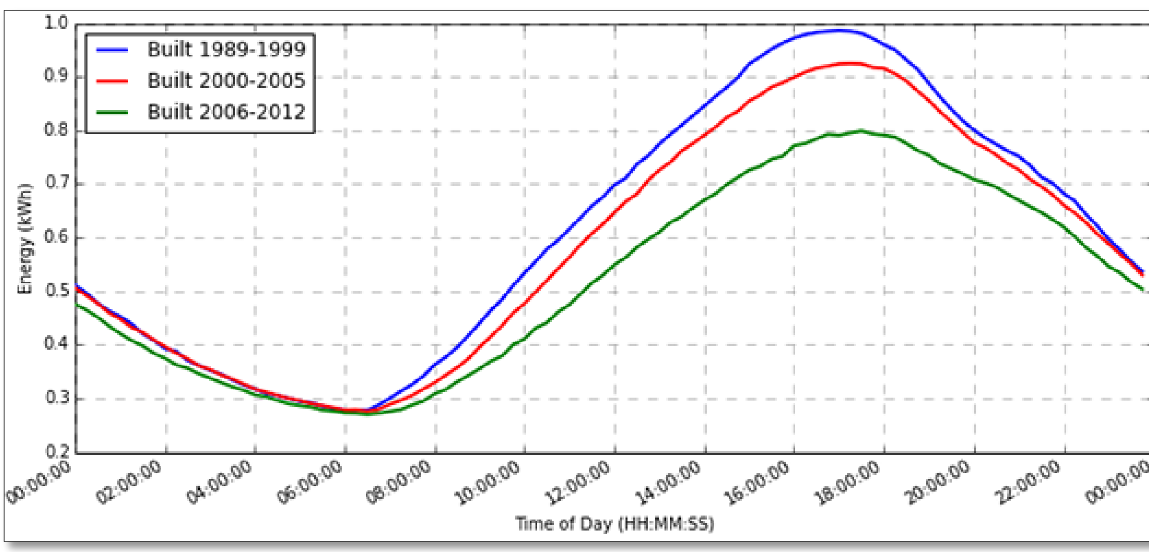


Figure 36 – Characteristic Energy Consumption by Home Construction Era

5.4.2 Passive Reduction

In terms of passive peak demand reduction, this is in reference to all of the days in which there were no external stimuli attempting to further reduce consumption. In essence, this reduction can be solely attributed to all of the energy efficiency measures that were built into the Villa Trieste homes.

Nearly 50 VT homes were outfitted with smart meters that were comparable to the meters used to gather data for the baseline comparators. Unlike the baseline, though, the smart meters installed at VT were capable of collecting and recording data at 12 minute intervals rather than 15. After some down sampling to ensure the scale would be usable for comparisons sake, Figure 37 was generated.

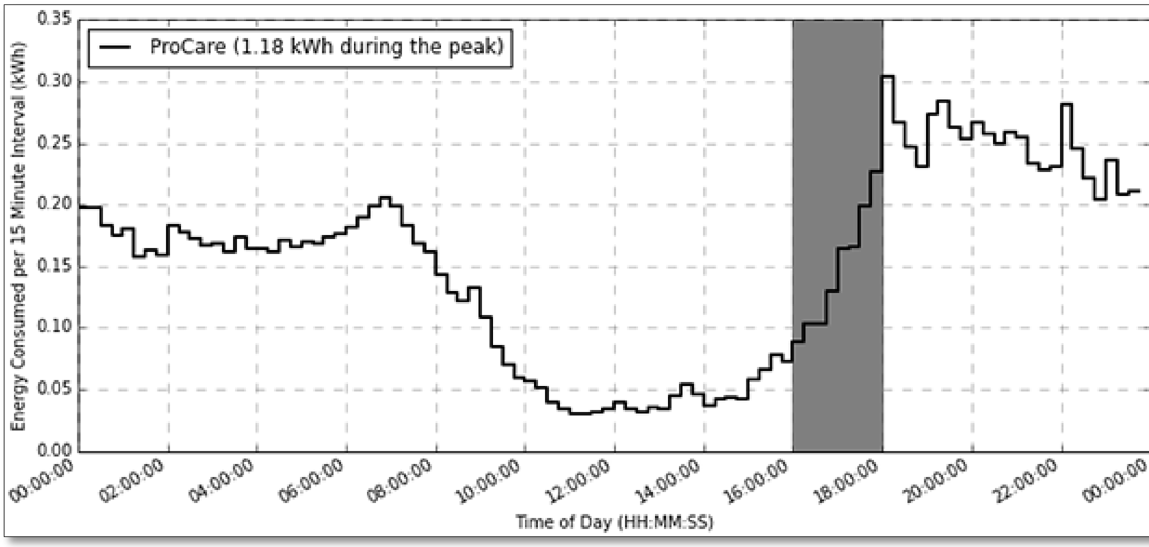


Figure 37 – Average Utility-Provided Energy Consumption Profile of 49 Villa Trieste Homes on September 23, 2013. Shaded gray indicates peak hours of 4-6PM.

At an aggregate level, across the entirety of the summer of 2014 (for the "hot" days previously described), substantial energy savings were realized by the Villa Trieste homes. For the sake of the points made in Section 5.1, three different peak-hour scenarios were examined, with the results summarized in **Table 11**. What the results show is that *passively*, the VT homes provide more than 38% peak energy saving from 4-6 PM over the collections of homes that were built under the most recent energy code (IECC-2006). Perhaps most impressively, this data shows that Villa Trieste homes actually use essentially half as much energy as the homes built to the codes applicable from 1989 to 1999.

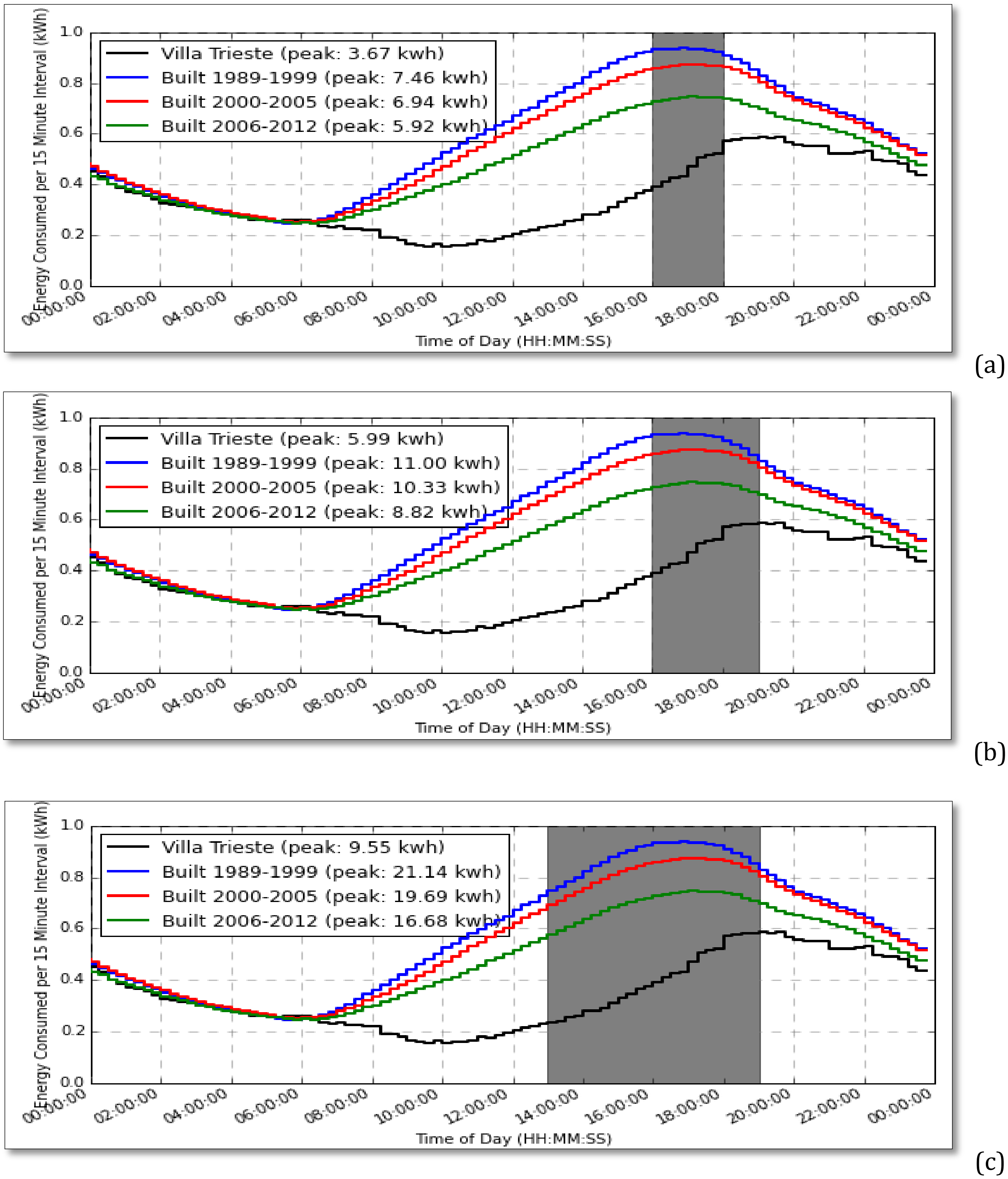


Figure 38 – Summer energy consumption Curves in 2014 during 24-hour period. Peak Energy consumption under shaded area of (a) 4-6pm, (b) 4-7pm and (c) 1-7pm were summarized in the upper left corner of each plot.

Table 11 – Energy Savings during Multiple Peak-hour Scenarios

Home Category	Energy Consumption (kWh)			Energy Savings (%)		
	1-7PM	4-7PM	4-6PM	1-7PM	4-7PM	4-6PM
Villa Trieste	9.55	5.99	3.67	-	-	-
1989-1999	21.14	11.00	7.46	54.8	45.5	50.8
2000-2005	19.69	10.33	6.94	51.5	42.0	47.1
2006-2012	16.68	8.82	5.92	42.7	32.1	38.0

5.4.3 Active Reduction – Demand Response

It was shown in the last segment that passive peak reduction, while significant, did not reach the 65% threshold that was outlined as the project's major objective. To realize further reductions during the peak period, active strategies were necessary. Section 3.4 spoke to the importance of demand response, and both NV Energy and UNLV worked together diligently to gather useful information on the efficacy of the demand response events that affected the participating homes of Villa Trieste.

The process for initiating an event would begin at NV Energy, where DR controllers would project, a day in advance, when they would intend to schedule an upcoming event. This information would be passed along to UNLV, and the IA system would be notified of the coming event. Appendix A includes more information on the mechanics behind this process.

There were a couple avenues through which DR events were implemented. Initially, NV Energy was able to enroll a number of households in their 'Cool Share' program. As part of this program, those household received thermostats that responded to NV Energy's over-the-air DR signals. Of those homes, 15 of them also had smart meters installed, which would allow researchers to quantify the impact of the DR strategies in terms of energy consumed during the peak period. Similarly, 3 of the homes with IA's installed had smart meters. An additional 29 homes that were smart metered and without DR-enabled thermostats were used as a control for comparison sake.

One of the IA system's capabilities allows for it to adjust thermostat setpoints dynamically, according to homeowner preferences, or statically without homeowner input. The latter is the technique used by Cool Share thermostats, which increases thermostat setpoints by 4 °F during peak periods. To emulate this program with the IA, UNLV ran what they referred to as *STANDARD* events. During the summer of 2014, four such events were implemented. Figure 39 shows, in 15-minute increments, how each subset of Villa Trieste homes reacted during the 4-6 PM peak period, and how they compared to homes built during differing eras. The Villa Trieste homes that did not have DR-enabled thermostats (designated as 'VT-None') consumed 3.95 kWh during this time period, roughly two-thirds as much energy as the homes built from 1989-2012. The VT homes with Cool Share thermostats (designated as 'VT-CS2N') improved on this number by consuming 3.21 kWh. The homes with IA hardware (designated as 'VT-IA') consumed just 1.93 kWh. The difference between the Cool Share and IA homes was unexpected, as the IA was emulating the Cool Share's default 4°F setpoint offset. Also of note, the non-VT homes exhibit signs of DR being shifted 30 minutes earlier than what was run at VT. This likely slightly skews the results. Regarding the different peak periods that could potentially be defined, Table 12 examines this in detail.

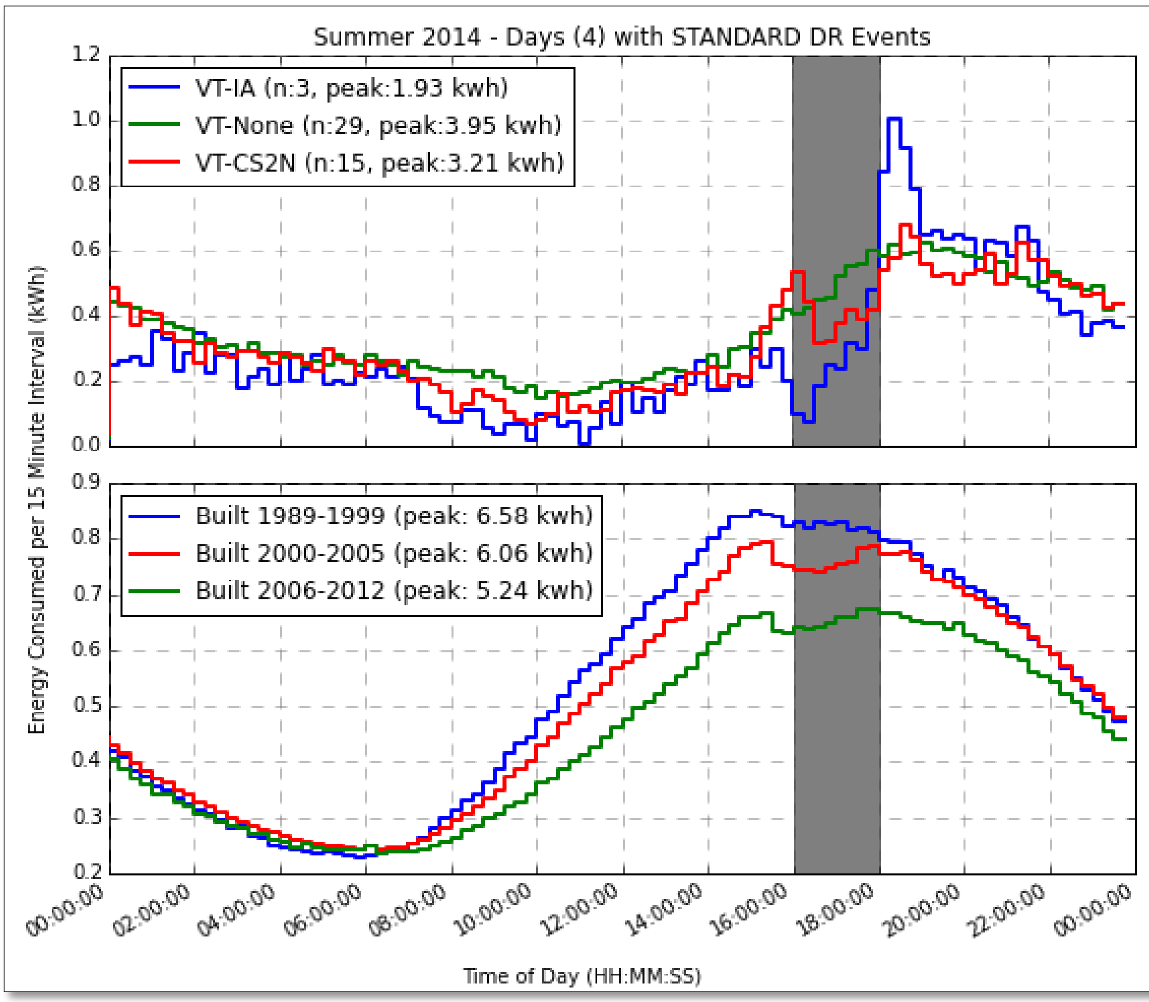


Figure 39 – Impact of STANDARD DR events during summer of 2014. Peak (4-6pm) energy consumption was further calculated and displayed with this plot.

Table 12 – Impact of STANDARD DR Events During the Summer of 2014 for Multiple Peak Periods

Home Category	Peak Hours Energy Consumption (kWh)	Energy Savings of IA by Comparison (%)

UNLV Howard R. Hughes College of Engineering

	1-7pm	4-7pm	4-6pm	1-7pm	4-7pm	4-6pm
Villa Trieste, Total *	9.42	6.06	3.59	-	-	-
Villa Trieste, IA	8.07	5.47	1.93	-	-	-
Villa Trieste, Cool Share	8.82	5.64	3.21	8.5	3.0	39.9
Villa Trieste, None DR	9.84	6.33	3.95	18.0	13.6	51.1
1989 Code-built Homes	19.36	9.73	6.58	58.3	43.8	70.7
2000 Code-built Homes	17.95	9.14	6.06	55.0	40.2	68.2
2006 Code-built Homes	15.28	7.89	5.24	47.2	30.7	63.2

**Energy consumption from all 47 smart-meter enabled homes.*

Table 12 also shows the overall energy savings achieved by the IA program over the other subsets of homes. From 4-6 PM, the time in which event was implemented, the IA-enabled homes achieved energy savings of over 63% compared to even the most recent code-built homes.

Figure 40 examines the same sort of energy reduction in response to a DR event, but the data that were used to formulate this graph came from the 13 days in which UNLV enacted the full dynamic capabilities of the IA platform – temperature setpoint offsets were dependent on homeowner preferences rather than automatic 4°F offsets. A full summary of consumption and savings over different peak periods can be seen in **Table 13**.

While the reduction in Villa Trieste's grid-demanded energy during the peak period of an IA DR event is encouraging, note the presence of a substantial secondary peak. UNLV must condition the thermostatically controlled loads – determining whether to address them during the peak period or not. In fact, when comparing Villa Trieste energy consumption profiles for IA DR, standard DR (constant 4° F setback), and unregulated days, the energy demand experienced an hour after an IA DR event is more than 150% more than the maximum demand during an unregulated day.

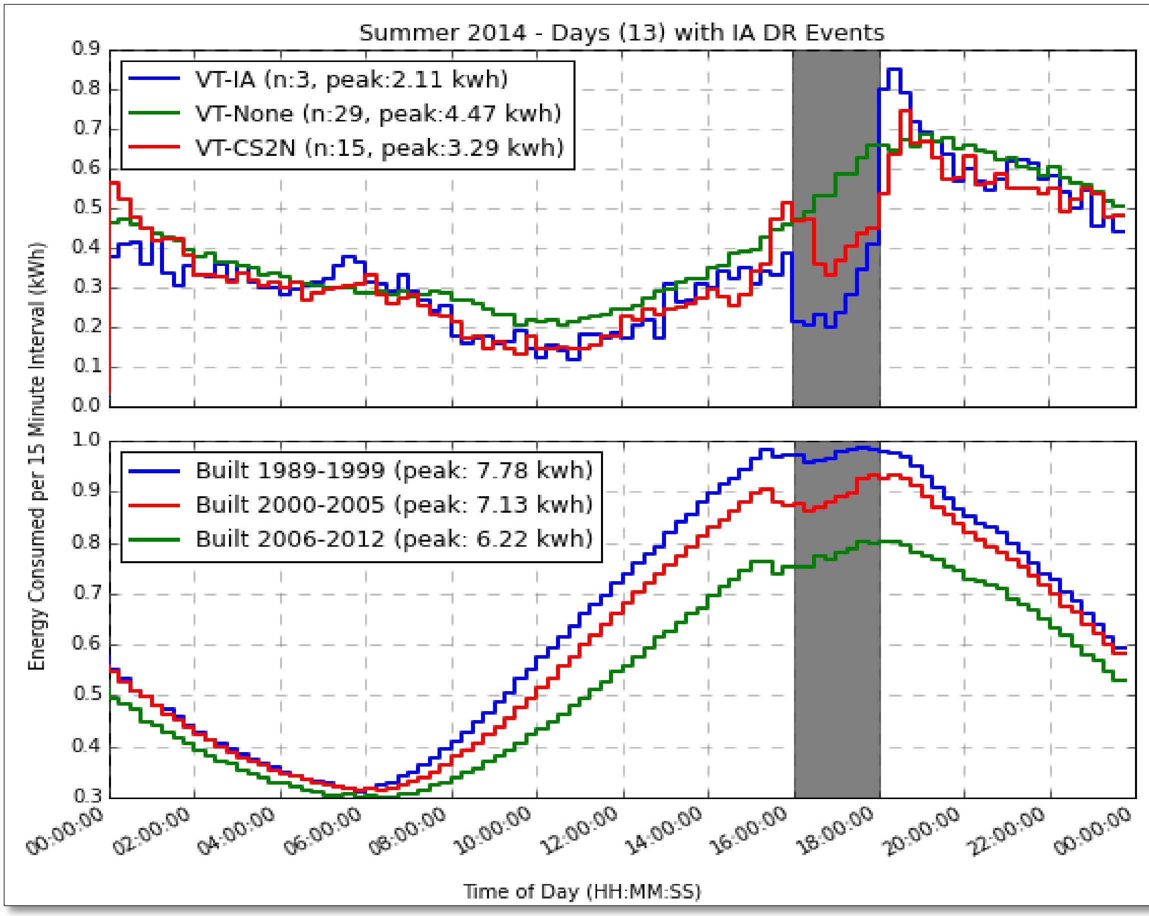


Figure 40 – Impact of IA DR Events During the Summer of 2014. Peak (4-6pm) energy consumption was further calculated and displayed with this plot.

Table 13 – Impact of IA DR Events during the Summer of 2014 for Multiple Peak Periods.

Home Category	Peak Hours Energy Consumption (kWh)			Energy Savings of IA by Comparison (%)		
	1-7pm	4-7pm	4-6pm	1-7pm	4-7pm	4-6pm
Villa Trieste, Total *	10.79	6.58	3.93	-	-	-
Villa Trieste, IA	9.10	5.27	2.11	-	-	-
Villa Trieste, Cool Share	9.68	5.87	3.39	6.0	10.2	37.8
Villa Trieste, None DR	11.56	7.10	4.47	21.3	25.8	52.8
1989 Code-built Homes	22.62	11.66	7.78	59.8	54.8	72.9
2000 Code-built Homes	20.93	10.83	7.13	56.5	51.3	70.4
2006 Code-built Homes	17.89	9.40	6.22	49.1	43.9	66.1

**Energy consumption from all 47 smart-meter enabled homes.*

When making comparisons between the amount of energy consumed while running STANDARD DR events compared to IA events, it is important to keep in mind the difference in average ambient temperature. Figure 41 shows the ambient dry bulb temperature for days in which IA events were run, and Figure 42 shows the same for STANDARD DR days. The average temperature difference between the two is over 4°F.

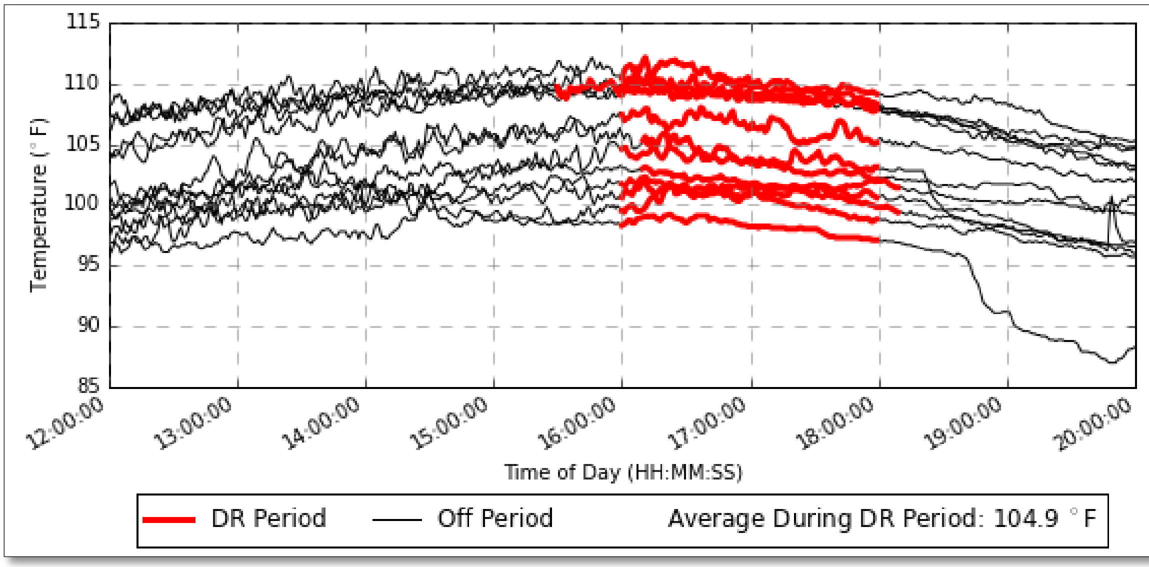


Figure 41 – Ambient Dry Bulb Temperature for IA DR Days (13) in 2014

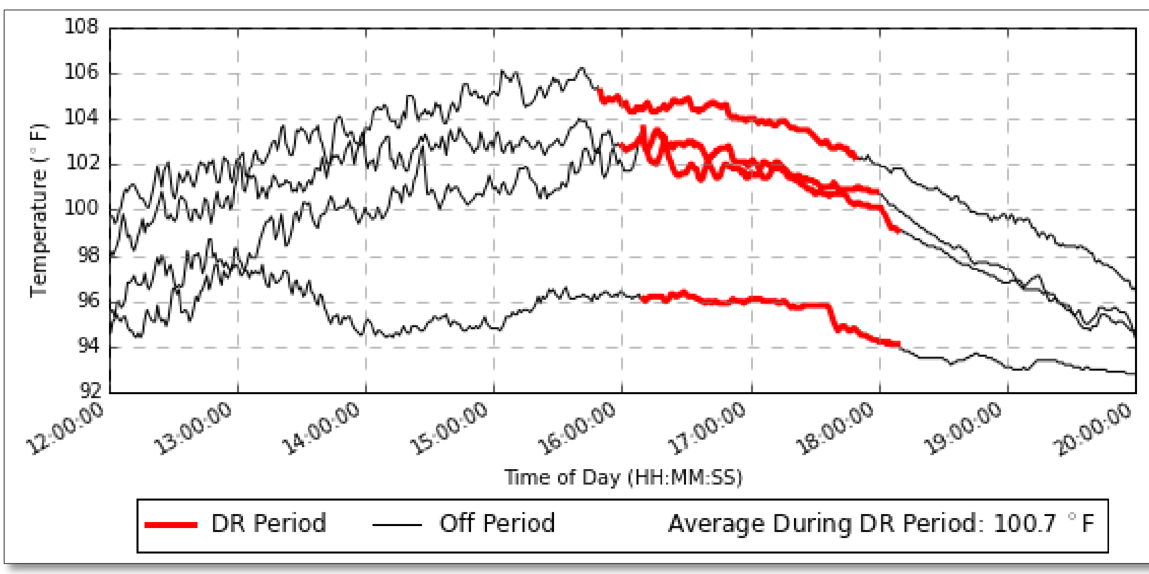


Figure 42 – Ambient Dry Bulb Temperature for STANDARD DR Days (4) in 2014

The influence of ambient temperature on energy consumption has been previously discussed, but Figure 43 shows the magnitude to which DR can affect this consumption.

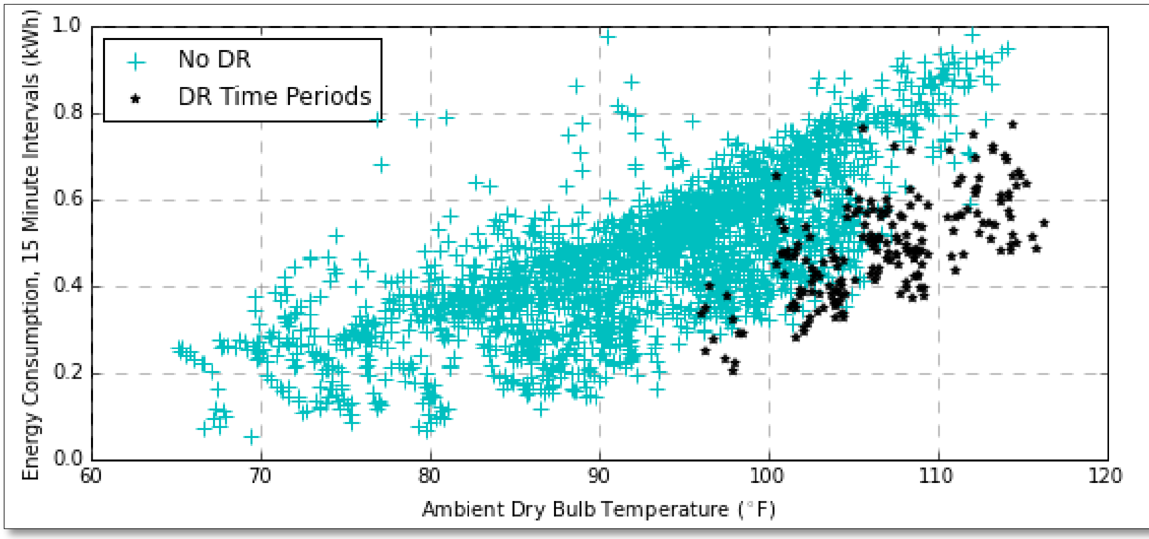


Figure 43 – VT Average Household Energy Consumption for 4-6 PM During Summer of 2013

5.5 User Behavior

5.5.1 Opt-out Concept and User Behavior Analysis

During a regular DR operation, the in-home thermostat, controlled by the utility company, increases to a pre-determined temperature. Homeowners either accept the setback temperature or perform an opt-out reaction during the DR events. The behavior that participants change their indoor temperatures during the DR window is defined as "opt-out" practice. General assumption of opt-out behavior comes from the presence of unacceptable indoor temperature during the DR event.

The UNLV developed IA DR system provides the customers with the option of deciding their indoor temperature during DR events. The participants can login to the UNLV IA DR online system and preset their indoor environment preference ("User Preference"). Based on their money saving and thermal comfort concerns, the fuzzy-logic-based IA algorithm can automatically calculate a setback temperature ranging between one to five degrees Fahrenheit as shown in **Figure 44**. 70% of the participants left the system on its default setting or 5° F setback temperature. 18% of the homeowners' preference generated a setback temperature to 2° F while 10% of them were at a 3° F mark. It is very likely that most homeowners "were not interested in changing the default setting" or "5° F setback temperature during DR event is acceptable". The hypothesis leads to the next interaction during DR events.

A triangular relationship between temperature setback, opt-out rate, and energy saving should be studied for optimizing the DR practice. A longer participation time (less opt-out rate) with higher setback temperatures can contribute higher energy savings during the period of DR execution. On the contrary, if small opt-out rate happens with very small setback temperatures engaged, the main purpose of DR energy shifted saving would be greatly discounted. Therefore, lowering the opt-out rate alone is not optimizing the energy saving. The correlation of those factors is discussed as follows.

From the preliminary observation shown in the actual opt-out behavior is correlated with the pre-defined value of setback temperature. Higher pre-defined setback values contribute to a higher opt-out rate as in **Figure 45**. Those customers with 4 to 5 degree setback performed higher than average opt-out practices. Initial deduction from this observation is the higher indoor temperature activated the opt-out. Knowing actual indoor temperature reading when the opt-out incident happened can help us understand the actual reason behind those opt-out behaviors.

We selected all homes with 3 and 5 degree setback setting and plotted out the relationship between the duration of opt-out time and the recorded temperature change (increase) at that point during all IA DR events (**Figure 46**). Once again the sampling size is quite limited for a complete derivation of user behaviors. A few points can be seen here. Some opt-out behaviors, data points under lower left side, were triggered even with little to no actual temperature change (from thermostat reading). Opt-outs identified at the upper right corner define a normal opt-out behavior triggered by the elevated three to four degrees. None of the homes was heated up more than four degrees of the previously defined temperature. Preset setback temperature does not really impact opt-out behavior but some specific thermostats (homeowners) rejected the DR events without any temperature elevation happening.

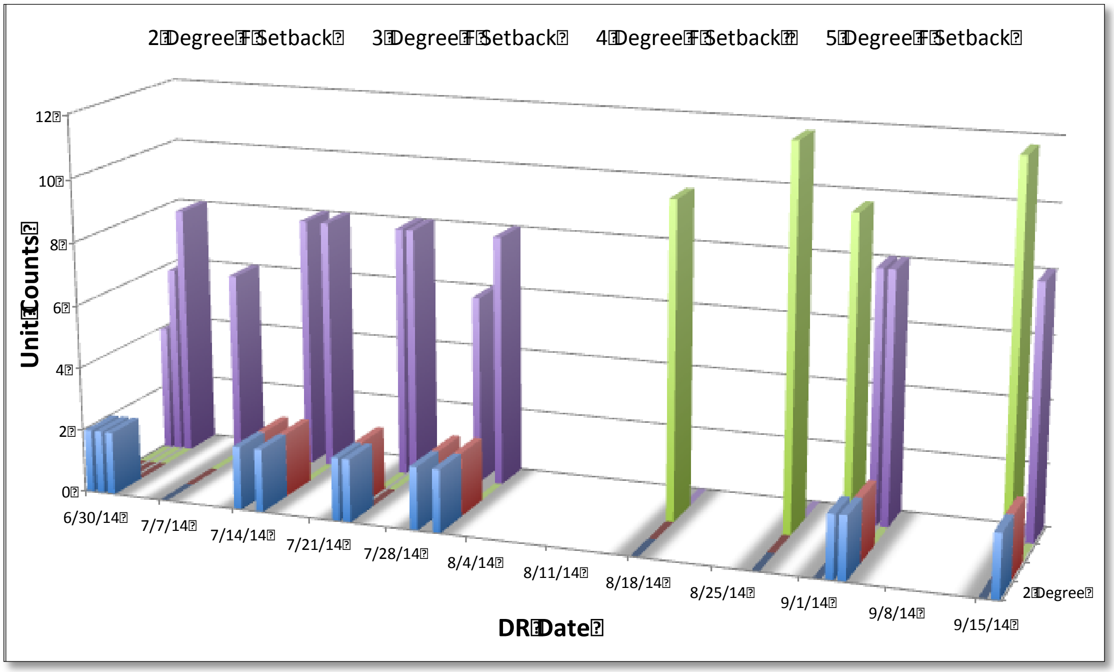


Figure 44 – Initial setback temperature determined by the online "user preference".

The actual opt-out behavior is correlated with the pre-defined value of setback temperature. Those customers with 4 to 5 degree setback performed higher than average opt-out practices. Initial deduction from this observation is the higher indoor temperature activated the opt-out. Knowing actual indoor temperature reading when the opt-out incident happened can help us understand the actual reason behind those opt-out behaviors.

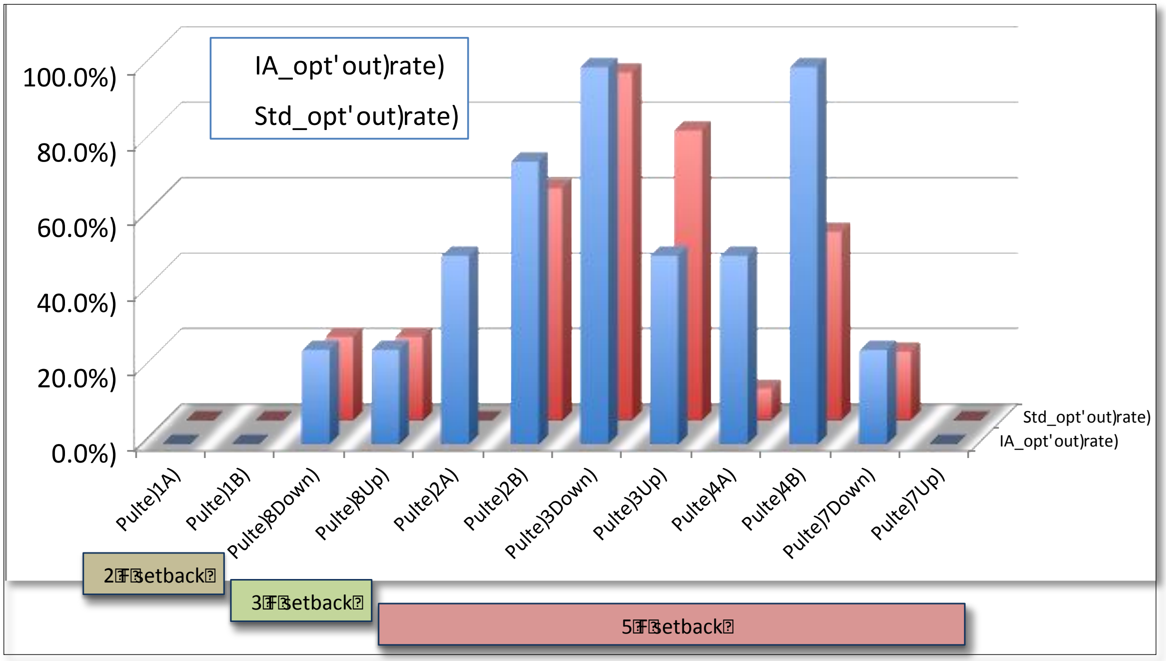


Figure 45 – Opt-out rate vs. setback temperature.

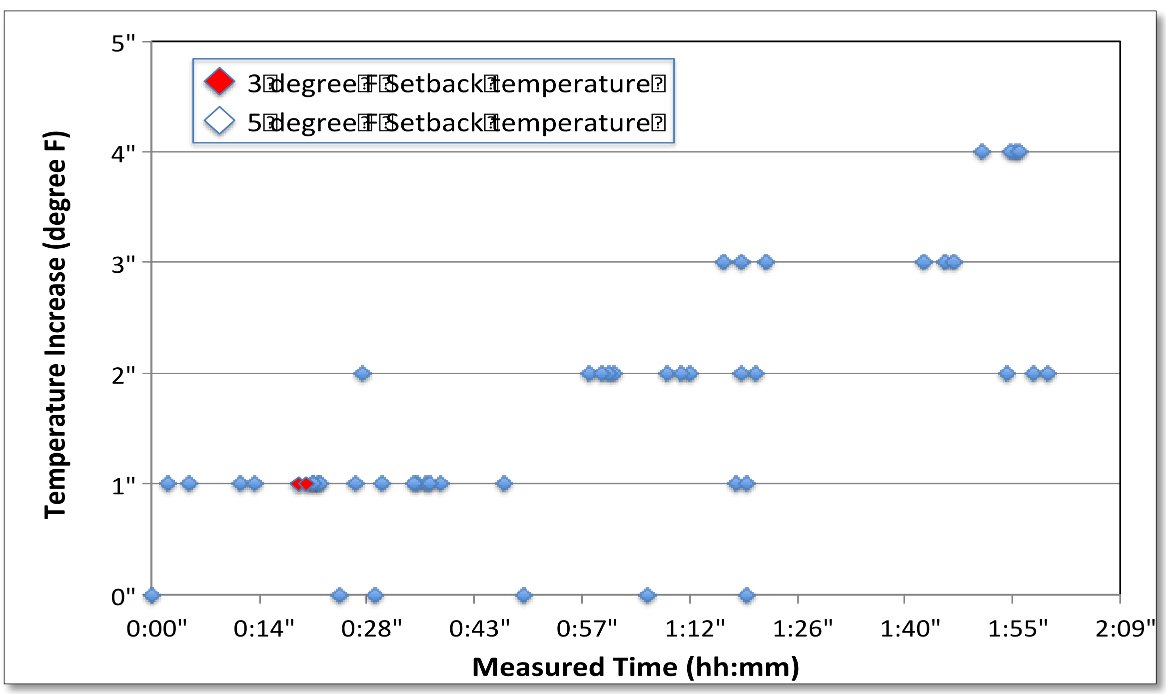


Figure 46 – Correlation between observed opt-out time and elevated temperatures.

Higher setback temperature increase implies the less utilization of air conditioning during DR events, eventually leading to higher energy saving. A positive correlation between hours of participation and temperature increases in **Figure 47** shows positive correlation between participated DR hours and increased temperatures.

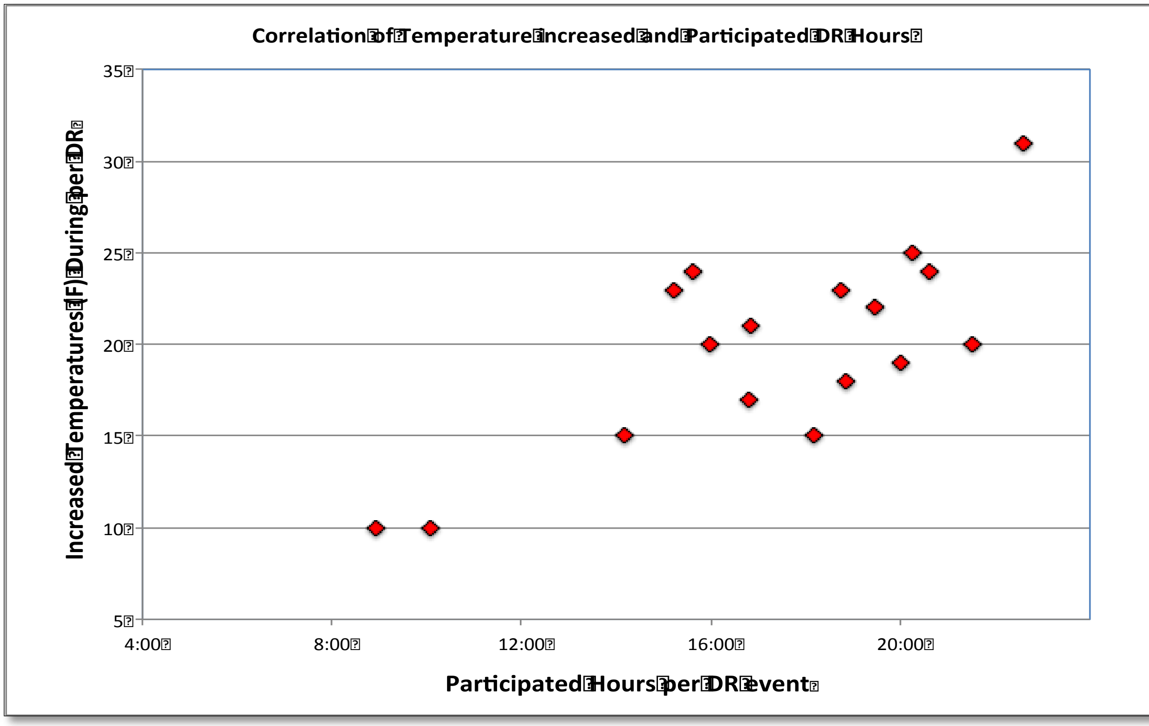


Figure 47 – Correlation of temperature increase and participated DR hours.

5.6 Battery Energy Storage System

While the BSP employed several energy management technologies, battery storage represented the key component. The battery storage industry has been on a very rapid growth trajectory over the last decade. The number of industry participants has increased, and production volumes have ramped up dramatically, driven by the expected growth in electrical vehicle sales. While the early focus of manufacturers was primarily on large, utility scale systems, many have turned their attention to the commercial space where the potential for reducing demand charges has enticed business owners to consider battery storage as a viable path to reducing electricity bills. A relatively few number of vendors have also expanded their focus to the residential market, but the high costs in this space have prevented rapid adoption of storage technologies. However, the recent entry of Tesla, primarily as a provider of residential emergency backup power, is likely to help drive prices down through economies of scale in production. In addition, a consolidation of participants in this market is likely to accelerate in the future.

Utilities are increasingly considering battery storage as one of ways to upgrade and modernize their transmission and distribution systems to prepare for integration of distributed generation and high levels of renewable energy. In some states, such as California, the Public Utilities Commission has mandated the installation of battery storage technologies by utilities. While the utilities have primarily focused on the large-scale transmission and distribution implementations, several, such as SCE and NV Energy, have also launched pilot tests involving the use of residential battery storage for the purposes of peak demand reduction, renewable firming, and to gauge the potential of storage for providing additional ancillary services.

While several battery storage technologies are in use, lithium ion (Li-ion) batteries have become dominant over the last decade. This may be due in part to the increasing use of this technology in electric vehicles, as well as its capability to accommodate a large number of cycles.

5.6.1 Accomplishments

The project team successfully installed the first battery storage system at one of the model homes in the Villa Trieste development in late November 2012. The system, which was called the OnDemand Energy Appliance (ODEA), was purchased from Silent Power, Inc.

After some initial technical problems, the team launched the first phase of the project in January, 2013, to test the peak demand reduction capabilities of the battery storage system. However, the ODEA experienced a number of severe technical issues, initially triggered by a software update by Silent Power and followed with several problems with the ODEA's battery modules (manufactured by Saft). The ODEA did not become operational again after being powered down for the last time in June 2013. Subsequently, the unit was completely removed on August 27, 2013 to be returned to Silent Power. The removal was primarily prompted at the request of Pulte Homes, the developer of Villa Trieste, because the model home containing the ODEA had been placed on the market for sale.

Silent Power offered NV Energy the option of remotely testing a new ODEA unit, which was installed in Silent Power's laboratory environment, beginning in July, 2013. This new ODEA unit contained battery modules manufactured by Samsung, while the original malfunctioning ODEA unit contained battery modules from Saft. The Samsung unit proved more stable and less prone to malfunction. More importantly, the NV Energy team realized a substantial gain in available energy from the Samsung unit. Whereas the initial Saft unit had yielded 5.5 kWh of energy, the team was able to extract approximately 7.8 kWh from the Samsung unit on a consistent basis. In addition to the battery storage system, NV Energy continued to test the capabilities of Silent Power's OnCommand remote interface software. However, all testing and customer recruitment activity had to be stopped in early

February, 2014 because Silent Power's primary financial backers (The Hanwha Group) elected to discontinue any further funding of Silent Power's operations. As a result, Silent Power stopped all business activities and most of its management team was dismissed.

Project activities were resumed after Backup Power Source acquired Silent Power's assets and agreed to support NV Energy's pilot efforts and accommodate NV Energy's needs. NV Energy negotiated an agreement for the purchase of up to five ODEA units to be installed at Villa Trieste homes as the units became available. The first two of these ODEA units began testing in December 2014, and the third became operational in April 2015. The fourth unit is scheduled to be installed in June 2015. The batteries are being tested to assess the feasibility of load limiting and solar firming in residential homes. Due to remaining unresolved technical issues, planned testing for integration with NV Energy's Management System (DRMS) based on OpenADR 2.0b standards, has not been conducted yet.

During the entire pilot testing period, the BSP team was actively seeking out and engaging a number of battery storage technology vendors, including Sunverge, Solar City, K2 Energy, Stem, Samsung, LG, Juicebox, and Tesla. For a variety of reasons, including lack of focus on the residential market, lack of market-ready technology, lack of UL listing, and high price points that were to high, none of these discussions, other than those involving Sunverge, led to a fruitful acquisition of battery storage technology for testing in customer homes. However, the BSP team did learn a great deal from these interactions. Some of these learnings have been shared below in the 'Lessons Learned' section.

Interactions with Sunverge continued for almost four years until the company's Sunverge Integration System (SIS) units were market-ready. Negotiations ultimately led to an agreement for the purchase of five SIS units in 2015 that have not been installed yet. The BSP team is actively working with Sunverge and the SunPower to address technical issues related to integration of the SunPower solar systems at Villa Trieste homes with the SIS unit. Once these issues have been resolved, the SIS units will be installed and will undergo tests pertaining to load limiting, solar firming, integration with NV Energy's DRMS through OpenADR 2.0b standards, and serving as a backup energy resource though installation of a critical load panel.

A representation of the general structure of pilot testing has been provided in Appendix C. The specifications sheet for the ODEA (with three battery options, including the Samsung battery modules), as well as photographs of the ODEA unit, are available in Appendix D. The specifications for the SunVerge SIS unit are included in Appendix E. Graphs representing data gathered from testing of these batteries, as well as high level operational settings have been provided in Appendix F.

5.6.2 Lessons Learned

A number of key lessons were derived from the testing that was conducted as part of this project. Some of these lessons pertained to broad industry factors, while others were more specific to various aspects of launching and managing a project of this type.

- The residential battery storage market is still nascent - while holding a great deal of promise in the long term, the residential battery storage market is still in its infancy. As a result, the systems are still somewhat crude and prices are still far too high. The BSP team faced a host of technical issues throughout the pilot testing, many of which were due to the fact that the battery systems have undergone very little or no field/pilot testing of this type. This market is still geared towards backup power applications and not quite ready for demand limiting functionality. Continued industry consolidation, increasing economies of scale, and corresponding reductions in battery costs are still needed to make this a viable market in the future. How soon this will happen will likely depend on the rate of price decreases.
- Utilities can facilitate the growth of residential battery storage applications - Given their unique position as trusted providers of electricity service to homes, utilities should have an active role in conducting the type of pioneering testing undertaken in this project. By sharing their learnings, utilities can help the industry tailor future offerings to match utility and customer needs more closely and speed up the adoption of this technology.
- Planning for the permitting process should begin as early as possible - Due to the novelty of residential battery storage applications, permitting agencies are unlikely to have a 'streamlined' approval process. As a result, numerous data requests can be expected, and the timeframe for approval may stretch to many months. As a result, early engagement with the local planning/permitting departments to develop a list of required documentation may help speed up the process.
- Education of various stakeholder regarding battery storage technologies - Educating all stakeholders about battery storage technology can help ensure a smoother implementation of projects such as BSP. The stakeholders in this case include inspectors and other planning agency staff, customers, electricians, and even utility staff. Raising awareness about battery storage technologies will increase their adoption and streamline installation processes.
- All components of the battery storage value proposition should be communicated to customers. Aside from the potential to reduce electricity costs, customers should also be made aware of the emergency backup power functionality of residential battery storage. In addition, the environmental benefits of battery storage should also be communicated to homeowners.
- Autonomous operation or independent network connection capability would be helpful - The BSP team needed to network the installed units to enable remote control, which required the configuration of many different types of routers and

internet switches. Autonomously operating systems, or an independent network connection would help resolve this problem.

- Improved 'alarming' capability is needed - The systems tested by NV Energy did not have the capability to generate notifications when a technical or other issue prevented the normal operation of the battery storage device. As a result, the BPS team had to rely on 'manual' status checks. This was clearly not ideal, and resulted in delayed detection of system outages. Automated alarm capability should become a standard feature in residential battery storage systems, such that any time the unit goes offline an email or text would be sent out to staff.
- A centralized/master operational software should be used - During the BSP testing, each battery storage unit had to be accessed individually for operational updates and changes. Ideally, all batteries should be controlled through a 'master' software to speed up the update process.
- Battery system manufacturers should adopt openADR 2.0b standards - An increasing number of utilities and other entities engaged in demand response (DR) have adopted the openADR standards. Since battery storage can be used for DR applications, adding the ability to accommodate the latest openADR standards would speed the adoption of this technology for use in the DR space.

5.7 Energy Model Calibrations

It was desired to perform simulations of the houses to understand how the peak electrical usages occur and how they might be controlled. Energy 10 was a code that was available to us early in the project. While there were more powerful codes available, this particular one was chosen for three primary reasons. (a) It had a quick learning curve so that students could easily be using it productively in short order. (b) It appeared to produce reasonable results. (c) It allowed actual weather conditions to be entered so that the weather on specific days the houses experienced could be simulated. This latter aspect allowed us easily to compare simulations to measurements. These studies were performed quite early in the program prior to any of the houses having residents. (Studies near the end of the project, reported later, examined use when residents were present.) However, the indoor temperature was controlled so that energy use for air conditioning (understanding the summer use of energy was most important in this study) could be understood. Transducers were connected to all of the main circuits and the resulting signals were recorded on data loggers.

As would be anticipated, the residential energy use tracks quite closely with ambient temperature. Time of day energy use was tracked with instrumentation as shown in Figure 21 in the early part of the project. Later when remotely-reading instantaneous power meters became pervasive in the development, more of the data came from those sources.

Other typical kinds of results found are shown in **Figure 48** for one 24-hour period. Data type shown in **Figure 49** and **Figure 50** were used to check the accuracy of the simulations.

An example of this can be seen in **Figure 51**. Here the simulated amount of energy estimated follows quite closely to the measured values. We concluded that simulation was doing a good job in predicting what the resulting energy used would be for the various scenarios we wished to examine.

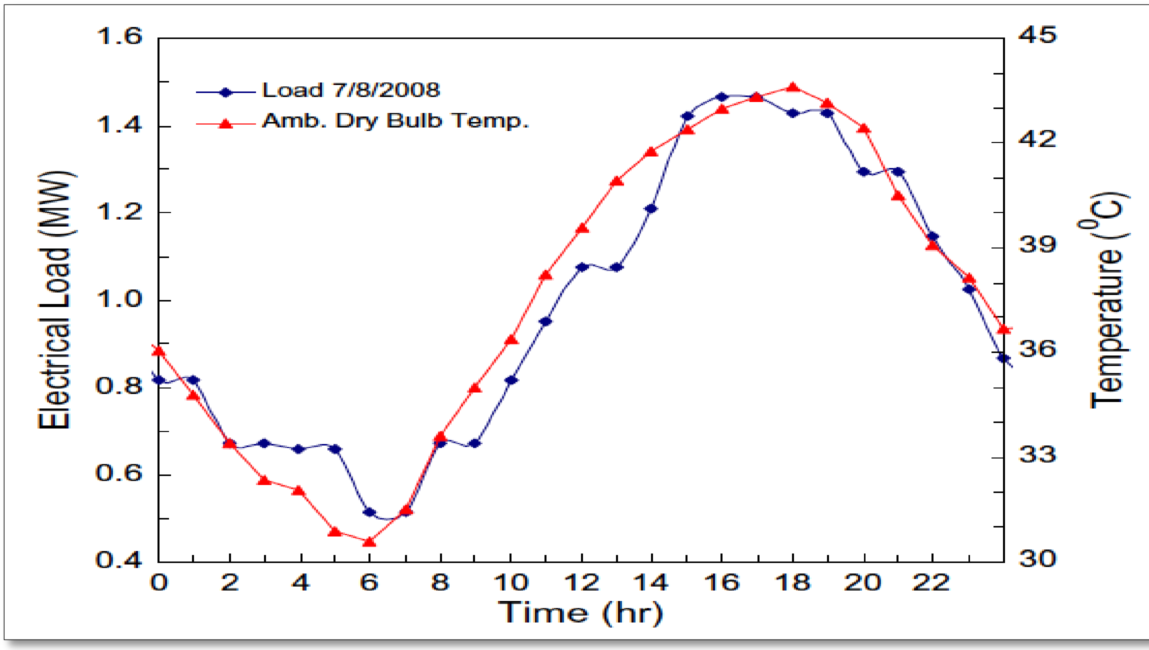


Figure 48 – A typical electrical load and ambient temperature from one occupied VT home during a peak summer day (From Sadineni, Atallah, and Boehm, 2012).

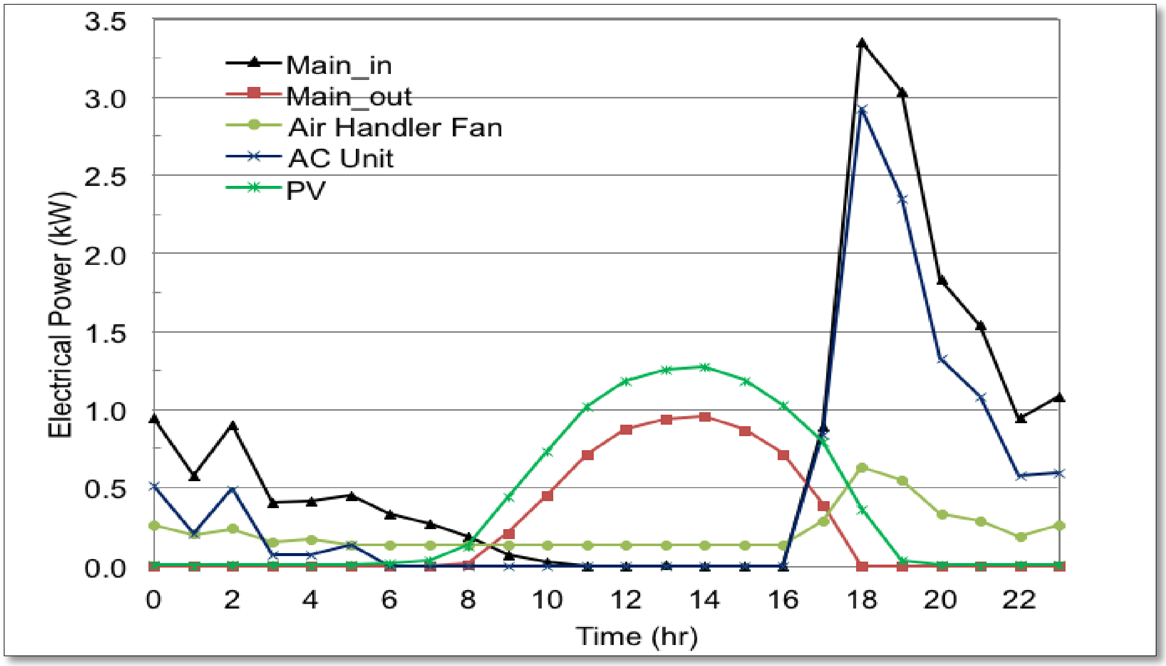


Figure 49 – Measured power usage/generation from one occupied VT home on 8/1/11 (From Sadineni, Atallah, and Boehm 2012).

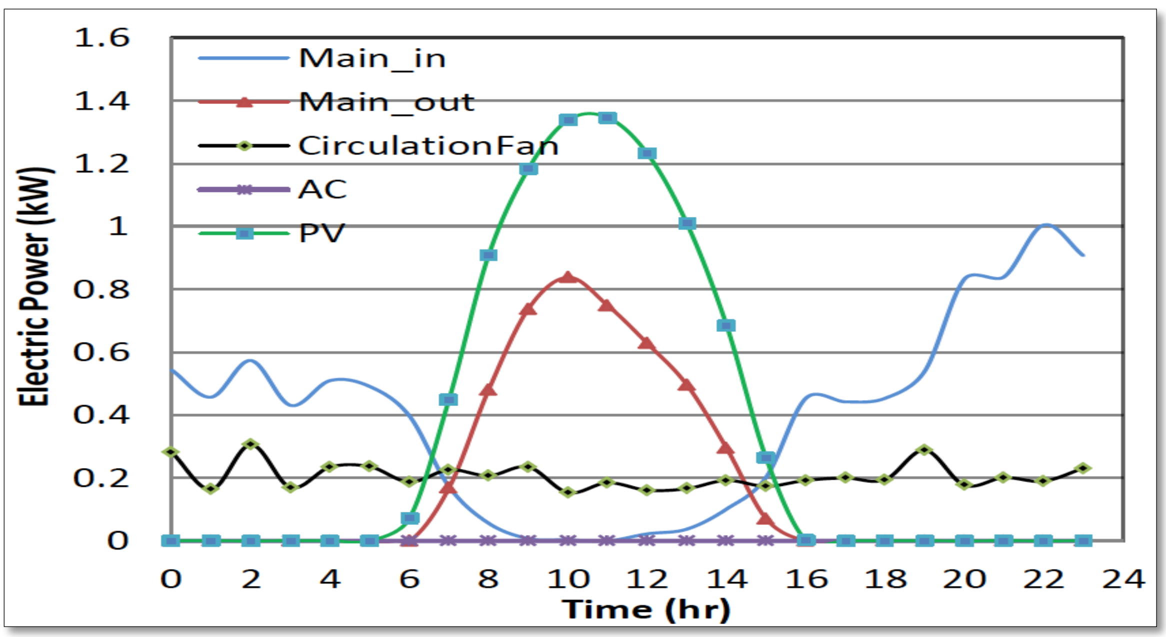


Figure 50 – Measured power usage/generation from one occupied VT home on 11/25/10 (From Sadineni, Atallah, and Boehm, 2011).

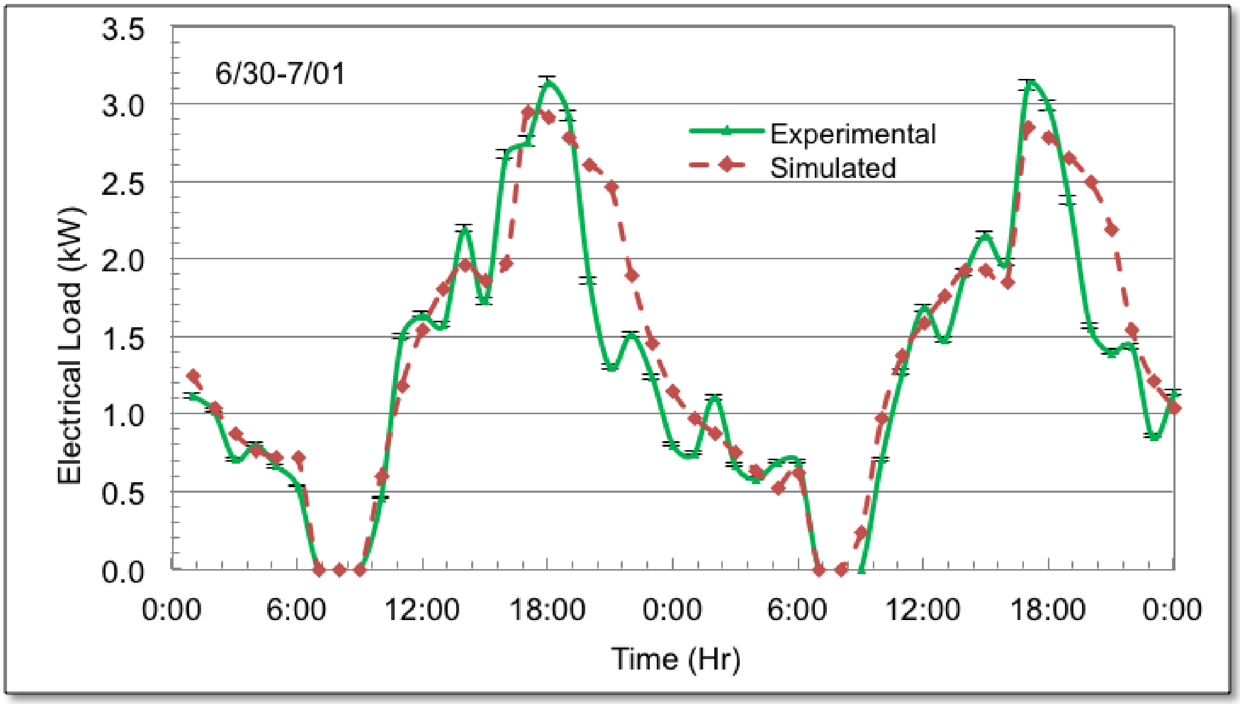


**Figure 51 – Measured and predicted cooling demand, summer 2009.
From Sadineni, Atallah and Boehm, 2012.**

5.7.1 Simulations Results

We used the Energy10 code to simulate a variety of houses to see how the VT units compared. Many of these studies used the basic VT design and modified it in various ways. For example **Figure 52** shows how a code standard design would compare to the VT design with energy efficiency aspects but without PV, while **Figure 53** shows results with PV considered. Since the houses were built in a variety of orientations, and the roof location of the PV installation was varied with the house orientation, it was important to understand the impacts of these variations.

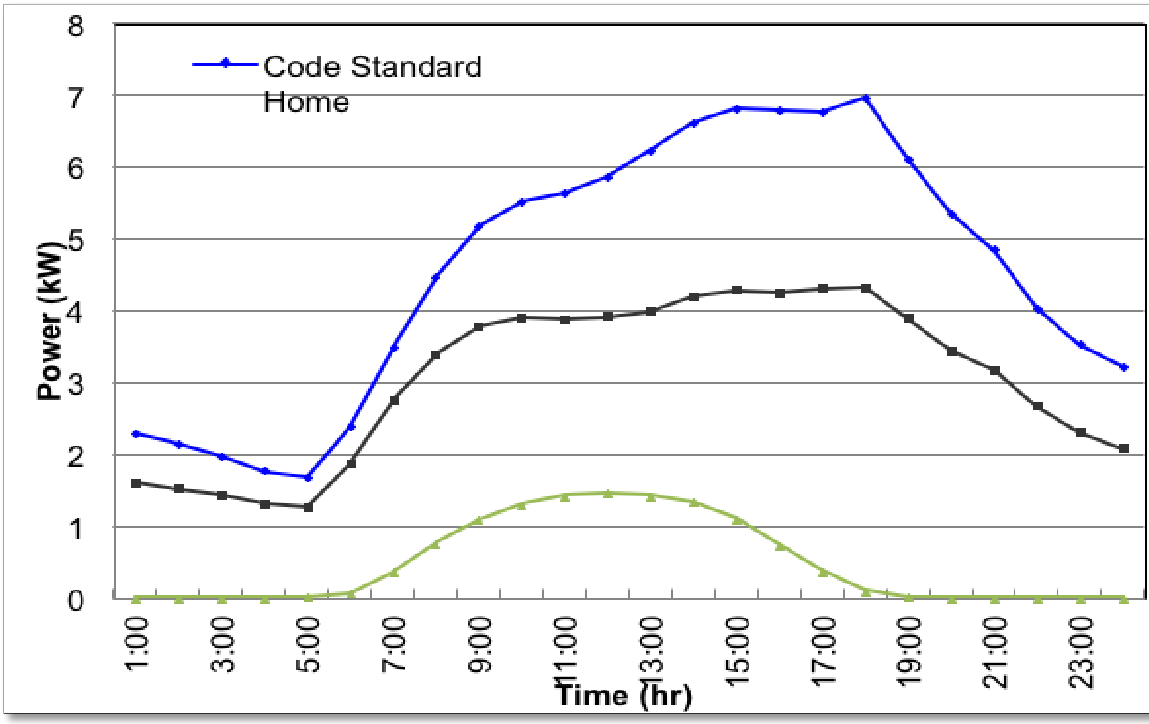


Figure 52 – Variation of electrical power demand for a summer day, code-standard house (in blue), and a VT house (shown in black). The PV generation on a VT house is shown in green (From Sadineni and Boehm, 2012).

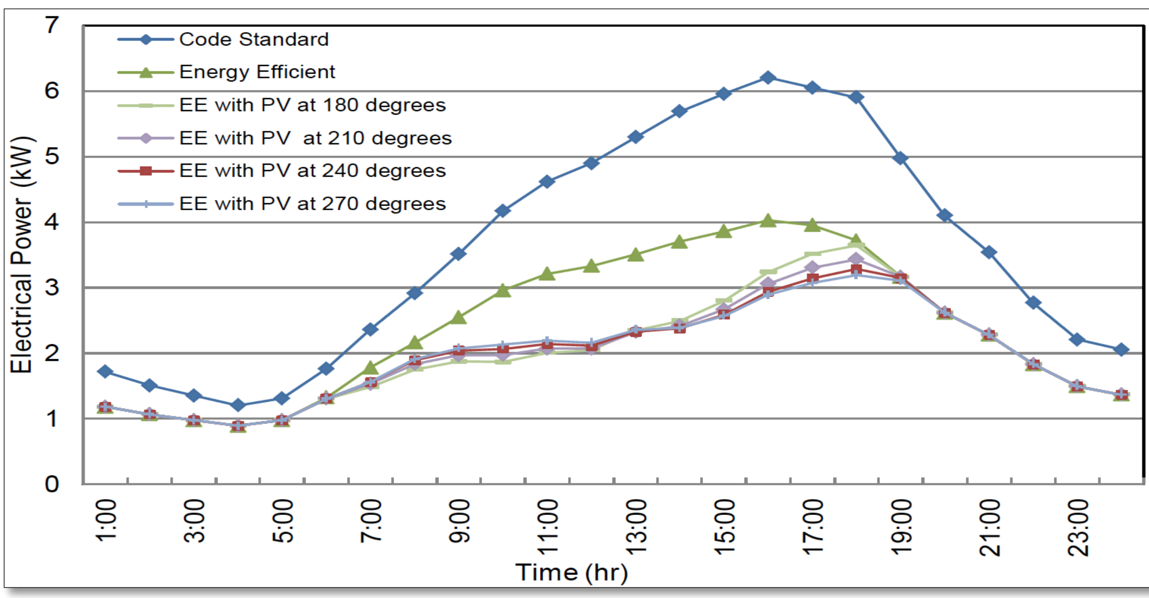


Figure 53 – Simulations of the PV orientations on a VT house resulted in some variations over a typical day. From Sadineni, Atallah, and Boehm 2011.

To give a more comprehensive view of the various elements of the design, see **Figure 54**. Here the power used for a code standard house is compared to the same home modified with energy efficiency measures. These two curves are then compared to the situation of energy efficiency with PV included (the VT situation). Clearly both energy efficiency and PV decrease the energy used, and there is a reduction in the peak. However, the peak usage is not changed by the PV from the energy efficiency case. As a result, another approach must be used to reduce the peak. In this figure a thermostat setback of 2.2 °C is used. This is related to simply shutting down the AC for an appropriate amount of time. It is clear that this action has a profound impact on the peak, and this is related to demand response approaches used by a variety of utilities (including NV Energy) as well as adapted in this study.

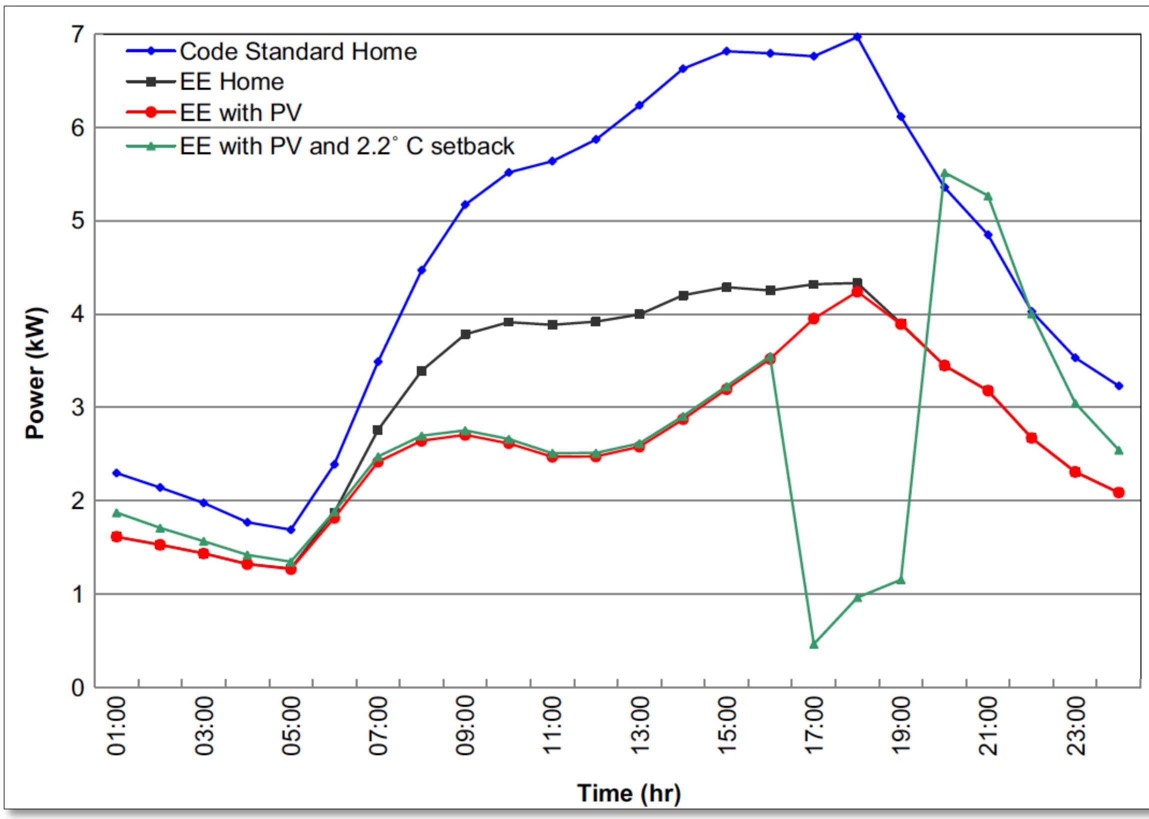


Figure 54 – Electrical power demand variation for a summer day. From Sadineni and Boehm 2011

Figure 55 shows the effect of varying setbacks. In addition to the 2.2°C setback shown in **Figure 54**, lesser setbacks are shown in this latter figure. Clearly even small setbacks have positive impact on decreasing the peak. It can be concluded that this approach is quite effective in peak reduction.

Batteries are also considered for peak reduction in the program, and these can be very effective. However, the analysis of these types of devices came toward the end of the project because of the difficulty in procuring appropriate batteries. See the battery section of this report for insights about what was done with battery aspects of the project.

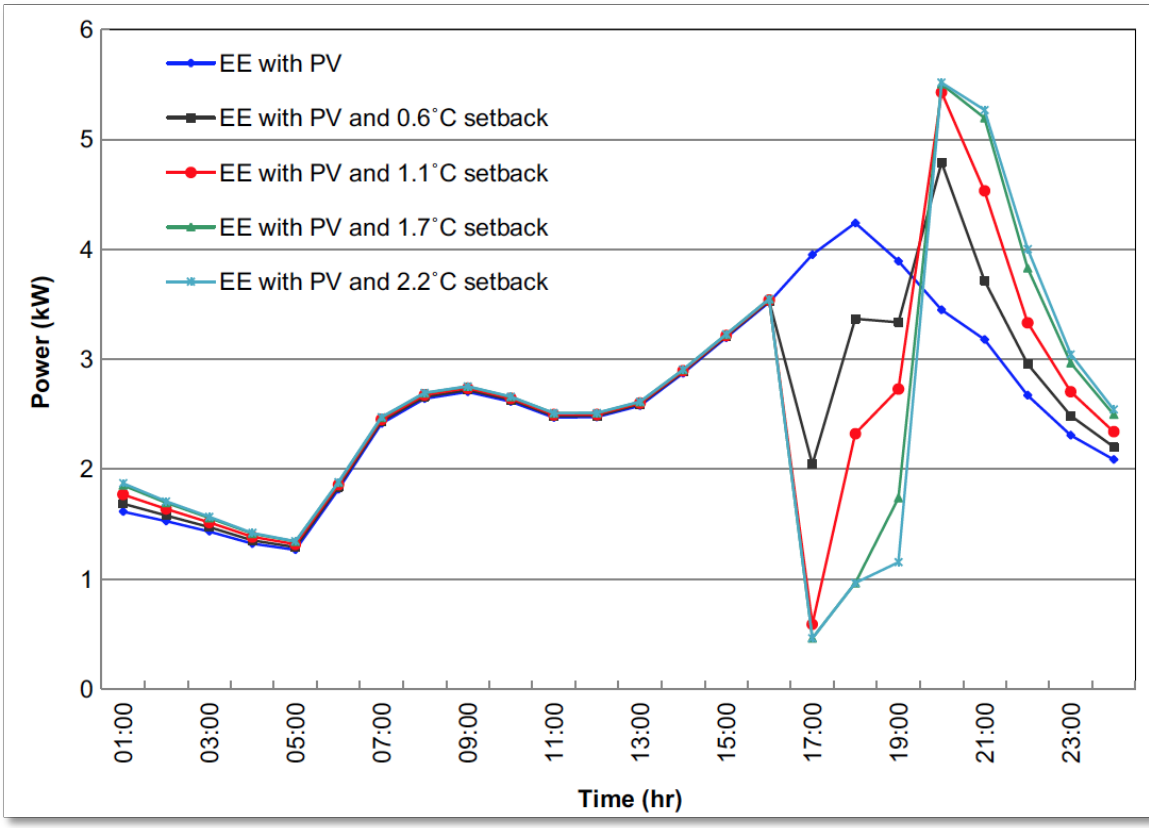


Figure 55 – Power consumption simulation based on various thermostat setback temperatures (From Sadineni and Boehm 2012).

5.7.2 Measurements and Simulations Results

1. Measurements were made on a number of houses both before they were inhabited as well as after residents moved in. This section focused on the former situation. Results when residents were living in the houses are covered later in this report.

2. The purpose of these measurements was primarily to calibrate the simulation code used to predict the response of the structure to the various energy impacts upon it, primarily including the meteorological effects. There included the solar incidence and the ambient temperature.

3. Good comparisons were found between measurements and predictions using the Energy10 building energy analysis code.

4. The increase in energy consumption for air conditioning follows the increase in ambient temperature increase.
5. As a result of the energy conserving nature of the building design, the energy use of the houses shows a major reduction compared to a code-built houses. However, the peak use of energy occurs at basically the same time as code built houses….it is simply decreased in magnitude.
6. It is shown that the PV generation that results from the array found on each house does drop the energy used during the peak period, but there is still a remaining peak right after the sun goes down.
7. Use of appropriate thermostat set backs (the thermostat is set to a higher temperature for some period of time) showed that this approach can effectively decrease the peak demand. This is closely related to the approach of shutting off the air conditioning unit for a period of time. Any of a range of setback levels are effective in reducing the peak.
8. Batteries can definitely be used for removing the peak, but their use was not investigated in this suite of evaluations. More is given on battery investigations later in this report.

6 Conclusion

6.1 Summary of the Results

6.1.1 *Intelligent Agent Demand Response System (IA DR System)*

The Intelligent Agent (IA) was proposed in an attempt to mitigate the problems associated with homeowner opt-out rates, and provide a platform for researching future advancements in dynamic pricing. Two major factors on residents' decisions to interact with thermostats' setpoints are comfort and cost. The IA DR proposed was aimed to understand the decision process from customer side during summer DR events. The system has been developed years back but didn't get the chance to deploy to the occupied homes for field test. The first attempt was in summer of 2013 with seven IA DR homes installed and observed. The system functioned as expected and provides encouraging insights regarding summer energy reduction and peak energy shifting between the investigated Villa Trieste homes and those homes built at various eras/building codes.

6.1.2 *Peak Energy Reduction*

To date, the IA control system has provided significant insight into home temperature fluctuations during DR periods. At an aggregate level, across the entirety of the summer of 2014 (for the "hot" days previously described), substantial energy savings were realized by the Villa Trieste homes.

Based on the different testing scenarios, energy consumption and saving from three different peak-hour scenarios of 4-6 PM, 4-7 PM and 1-7 PM, the Villa Trieste homes provide more than 38% peak energy saving from 4-6 PM over the collections of homes built under the most recent energy code (IECC-2006). Energy consumption from VT homes actually use essentially half as much energy as the homes built to the codes applicable from 1989 to 1999.

The above energy consumption differences are contributed to those energy efficiency features installed in the VT homes. While significant, it did not reach the 65% threshold that was outlined as the project's major objective. To realize further reductions during the summer peak periods, active controlling strategies were necessary. Combining with the application of IA DR system and energy saving features, more energy saving and peak shifting efforts were observed. There are 13 IA DR events that were executed during the summer of 2014 using full dynamic capabilities of the IA platform developed by the UNLV team. All temperature setpoint offsets were calculated based on homeowner preferences rather than direct load control of 4°F offsets. Energy saving during peak hours of 4-6 PM between VT and other code-built homes ranges from 66% observed among the latest code-built homes (IECC-2006) to 73% compared to the those built between 1989-1999 period.

6.1.3 USER BEHAVIOR

While energy consumption saving were achieved. User behavior can be a key issue to further increase the efficiency of DR events with IA interaction. A study of interaction among temperature setback, opt-out rate, and energy saving can be used to optimize future DR practices. An optimized objective function of energy saving would be a combination of longer customer participation time and higher setback temperatures. The preliminary result shows the actual opt-out behavior is correlated with the pre-defined value of setback temperature. Higher pre-defined setback values (four to five degrees F) contribute to a higher opt-out rate. However, opt-out behavior wasn't simply triggered by higher indoor temperature but possibly associated with personal perception on pre-defined setback temperature. Several opt-out cases were observed with little to no actual temperature change (from thermostat reading). None of the homes was heated up more than four degrees F. of course, some opt-outs were triggered by elevated temperature of three to four degrees F. Since most if not all thermostats were embedded with a temperature damping algorithm, using thermostat as a point of interaction with homeowners is one convenience but not a perfect solution. However, long-term historical user responses and indoor temperature data can be useful to predict future user behavior. One shortfall of this study is the small sampling size (7 out of 185 homes) that allows a complete understanding of user behaviors.

6.1.4 BATTERY ENERGY STORAGE SYSTEM

The project team successfully installed the first battery storage system at one of the model homes in the Villa Trieste development in late November 2012. The system, which was called the OnDemand Energy Appliance (ODEA), was purchased from Silent Power, Inc. After some initial technical problems, the team launched the first phase of the project in January, 2013, to test the peak demand reduction capabilities of the battery storage system. Project activities were resumed after Backup Power Source (BPS) acquired Silent Power's assets and agreed to support NV Energy's pilot efforts and accommodate NV Energy's needs. During the entire pilot testing period, the BSP team was actively seeking out and engaging a number of battery storage technology vendors.

Most of them ended with marketing or technology reasons. Sunverge was the only one with fruitful acquisition of battery storage technology for testing in customer homes. Interactions with Sunverge continued for almost four years until the company's Sunverge Integration System (SIS) units were market-ready. Once these issues have been resolved, the SIS units will be installed and will undergo tests pertaining to load limiting, solar firming, integration with NV Energy's DRMS through OpenADR 2.0b standards, and serving as a backup energy resource though installation of a critical load panel.

6.2 Recommendations

Besides peak shaving or load leveling where the goal is to avoid the installation of capacity to supply peak power – which is the main thrust of this project, it is perhaps important to add that battery storage (at a large scale) can also be used for multiple purposed including the following:

- *Demand limiting:* Demand charge, which is widely applied to commercial and industrial customers, may be on the verge spreading to residential customers. In such a case, the battery storage system can be utilized to limit customer demand in order to reduce such a charge.

- *Capacity firming:* The variable, intermittent power output from a renewable power generation plants, such as solar, can be maintained at a committed level for a period of time. The energy storage system smoothens the output and controls the ramp rate (MW/min) to eliminate rapid voltage and power swings on the electrical grid.

- *Frequency regulation:* Intermittent power generation from renewables and other sources, along with variable loads cause deviations from nominal frequency in the grid. Energy storage systems are an attractive way to restore the balance between supply and demand, featuring rapid response and emission-free operation. The energy storage system is charged or discharged in response to an increase or decrease of grid frequency and keeps it within pre-set limits.

- *Spinning Reserve:* To provide effective spinning reserve, the energy storage system is maintained at a level of charge ready to respond to a generation or transmission outage. Depending on the application, the system can respond within milliseconds or minutes and supply power to maintain network continuity while the back-up generator is started and brought on line. This enables generators to work at optimum power output, without the need to keep idle capacity for spinning reserves. It can also eliminate the need to have back-up generators running idle.

- *Power quality:* While the demand for high-quality power has grown with the digital economy and the proliferation of sensitive electronic equipment and microprocessor-based controls, investments in many electrical grids around the world have not kept pace, making them ever more susceptible to disturbances such as voltage sags and short supply interruptions. Offering accurate and rapid response, energy storage systems improve power quality and protect downstream loads against short-duration disturbances in the grid, affecting their operation.

7 References

- R. Boehm, Minimizing Peak Residential Electrical Demand in Hot Climates, 2nd Asian-US-European Thermophysics Conference—Thermal Science for Sustainable World, January 3-6, 2012, Hong Kong.
- S. Sadineni, F. Atallah, and R. Boehm, 2012. Impact of Roof Integrated PV Orientation on the Residential Electricity Peak Demand, APPLIED ENERGY, 92, 204-210.
- S. Sadineni and R. Boehm, 2012. Measurements and Simulations for Peak Electrical Load Reduction in Cooling Dominated Climate, ENERGY, 37, 689-697.
- R. Boehm, An Approach to Decreasing Peak Electrical Demand in Residences, 2nd International Conference on Advances in Energy Engineering, 2011, Bangkok, Thailand.
- S. Sadineni, F. Atallah, and R. Boehm, 2011. Measurement and Simulations of Electrical Demand of Residential Building for Peak Load Reduction, ASME paper ESFuelCell 2011-54291.

Appendix A: Demand Response System

Demand Response System was implemented to reduce peak energy at hot summer season. ZigBee wireless thermostats [1], Figure 1, and ZigBee wireless to Ethernet gateway [2], Figure 2, were installed at each house. The DR (Demand Response) control server is operated at UNLV as Figure 3. The thermostats at each house are connected through internet to Demand Response server. Every activity of thermostats, including following information are saved at DR server:

- Current temperature, Heat and Cool Set, System Mode (Cooling, Heating, or Off), Fan Status (Auto, On, or Off), schedule mode (Run or Hold), internet connectivity, A/C On/Off Events

And, DR server can control following:

- Heat and Cool Set, System Mode (Cooling, Heating, or Off), Fan Status (Auto, On, or Off), schedule mode (Run or Hold)

Fig. 1. ZigBee wireless thermostat

Fig. 2. ZigBee wireless to Ethernet gateway

Fig. 3. UNLV web and database server, DELL Power Edge 2950 (quad-core)

1. DR Server

Figure 4 shows the block diagram of DR server. The DR server was developed using Ubuntu Linux operating system [3] and MySQL database server [4]. To monitor and to control the thermostats, thermostat event handling task and thermostat command handling task were developed. Any event of thermostat is noticed to intelligent agent server by event handling task. For example, home residence changes the cool set value or heat set value, the value goes to server through event handling task. To control the thermostat, the command handling task makes a protocol to talk with ZigBee to Ethernet Gateway. The command handling task periodically scans the database to check which commands are updated to make command to the thermostats. The monitoring task of DR server is to collect data from thermostats, temperature sensors and power meters. The Intelligent Agent Algorithm task is providing the desired cool set value using the customer's preference, the current cool set value and the home's temperature. Details of the algorithm are commented in the Intelligent Agent Fuzzy Control section. The following databases and information are saved:

- Database Thermostat/Preference: Gateway ID, ZigBee Address, DR event status, label, current temperature, fan status, system mode, cool set, heat set, backup of schedule mode and cool set during DR event, customer preferences for IA (Intelligent Agent) algorithm,
- Database DR Events: DR status (Ready, Done, Cancel), event date, start time, end time, level (IA or standard), and comment,
- Database Temperature/Power Usage: current temperature from thermostat and room temperature sensor, ambient temperature, and power meters (PV, main in, A/C, Fan),

- Database Home residence: Home resident id, password, name, telephone number, e-mail, gateway ID.

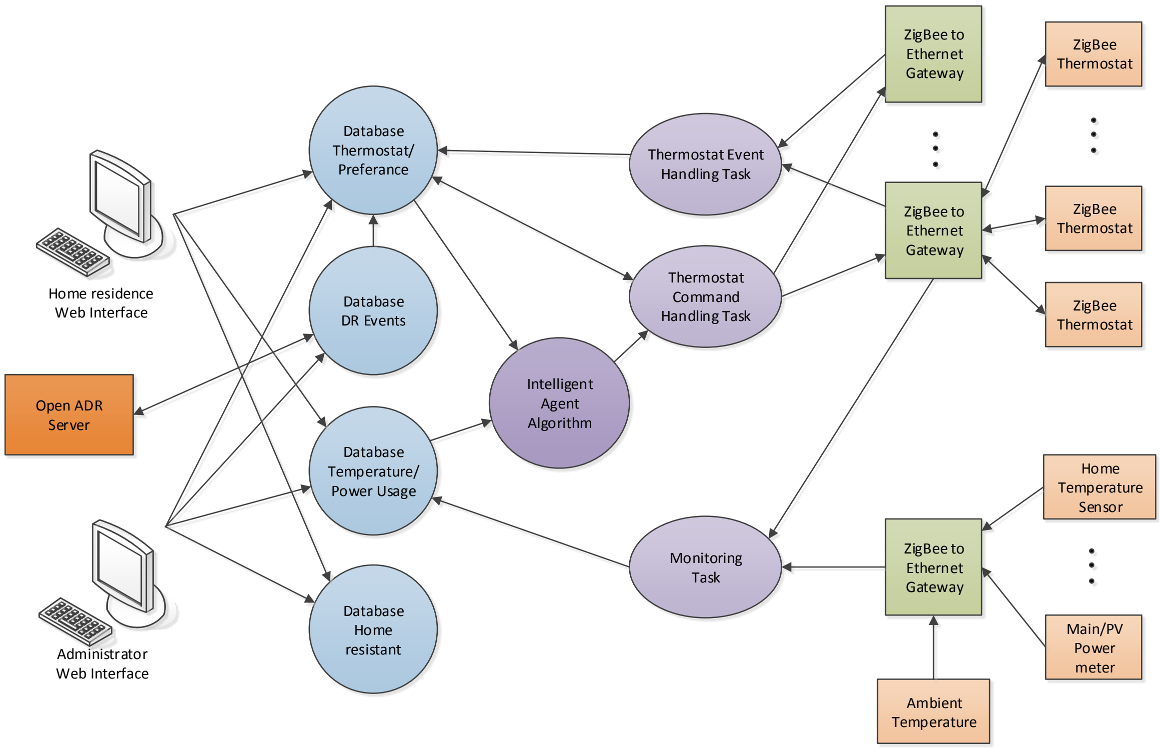


Fig. 4. Block diagram of overall system

2. Web Interface

Administrator and home resident can login to DR server as shown in the Figure 5 login page. The address is http://iecopower.unlv.edu.

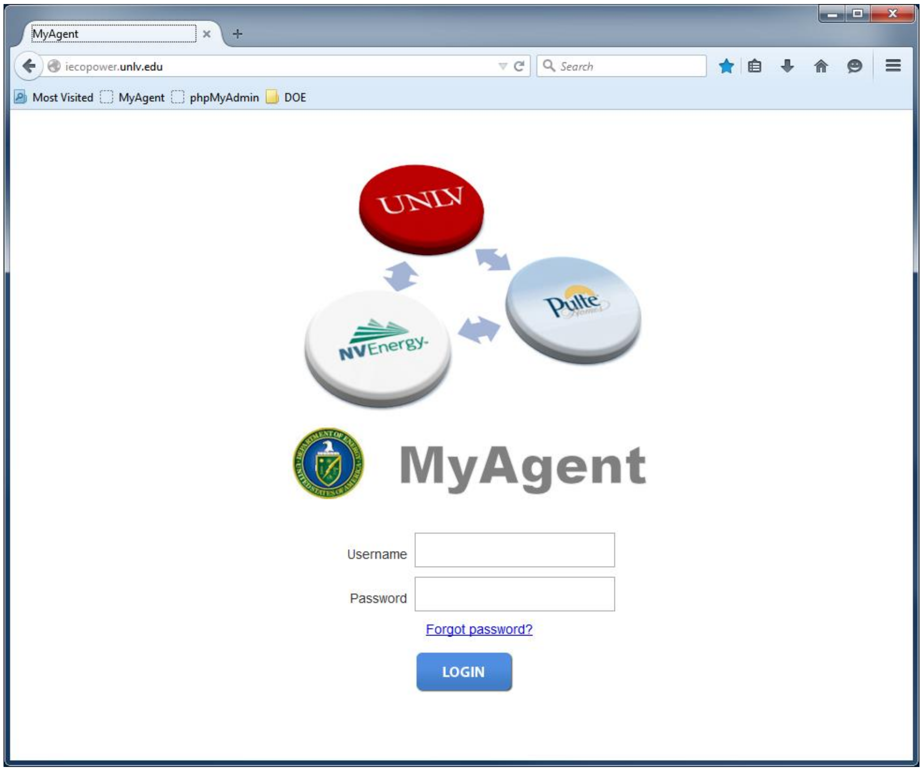


Fig. 5. Login page

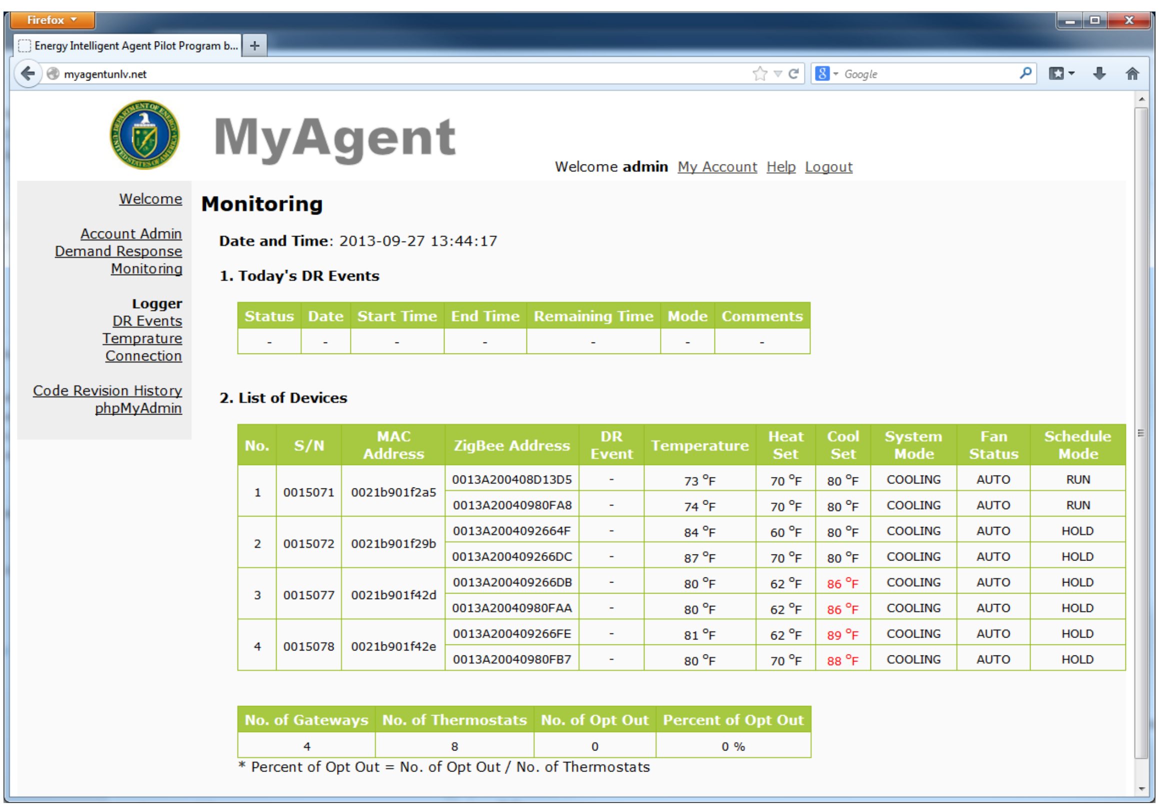


Fig. 6. Administrator's home page

If the administrator logs in to DR sever they can monitor the current status of DR events and thermostats as shown in Figure 6 which include:

- Today's DR Events: shows today's registered DR event and operation
- List of devices: list the information and current status of online gateway and thermostats
- Opt out ratio: opt out ratio during DR event period

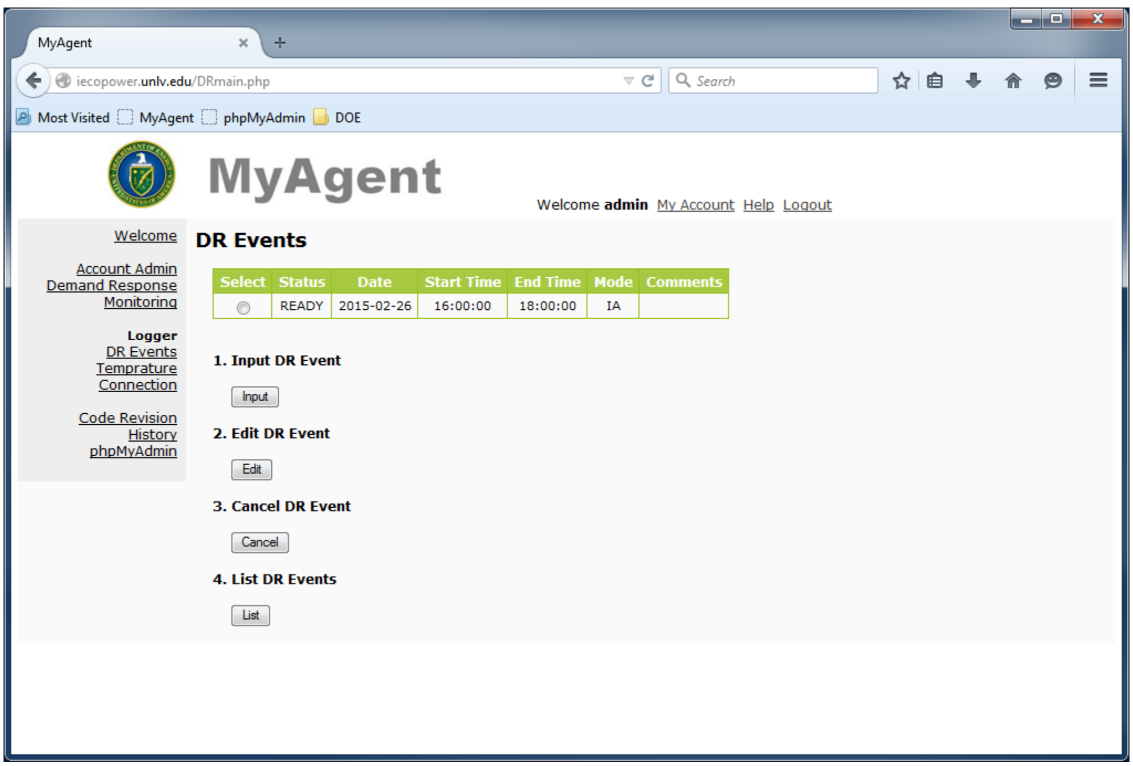


Fig. 7. DR events operations

Figure 7 shows the screen of DR events operations. On the top of the screen, a table shows the registered DR events to be executed. The Administrator can input a new DR event, and edit and cancel the events. The administrator page lists the DR events on the database as shown in Figure 9.

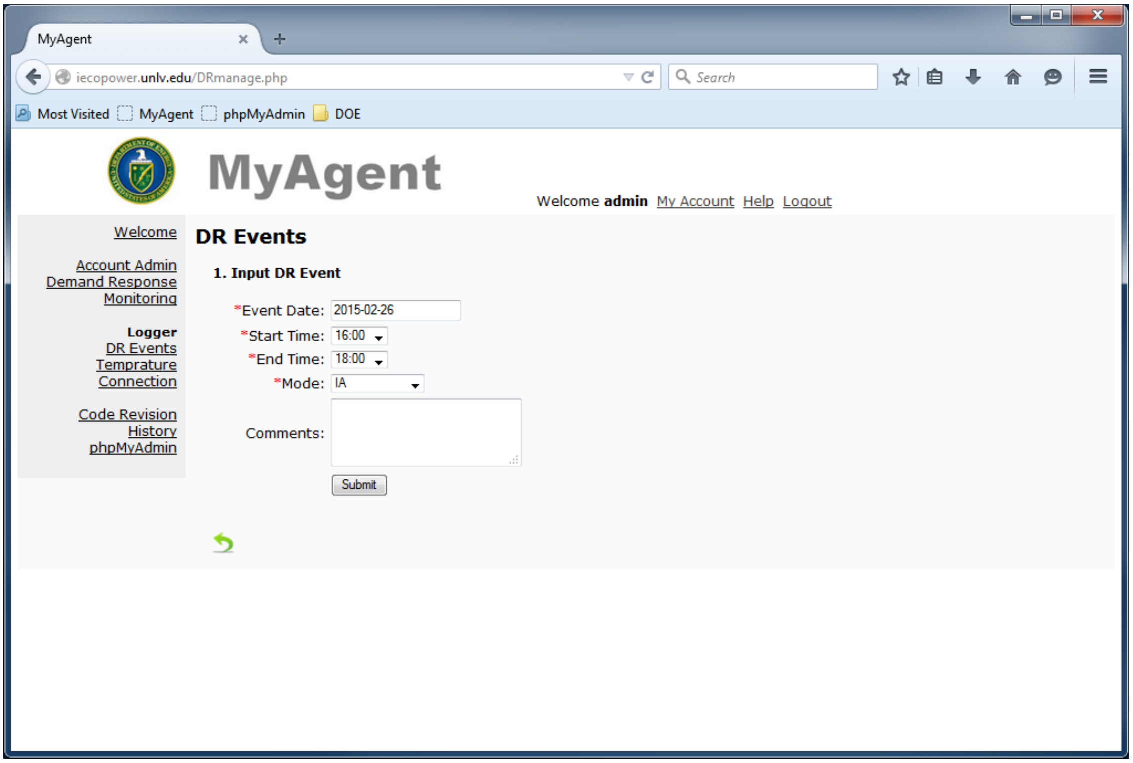


Fig. 8. Input new DR event

Figure 8 shows the screen used to input a new DR event. The Administrator needs to input event date, start time, end time, mode and comments. For the mode, there are STANDARD and IA (Intelligent Agent) modes. The STANDARD mode is used for a predefined fixed offset temperature of 4°F. IA mode uses Fuzzy Logic control by the resident's preference values to set a varying offset temperature, from +1 °F to +5 °F. The Fuzzy Logic control is explained in more detail in a later section.

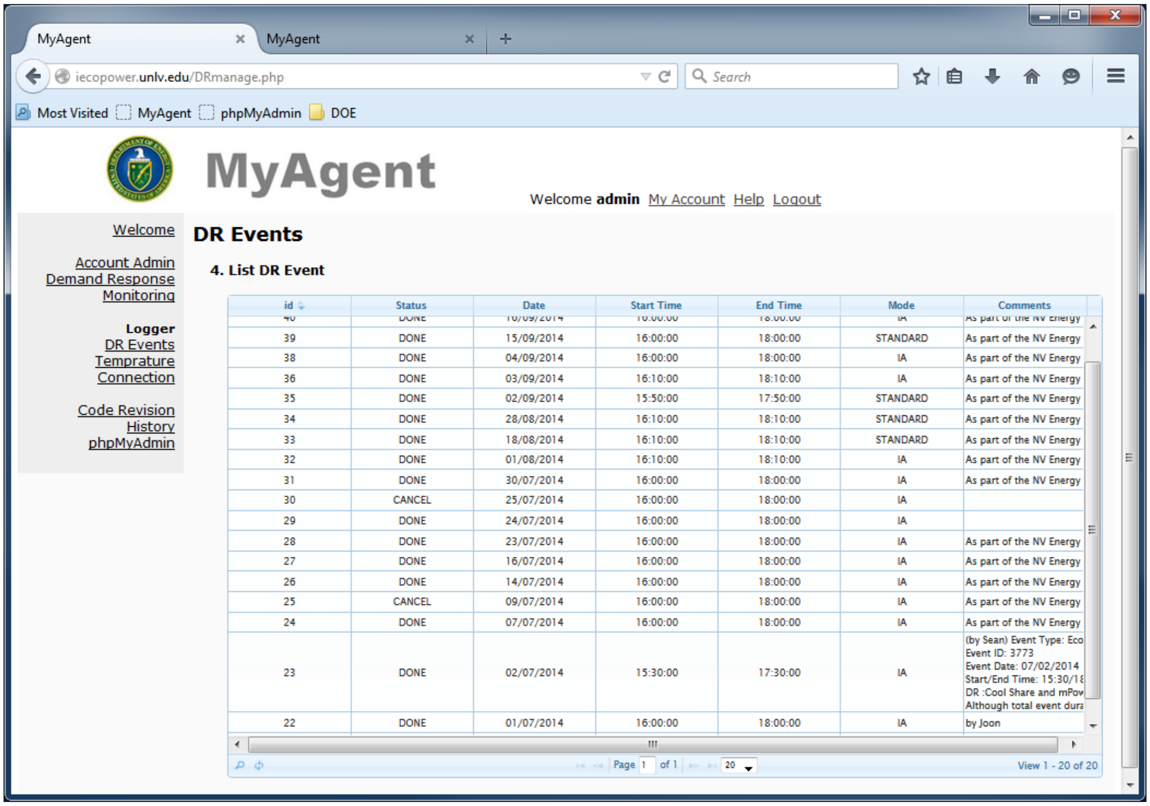


Fig. 9. List of DR events

Figure 9 shows the list of DR events. The list shows following information:

- Status of event: READY, DONE or CANCEL
- Date, start time and end time
- Mode: STANDARD or IA
- Comments

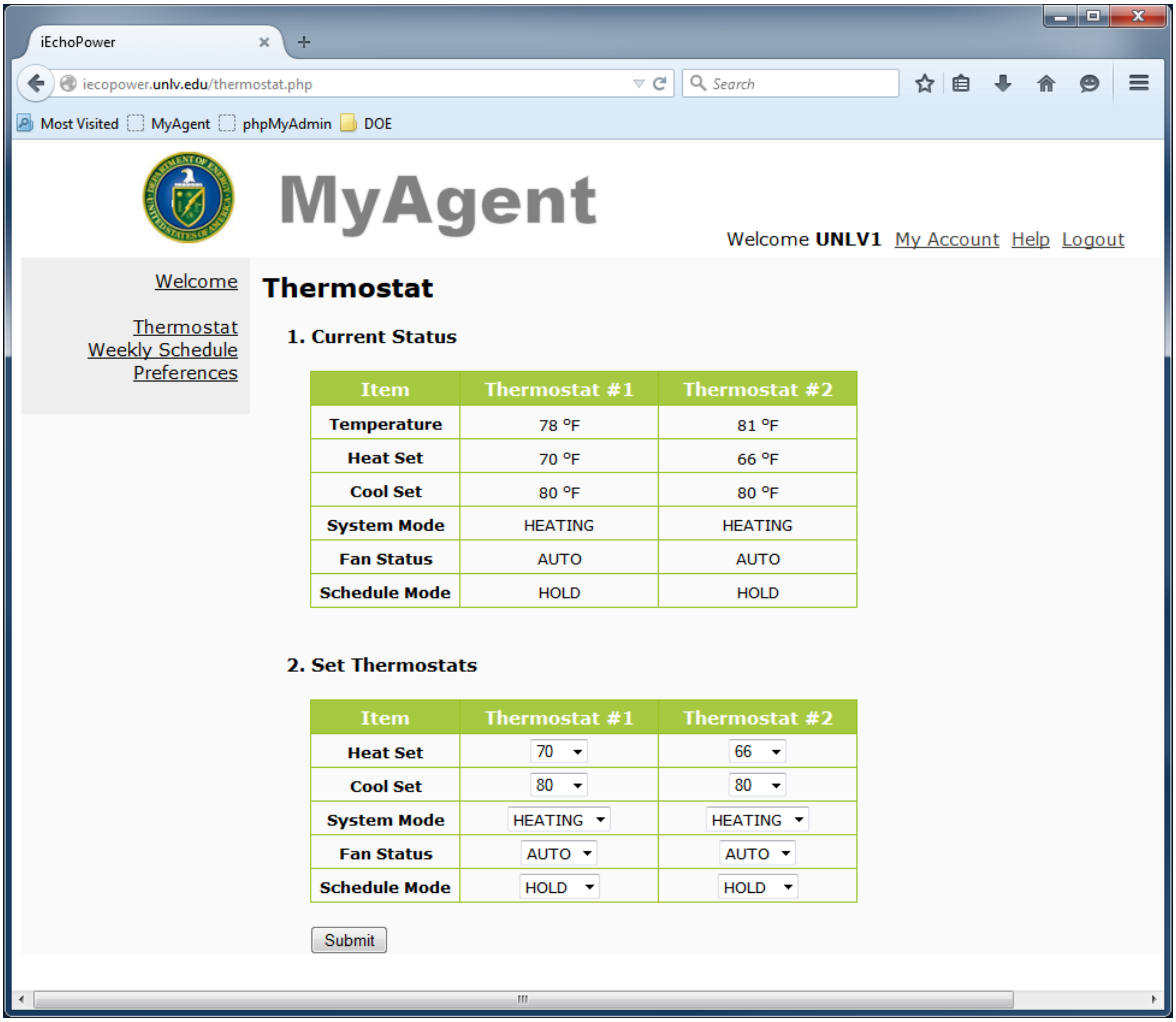


Fig. 10. Customer web interface

Figure 10 shows the customer (home resident) web interface. The User can see the current status of thermostats as follows:

- Room temperature
- Heat and Cool Set Points
- System mode: HEATING, COOLING, or OFF
- Fan Status: Auto, ON or OFF
- Schedule Mode: HOLD or AUTO

And, user can set the following values:

- Heat and Cool Set Points
- System mode: HEATING, COOLING, or OFF
- Fan Status: Auto, ON or OFF
- Schedule Mode: HOLD or AUTO

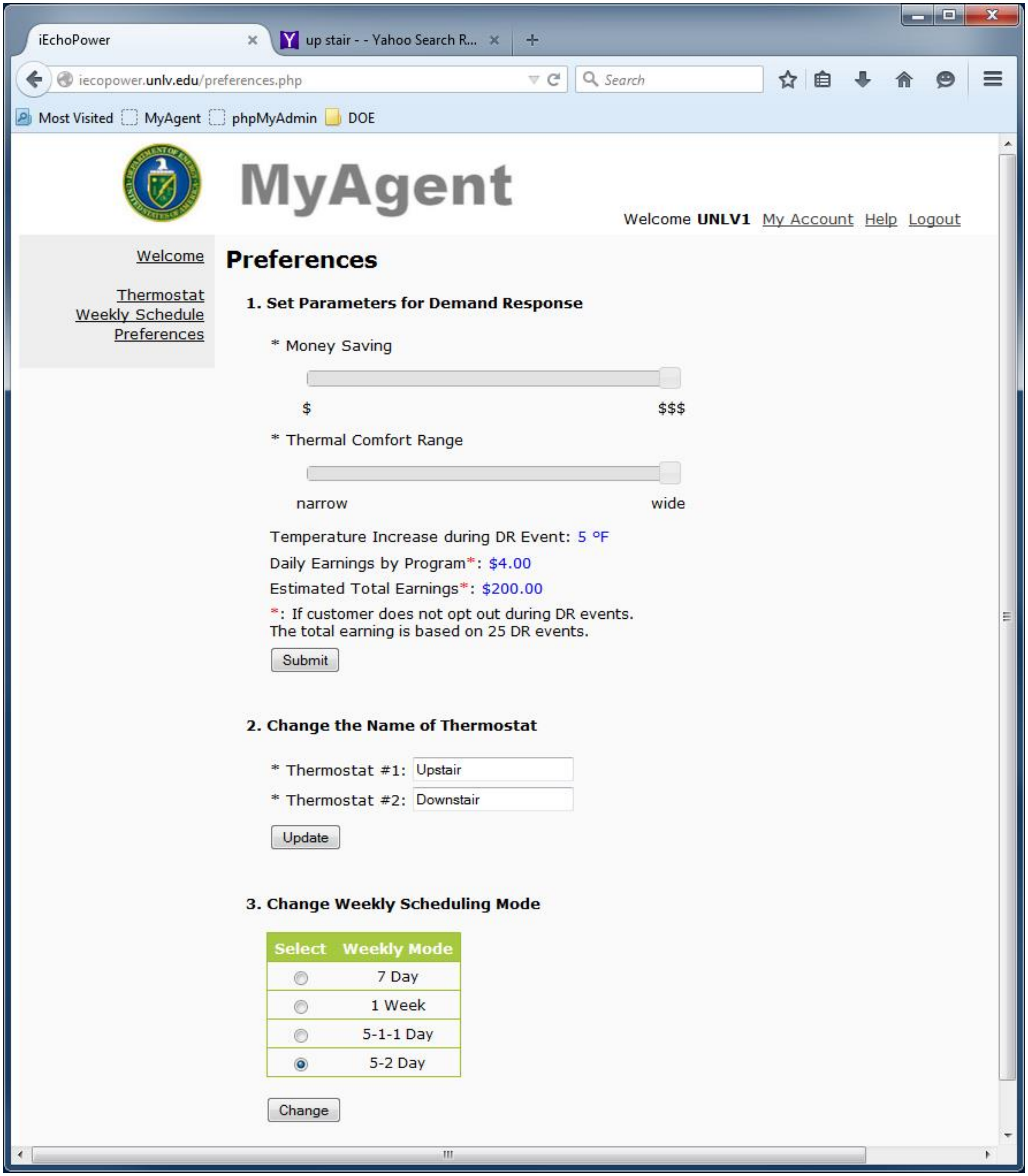


Fig. 11. Customer preference menu

Figure 11 shows customer preference menu. The User can set parameters for Demand Response: Money Saving and Thermal Comfort Range. The preference values are input values to the Intelligent Agent algorithm (Fuzzy Logic Control). When the user adjusts the value, the temperature increase (offset) during the DR event is calculated and displayed from +1 °F to +5 °F. If there are DR Events rebates by the offset value, the daily earning by the program and the estimated total earning are calculated and displayed. The user can change the nick name of each thermostat and change the weekly schedule modes.

3. Data Logger

The UNLV Database server logs several events and data to keep track the performance of developed system. Figure 12 shows the logged data of DR events. The DR event logger keeps the following data with any change of the DR events start, end, or opt out:

- ZigBeeAddress of thermostat
- Current temperature
- Systems mode: OFF, HEARING or COOLING
- Schedule mode
- Current cool set value
- Event mode: STANDARD, IA, DONE or opt out by CHGSET (change set temperature)
- Customer preference: Economy (Money saving) and Comfort (Thermal comfort range)
- Delta temp (offset temperature)
- Date and time of event

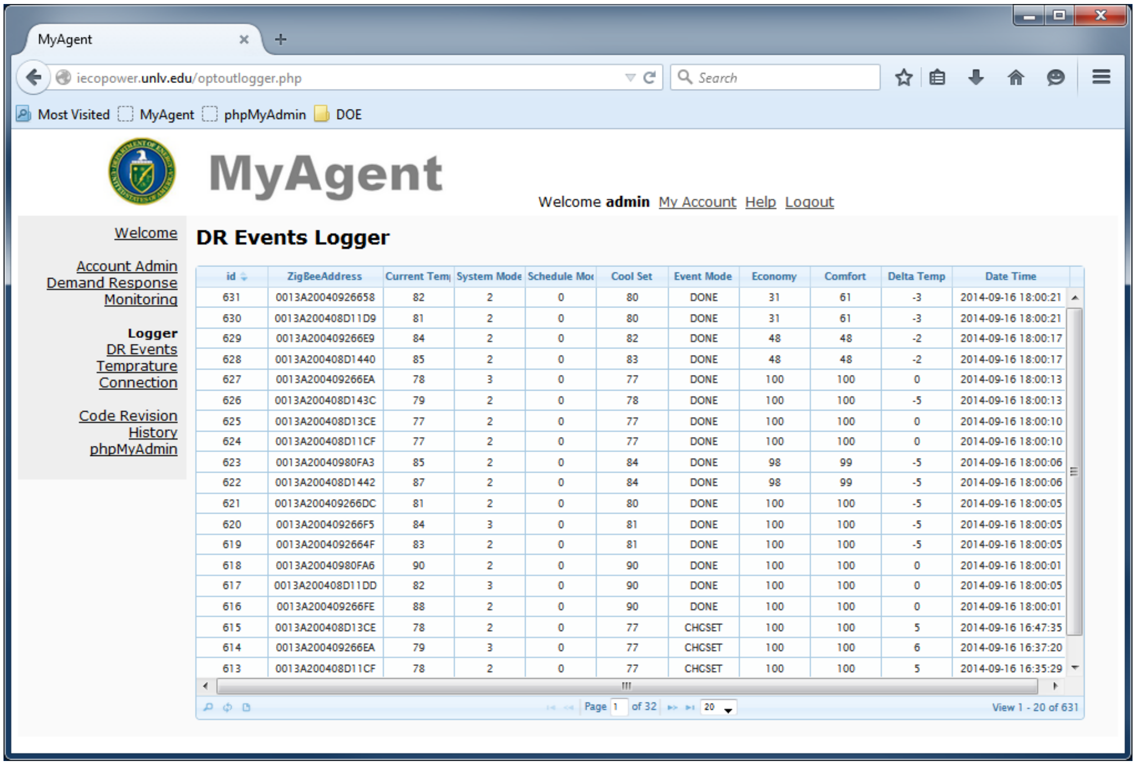


Fig. 12. DR Event logger

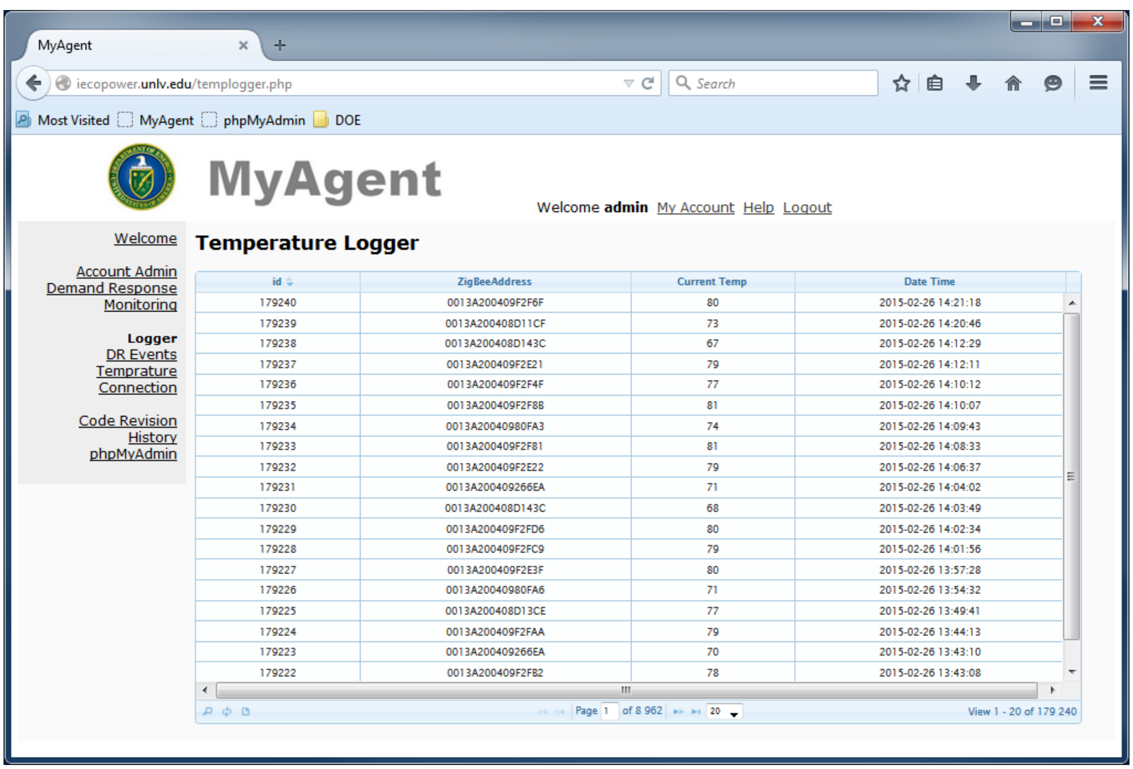


Fig. 13. Temperature logger

Figure 13 shows the logged data of temperature changes of the thermostat. Figure 14 shows the connectivity of gateway to the UNLV server. Depending on the Internet connection, the gateway can be disconnected and reconnected to Internet while the logger keep track of the events.

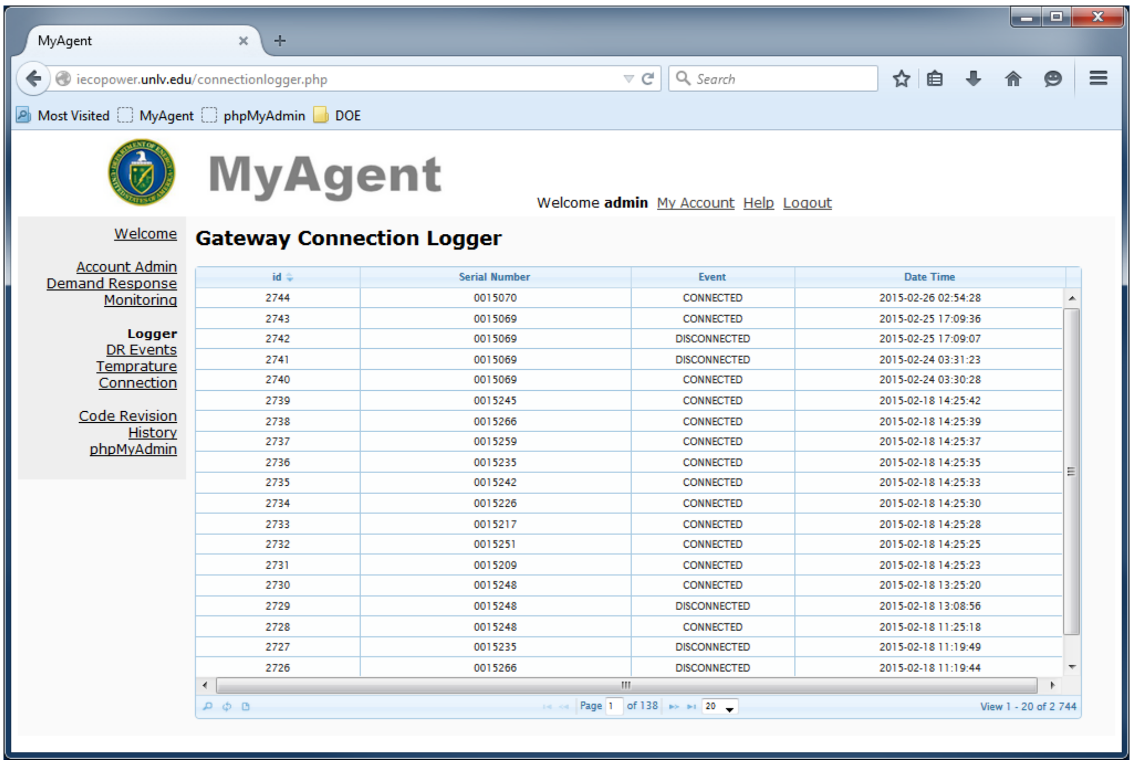


Fig. 14. Gateway connection logger

Reference

[A1] ZigBee Thermostat, *Installation manual*, Model TZB45, RCS Technology

[A2] ZigBee to Ethernet Gateway, *Portal integration manual*, ISY-994iZ Pro, Universal Devices

[A3] Ubuntu Linux Operating System, *http://www.ubuntu.com*

[A4] MySql database, http://www.mysql.com

Appendix B: Intelligent Agent Fuzzy Logic Control

Conventional DR operations set the offset temperature as a fixed value by the utility company. Customers have no way to change the set temperature value except opt out during DR events. With the proposed novel algorithm (Intelligent Agent) of DR operation the customer can participate in the decision of the offset temperature amount by using a customer preference setup.

Intelligent control (Intelligent Agent) using Fuzzy logic is proposed to compromise between the customer and the utility company. The customer can participate in the DR operation by using preferences of how much they want to save and how much they will allow the thermal comfort (temperature variation) range to vary during DR events. The utility company can set their urgency of the Demand Response by setting DR Level as normal, high, or peak. The DR levels can coincide and be incentivized with dynamic pricing. Figure A-1 shows the input and output relation of the intelligent control. Figure A-2 shows the dialog of customer preference. Using the two preference slides, the customer can participate in the DR operation. With changing the slides, the customer can check how the temperature will increase during the DR events, and how much of incentives they can earn during the DR events.

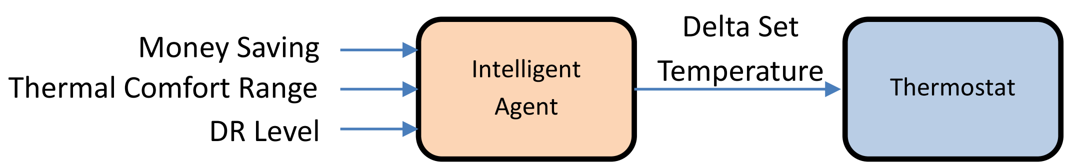


Figure 1 – Block diagram of Input and output of Intelligent Agent

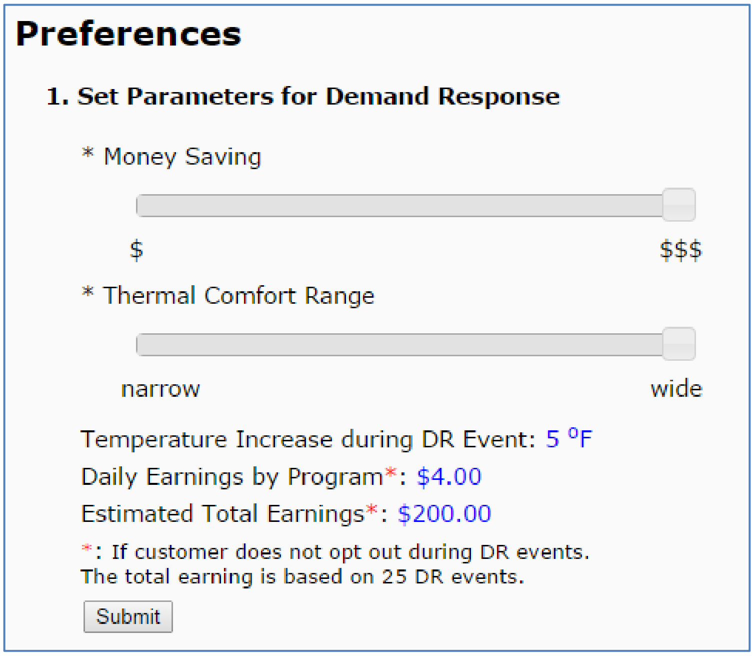


Figure 2 – Dialog of customer preference

1. Intelligent Agent

Fuzzy logic control [A1][A2] is used in the Intelligent Agent. Fuzzy logic is used to infer the rules and handle linguistic variables proposed by Zadeh [A3]. The preferences of customers are how much do they want to save (earn) and how much do they want to allow thermal comfort range to vary during DR events. Regarding how much a customer wants to save, the level of savings could be "a lot", "moderate" or "little". And, for the how much the customer opts for on the thermal comfort aspect, the range could be a "narrow", "medium" or "wide" range. To handle these kinds of linguistic values, Fuzzy Logic was used.

For the Fuzzy Membership function, a Gaussian shape function is used. Figures A-3 and A-4 show the defined membership functions for the preferences of Money Saving and Thermal Comfort Range. Figure A-5 shows the defined membership function of the Delta Set (Offset) Temperature for thermostat.

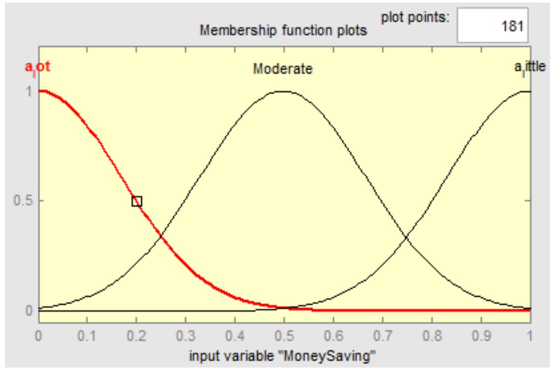


Figure 3 – Membership function of Money Saving

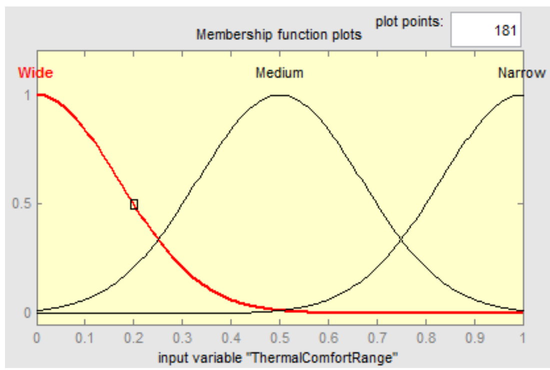


Figure 4 – Membership function of Thermal Comfort Range

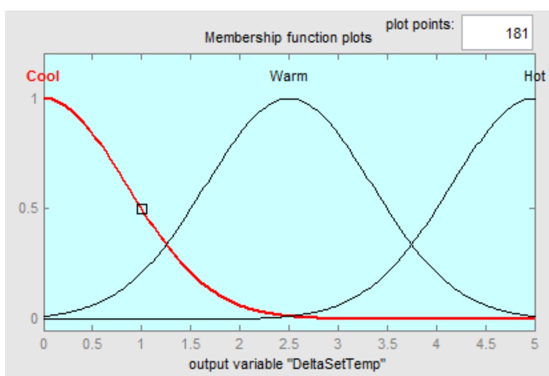


Figure 5 – Membership function of Delta Set Temperature

Fuzzy inference rules are defined to map between input of the customer preferences and output of delta set temperature. To handle the DR Level of "normal", "high" and "peak", three sets of inference rules are defined.

The examples of inference rules are as follows:

- IF (DR Level IS Normal) AND (Thermal Comfort Range IS Narrow) AND (Money Saving is a Lot) THEN (Delta Set Temperature is Cool) from Table 1.

- IF (DR Level IS Normal) AND (Thermal Comfort Range IS Medium) AND (Money Saving is a Lot) THEN (Delta Set Temperature is Warm) from Table 2.
- IF (DR Level IS Peak) AND (Thermal Comfort Range IS Wide) AND (Money Saving is Little) THEN (Delta Set Temperature is Hot) from Table 3.

Table 1. Inference rules for normal DR Level

		Money Saving		
		a Lot	Moderate	Little
Thermal Comfort Range	Narrow	Cool	Cool	Cool
	Medium	Warm	Cool	Cool
	Wide	Hot	Warm	Cool

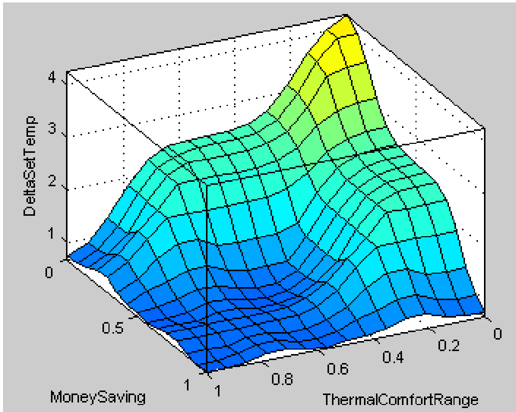
Table 2. Inference rules for high DR Level

		Money Saving		
		a Lot	Moderate	Little
Thermal Comfort Range	Narrow	Warm	Cool	Cool
	Medium	Hot	Warm	Cool
	Wide	Hot	Hot	Warm

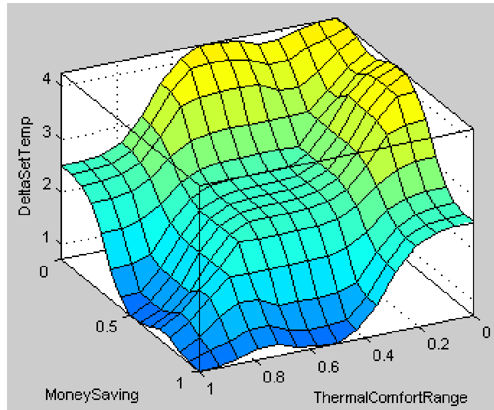
Table 3. Inference rules for peak DR Level

		Money Saving		
		a Lot	Moderate	Little
Thermal Comfort Range	Narrow	Hot	Warm	Cool
	Medium	Hot	Hot	Warm
	Wide	Hot	Hot	Hot

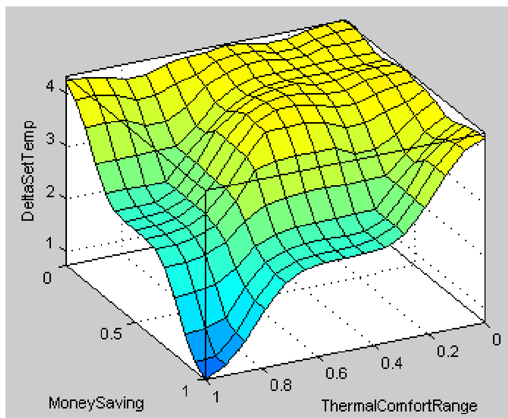
Figure 6 shows the resulting control output, Delta Set Temperature, of each of the DR levels determined by the customer's preference. Depending upon on the urgency of the DR events, the delta set temperature is set to small on the normal DR level, and set to mostly high on the peak DR level.



(a) Surface of normal DR level



(b) Surface of high DR level



(c) Surface of peak DR level

Figure 6 – Fuzzy control surface plot

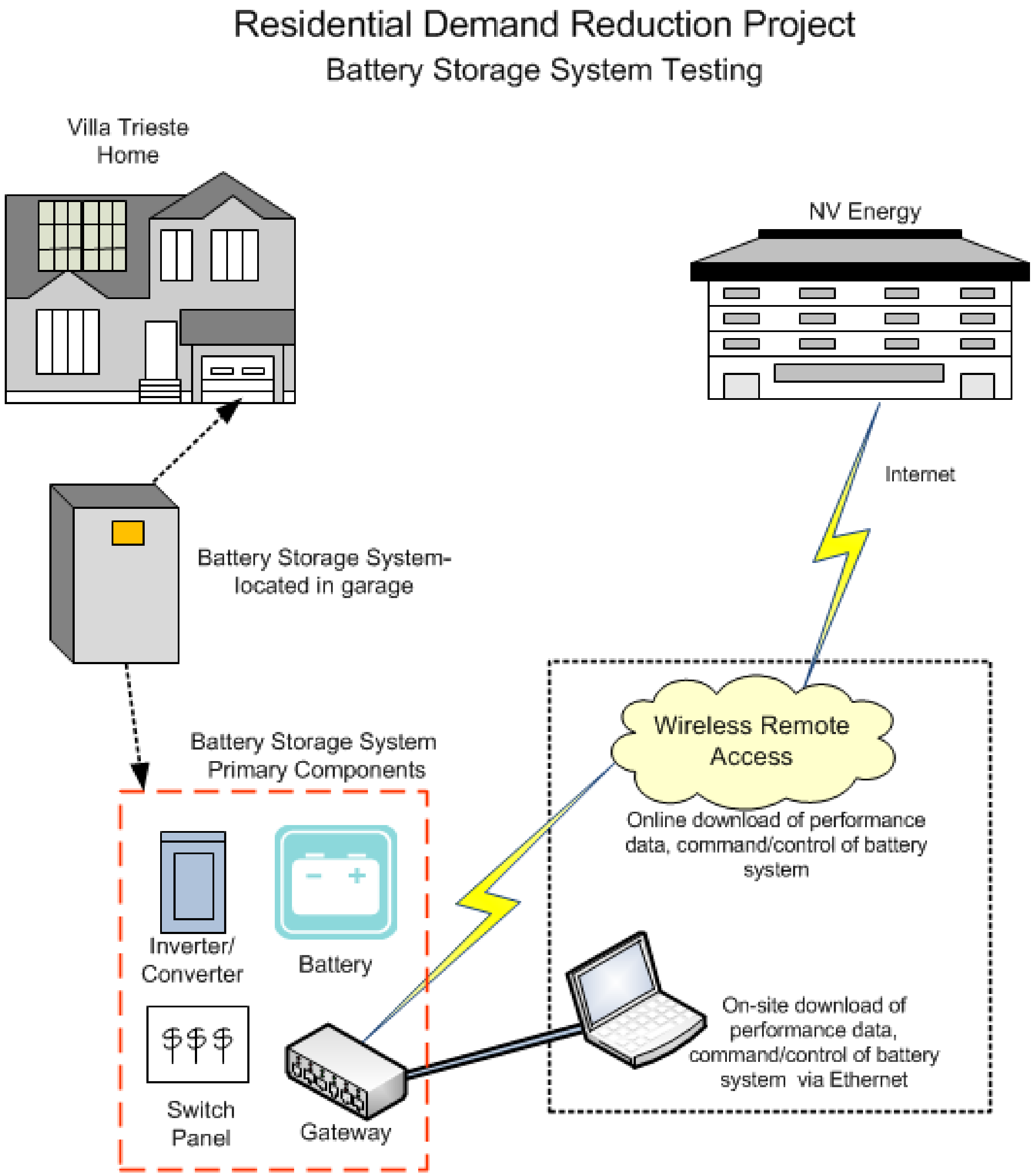
Reference

[1] E.H. Mamdani, "Advanced in the linguistic of fuzzy controllers," Int. Journal of Man-Machine Studies, Vol. 8, pp. 669-678, 1976

[2] M. Sugeno, *Industrial applications of fuzzy control*, Elsevier Science Pub. Co., 1985

[3] L.A. Zadeh, "Fuzzy sets," *Information and Control,* Vol.8, pp. 338-353, June 1965

Appendix C: Structure of Battery Storage System Pilot Test



Appendix D: Specifications and Photos of Silent Power ODEA

OnDemand Energy Appliance
Technical Specifications

Key Features

- Comes standard with 10 kWh of energy storage (20kWh/XLT cabinet)
- Available up to 9.2 kW (120/240V) or 8.0 kW (120/208V) AC electrical output
- Multiple units also can be used in parallel for higher output or additional energy storage
- Built-in PV charge controller
- Batteries can be charged by solar or grid
- Several battery chemistry options, including lithium ion
- Touch screen display
- Backup power
- Remote operation
- Qualifies for various energy incentive programs

C US 1741

Silent Power INC.
Energy when you need it

For more information call
888.818.1001 (press 1)
or visit our website: **www.silentpwr.com**

8175 Industrial Park Rd.
Suite 100, Baxter, MN 56425

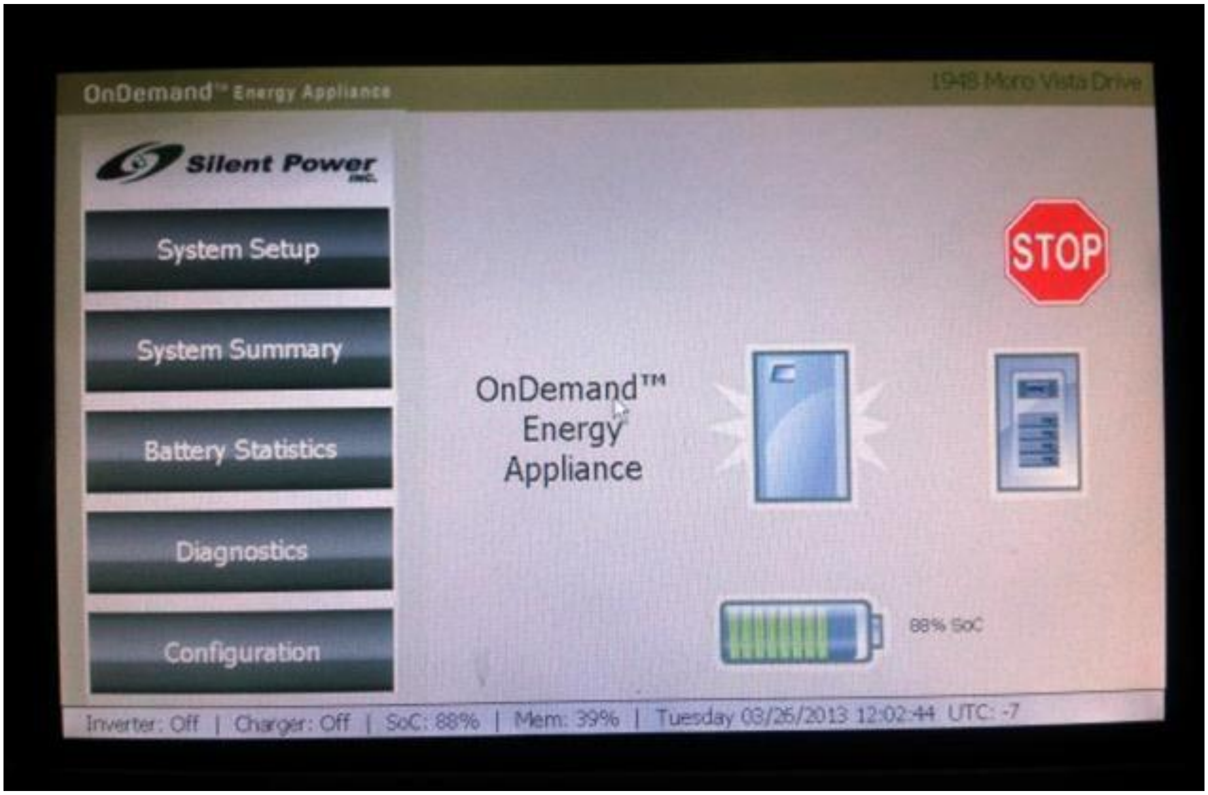
Inverter		
Inverter Output Rating – Voltage (AGM Battery)	4.6kW-120VAC, 9.2kw-120/240 VAC 8.0kW-120/208 Y Single phase	
Inverter Output Rating – Voltage (Samsung LI Battery)	4.6kW-120VAC, 7.6kw-120/240 VAC 6.6kW-120/208 Y Single phase	
Inverter Output Rating – Voltage (Sony LI Battery)	4.6kW-120VAC, 9.2kw-120/240 VAC 8.0kW-120/208 Y Single phase	
Inverter Output Rating – Current	38Aac	
Maximum AC breaker rating	60Aac	
Phase Angle Control	± 45 degrees	
Backup Power Features		
AC Pass-through Current to Critical Circuits Panel	42A at 120VAC, 100A at 120/240VAC	
Switching Time upon Grid Outage	< 30 mS	
AC Surge Rating	2X for 600mS	
Zero to Full-Power Ramp Time	3mS	
Backup Switching Criteria	Per IEEE 1547	
Continued Solar Production in Backup Mode	Yes	
Battery Charger		
Battery Charger Power Rating	60A DC (2800 W max power)	
Maximum Input Current	22A @240 VAC, 25A @208 VAC	
Input Battery Voltage Range	30 to 65 VDC	
Continuous Input Battery Current	4.6kW -115A, 7.6kW-190A	
LVDC PV MPPT Charge Controller		
Maximum Power Input (per charge controller)	3,200 Watts	
Maximum Open Circuit Solar Voltage	150 VDC	
Maximum Output Current (per charge controller)	60 A DC	
HVDC PV MPPT Charge Controller		
Maximum Power Input (per charge controller)	4,800 Watts	
Maximum Open Circuit Solar Voltage	550 VDC	
Maximum Output Current (per charge controller)	80 A DC	
Communications		
User Interface	7" Touch Screen Display, Ethernet for Web-based PC Interface	
External Command & Control	Ethernet for Broadband Internet, XML Protocol	
Miscellaneous	CAN Bus Communication Port	
Environmental Specifications		
OnDemand Operating Temperature*	-20ºC to +55ºC (-4ºF to +131ºF)	
OnDemand Storage Temperature	-40ºC to + 70ºC (-40ºF to 158ºF)	
Enclosure Environmental Rating	NEMA-2 (indoor)	
Recommended Battery Operating Temperature	-15ºC to 45ºC	
Operating Power Derating @ Temperature	83% @ 45ºC, 67% @ 50ºC, 50% @ 55ºC	
Certification	UL-1741, UL-1778, CSA 107.1	
Physical Specifications		
OnDemand Model	Standard Cabinet	XLT
Dimensions (H x W x D)	54.5" x 27" x 29.5"	73" x 27" x 29.5"
Installation Clearance Dimensions (H x W x D)	60.5" x 39" x 31.5"	79" x 39" x 31.5"
Enclosure Weight (without batteries)	375 lbs	400 lbs
Sealed Lead Acid Battery – Concorde		
Battery	PVX-2580L, Sealed VRLA-AGM, 12Vdc	
Format	8D	
Rated Battery Capacity (24-hour rate)	258 AH @ 12V = 3.096 kWH	
OnDemand Battery Configurations	4 Batteries	8 Batteries
Battery Configurations	1 string – 48Vdc	2 strings – 48Vdc
Total Energy Storage Capacity	12.4 kWH	24.8 kWH
Total Useable Energy (50% DoD)	6.2 kWH	12.4 kWH
Total Useable Energy (80% DoD)	9.9 kWH	19.8kWH
Weight	660 lbs	1320 lbs
Lithium-Ion Battery – Samsung		
Battery Tray	Samsung 13S1P, 48Vdc	
Battery Tray Capacity (rated)	2.8 kWH per tray	
OnDemand Tray Configurations	4 trays	8 trays
Maximum Battery Current	150Adc max	150Adc max
Total Energy Storage Capacity	11.5 kWH	23 kWH
Total Useable Energy (at 90% DoD)	9.2 kWH	18.4 kWH
Weight	225 lbs	450 lbs
Lithium-Ion Battery – Sony		
Battery Module	Sony IJ1001M, 48Vdc	
Module Rated Capacity	1.2 kWh per module	
OnDemand Module Configurations	8 Modules	15 Modules
Controller Configurations	2 – 200Adc max	3 – 300Adc max
Total Energy Storage Capacity (rated)	9.6 kWh	18 kWh
Total Useable Energy at 100% DoD	9.6 kWh	18 kWh
Weight	300 lbs	551 lbs

*System output derates between 40°C and 55°C

Standard ODEA unit


Silent Power

ODEA touchscreen customer interface (manual control panel)



ODEA breaker panel

Appendix E: Sunverge SIS Specifications

AC Electrical Specifications		
Model	**SIS-6048-X**	**SIS-4548-X**
Continuous Output Power	6,000 W	4,500 W
Surge Rating (10 Seconds)	12,000 W	9,000 W
AC Voltage	120/240 Vac Split-Phase	
Surge Current	105 A-L-N (15 sec) 52.5 A-L-L (15 sec)	75.5 A-L-N (20 sec) 40 A-L-L (20 sec)
AC Inputs (Grid | Generator)	2-60A 2-Pole: IEEE 62.41, 62.45 & 1.2x50ms, C37.90.1	
Nominal Frequency	58.5 to 60.5 Hz	
Output Waveform	True Sine Wave; Stable at 120 Vac within 4 cycles	
AC Output Voltage	L-N: 120 Vac ± 3%; L-L: 240 Vac ± 3%	
AC1 Frequency Range	59.4 to 60.4 ± 0.05 Hz (automatically adjusts)	
AC Transfer SW Speed	Isolation Contactor (30 KV BIL, 400 A continuous & interrupt 50 Ka fault duty for 2 cycles) 10 Ka Residential < 8 ms.	
Total Harmonic Distortion	< 5%	
Voltage Correction	Yes. ± 10%	
CEC Weighted Efficiency	92.5%	93.0%
Idle Consumption — Search Mode	< 8 W	
Ambient Air Temperature Operating Range	-13 to 122°F (-25 to 50°C)	
Emissions	FCC Class B	
Anti-islanding	UL1741:2005, CSA 107.1-01, Rule 21 Compliant.	
System Network	CAN BUS	
Cooling	Forced Air — Induction	
Backup Power	Yes. Configurable.	

Front View (Open Door)
72.5" high, 24.3" wide, 13.9" deep

DC Specifications	600V MPPT
Maximum PV Array Operating	550 Vdc
DC Output (Nominal)	48 Vdc
MPPT PV Operating Range	195 to 510 Vdc
Maximum PV Open Circuit Volts	600 Vdc
Maximum PV Short Circuit Amps	35 A
Ground Fault Protection	GFDI Rated: 1 A
Electronic Overcurrent Protection	Yes. > 0.5 A
Separate MPPT Inputs	Yes. Two (2)
DC Bus Ground	Enclosure Ground
Battery Chemistry	Li-Ion
Battery Voltage	48 Vdc Nominal 42 to 58 Vdc Op. Range
Battery Capacity	11.7 kWh, 225 Ah
Max. Discharge Rate	120 A (6kW), 90 A (4.5kW)
Max. Charge Rate	80 A from SCC, 120 A from 6kW Inverter, 90 A from 4.5kW Inverter
Cycle Life (80% DoD)	3,000 to 5,000 Cycles (temp & usage dependent)

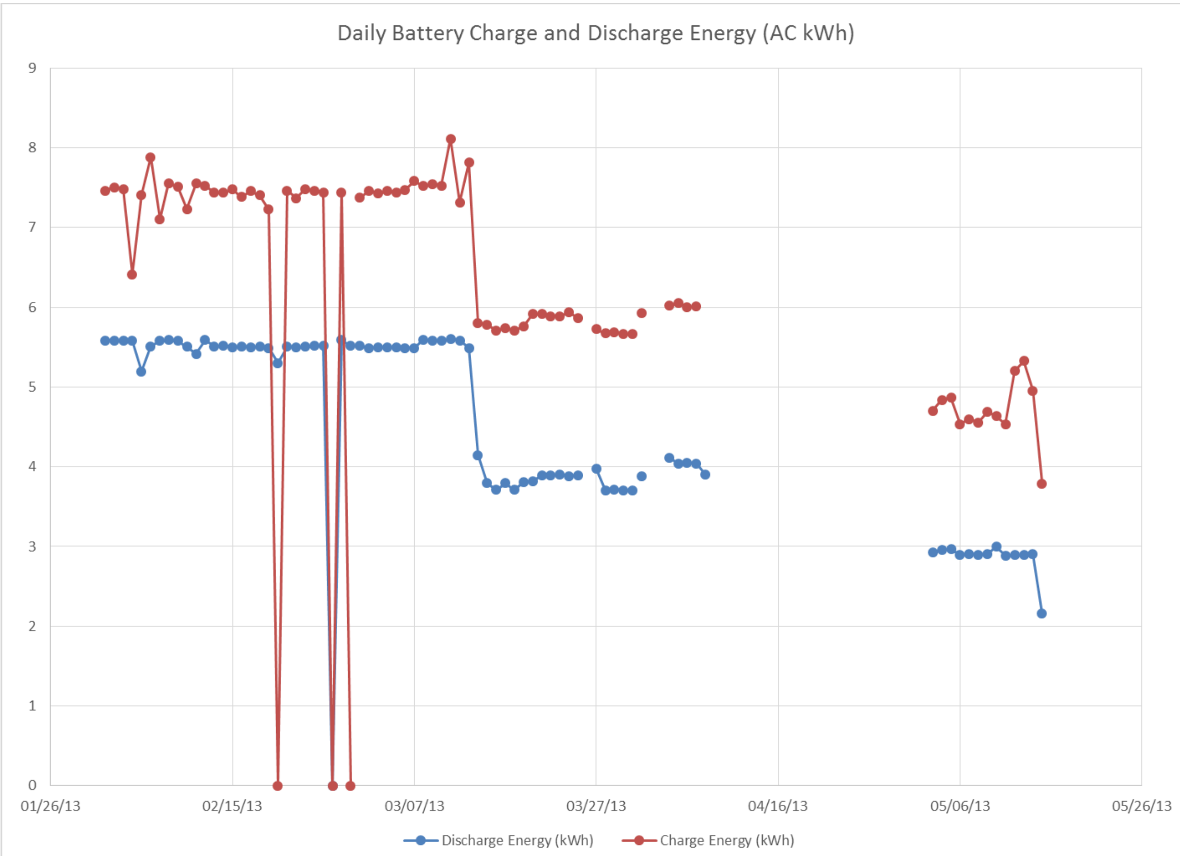
Mechanical Specifications	
Outdoor | Rainproof	NEMA 3R: IEEE C57.12.52 Section 6, C57.28 Section 4
Material	Mild Steel (12 ga.)
Paint	IEEE C57.12.28 Section 5, Powder Coating
Mounting	Anchor/Polycrete Pad
Hardware	Stainless Steel
Weight	629lbs. (285kg) w/ 11.7kWh Battery
Grounding	Utility Ground
Nameplate	Conn. Diag. Rating ETC IEEE c57.12.00

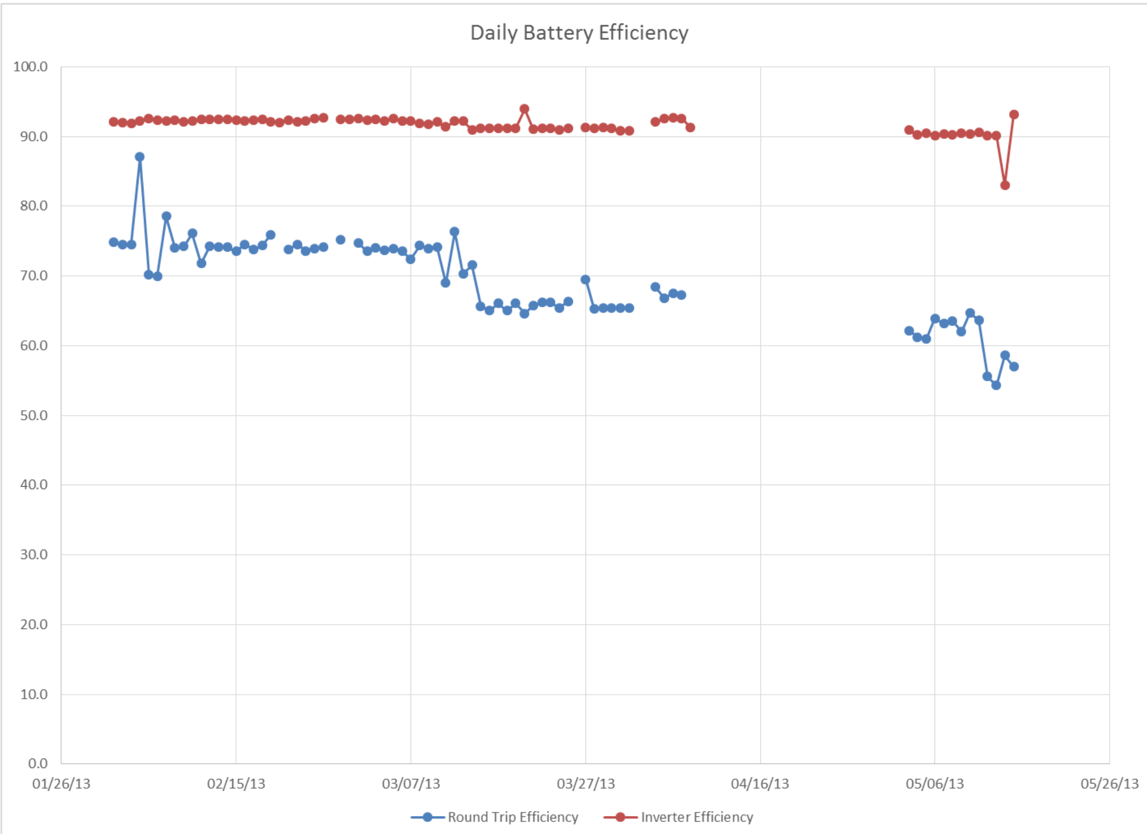
ETL US LISTED
Intertek
File number: 4007361

Sunverge Energy
6665 Hardaway Rd.
Stockton, CA 95215
209.931.5677 | sunverge.com

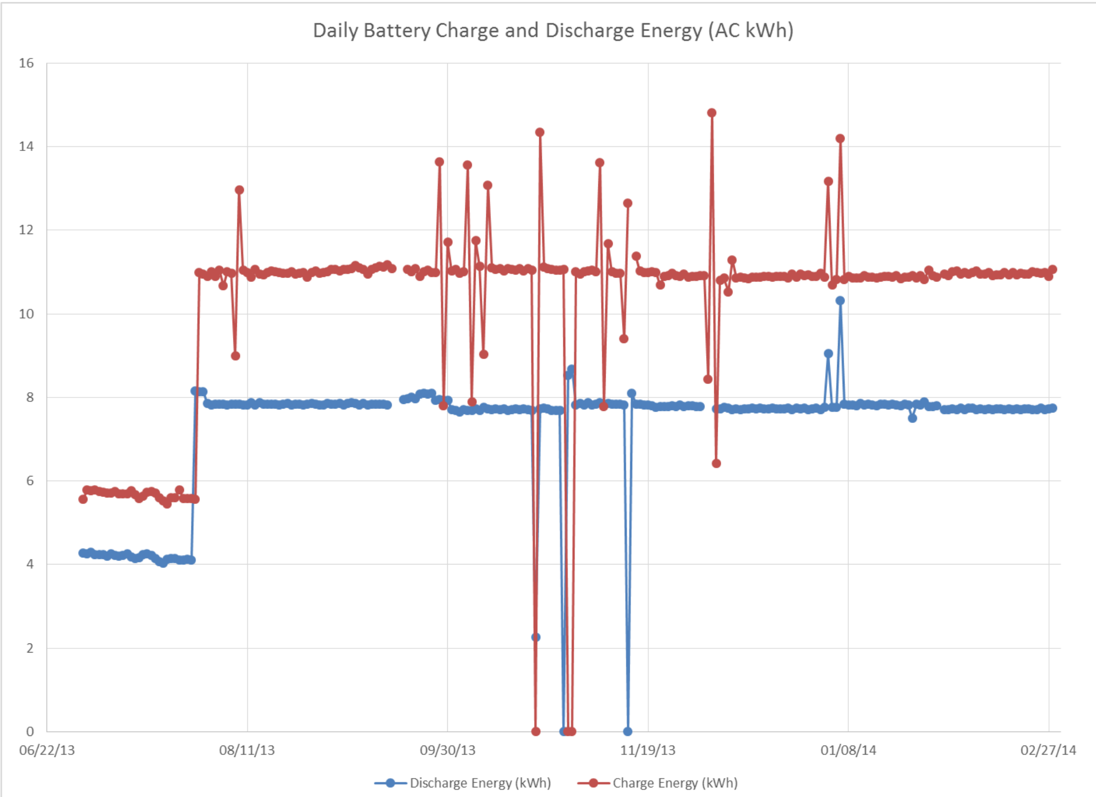
Appendix F: Performance of Installed ODEA Units

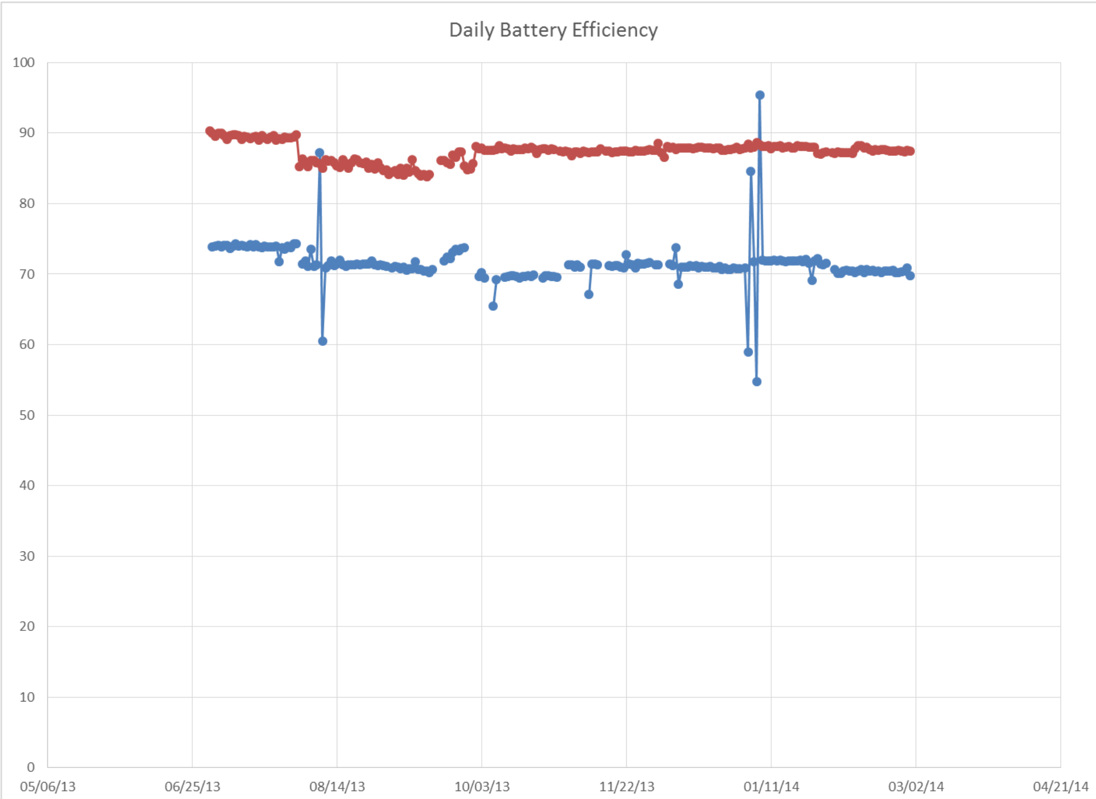
1. First ODEA unit with Saft Battery – installed at Villa Trieste model home and active from February 2013 until May 2013. Data in April and late May were lost due to operational and communication issues. Unit was removed and returned to Silent Power in August 2013.



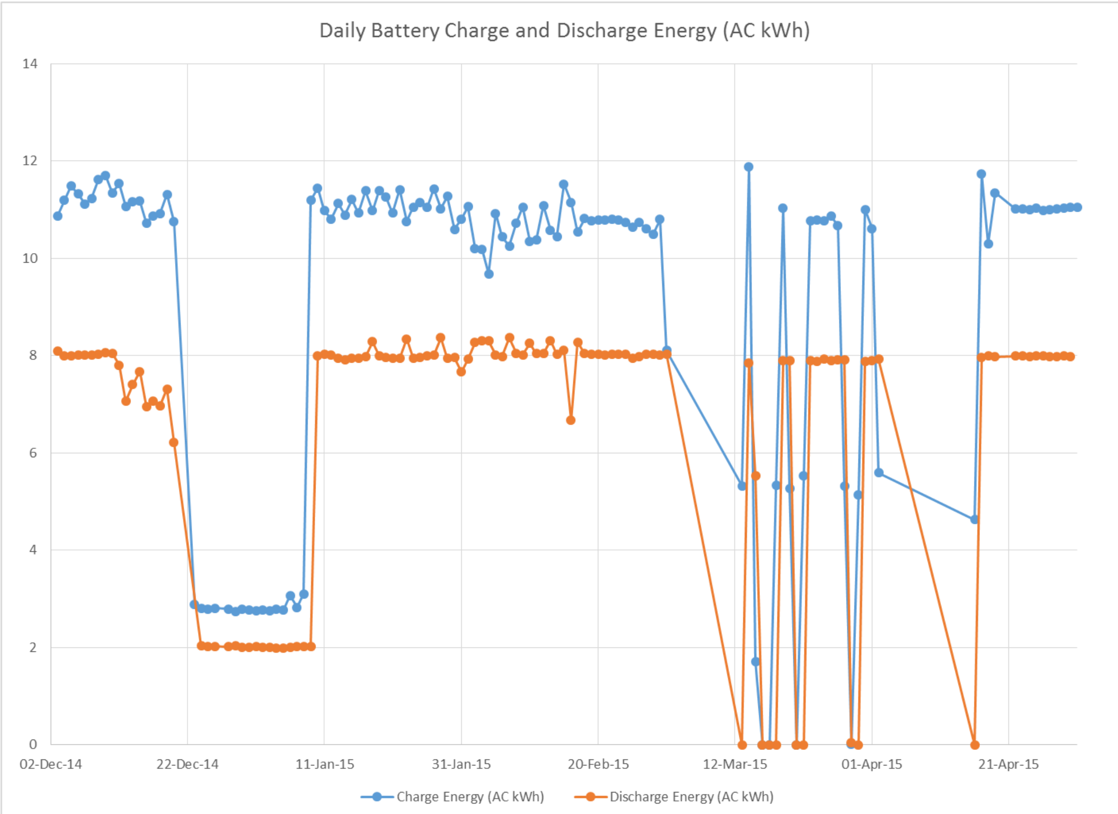

Daily Battery Efficiency
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
01/26/13
02/15/13
03/07/13
03/27/13
04/16/13
05/06/13
05/26/13
Round Trip Efficiency
Inverter Efficiency

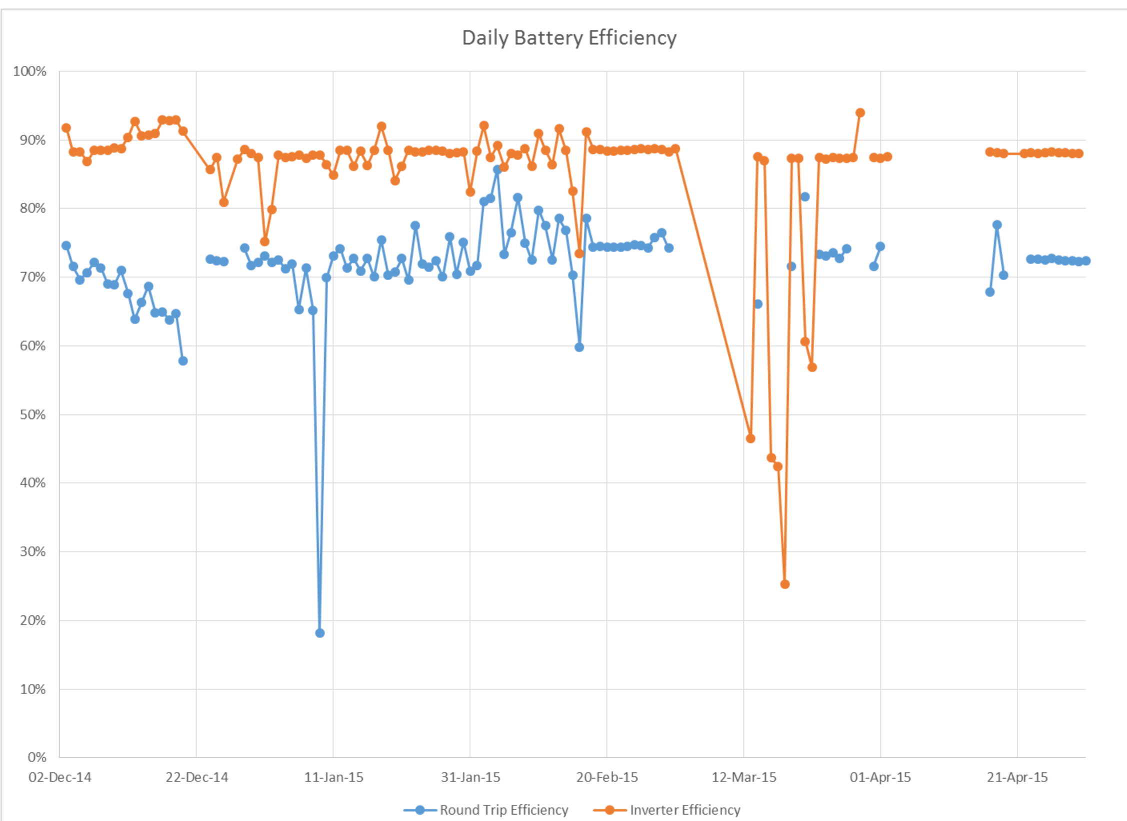
2. ODEA with Samsung Batteries – installed and tested at Silent Power's facility from July 2013 until February 2014





3. ODEA installed at a Villa Trieste home on October 31, 2014. Testing began in December 2014 and is continuing at the present. See next page for operational observations.


Daily Battery Charge and Discharge Energy (AC kWh)
0
2
4
6
8
10
12
14
02-Dec-14
22-Dec-14
11-Jan-15
31-Jan-15
20-Feb-15
12-Mar-15
01-Apr-15
21-Apr-15
Charge Energy (AC kWh)
Discharge Energy (AC kWh)


Daily Battery Efficiency
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
02-Dec-14
22-Dec-14
11-Jan-15
31-Jan-15
20-Feb-15
12-Mar-15
01-Apr-15
21-Apr-15
Round Trip Efficiency
Inverter Efficiency

Operational Observations:

12/2/2014: Set ODEA to discharge daily 4 – 6 pm at 4000 W to 80% depth of discharge (DOD) and start daily charging at 4 am

12/22/2014: Revised charge/discharge schedule:

discharge - Dec 22 - Jan 7, 2015, from 4 – 6 pm at 4000 W to 20% DOD. The DOD was mistakenly set at 20%, instead of 80% during this period.

charge - Dec 23 - Jan 8, 2015, from 4 – 8 am

1/8/2015: Revised charge/discharge schedule:

discharge - until Jan 31, from 4 – 6 pm at 4000 W to 80% DOD

charge - until Feb 1, from 4 – 8 am

1/30/2015: Revised charge/discharge schedule:

discharge - Feb 1 until Feb 28, from 4 – 6:15 pm at 4000 W to 80% DOD

charge - Feb 2 until Mar 1, from 4 – 9 am

3/10/2015: Set new schedules for Load Limiting to 1 kW from 1 – 7 pm until 80% DOD

This capability did not function properly because the system did a full discharge anytime the demand exceeded the threshold.

charge – 4 – 9 am until April 1, 2015

gap – waiting to set new modes

4/14/2015: Revised charge/discharge schedule until May 1, 2015:

discharge - from 4 – 6:15 pm at 4200 W to 80% DOD

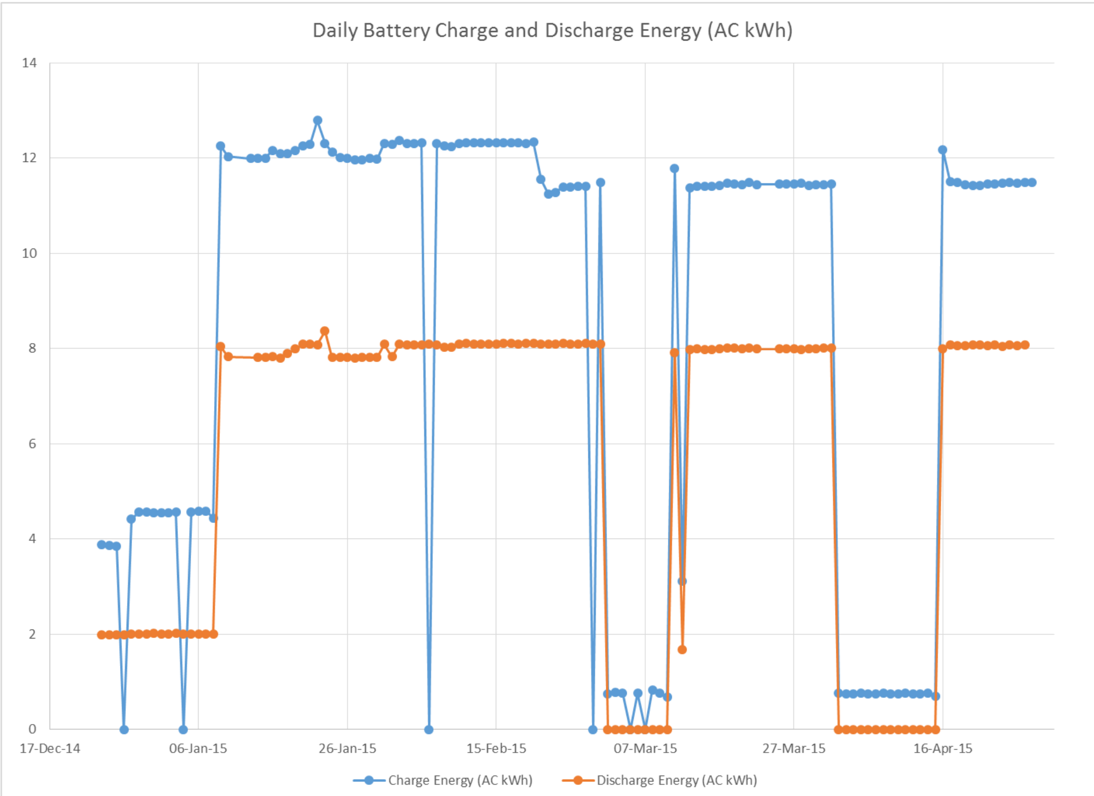
charge - from 4 – 9 am

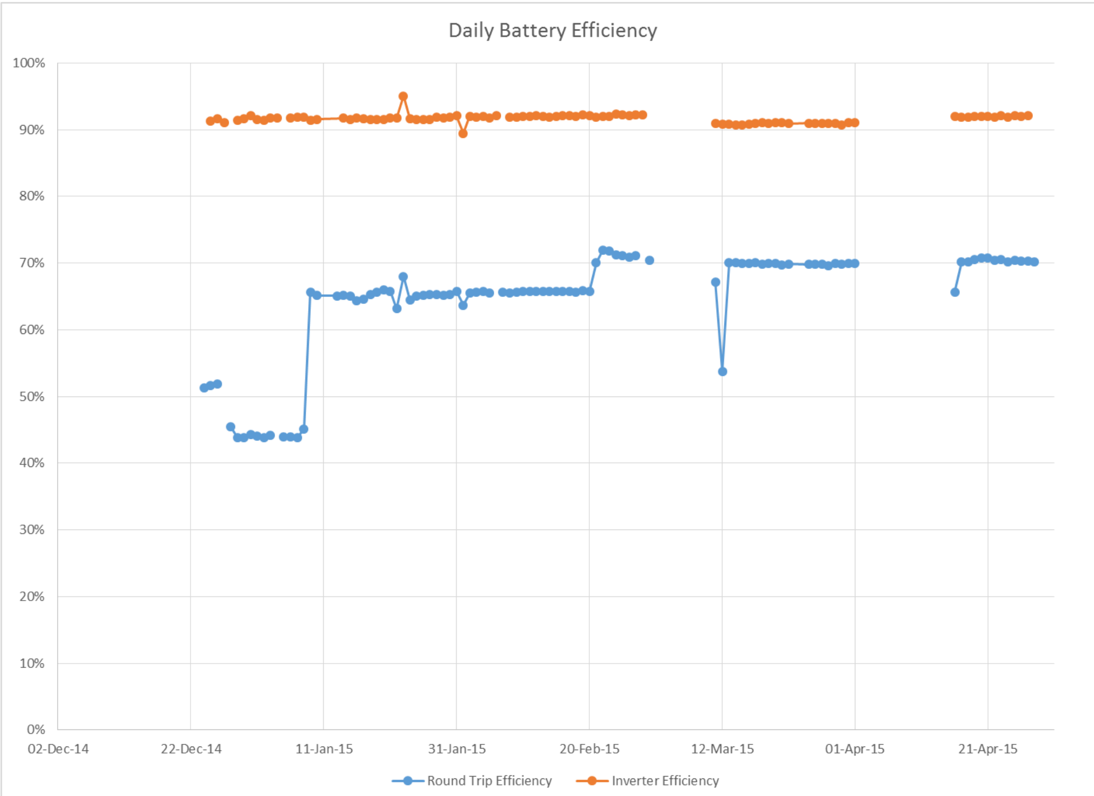
gap – waiting to set new mode

5/18/15: Set schedules for solar firming from 12 – 6 pm to 80% DOD

Solar firming capability has not been operating as expected. As a result, there is no data available after April 2015.

4. ODEA unit installed at a Villa Trieste home on December 16, 2014. Fully operational from December 2014 through present. See next page for operational observations.





Operational Observations:

12/22/2014: Set ODEA to start daily discharge from 4 – 6 pm, from Dec 23 through Jan 7, 2015. The DOD was mistakenly set at 20%, instead of 80% during this period. Daily charging was set for 4 – 8 am from Dec 23 through Jan 8, 2015.

1/8/15: Revised charge/discharge schedule ending on Jan 31/Feb1:

discharge 4 – 6 pm at 4000 W to 80% DOD

charge 4 – 8 am until Feb 1

1/30/2015: Revised charge/discharge schedule:

discharge - Feb 1 until Feb 28, from 4 – 6:15 pm at 4000 W to 80% DOD

charge - Feb 2 until Mar 1, from 4-9 am

gap – Wating for mode switch

3/10/2015: Set new schedules for Load Limiting to 1 kW from 1 – 7 pm until 80% DOD:

charge – 4 – 9 am until Apr 1 2015

gap – waiting to set new mode

4/14/2015: Revised charge/discharge schedule until May 1, 2015:

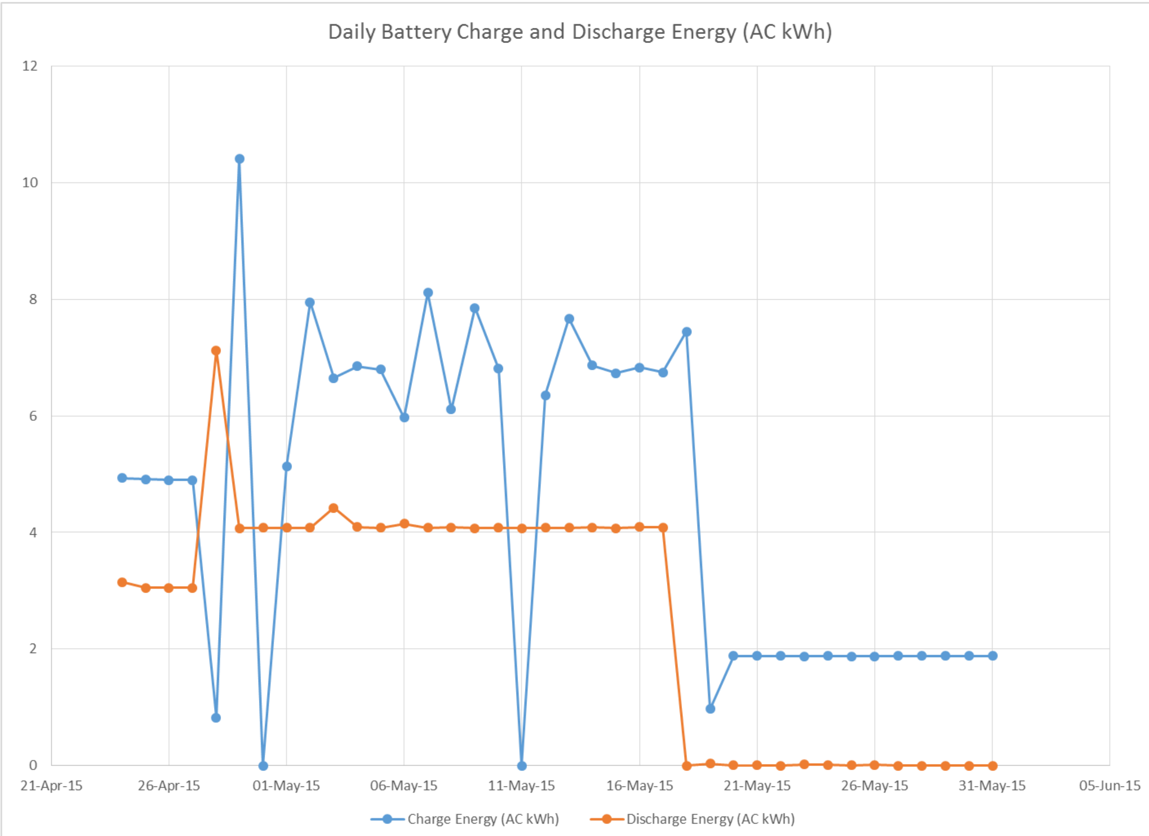
discharge - from 4 – 6:15 pm at 4200 W to 80% DOD

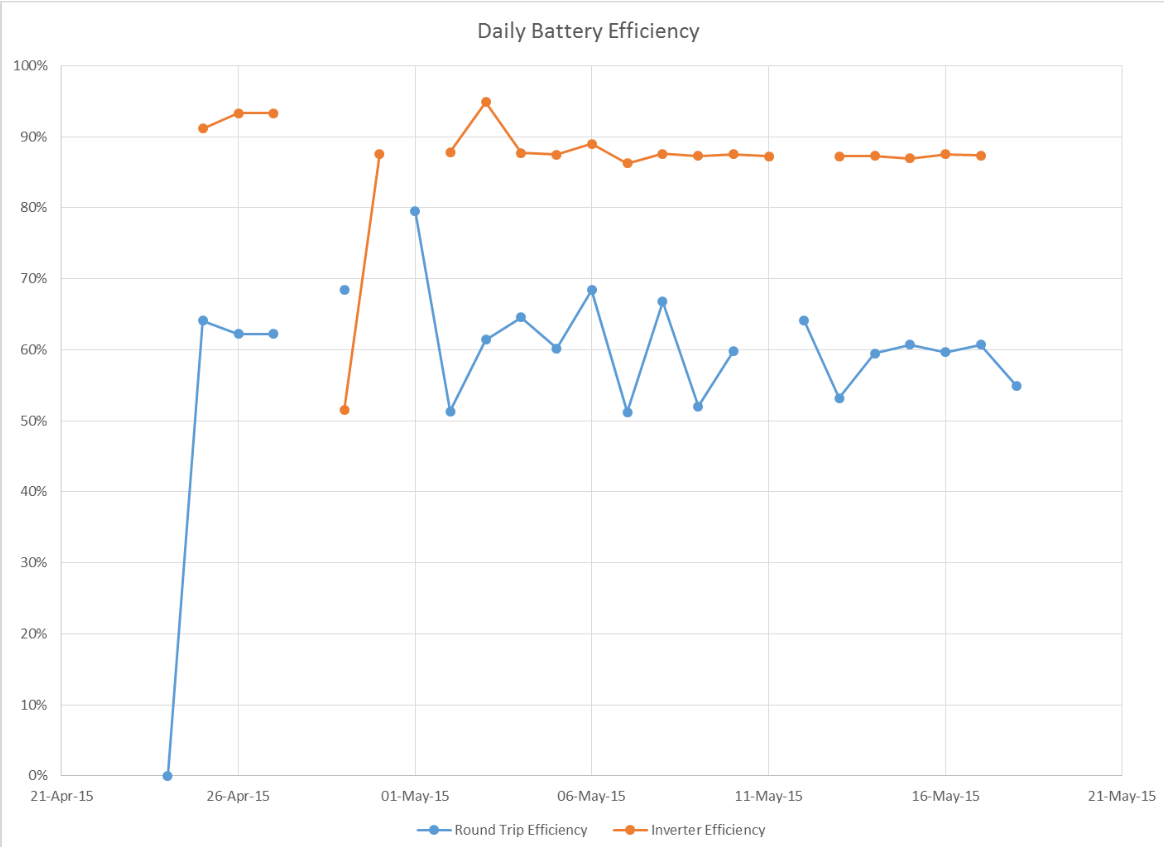
charge - from 4 – 9 am

gap – waiting to set new mode

5/18/15: Set schedules for solar firming from 12 – 6 pm to 80% DOD

5. ODEA installed at a Villa Trieste home on April 24, 2015, and operating until present. See next page for operational observations.





Operational Observations:

Tested initially to 40% DOD until 4/28/2015

4/28/15: Revised charge/discharge schedule:

charge: 4 – 9 am

discharge: 4 – 7 pm at 4000W to 80% DOD

5/18/15: Set schedules for solar firming from 12 – 6 pm to 80% DOD

charge: 1 – 6 am

power level :2000 W

ramp rate: 10

Appendix G: Wireless Temperature and Power Monitoring System

To monitoring the temperature and power usage of homes, ZigBee wireless mesh networked sensor systems were developed and deployed. Figure F-1 shows the configuration of the wireless temperature and power monitoring system. The ZigBee temperature sensor collects temperature data, and the ZigBee power sensor collects energy usage data such as main power in, main power out, fan power, a/c unit power, and PV power. Collected sensor data are centralized to the ZigBee network and sent to Ethernet Gateway, and then transmitted to the UNLV Database Server.

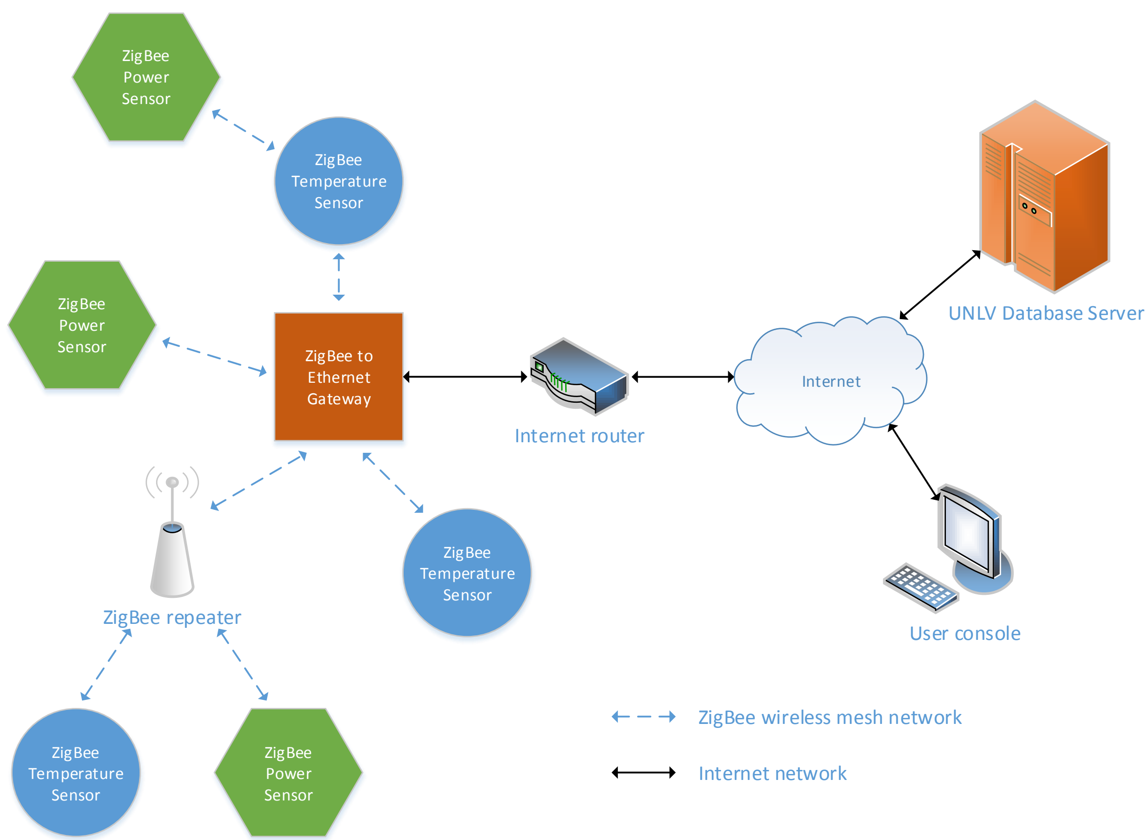


Figure 1 – Configuration of wireless temperature and power monitoring system

1. ZigBee Mesh Networks

ZigBee is an open global standard built on the IEEE 802.15.4 Mac/Phy. [F1][F2] ZigBee defines a network layer above the 802.15.4 layers to support advanced mesh routing capabilities. The ZigBee specification is developed by a growing consortium of companies that make up the ZigBee Alliance.

There are three different types of devices: coordinator, router and end devices. The coordinator controls the network. The router can transmit, receive and route data. And, the end device can transmit and receive data. Though its low power output limits transmission distance to 10 – 100 meters, however devices can transmit data over long distances by passing data through a mesh network of intermediate devices. Figure F-2 shows the example of ZigBee mesh network.

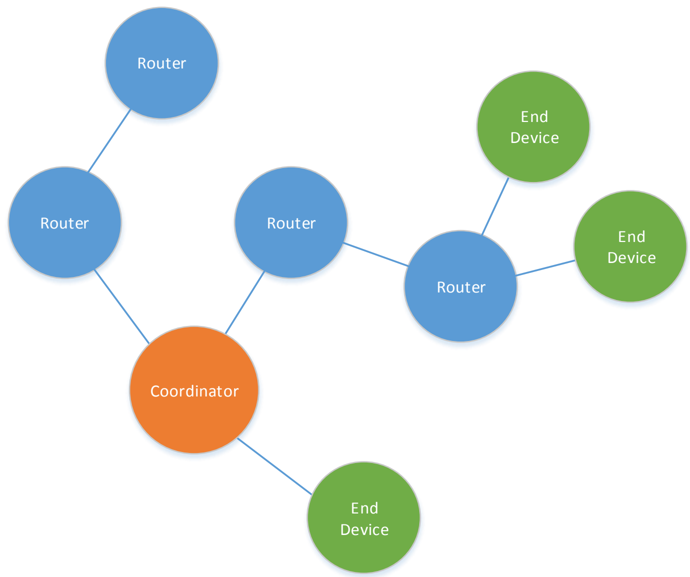


Figure F - 2 – ZigBee mesh network

The Figure F-3 shows the ZigBee communication module from Digi International Inc. [F2]. And, Table F-1 shows the technical specification of the module. Figure F-4 shows a ZigBee to Ethernet gateway used to transmit the collected data through the Internet to UNLV database server. The gateway acts as a coordinator in the ZigBee mesh network.

Figure F - 3 – ZigBee Wireless communication module

Table F1. Technical specification of ZigBee Wireless module

Parameter	Data
Manufacturer	Digi International
Model	XBee-PRO
Indoor/Urban	Up to 300ft (90m)
Outdoor line-of-sight	Up to 1 mile (1600m)
Transmit power	50mW (17dBm)
RF data rate	250,000 bps

Figure F - 4 – ZigBee to Ethernet Gateway

2. ZigBee Temperature Sensor

To measure temperatures of the homes, a wireless temperature sensor was developed. Table F-1 shows the technical specification of the temperature sensor.

Table F-1. Technical specification of temperature sensor [F3]

Parameter	Data
Manufacturer	Texas Instrument
Model number	TMP275
Temperature range	-40 ~ +125 oC
Accuracy	+/-0.5 oC max
Resolution	9-bits
Digital output	Two-wire serial interface

Figure F-5 shows the block diagram of the temperature sensor. A microcontroller reads the sensor data and sends the data through the ZigBee wireless communication module every minute.

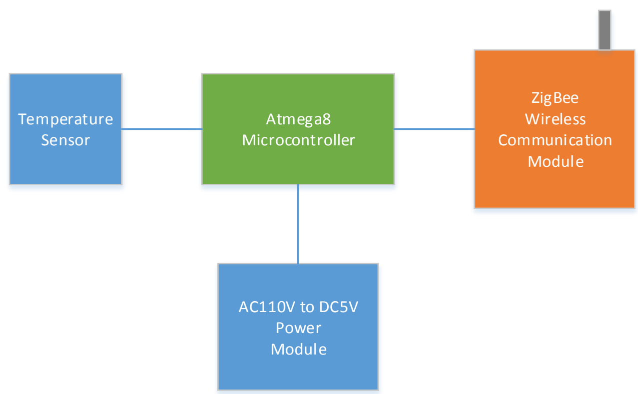


Figure F - 5 – ZigBee temperature sensor block diagram

Figure F-6 shows the wireless temperature sensor device. This is a wall outlet plug-in type as shown in Figure F-7. Figure F-4 shows the wireless to Ethernet gateway which is a bridge between the ZigBee wireless mesh network and the Ethernet. The gateway relays the collected data to the UNLV data server.

Figure F - 6 – Picture of ZigBee temperature sensor device

Figure F - 7 – Wall plug mounted ZigBee temperature sensor device

3. ZigBee Power Measurement Device

Figure F-8 shows a block diagram of the wireless power measurement device. It can measure up to 6 data streams from 5 electrical power meters and 1 gas meter. The power measurement device measures main power in, main power out, fan power, A/C unit power and PV power. The energy measuring sensor is a WattNode, Figure F-9, from Continental Control Systems [F4]. The WattNode reads current and voltage of the power line and outputs energy readings as pulses. A microcontroller reads the pulses for a minute and converts to energy per minute. The data of six WattNodes are transmitted through ZigBee wireless communication module to the UNLV Server every minute. Figure F-10 shows the picture of the microcontroller with the ZigBee module.

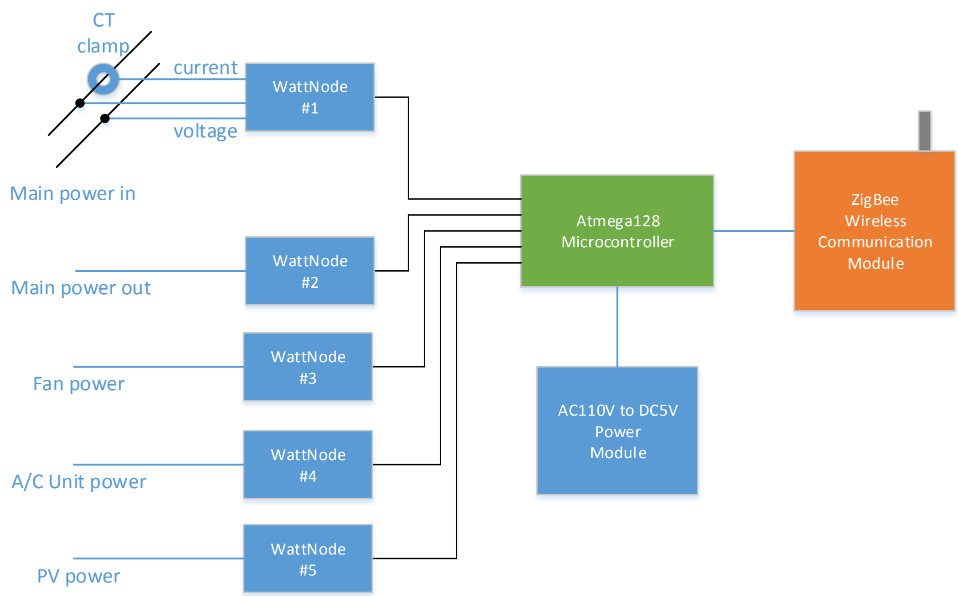


Figure F - 8 – Block diagram of ZigBee power measurement device

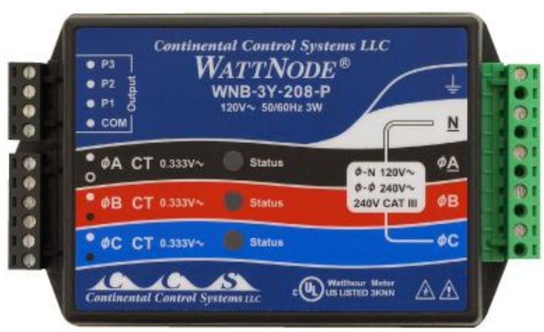


Figure F - 9 – WattNode

Figure F - 10 – Wireless power measurement device

Figure F-11 shows a picture of the of energy measurement system. Five WattNodes are connected to digital inputs of microcontroller.

(a) (b)

Figure F - 11 – (a) Outside and (b) inside of assembled power measurement system

4. Installation and Collected Data

Seven set of temperature sensors and power measurement systems were installed at seven homes. Figure F-12 shows the map of homes where the sensors were installed. Indicator "A" shows the location of where the ZigBee to Ethernet gateway and the repeater tower were installed. Figure F-13 shows the graph of main power into the house and PV generated power. Actual power usages are measured every one minute and integrated to every one hour to show the following graph. Figure F-14 shows the measured Fan power usage and the A/C power usage. Figure F-15 shows the measured temperature at the 1st and 2nd floors of the model house with a one minute sample period. Oscillating temperatures are caused by the air conditioner operation. Detailed analysis of power usage and temperature changes are given elsewhere in this report.

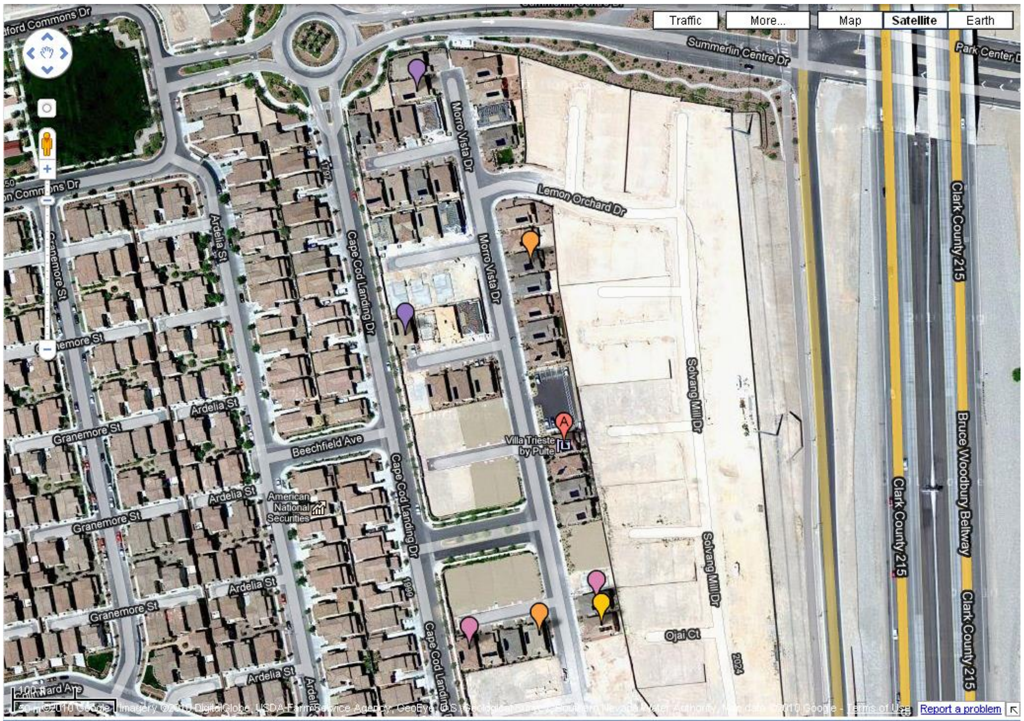


Figure F - 12 – Map of homes where the sensors were installed

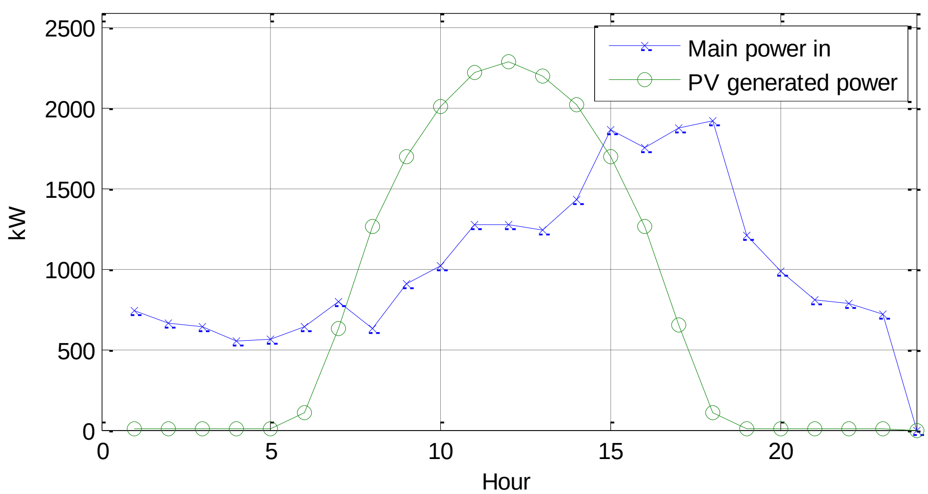


Figure F - 13 – Graph of main power into the house and PV generated power (July 29, 2010)

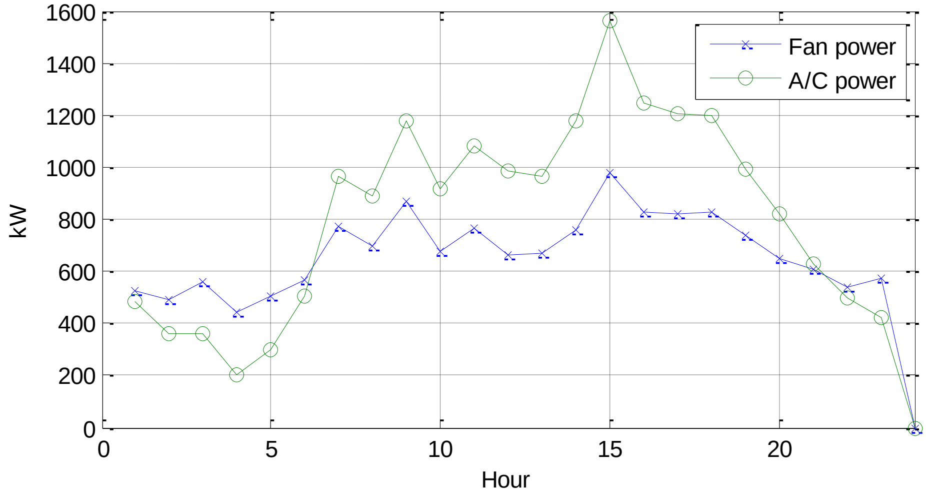


Figure F - 14 – Graph of Fan power usage and A/C power usage (July 29, 2010)

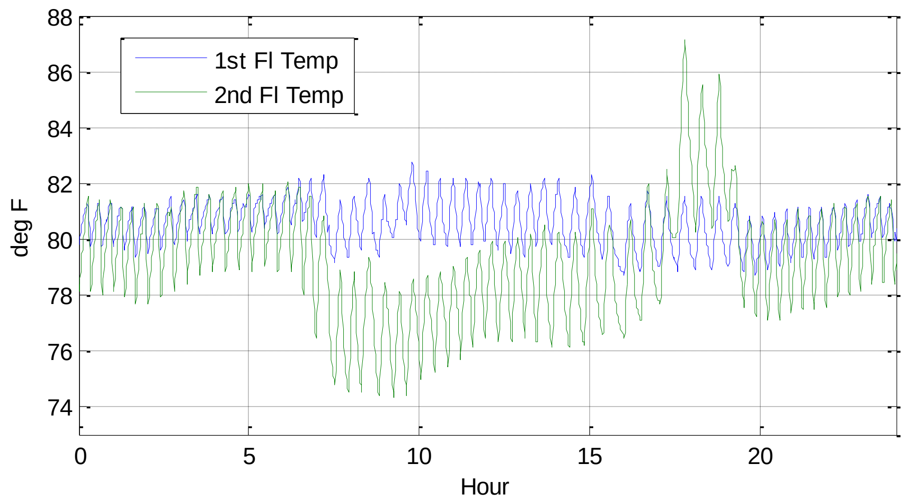


Figure F - 15 – Measured temperature of 1st and 2nd floor (July 29, 2010)

Reference

F1. ZigBee, ZigBee Alliance, www.zigbee.org

F2. XBee Pro, manual, Digi International, 2009

F3. *Digital Out Temperature Sensor, TMP275, datasheet*, Texas Instruments 2007

F4. *WattNode Plus, WNB-3Y-208-P, datasheet*, Continental Control Systems LLC, 2015

Appendix H: Pulse Output Conversion

The WattNode Pulse that was used for the energy measurements is a commercial watt-hour transducer. It works by pulsing a low-voltage output signal (through the use of opto-isolated solid state relays) that is proportional to a given amount of energy flowing through a monitored wire, as measured by a current transducer (CT). It converts current measurements to energy measurements by assuming a nominal voltage that is determined by the wiring of the device. The proportionality constant that scales the pulses to energy units is dependent on the rating of the CT used during the measured period. To determine the proportionality constant (in watt-hours per pulse) for a given CT, Eqn.(C.1) is used. It is set by the particular WattNode model, which is consistent across each of the installations.

$$WhPP = \frac{Watt - hours}{pulse} = \frac{CT\ Rating\ (Amps)}{40} \tag{C.1}$$

Since the system was configured to record data at 1-minute intervals, this results in pulses being accumulated, then stored, for each WattNode over a given minute. Understanding that these pulses represent energy measurements over a consistently short duration, an estimation for the average power per pulse over a given minute can be calculated as shown in Eqn.(C.2).

$$\overline{kW}PP = \frac{WhPP \times 60}{1000} \tag{C.2}$$

Three different CT sizes, 15A, 30A, and 50A, were installed at Villa Trieste. Using Eqns.(C.1) and (C.2), constant scale factors can be calculated to transform WattNode pulses into both energy and power units, as seen in Table C.1..

Table C.1 – WattNode Proportionality Constants

Valid for WNB-3Y-208-P Only

CT Rating (Amps)	$\mathbf{WhPP}$	$\overline{\mathbf{kW}}\mathbf{PP}$
30	0.75	0.045
50	1.25	0.075
150	3.75	0.225

Equipped with the proportionality constants recorded in Table C.1 for scaling WattNode pulses to both energy and power, the power consumption tendencies for these six sensors were examined. The analysis involved making use of MATLAB's built-in timeseries class. The timeseries class made it computationally efficient to sync all of the sensors' data to a common time domain, thereby making their "signal" summations extremely quick. A linear interpolation method was used when resampling each of the sensors' "signals" to the common 1-minute incremented time vector, as demonstrated below by Figure C - .

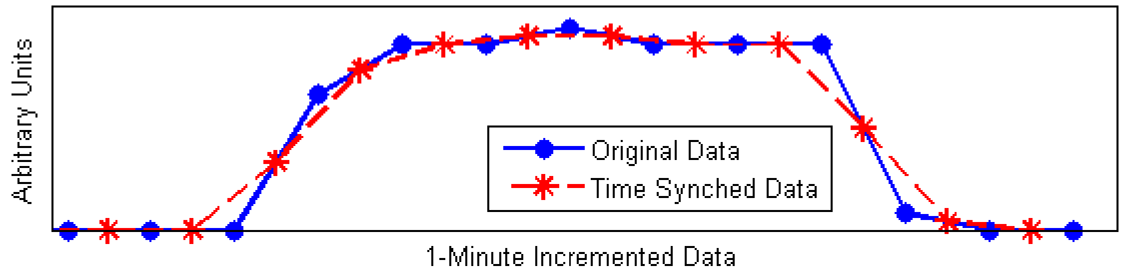


Figure C - 1 – Generalized Linear Resampling Method

In terms of the script's resulting plots, each figure features two subplots; the top plot indicates the total amount of power (averaged over minute intervals) the 6 homes collectively draw, and the bottom plot reflects the percentage of air conditioners that are simultaneously on at a given time. The bottom subplot also includes the ambient outdoor temperature, so that observations can be made on when the peak demand occurs, and how this relates to the maximum daily ambient temperature.

Due to the availability of equipment different sizes of CT clamps were installed as documented in Table 2. The only appreciable difference in these installations is the scaling factor that is ultimately used to convert the WattNode measurements to energy or power units, as defined in the Appendix.

TABLE 1 – CURRENT TRANSDUCER APPLICATIONS FOR ENERGY MONITORING

Circuit Description	Database Designation
Mains Out	data2
Air Conditioner	data4
Mains In	data1
Fan Circulating Unit	data3
PV Array	data5

TABLE 2 – SENSOR NAME DESIGNATIONS AND CT RATINGS

Temperature	House	1	2	3	4	5	6	7
Sensor ID CT	ZigBee	PWR4	PWR	PWR	PWR	PWR	PWR	PWR
Ratings	ID	TEMP5	7	6	8	3	2	5
(Amps)	First	TEMP	TEMP	TEMP	TEMP	TEMP	TEMP	TEMP
	Floor	6 150 -	7	9	11	13	15	17
	Second	30 50	TEMP	TEMP	TEMP	TEMP	TEMP	TEMP
	Floor	30	8 150	10	12	14	16	18
	Mains		30 50	150 -	150	150	150	150
	In		150	30 50	30 50	30 50	30 50	30 50
	Mains		50	30	150	150	150	50 50
	Out				50	50	50	
	FCU							
	Cond							
	PV							

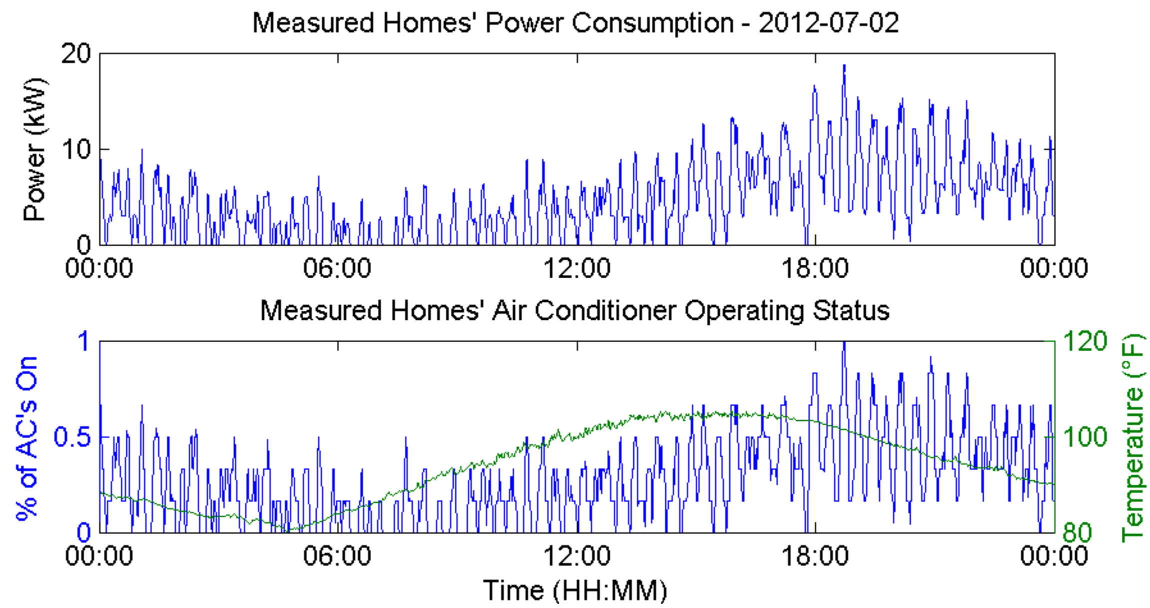


Figure C - 1 – Measured Homes' Power Consumption for 2012-07-02

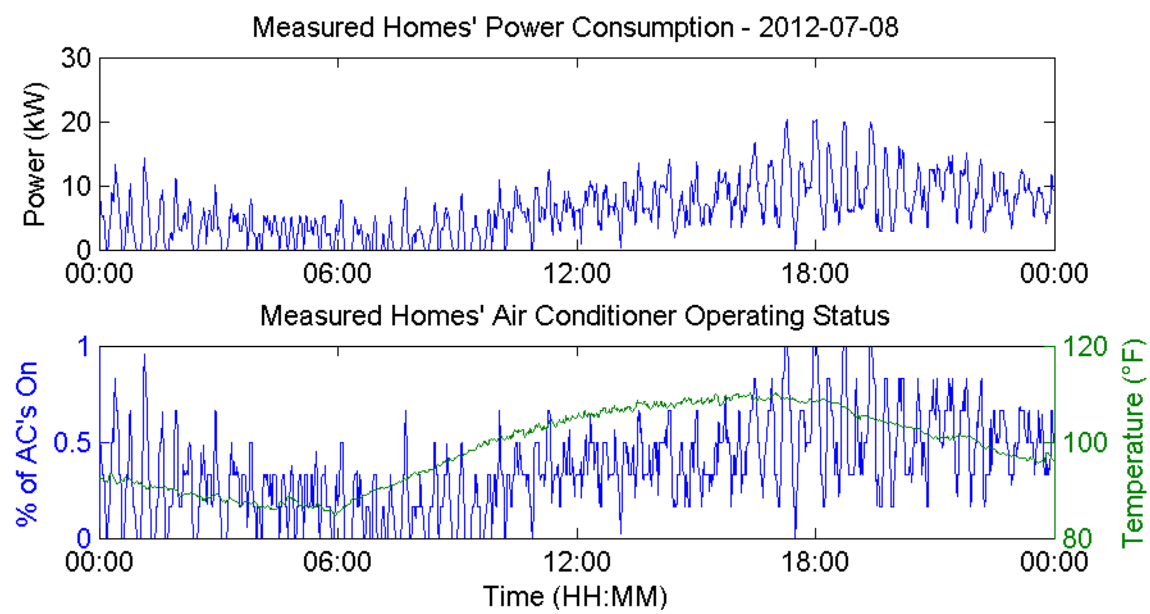


Figure C - 2 –Measured Homes' Power Consumption for 2012-07-08

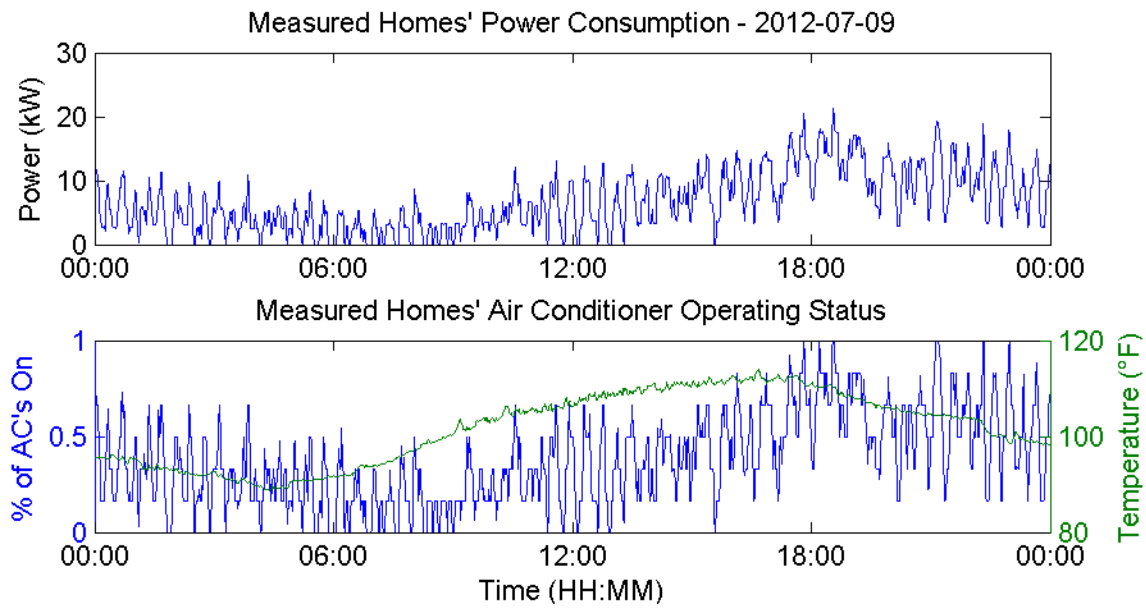


Figure C - 3 – Measured Homes' Power Consumption for 2012-07-09

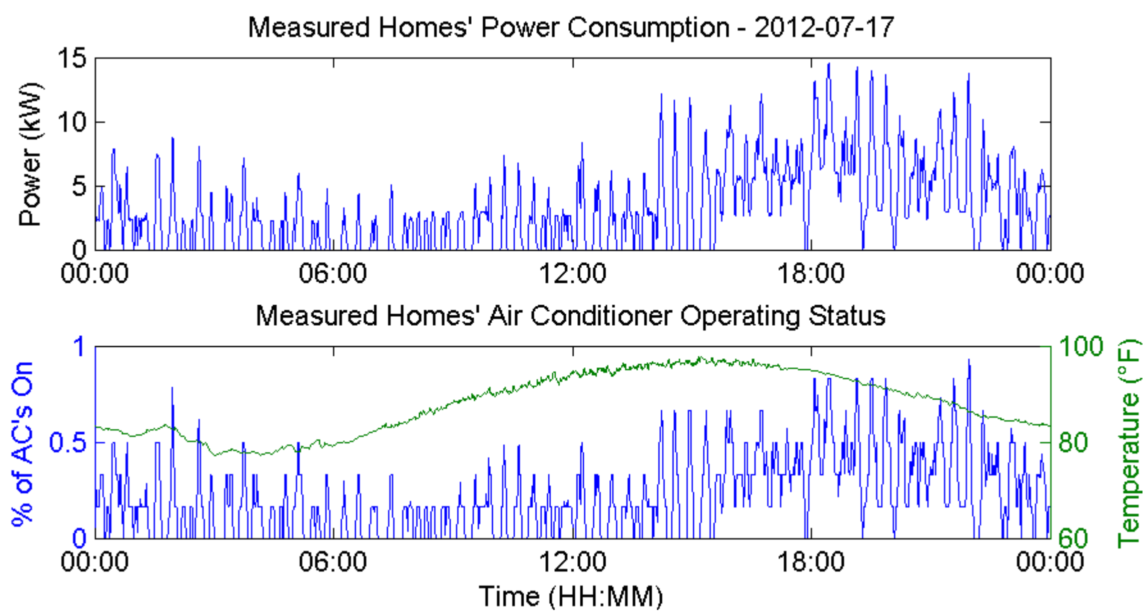


Figure C - 4 –Measured Homes' Power Consumption for 2012-07-17

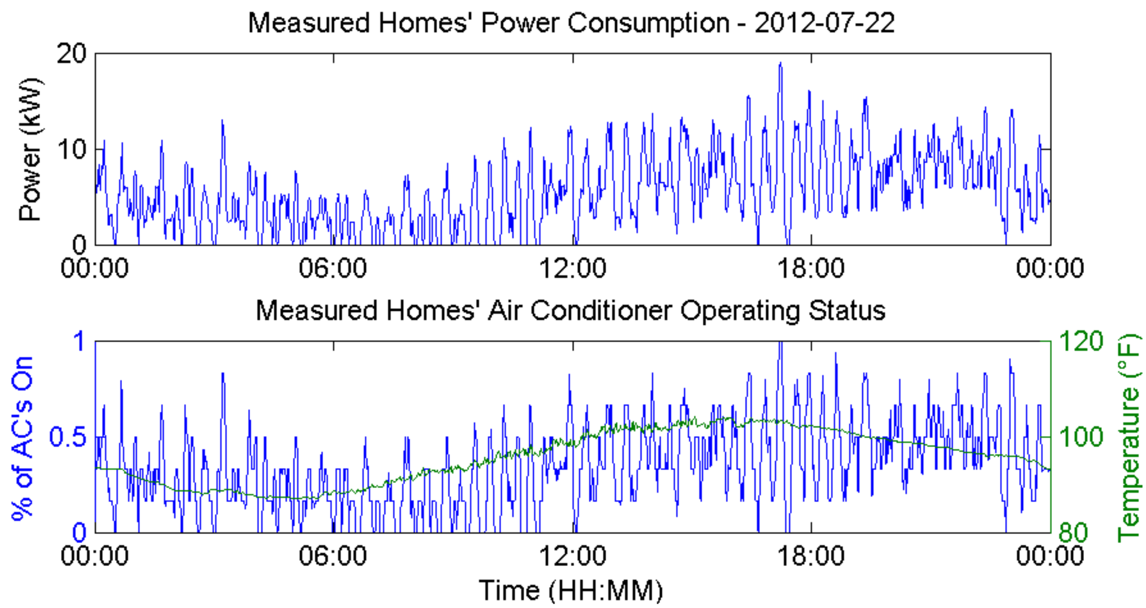


Figure C - 5 –Measured Homes' Power Consumption for 2012-07-22

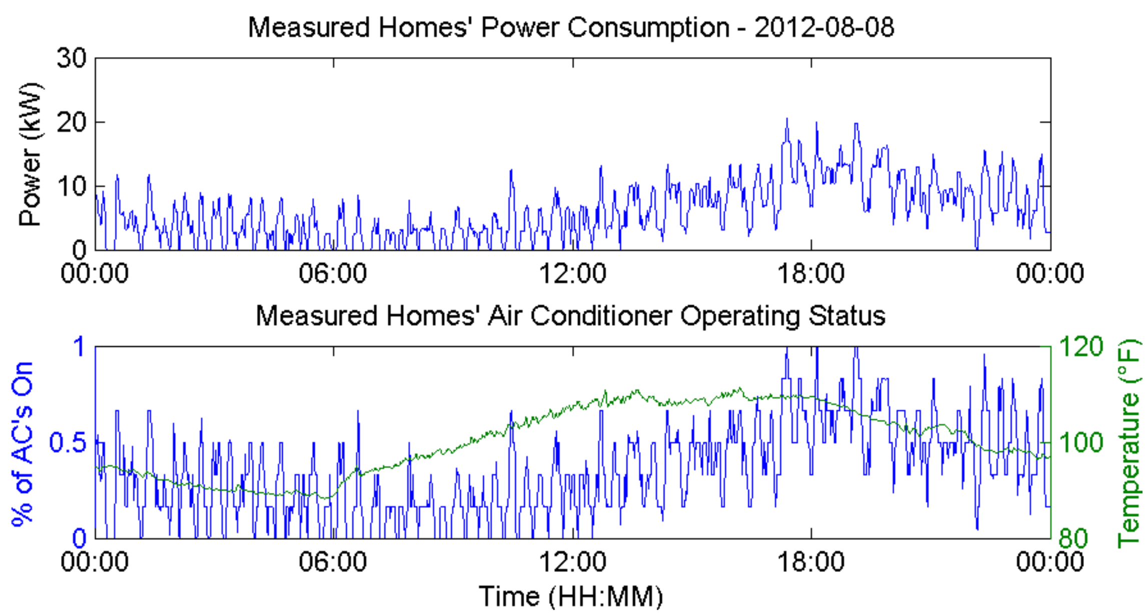


Figure C - 6 – Measured Homes' Power Consumption for 2012-08-08

Immediately, several observations can be made about these plots. First and foremost, the lag between elevated air conditioner usage and the hottest part of the day is several hours in every case. This corroborates the published literature introduced earlier in this paper, and validates the assertion that DR programs are most effectively applied from the late afternoon to early evening hours. Additionally, it is observed that the only day out of the batch that did not feature all air conditioners running simultaneously was the only day in which the ambient temperature never exceeded 100°F; this is why DR events are typically planned in advance when the ambient temperature is projected to exceed a given threshold–the measures are simply otherwise unnecessary for the strictest implementations of DR that only aim to reduce maximum power draws.

Lastly, the plot for July 22nd (Figure C - 5 –) is a telling example of the sample's air conditioners inadvertently synchronizing their cut-in/cut-out times, collectively resulting in an extremely variable load from the utility's point of view. Though it will be impossible to test this conjecture given the data available at this time, the author wonders if the uniformity of the homes, given that they were built within weeks of each other by the same contractors in the same housing development, contributes in any way to this synchronization. A collection of less homogenous homes, with significantly different architectural aspects, mechanical equipment, and thermal capacities, may inherently exhibit a tendency toward more regular power demands.

Though there is evidence in all of the plots above, the excessively variable load of July 22nd illustrates exactly how a thermal model may be used to reduce peak demand. Right at about 5:30 PM, it can be seen that all 6 air conditioners are running simultaneously before they all shut off at nearly the same time. This trend continues, though not quite to the same degree, for the next hour and a half. If, for the several minutes leading up to 5:30 PM, each home's thermal model was able to accurately predict its air conditioner's cut-in time, UNLV's central controller could quickly derive a plan for offsetting the operation of several air conditioners by increasing their thermostats' setpoints and delaying the next air

Appendix I: Villa Trieste Data

The sample floor plan for a particular home that will be used later for the study is as follows:

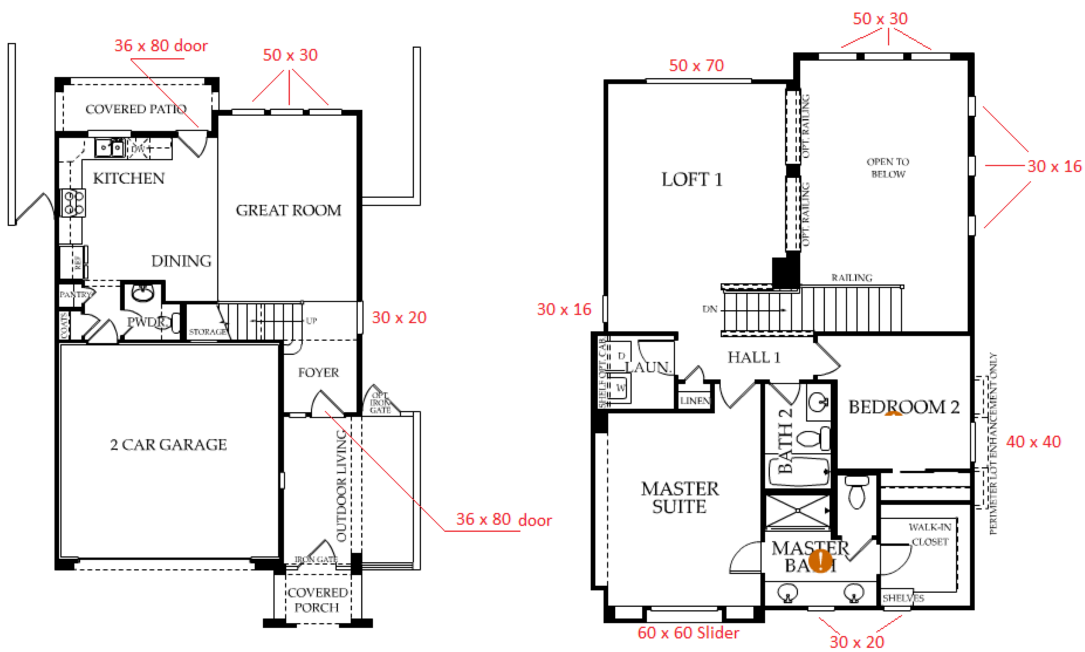


Figure A - 1 – Villa Trieste floor plan under Investigation

All the homes in the community have several energy efficiency features pertaining to the building envelope, cooling and heating systems and lighting. The marketed energy efficiency features include:

- Environments for Living® Certified Green Energy Efficient
- Homes with 3-Year Heating and Cooling Guarantee
- 100% ENERGY STAR Certified
- SunPower Solar Roof Paneling
- Envelope Insulation System with Blown-In Cellulose
- 15 SEER-Rated Air Conditioning System
- Energy Efficient Gas Furnace
- Low-E, Dual Pane Windows with Vinyl Frames

- Rinnai Tankless Water Heater
- Jump Ducts in Master Bedroom
- Digital Programmable Thermostat
- Pre-Wire for Ceiling Fan in Master Bedroom and Great Room
- Fluorescent Lighting in Garage, Laundry and Master Closet
- Compact Fluorescent Light (CFL) Bulbs throughout the Rest of the Structure

Appendix J: Data Verification

CSE Meters

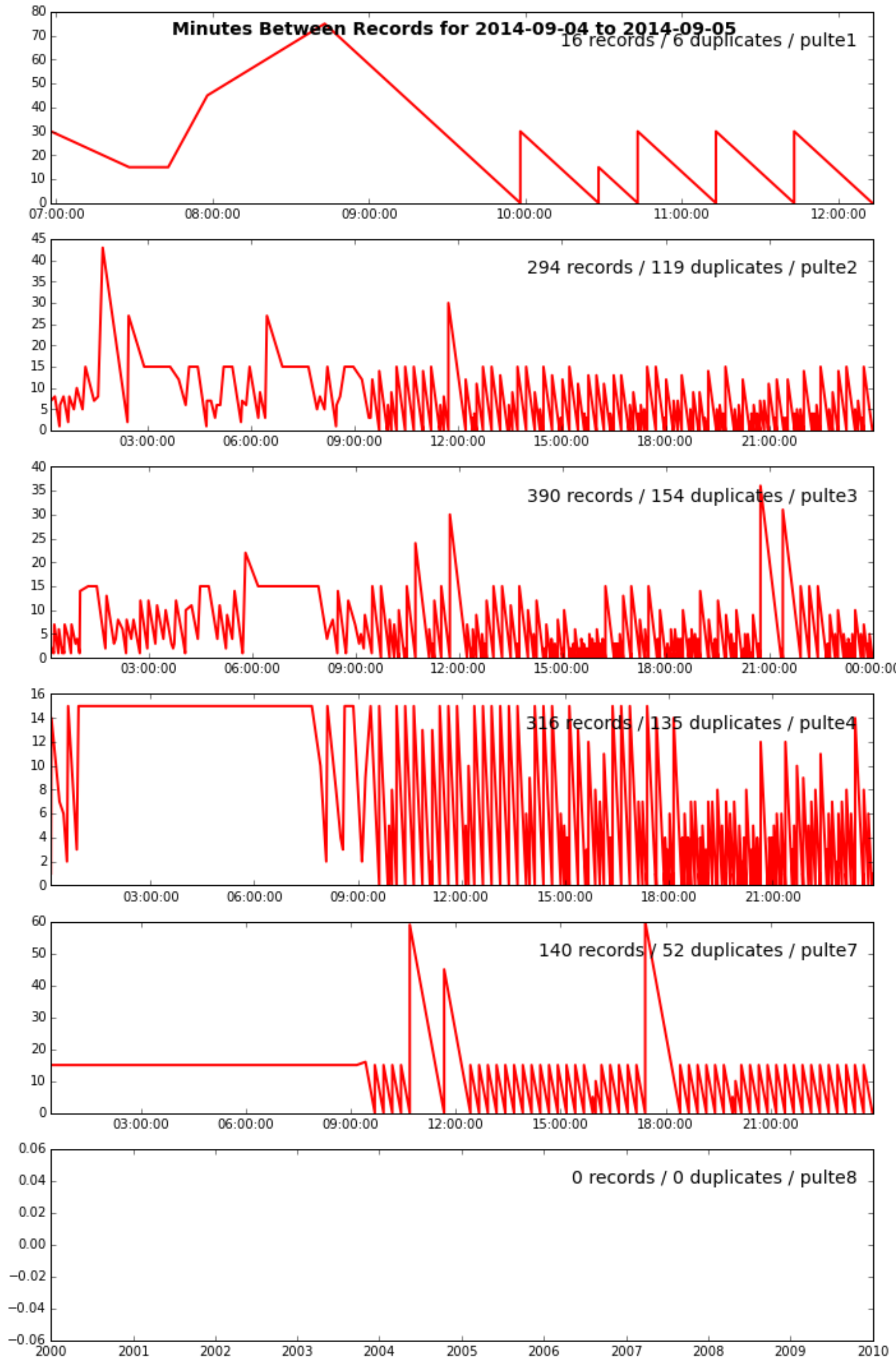
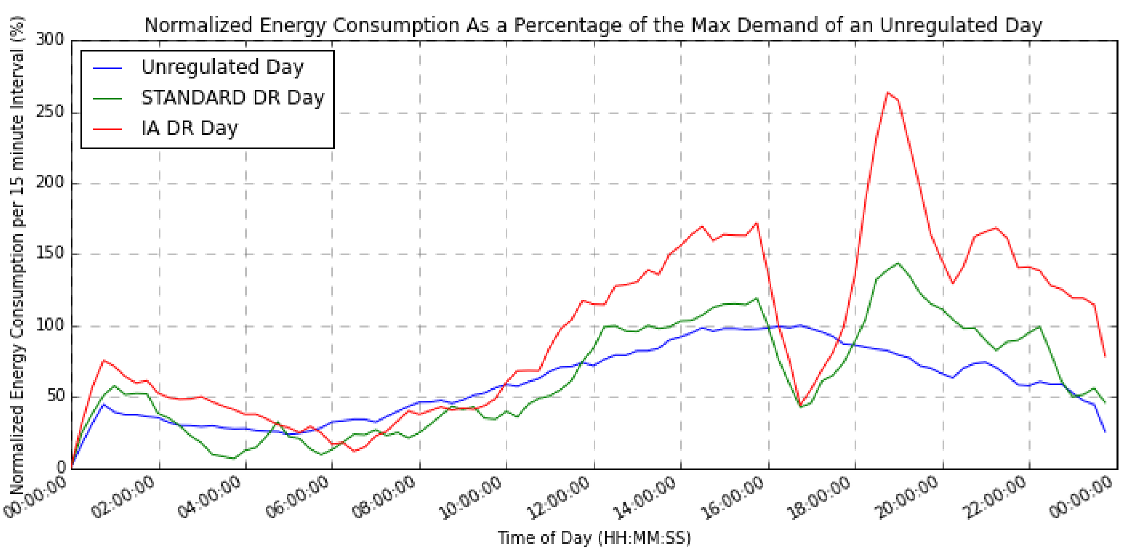


Figure B - 1 – *CSE meter data*

The CSE meters were installed by HDR Consulting in conjunction with NVE as a test to see if the meters would work well for smart-metering purposes. They were configured to log data on an event-driven basis when any of the measured parameters changed, or at 15-minute intervals, whichever came first. It turned out they weren't giving the type of numbers expected based on WattNode data that were at hand, so Figure B - 1 – *CSE meter data* was created to plot the time between records for each of the installed devices. What was discovered is that *some* of the devices appeared to be working *some* of the time, but there were large gaps in the data in which no data was reported. On top of that, there were a multitude of records that were perfectly copied and duplicated. This figure was used as a part of the discussion with HDR in which it was explained to them that the devices were not working as intended.



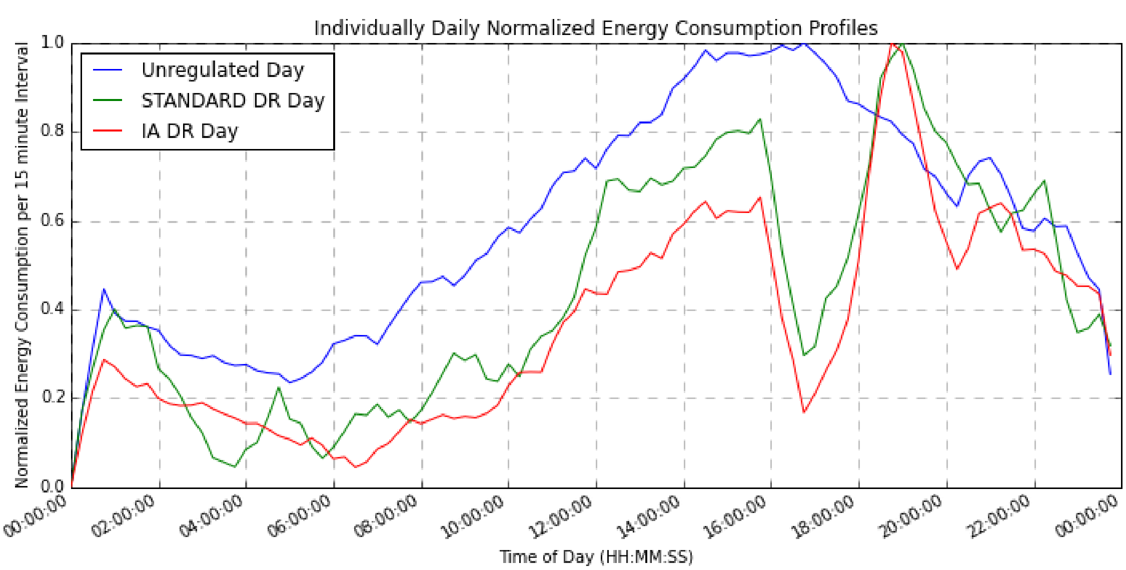
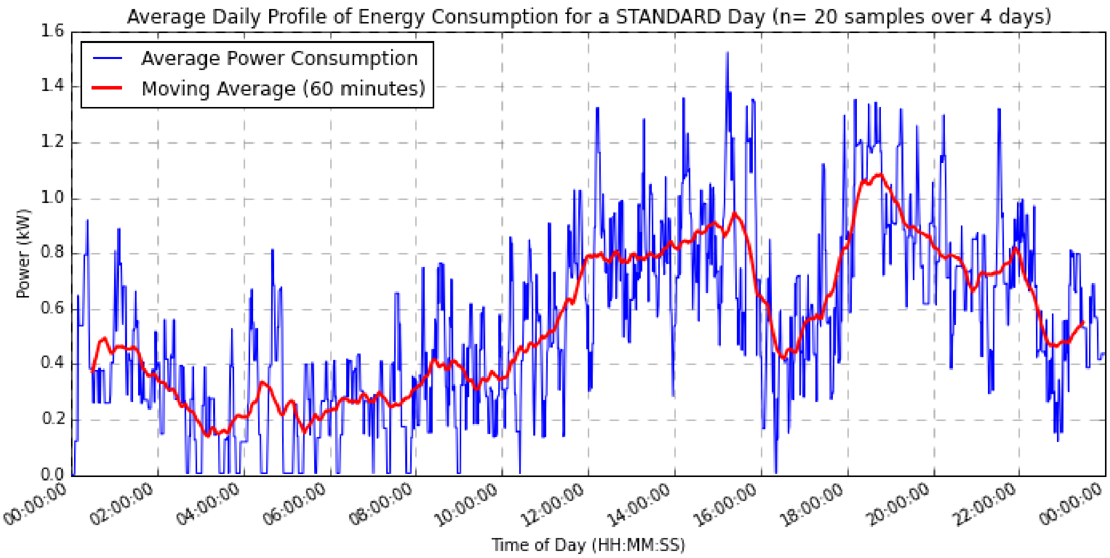


Figure B - 2 –



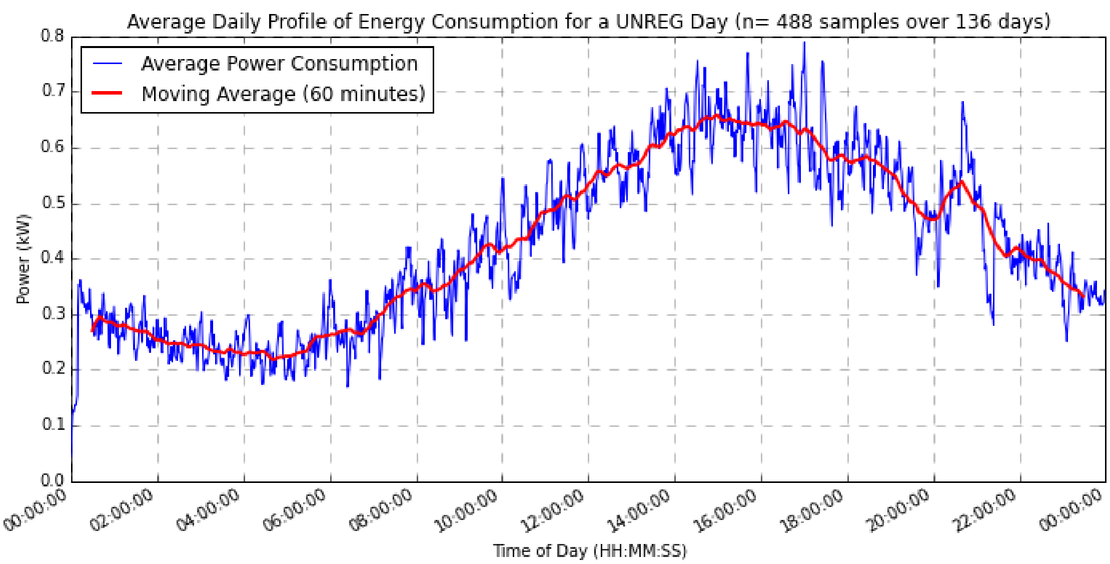


Figure B - 3 –

There are several of these plots that were done in an attempt to justify the “peak” period definition.

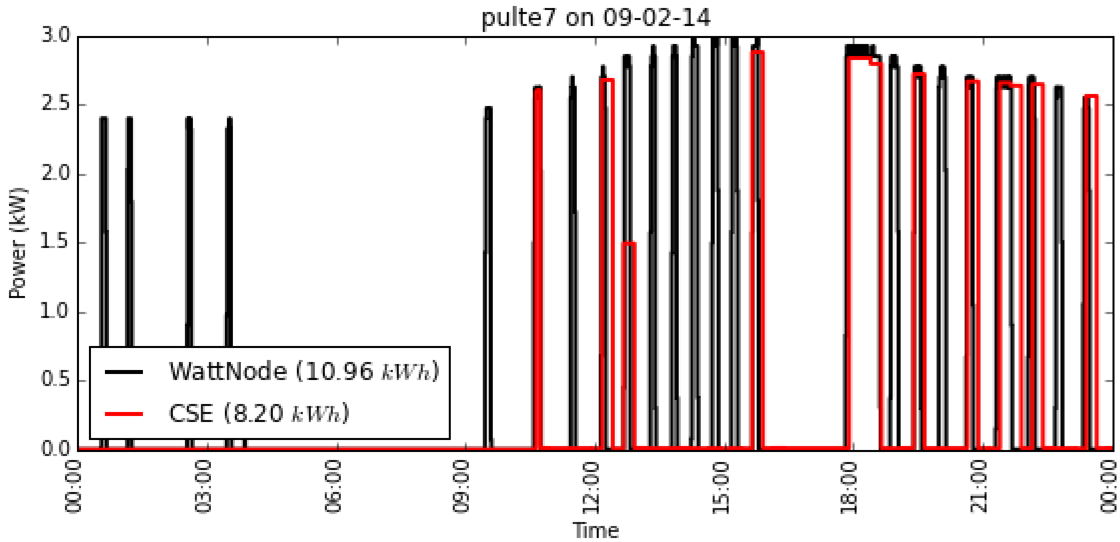


Figure B - 4 –

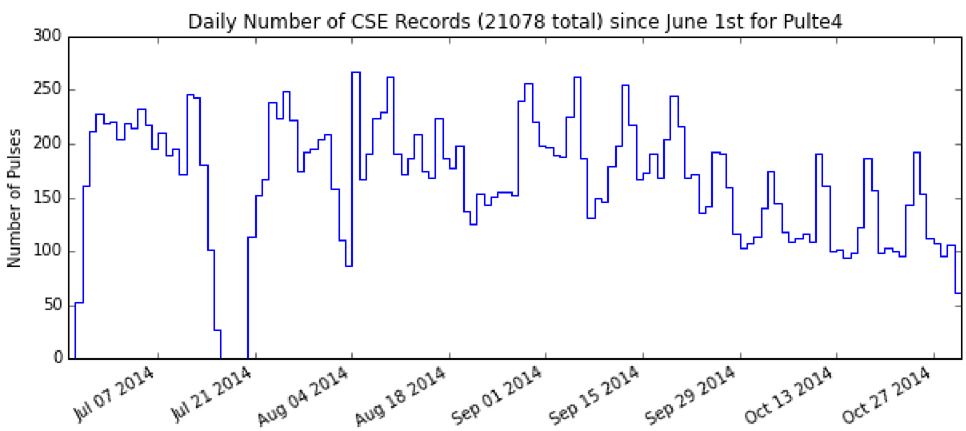


Figure B - 5 –