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Investigation of Peak Load Reduction Strategies in Residential Buildings in Cooling Dominated Climates

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INVESTIGATION OF PEAK LOAD REDUCTION STRATEGIES

IN RESIDENTIAL BUILDINGS IN COOLING

DOMINATED CLIMATES

By

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ABSTRACT

Study of Energy Efficiency In Residential Buildings And
Investigation Of Peak Load Reduction Strategies

By

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This investigation of peak load reduction strategies in residential buildings contributes to the global international efforts in reducing energy consumption and is related directly to energy efficiency in residential and commercial buildings. Work reported here involves computer aided building energy simulation of energy efficient and non-energy efficient residential homes coupled with empirical energy consumption data gathered from monitoring an array of energy efficient residential homes. The latter have been implemented for peak load reduction strategies. In addition non-energy efficient residential homes have been monitored to compare performance to the energy efficient homes. This study demonstrates the crucial importance of energy efficiency and peak load reduction strategies in sustaining the energy needs of the southwest US region using Las Vegas for the actual setting. It provides the largest energy consumption data set examined, specifically peak consumption, from energy efficient and non-energy efficient homes at this location. The study demonstrates the peak load reduction benefits of a variety of strategies, namely roof-integrated PV panels, energy efficient building envelope, and substation battery storage. The study focuses on the month of August 2011 and shows how the load reduction can reach 75% at peak times during that month using the computer aided energy simulation. Moreover, the study compares the recorded electrical consumption data from the collection of energy efficient and non-energy efficient residential homes and proves the simulation results in reaching the 75% reduction in electrical consumption at peak times. The study also tries to marry the gathered electrical consumption data of the energy efficient and non-energy efficient homes with the computer simulation model. This is done to reach an actual representative model which behaves similarly to the average of the group of energy and non-energy efficient homes. The benefit of the energy efficient strategies in reducing the load in peak times is emphasized.

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I have also benefited greatly from my work with NV Energy and Pulte Homes on their work in progress research on a project funded to UNLV by the US Department of Energy. I also wish to thank my friends and colleagues at UNLV and the CER team.

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CHAPTER 1 – INTRODUCTION

Rationale

Due to harsh weather in the summer season, significant peaks in the electricity demand from buildings in general are formed especially in the Desert Southwest in the US. These peaks are attributed to the cooling load increase during the hottest part of the day and last only for short periods of time. Hence, it is economically not feasible for utilities to maintain generation capacity that will be used only for a few hours in a year. Therefore a lot of research has been performed on strategies that could reduce the peak electrical loads. This study presents several strategies that reduce the peak electrical loads in residential buildings located in Las Vegas, Nevada and demonstrates some of these strategies by comparing the electrical consumption for energy-efficient and non energy-efficient homes.

Literature Review

Energy efficiency is a topic subject to extensive debate in all shapes of written and broadcast media and is an essential topic of research all over the world. Energy efficiency is also instrumental in promoting sustainability environmentally and economically. Defining the widely used term is simple by nature; energy efficiency is simply using less energy to accomplish the same daily tasks while getting the same quality of life, although one can argue that this would in fact lead to a better quality of life. Consequently, the more efficient use of energy results in less economic resources spent on energy by several sectors including residential buildings, schools, hospitals, and commercial buildings by acknowledging that in 2009, the building sector consumed 41.2% of the total primary energy consumed in the US (Building Energy Data Book, 2012). Contrary to common belief, an energy-efficient economy can grow without using more energy. As a matter of fact, in 2001, for instance, the U.S. gross domestic product increased from $9.8988 trillion in the year before to $10.2339 trillion, while the total U.S. energy use decreased from 98.814 quadrillion Btus in 2000 to 96.168 quadrillion Btus in 2001 (Google Public Data, 2012).

Actually, research in energy efficiency did not recently come into light. In fact, the need for energy efficiency emerged, shortly after the 1973 oil crisis, which was a result of members of the Organization of Arab Petroleum Exporting Countries or the OAPEC proclaiming an oil embargo and raised the posted price of oil by 70% (Yergin, 2008), which eventually led to a devaluation of the market value of the US corporations by nearly a half of their original value prior to the crisis (Alpanda et al., 2008). The economic crisis back then is reflected nowadays by the current picture of the economy drawn after the recession of 2007 when the oil prices increased significantly as the global economy recovered. This resulted in the industrialized nations recognizing the importance of energy efficiency as a solution to counterbalance the rise of oil prices and fulfill their energy needs. This recognition is empowered by social awareness and the global effect of what one simple effort can initiate. In fact, energy efficiency awareness connects energy consumers to the bigger picture. A lot of these efforts have been speared by energy efficiency driven alliances, non-profit organizations and agencies in the developed countries, namely the United States, Canada and cost of the countries that constitute the European Union. To name a few in the U.S.; The American Council for an Energy-Efficient Economy, the Alliance to Save Energy, the Environmental Protection Agency and much more. These alliances, non-profit organizations and Federal agencies are implementing programs that are aimed at supporting energy efficiency as a cost-effective energy resource and advocating energy-efficiency policies that minimize costs to society, and that lessen greenhouse gas emissions and their impact on the global climate. Moreover, major OECD (Organization for Economic Co-operation and Development) countries have adopted specific policies aimed at improving the energy efficiency in all sectors of their economies. It was estimated that if it weren't for those improvements, the OECD nations would have consumed 49% more energy than was actually consumed as of 1998 (Geller et al., 2006).

As was mentioned, energy efficiency implementation in the buildings sector has been the focus of most industrialized nations. In effect, the benefits of energy efficiency are economical as well as environmental. By nature, implementing energy efficiency strategies in buildings would decrease the site energy consumption and thus the source energy consumption which will eventually lead to a decrease in greenhouse gas emissions. Moreover, this would economically benefit institutions and homeowners by reducing their operational costs and utility bills. In fact, according to the Department of Energy's Energy Efficiency and Renewable Energy program's webpage (Department Of Energy, 2012), Americans saved $7 billion on residential energy bills in 2004 from energy saving measures and by building energy efficient homes. Reduced greenhouse gas emissions and industrial pollution also result from increased energy efficiency. As of 2000, electricity production was responsible for 62.6% of U.S. sulfur dioxide emissions, 21.1% of U.S. nitrous oxides emissions, and 40% of U.S. carbon emissions. An additional 56% of nitrous oxide emissions and 34% of carbon emissions are a by-product of transportation (United States Environmental Protection Agency, 2012). Adopting energy efficiency measures helps reduce these pollutants and save money. For example, the American Council for an

Energy Efficient Economy (ACEEE) estimates that from 2006-2020, extended energy efficiency tax incentives could reduce consumer energy bills by $27 billion, prevent more than 51 million metric tons of carbon emissions, and reduce peak electric demand by more than 6,000 MW (equivalent to the capacity of twelve 500 MW coal plants) (REAP Renewable Energy Alaska Project, 2012).

In the United States, measures have been taken on a national level down to municipal and local level to promote green building and increase energy efficiency as was described by Edna Sussman (Sussman et al., 2008). Furthermore, recent financial incentives on a Federal level which include corporate deductions, depreciation, exemptions and tax credits, Federal grant and loan programs and personal energy efficiency tax credit have been implemented. These aspects along with rules, regulations and policies implemented by the US government represent a clear statement confirming the need for energy efficiency which is key for sustainable growth. As an example of the benefits of energy efficiency, one of the most green states in the US, California, had some noticeable energy savings. In fact, California's building efficiency standards (along with those for energy efficient appliances) have saved more than $56 billion in electricity and natural gas costs from 1972-2006, equivalent to more than $1,000 per household and increased Gross State Product by 3%, or $31 billion (City Of Fremont, 2012). It is also estimated that the energy efficiency standards will save an additional $23 billion by 2013 (Wong, 2005). Academically, several studies have been performed on energy efficiency in buildings to reduce their grid dependence; net zero-energy homes have also been studied comprehensively (Rosta S. et al., 2006) (Rosta et al., 2008) (Wilkinson et al., 2005) (Zhu et al., 2009). Moreover, various energy saving strategies in buildings have been studied and economically analyzed (Lam et al., 2005).

Several studies demonstrate the high economic benefit to cost ratios and the relatively low payback periods of these energy efficient strategies, namely, the implementation of energy efficient building envelopes including better insulated walls, low emissivity windows, coupled with the use of efficient lighting such as compact fluorescent (CFL) lights and higher efficiency heating and cooling air-conditioning systems (Florides et al., 2002) (Gieseler et al., 2004) (Sadineni et al., 2011). Actually, according to Florides et al., the implementation of the methods to increase the performance of roof insulation and exterior wall insulation carry payback periods of 3.5-5 years and 10 years respectively (G.A.Florides et al., 2002).

Due to harsh weather in summer, significant peaks in the electricity demand are formed especially in the Desert Southwest in the US. These peaks are attributed to the cooling load increase during the hottest part of the day and last only for short periods of time. Hence, it is economically not feasible for utilities to maintain generation capacity that will be used only for a few hours in a year. This was the case for Australia's New South Wales' transmission upgrade in order to accommodate the increase in peak load which was estimated to cost over $13 billion. Consequently, there has been an increased interest internationally in research on energy efficient strategies that would reduce the peak loads. One of the prominent strategies is building-integrated PV systems which would not just be beneficial for peak reduction, but also for distributed generation of electricity to reduce grid dependence. Studies have been reported on the performance of these systems and their economic viability (Walker, 2003) (Bakos et al., 2003). In urban Brazil, a study on the potential of building-integrated photovoltaic (PV) systems in assisting the daytime peaking feeders found that these systems can significantly reduce the summer demand peaks (Ruther et al., 2009).

Project Background

Short term peak demands due to cooling loads during summer have been an issue in Las Vegas for a number of years. Through a grant support from the US Department of Energy (DOE) a consortium has been formed between the University of Nevada Las Vegas, Pulte Homes (a production homebuilder), and NV Energy (local utility) to demonstrate a substation level peak reduction for an energy efficient residential housing development. The project is expected to reduce the peak demand from the community by a minimum of 65% as compared to a standard production housing development. The new energy efficient LEED Platinum certified housing development, called Villa Trieste, was developed in Las Vegas to demonstrate the proposed peak reduction. There are four different floor plans and sizes ranging from 1,487 ft^2 to 1,960 ft^2. A majority of the planned homes are already built and building is picking up in pace.

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

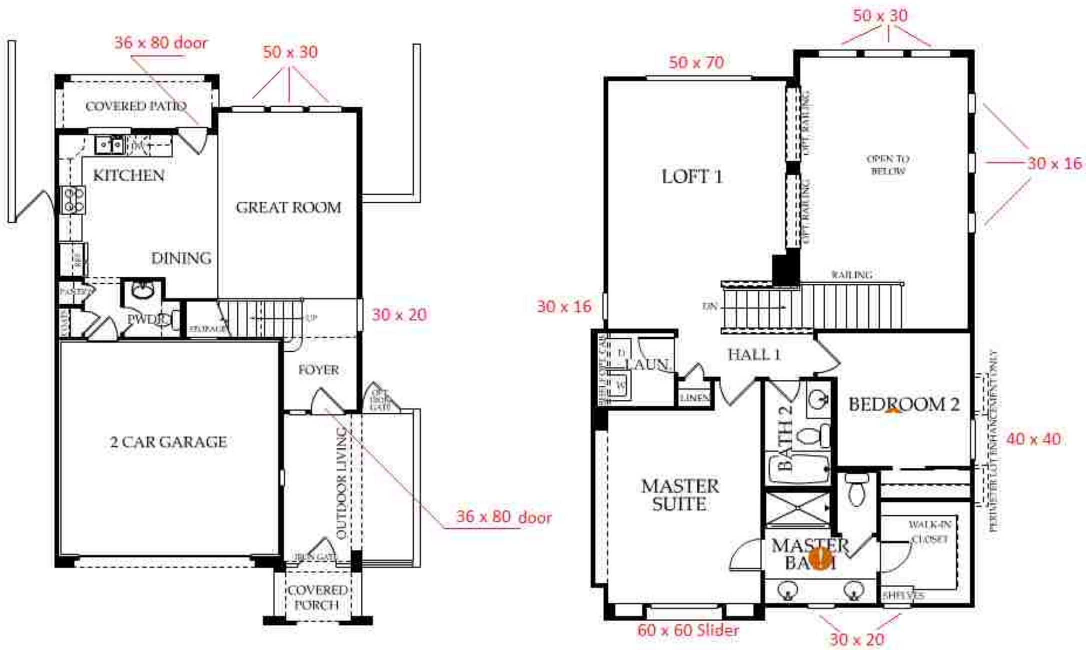


FIGURE 1 - VILLA TRIESTE FLOOR PLAN UNDER INVESTIGATION

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

Before getting into the details of the energy efficiency strategies implemented at the Villa Trieste community located in the Summerlin area in west of Las Vegas (Latitude 36° 9' 7.3434" N, Longitude 115° 20' 20.9796" W), the International Energy Conservation Code 2006 (IECC 2006) which is the Clark County building code which became effective on May 1st, 2007 will be presented.

IECC 2006

The U.S. Department of Energy's Building Energy Codes Program supports increased energy efficiency in residential and commercial buildings by helping to advance building energy codes. The first measurement code to discuss would be the 2006 International Energy Conservation Code IECC which is the Clark County building code effective May 1, 2007, through July 4, 2011. As shown in the IECC map below, the climate zone 3 of Las Vegas will be the main focus of the discussed subject.

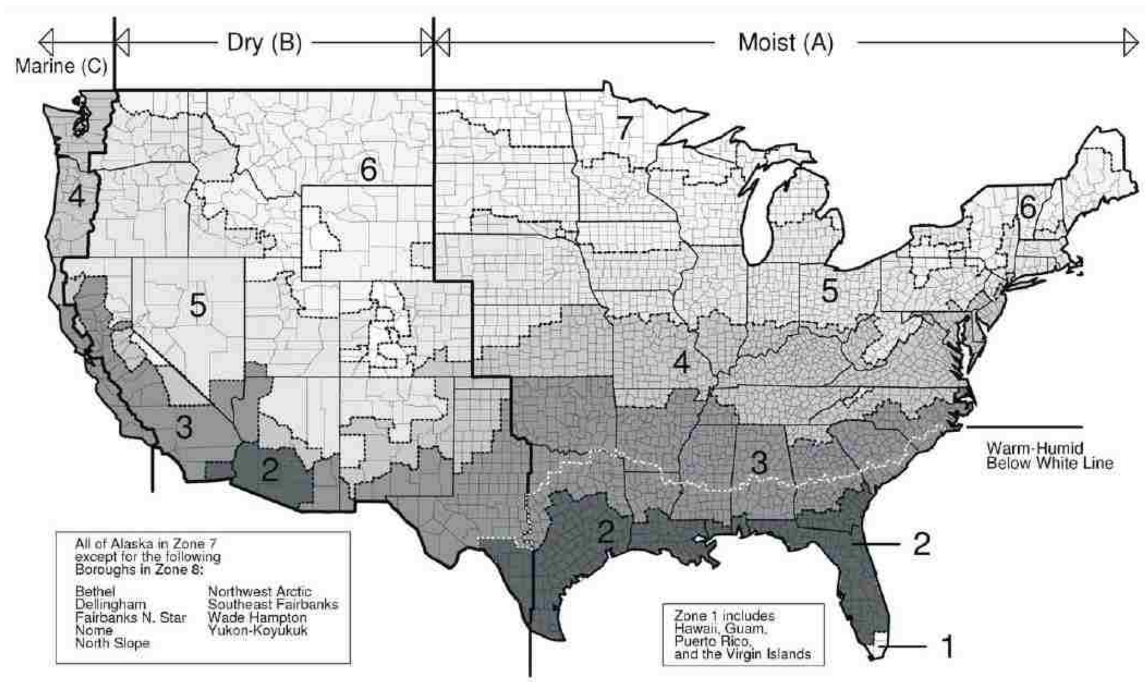


FIGURE 2 - IECC 2006 FIGURE 301.1 - CLIMATE ZONES

The IECC 2006 Insulation and Fenestration Requirements by Component (Table 402.1.1) is shown in the table below. The equivalent U-Factor table (Table 402.1.3 IECC 2006) is also shown below in Tables 1 and 2.

The mechanical requirements in the code 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. These requirements include the minimum allowable standard for air conditioning efficiency SEER to be 13. IECC does not specify any efficiency requirements for mechanical appliances; however it specifically references those EPA 2005 minimums as a baseline efficiency requirement in the performance of air conditioning units.

TABLE 1 - INSULATION AND FENESTRATION REQUIREMENTS BY COMPONENT - IECC 2006

Climate Zone	Fenestration U-Factor	Skylight U-Factor	Glazed Fenestration	Ceiling R-Value	Wood Frame Wall R-Value	Mass Wall R-Value	Floor R-Value	Basement Wall R-Value	Slab R-Value & Depth	Crawl Space Wall R-Value
1	1.2	0.75	0.4	30	13	3	13	0	0	0
2	0.75	0.75	0.4	30	13	4	13	0	0	0
3	0.65	0.65	0.4	30	13	5	19	0	0	5/10
4 except Marine	0.4	0.6	NR	38	13	5	19	10/13	10, 2ft	10/13
5 and Marine 4	0.35	0.6	NR	38	19 or 13+5	13	30	10/13	10, 2ft	10/13
6	0.35	0.6	NR	49	19 or 13+5	15	30	10/13	10, 4ft	10/13
7 and 8	0.35	0.6	NR	49	21	19	30	10/13	10, 4ft	10/13

TABLE 2 - EQUIVALENT U-FACTORS - IECC 2006

Climate Zone	Fenestration U-Factor	Skylight U-Factor	Ceiling U-Factor	Frame Wall U-Factor	Mass Wall R-Value	Floor U-Factor	Basement Wall U-Factor	Crawl Space Wall U-Factor
1	1.2	0.75	0.035	13	0.082	0.064	0.36	0.477
2	0.75	0.75	0.035	13	0.082	0.064	0.36	0.477
3	0.65	0.65	0.035	13	0.082	0.047	0.36	0.136
4 except Marine	0.4	0.6	0.03	13	0.082	0.047	0.059	0.065
5 and Marine 4	0.35	0.6	0.03	19 or 13+5	0.06	0.033	0.059	0.065
6	0.35	0.6	0.026	19 or 13+5	0.06	0.033	0.059	0.065
7 and 8	0.35	0.6	0.026	21	0.057	0.033	0.059	0.065

A comparison of the IECC 2006 standard with the Villa Trieste community standard is shown in the table below.

TABLE 3 - COMPARISON OF IECC2006 CODE WITH VILLA TRIESTE

Climate Zone	Fenestration U-Factor	Skylight U-Factor	Glazed Fenestration SHGC	Ceiling R-Value	Wood Frame Wall R-Value	Mass Wall R-Value	Floor R-Value	Basement Wall R-Value	Slab R-Value & Depth	Crawl Space Wall R-Value
IECC 2006 Code	0.65	0.65	0.4	30	13	5	19	0	0	5/10
Villa Trieste	0.325 – 0.339	N/A	0.56	30	15 (2 x 4 frame Wall) 20 (2 x 6 frame Wall)	Thermal Mass added	24	N/A	0	N/A

As can be seen from the table, the homes are built with highly insulated floors, roofs, walls, and doors compared to code standard homes. Moreover, double pane low-E glass windows with vinyl frames were used throughout. In order to achieve the high envelope insulation and increased home tightness (low infiltration), blown in cellulose is used as insulation both in the walls and the roof. Naturally, due to the better filling of the cellulose in the wall and roof cavities compared to the glass fiber insulation, the air leakage of these homes is less than the code standard homes. Furthermore, higher efficiency cooling and heating (SEER = 15, HSPF=0.92) and on-demand hot water systems are installed in all the homes. All the permanent lighting fixtures are provided with compact fluorescent lights (CFL). On top of that, every home in the new housing development has a roof-integrated PV system. Local and federal rebates were the main reason that allowed a 1.8 kWp system to be installed on every roof without substantial increase in home prices. The PV systems are paired with 94% efficient grid interactive inverters. The figure below shows the roof tile PV cells integrated into one of the homes in the new housing development.

FIGURE 3 - ROOF TILE PV CELLS AT VILLA TRIESTE

Additionally, all the homes are equipped with dashboard energy monitoring systems and a demand-side management system and automated meter infrastructure. This allows the homeowners to keep track of the instantaneous and hourly/daily energy use in their home. The home owners are rewarded for their participation in the load control program, so the unit allows the utility company to remotely control the load in the homes either through a direct load control scheme and/or a price-responsive load control scheme.

CHAPTER 2 – THEORETICAL ANALYSIS

Modeling IECC 2006 Code vs. Villa Trieste

In order to better understand the effects of the energy efficiency strategies on the peak load reduction, a building energy simulation software was used. The software which was used is Energy-10 which performs hour-by-hour simulations for a typical year based on a detailed thermal network model.

Energy-10

The building energy software that was used to simulate the electrical consumption of the homes is Energy-10. Energy-10 is a conceptual design software tool that helps architects, builders, and engineers quickly identify the most cost-effective, energy-saving measures to take in designing a low-energy building. The simulation software is suitable for examining small commercial and residential buildings that are characterized by one, or two thermal zones (generally less than 10,000 ft^2.). The program does hour-by-hour simulations for a typical year based on a detailed thermal network model.

Weather data used in the simulation

Originally, the Typical Meteorological Yearly data (TMY2) is the standard weather data used by the building energy simulation software Energy-10. In order to accurately compare the energy performance of the computer models to the actual energy performance of the homes, the weather data for year 2011 was acquired from the Nevada Power Clark Station and the University of Nevada Las Vegas which are both part of the National Renewable Energy Laboratory meteorological stations. The reason which led to the use of two sources for the 2011 meteorological data is the lack of wet bulb temperature (or relative humidity) in the UNLV weather data and the average direct normal weather data was not consistently available for the whole 2011 year. Therefore, the average global horizontal radiation, the average direct or beam normal radiation, and the average diffuse horizontal radiation were taken from the UNLV data, and the rest of the data which includes dry bulb temperature, the dew point temperature, the wind direction and the wind speed were taken from the from the Nevada Power Clark Station.

The software used to convert the weather data is “WeatherMaker”, which is included in Energy-10’s building energy simulation package. The weather data needed by WeatherMaker is as expected, the following:

- Month, Day, Hour
- Global Radiation (Btu/h-ft^2)
- Beam Radiation (Btu/h-ft^2)
- Diffuse Radiation (Btu/h-ft^2)
- Dry bulb temperature (°F)
- Wet bulb temperature (°F)
- Wind direction
- Wind speed (MPH)
- Cloud cover

The cloud cover was set to 0, because it is not a recorded parameter for the Las Vegas meteorological stations, but it is assumed to be implicit from the solar flux readings.

The radiation was converted from W/m^2 to Btu/h-ft^2 by first multiplying by 3.412 to convert W to Btu/h and then multiply by 0.0929 to convert from 1/m^2 to 1/ft^2.

Moreover, the wet bulb temperature had to be computed in order to get the complete weather data. To do that, the relative humidity RH was calculated using the August-Roche-Magnus equation, which is

$$RH = 100\frac{exp\left(\frac{aT_d}{b+T_d}\right)}{exp\left(\frac{aT}{b+T}\right)}$$

Where a = 17.271, b = 237.7 T is the dry bulb temperature in °C and T_d is the dew point temperature in °C. Next, the wet bulb temperature is calculated using the empirical equation developed by Roland Stull from the University of British Columbia, Vancouver Canada (Stull, 2011) which is

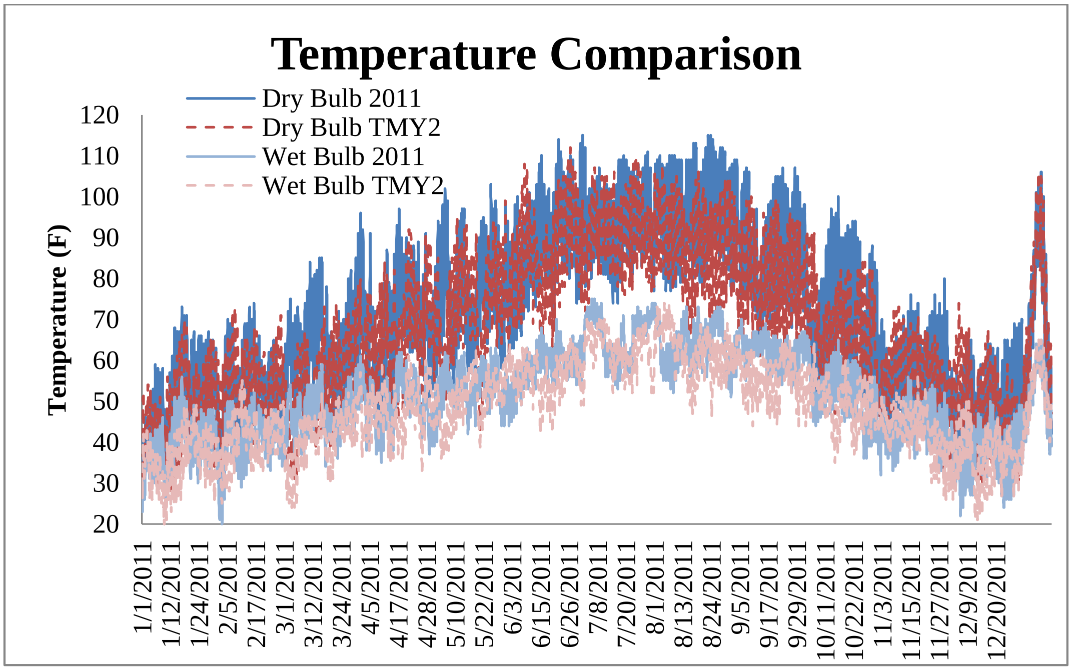
$$\begin{aligned} T_w = T\, atan\left[0.151977(RH\% + 8.313659)^{1/2}\right] + atan(T + RH\%) \\ - atan(RH\% - 1.676331) \\ + 0.00391838(RH\%)^{\frac{3}{2}} atan(0.023101 RH\%) - 4.686035 \end{aligned}$$

where T_w and T are in °C.

The weather data needed was input to the WeatherMaker software as a comma separated values weather data file and the output weather data file was used in the simulation.

Table 4 below shows the dry bulb and wet bulb temperatures for the year 2011 compared with the TMY2 weather data.

TABLE 4 - TEMPERATURE COMPARISON 2011 & TMY2



Parameters

The house that was chosen to be modeled as a non-energy efficient and an energy efficient house is the Roma House from Villa Trieste which has the floor plan shown below.

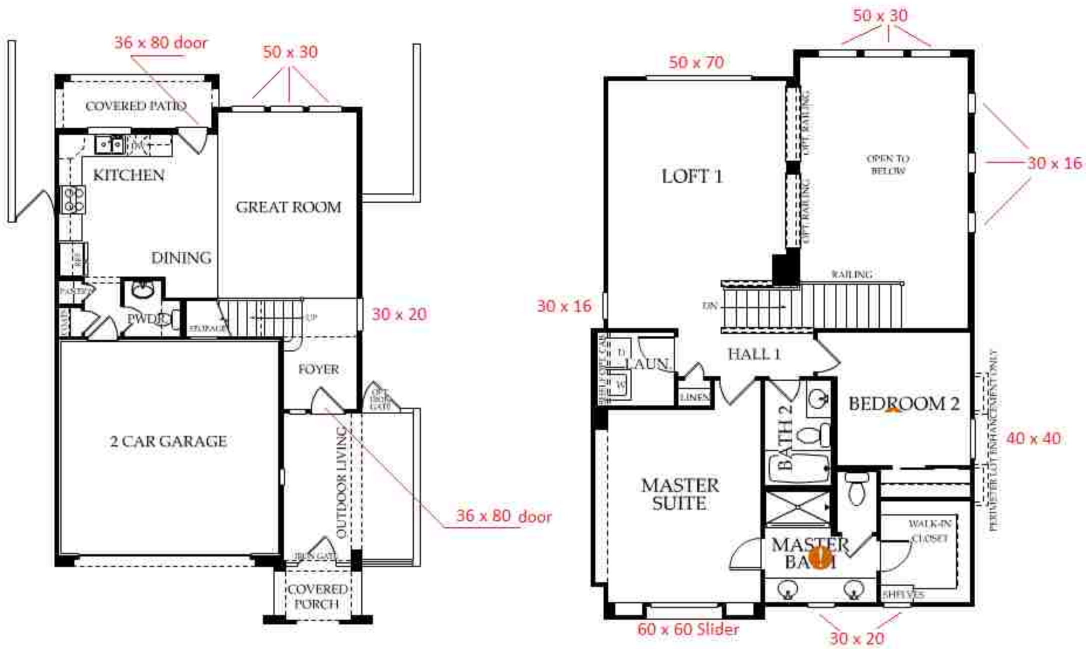


FIGURE 4 - FLOOR PLAN FOR ROMA HOUSE FROM VILLA TRIESTE

Moreover, the parameters that were used to model those homes are shown below.

TABLE 5 - PARAMETERS USED IN THE VILLA TRIESTE MODEL

Climate Zone	Fenestration U-Factor	Skylight U-Factor	Glazed Fenestration SHGC	Ceiling R-Value	Wood Frame Wall R-Value	Mass Wall R-Value	Floor R-Value	Basement Wall R-Value	Slab R-Value & Depth	Crawl Space Wall R-Value
IECC 2006 Code	0.65	0.65	0.4	30	13	5	19	0	0	5/10
Code Built Model	0.65	N/A	0.4	30	13	5	19	N/A	0	N/A
Villa Trieste Model	0.325 – 0.339	N/A	0.56	30	14.74 (2 x 4 frame Wall) 19.85 (2 x 6 frame Wall)	Thermal Mass added	24	N/A	0	N/A

To better understand these parameters, a detailed explanation of each aspect of the modeling will be presented.

<u>Code Built Home Parameters</u>

<u>Walls</u>

A standard 2x4 frame wall with layers of softwood (0.63”) sheathing (0.5”) fiberglass (3.5”) drywall (0.5”). The calculated R-Value is 12.55 h-ft^2-F/Btu; however it was forced to 13.

Fenestration

Glazing fenestration was assumed to be as closely similar as the Villa Trieste Roma fenestration in dimensions/area. All the windows have double glazing and the table below summarizes the different windows on the model house.

TABLE 6 - LIST OF DIFFERENT WINDOWS USED

	Window Type	Qty	Width (in)	Height (in)	Whole Window U-value	SHGC
North Face	Plain	3	20	30	0.408	0.4
	Single Slider	1	60	60	0.448	0.4
East Face	Plain	3	16	30	0.397	0.4
	Plain	1	20	30	0.408	0.4
	Single Slider	1	40	40	0.428	0.4
South Face	Plain	7	30	50	0.436	0.4
	Plain	1	70	50	0.455	0.4
West Face	Plain	1	16	30	0.397	0.4

There are two doors, one at the north face and another one at the south face for the particular house analyzed, and both of them have their U-values set at 0.65.

Roof

A roof with a 22 degree tilt was used. It consists of softwood (0.75”), fiberglass (10”) and gypsum board (0.38”). The calculated R-value is 29.38 however it was rounded to 30.

Infiltration

The 2009 ASHRAE Fundamentals Handbook states that the only accurate procedure for determining the Effective Leakage Area is by measurement using a pressurization test (commonly called a blower door test). The handbook also suggests that if a pressurization test is not possible, the leakage can be estimated using a simple approach which is based on an assumed average leakage per unit of building surface area, calculated by the following equation

$$A_L = A_{es} A_{ul}$$

where

A_{es} = building exposed surface area, ft^2

A_{ul} = unit leakage area, in^2/ft^2 (from the table below)

TABLE 7 – BUILDING LEAKAGE BY CONSTRUCTION - 2009 ASHRAE FUNDAMENTALS HANDBOOK

Construction	Description	A_{ul} in^2/ft^2
Tight	Construction Supervised by air-sealing specialist	0.01
Good	Carefully sealed construction by knowledgeable builder	0.02
Average	Typical current production housing	0.04
Leaky	Typical pre-1970 houses	0.08
Very Leaky	Old houses in original condition	0.15

The building exposed area is around 3000 ft^2. Therefore, assuming an average construction house yields an effective leakage area of 120.0 in^2.

HVAC System

The HVAC system was set as a direct expansion cooling system with gas furnace. When it comes to the efficiency of the cooling system, the efficiency of air conditioners is often rated by the Seasonal Energy Efficiency Ratio (SEER) which is defined by the Air Conditioning, Heating and Refrigeration Institute in its standard ARI 210/240, Performance Rating of Unitary Air-Conditioning and Air-Source Heat Pump Equipment. However, Energy-10 accepted efficiency parameter is the Energy Efficiency Ratio (EER) which is efficiency of a particular cooling device is the ratio of output cooling (Btu/hr) to input electrical power (Watts) at 95°F outdoor dry bulb temperature and an 80°F indoor dry bulb temperature with 50% relative humidity. These two efficiency ratios are not directly related and one cannot calculate one from the other. The SEER depends on many factors which include the type of indoor coil being used, the type of TXV (Electronic or Mechanical), the type of thermostat and the number of indoor blower speeds. For example one can notice that a Goodman residential split system outdoor unit DSXC160361A* 3-ton air conditioner, which is advertised as having a SEER of "up to 16", has multiple SEER and EER values depending on the air handler/coil and furnace used as shown in the table below (Table 8) which was extracted from the product specifications (Goodman Air Conditioning and Heating).

TABLE 8 - SEER & EER VARIATION FOR DIFFERENT GOODMAN COIL/AIR HANDLERS

Coils/Air Handlers	Furnaces	SEER	EER
AVPTC313714A*		16.0	12.8
CA*F3642*6D*+MBVC1600**-1A*+TXV		15.5	12.0
CA*F3642*6D*+TXV	A*VC950714CXA*	16.0	12.3
CA*F3642*6D*+TXV	A*VM960604CXA*	16.0	12.3
CA*F3743*6D*+EEP+TXV		14.5	11.5
CHPF3642D6C*+TXV	G*VC950905DXA*	16.0	12.5

Table 8 shows that a SEER could be 16 for a particular unit while its EER is 12.8 in one case 12.5 in another, and 12.3 in a third case. Also, this table shows that for the same outdoor condenser unit (which is the DSXC160361A* in our case), the EER can change from 11.5 to 12.8 depending on the furnace and air handler/coil used.

The HVAC Energy Efficiency Ratio (EER) of the non-energy efficient house was set at 11, which is a fair rating for a standard air conditioner, with a supply air temperature set at 57°F.

The heating gas furnace supply air temperature was set at 120°F with an efficiency of 80% (typical efficiency). The air handler system was assumed to be operating at a static pressure of 0.5 in-wg with a fan efficiency of 15% (The mechanical energy required to move the rated airflow at the rated static pressure/The electric energy required to operate the fan motor under these conditions).

The cooling and heating set points were set at 80°F and 68°F respectively, without making use of setup and setback settings.

Villa Trieste Home Parameters

Walls

Two types of walls were used: A 2x4 frame wall with layers of plaster (0.2”), EPS foam (1”), spray cellulose (3.5”) and drywall (0.63”). The calculated R-Value is 14.74 h ft^2-F/Btu. Also, a 2x6 frame wall with layers of plaster (0.2”), EPS foam (1”), spray cellulose (5.5”) and drywall (0.63”) was used. The calculated R-Value is 19.85 h-ft^2-°F/Btu.

Fenestration

Glazing fenestration was assumed to be as closely similar as the Villa Trieste Roma fenestration in dimensions/area as was the case for the code built home model. All the windows have double glazing and the table below summarizes the different windows on the model house.

TABLE 9 – LIST OF DIFFERENT WINDOWS USED

	Window Type	Qty	Width (in)	Height (in)	Whole Window U-value	SHGC
North Face	Plain	3	20	30	0.328	0.56
	Single Slider	1	60	60	0.339	0.56
East Face	Plain	3	16	30	0.325	0.56
	Plain	1	20	30	0.328	0.56
	Single Slider	1	40	40	0.334	0.56
South Face	Plain	7	30	50	0.336	0.56
	Double Slider	1	70	50	0.337	0.56
West Face	Plain	1	16	30	0.325	0.56

Moreover, the windows are shaded based on a 36 degree latitude shade design as shown the schematic below.

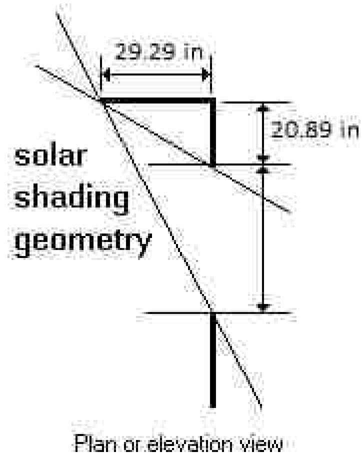


FIGURE 5 - WINDOW PLAN / ELEVATION VIEW

There are two doors, one at the north face and another one at the south face and both of them are modeled as foam core doors and their U-values were set at 0.18.

<u>Roof</u>

A roof with a 22 degree tilt was used. It consists of softwood (0.75”), fiberglass (10”), gypsum board (0.38”). The calculated R-value is 29.38.

<u>Infiltration</u>

Following the 2009 ASHRAE Fundamentals Handbook approach for determining the effective leakage, the infiltration was assumed at an effective leakage area of 60 in^2 (assuming carefully sealed construction by knowledgeable builder).

<u>HVAC</u>

HVAC system was set as a direct expansion cooling system with gas furnace. The HVAC Energy Efficiency Ratio (EER) was set at 12.5, with a supply air temperature set at 57°F.

The heating gas furnace supply air temperature was set at 120°F with an efficiency of 90%. The air handler system was assumed to be operating at a static pressure of 0.5 in-H_2O with a fan efficiency of 25%.

The cooling and heating set point were set at 80°F and 68°F respectively, without making use of setup and setback of temperatures.

Internal Loads

The internal loads were kept at their original values. These internal load schedules represent an average of the typical residential house.

In fact, these default peak values were developed by the creators of the building energy simulation software used, Energy-10 by matching the average total energy consumption in each use category with the numbers reported by the Energy Information Administration (EIA). Thus, the values represent the national average values for annual water heating, lighting (sum of internal and external lights), and "other". Describing internal load heat gains presents a difficult problem because it strongly affects both heating and cooling loads, however it is always a guess because no one can accurately and precisely predict occupant behavior and building use. Therefore, the best option in describing the internal load peaks is to rely on the national average internal-heat values provided by the EIA. However, because the EIA reports do not give time-of-day information (profiles/schedules), Energy-10's default hourly profiles are based on the ELCAP, which stands for End-Use Load and Consumer Assessment Program (DOE-BP-13795-22) at Pacific Northwest Laboratory (PNL). This program contains data taken from many buildings in the Pacific Northwest.

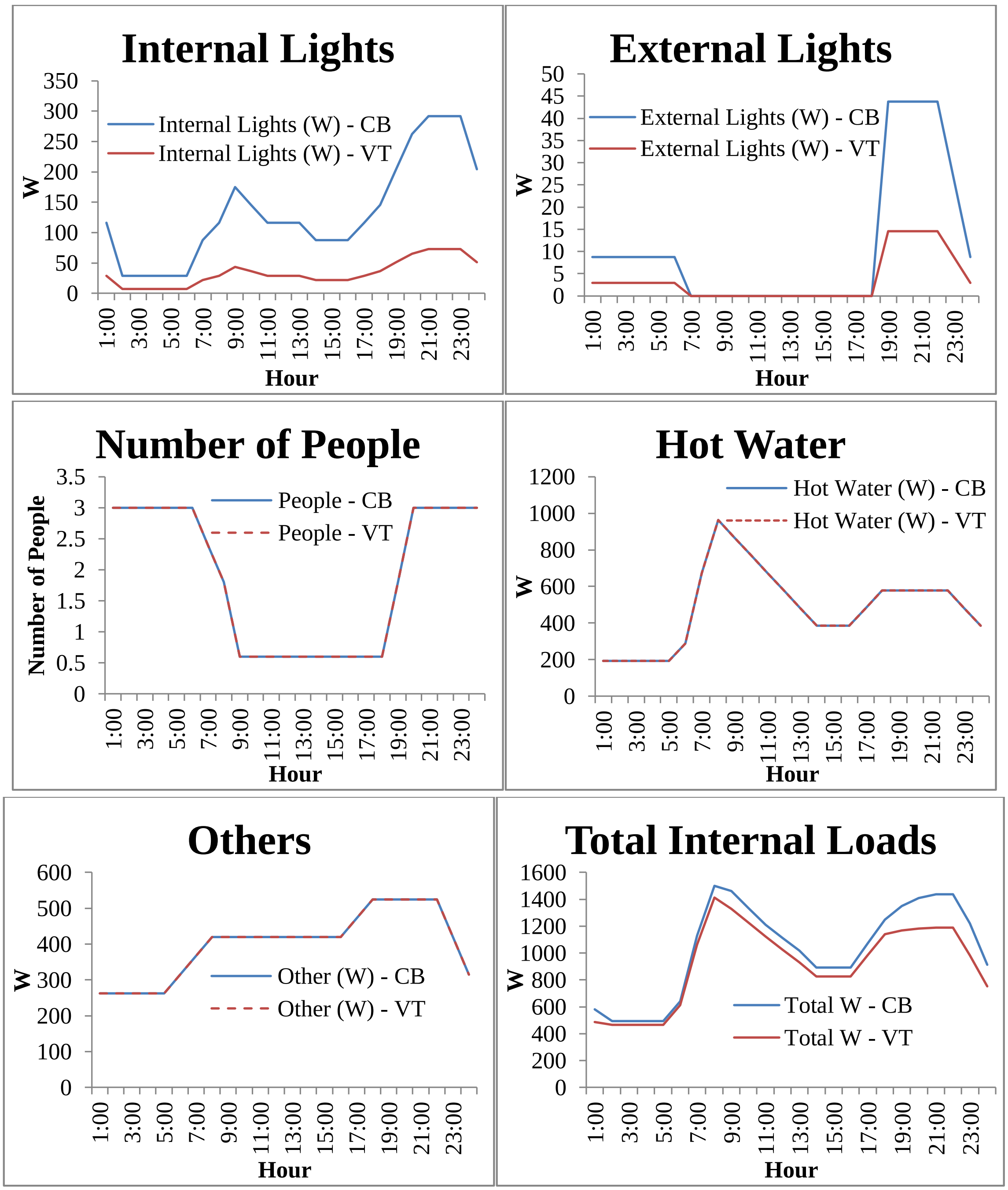


FIGURE 6 – INTERNAL LOAD PROFILES

Results of Simulation

After running the simulation under the parameters that were presented in the previous section, without including the photovoltaic roof panels' power production, the reduction of the electrical power consumption of the energy efficient Villa Trieste home compared with the home built to the IECC 2006 code peaked at up to 47%.

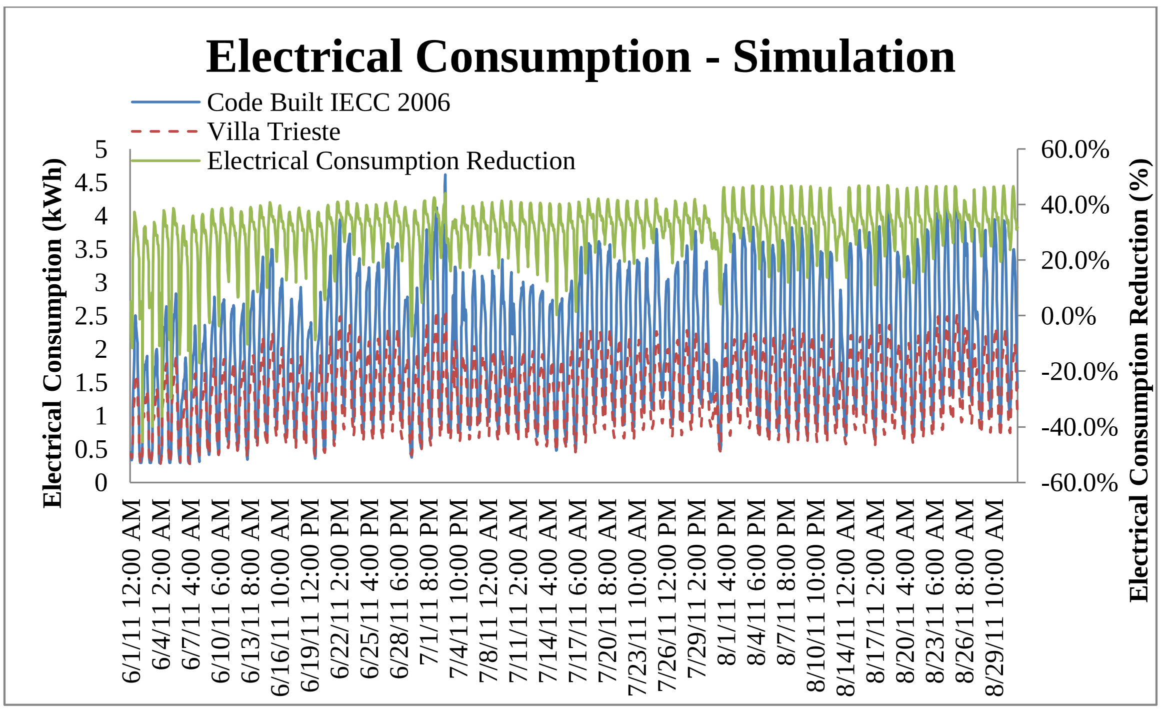


FIGURE 7 - ELECTRICAL CONSUMPTION COMPARISON FOR JUNE – JULY & AUGUST 2011

Figure 7 above shows the electrical power consumption of the energy efficient Villa Trieste home compared with the home built to the IECC 2006 code for the three months of June, July and August 2011. The graph also shows the electrical consumption reduction which is calculated by dividing the difference between the code built electrical consumption and the Villa Trieste electrical consumption by the code built electrical consumption. A closer look at a week in August shows a more detailed hour by hour electrical consumption reduction as is shown in Figure 8.

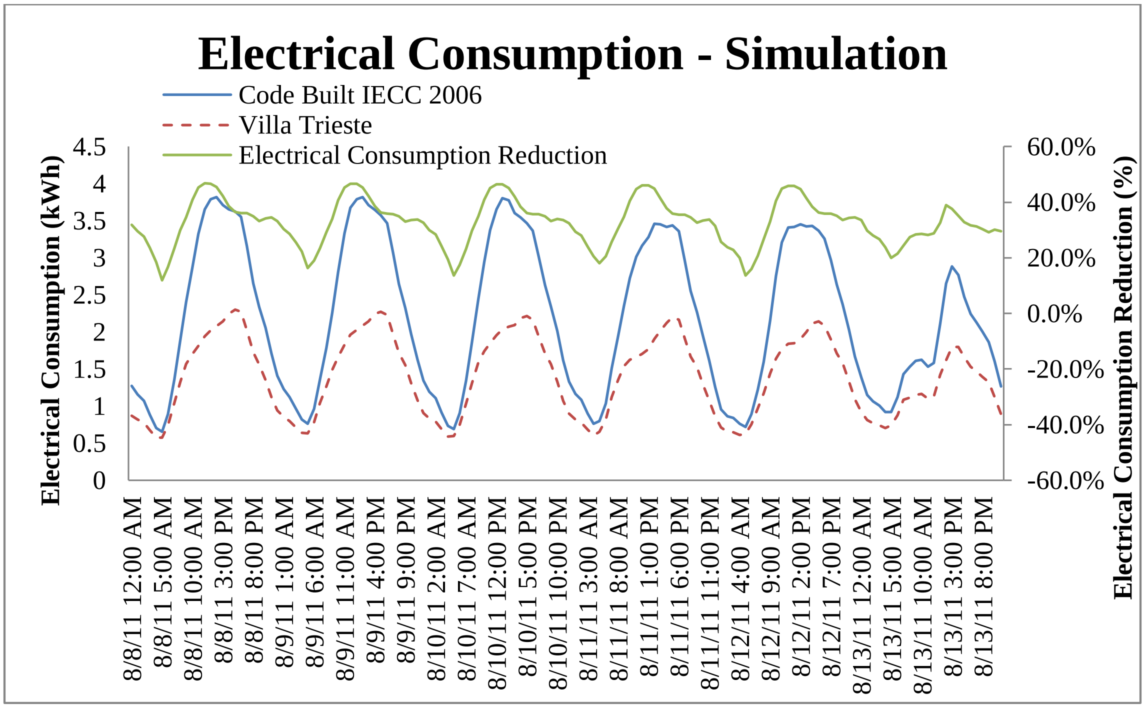


FIGURE 8 - ELECTRICAL CONSUMPTION COMPARISON FROM SIMULATION RESULTS FOR ONE WEEK IN AUGUST 2011

As can be seen in Figure 8, the electrical consumption reduction is highest at 11:00 AM to 3:00 PM and reached the 47% electrical consumption reduction. It should be repeated that this electrical consumption does not include the added benefit of photovoltaic power production which is shown next.

PV Simulation

In order to simulate the effect of the roof tile photovoltaic panels' power production on the overall electrical power consumption of the Villa Trieste house, the radiation on a tilted surface was modeled using MatLab. Duffie and Beckman's Solar Engineering of Thermal Processes book was used (Duffie & Beckman, 2006).

First, different meteorological parameters were extracted from the NREL 2011 data supplied by the Nevada Power Clark Station and the University of Nevada Las Vegas. The latitude and longitude were taken to be 36.083° and 115.15° respectively. The albedo (or ground reflectivity) was assumed to be 0.1. The photovoltaic surface tilt with the respect to the horizontal was set at 22.5° which is the slope of the roof of a typical Villa Trieste house. Moreover, the standard meridian for that location is determined automatically.

After these parameters are set, the Matlab script enters a loop which calculates the following parameters for every hour. The standard meridian that was determined earlier is used to calculate the solar time for each hour which is the time based on the apparent angular motion of the sun across the sky, with solar noon the time the sun crosses the meridian of the observer. In fact, solar time is the time used in all the sun-angle relationships, and in most cases it does not coincide with the local clock time. This step is crucial because the gathered data is logged using standard local time, thus the need to be converted to solar time. Next, the hour angle, which is the angular displacement of the sun east or west of the local meridian due to rotation of the earth on its axis at 15° per hour, is calculated.

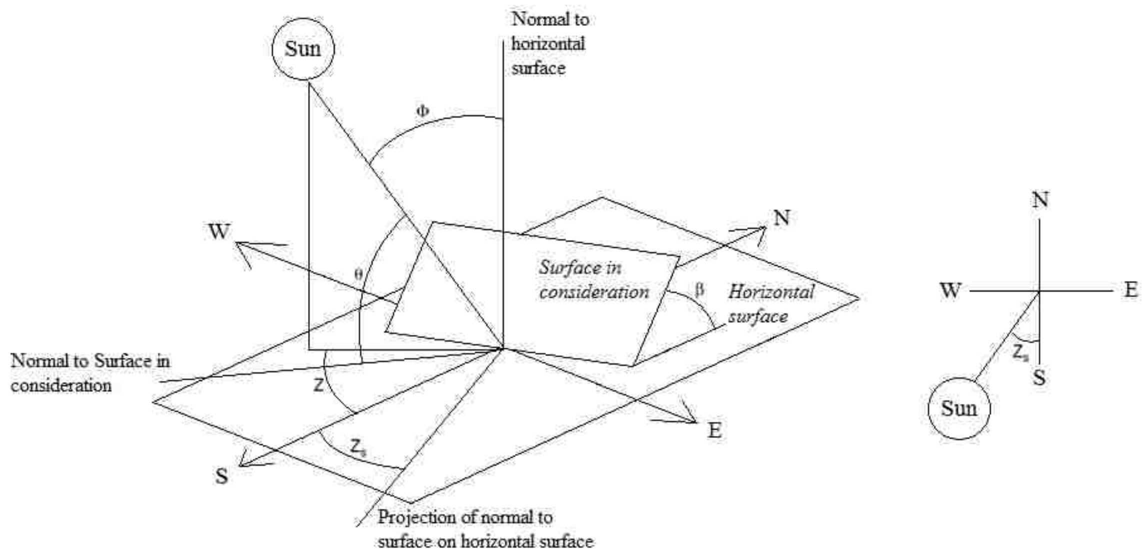


FIGURE 9 - SOLAR ANGLES

Next, the declination which is the angular position of the sun at solar noon with respect to the plane of the equator is calculated and is used to calculate the zenith angle Φ, which as the figure above shows, is the angle between the vertical and the line to the sun. Next, the angle of incidence θ is calculated, which is the angle between the beam radiation on a surface and the normal to that surface. Following that, the ratio of beam radiation on a tilted surface to that on a horizontal surface is calculated. Finally, assuming an isotropic sky diffuse model, the total radiation is calculated.

FIGURE 10 - PV PANELS ON EACH VILLA TRIESTE MODEL HOME

As is shown in Figure 10 above, all homes at Villa Trieste are equipped with 28 photovoltaic panels, or solar roof tiles (Suntile® by SunPower) tiles which are rated at 63W each (Peak Power at STC). These solar tiles are formed by 22 monocrystalline silicon cells connected in series which have a rated open circuit voltage of 14.6 V, a maximum power voltage of 12.0 V, a short circuit current of 5.65 A and a maximum power current of 5.25 A.

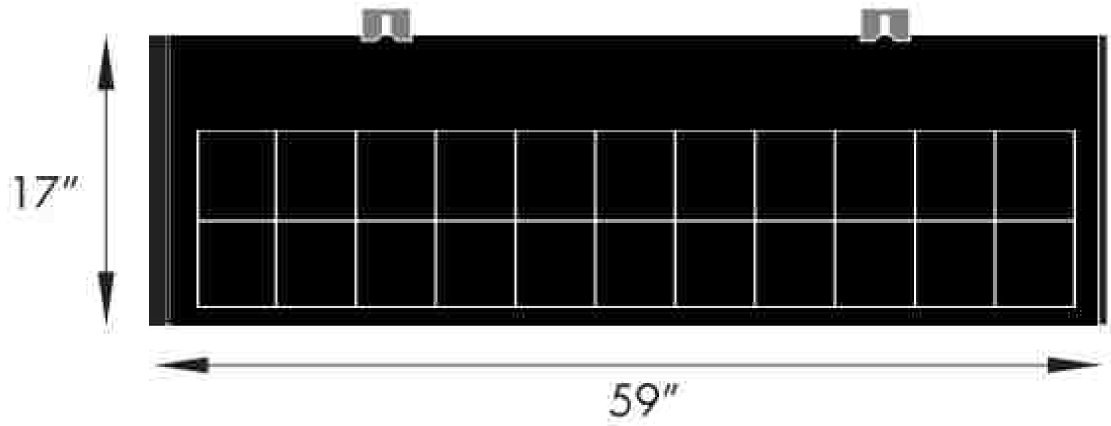


FIGURE 11 - SURFACE AREA CALCULATION FOR ONE TILE

As can be seen in Figure 11 above, the surface area for each tile is 1003 sq in or 6.97 sq-ft each which equates to around 195 sq-ft for 28 tiles. However, the actual PV cells that cover the tile have an area of approximately 573.33 sq in and cover around 57% of the actual tile area. Therefore the actual PV area is around 111.5 sq-ft, and the sun tiles are sloped at 22.5° facing south.

Assuming 10% efficiency from the PV system (AC electrical energy/solar radiation absorbed by the PV tiles), the AC electrical power generated by the PV sun tiles is shown in Figure 12 for the year 2011.

The AC electrical power generation shown in Figure 13 was calculated using the measured solar flux radiation data from the modified weather file which was used for the building energy simulation and the Matlab code in Appendix C.

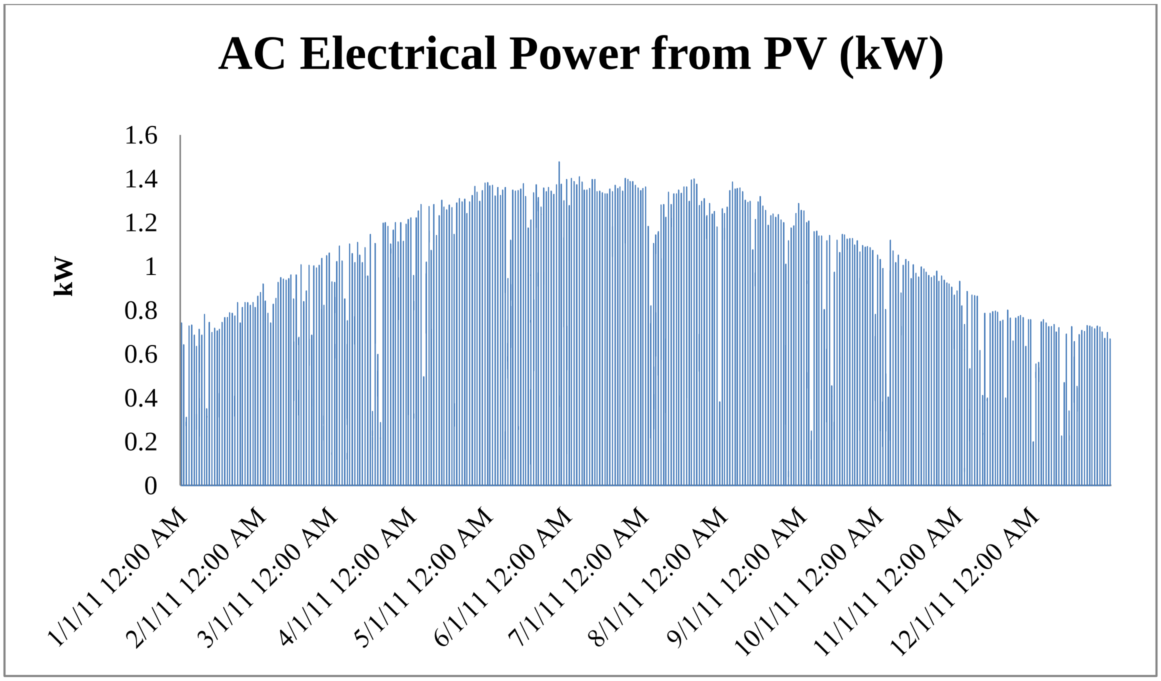


FIGURE 12 - AC SIMULATED ELECTRICAL POWER PRODUCTION FROM PV

Assuming that the electrical energy produced by the PV panels can be used by all the electrical equipment in the house, the electrical consumption of Villa Trieste can be calculated by subtracting the PV power production from the total electrical power production. Figure 13 shows the electrical consumption of a simulated Vila Trieste house which includes PV sun tiles, a Villa Trieste house which does not include PV panels and an IECC 2006 code built house and the corresponding electrical power consumption reduction.

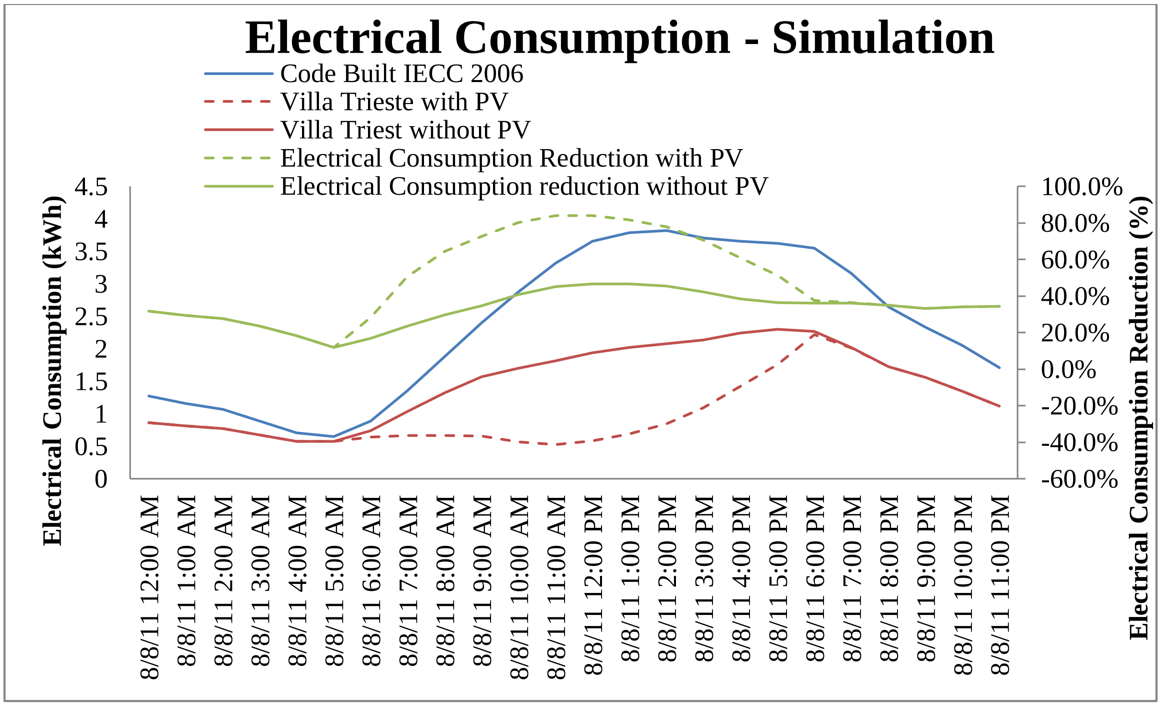


FIGURE 13 – ELECTRICAL CONSUMPTION COMPARISON INCLUDING PV PANELS FOR ONE WEEK IN AUGUST 2011

As can be seen in Figure 13, the highest energy consumption reduction occurs at hours 11:00 AM and 12:00 PM and reaches around 85% when the power produced by the PV sun tiles is taken into account. The reduction drops down gradually from 81.8% at 1:00 PM to 77.8% at 2:00PM to 70.6% at 3:00PM to 61.1% at 4:00 PM to around 52% at 5:00 PM and equalizes with the electrical power reduction when no PV output is included at 6:00 PM.

Certainly, the building energy simulation shows that the implemented energy efficiency strategies at the Villa Trieste community reduce the peak load by a substantial amount as was shown above. The next section will analyze the measured data gathered by NV Energy (the electric utility company) and the subsequent section will show if the simulated energy consumption agrees with the real measured electrical consumption.

CHAPTER 3 – EMPIRICAL DATA ANALYSIS

Data Processing

Modeling the energy efficient homes and the code built homes is helpful for understanding the theoretically expected benefits of implementing energy efficient strategies. However, using the building energy simulation software does not account for different human energy consumption behavior. This is why actual energy consumption was recorded for the five Villa Trieste homes and total data for 30 homes were acquired through NV Energy (electric utility). A table detailing the array of Villa Trieste homes is shown below.

TABLE 10 - LIST OF VILLA TRIESTE HOMES

Model	Living Space Area Sqft	Sample Size
Roma	1,487	15
Torino	1,612	7
Venezia	1,758	9
Venezia	1,777	8

Moreover, different neighborhoods were identified which will be used as a benchmark to compare to the Villa Trieste energy efficient homes. In fact, two batches of non-energy efficient homes electric consumption data were also acquired from NV Energy. The first batch is a set of 15 homes, 6 of which were built in 2001, 3 were built in 2000, another 3 were built in 1999 and the last three were built in 1989. The second batch is a set of 5 homes that were built in 2006. The tables below show the different homes that had their electrical consumption data taken.

TABLE 11 - LIST OF HOMES BUILT PRE-IECC 2006

Location	Living Space Area sq-ft	Year Built	Sample Size requested	Sample Size received
NV 89074	1,567	1989	8	3
NV 89135	2,113	1999	6	3
NV 89135	1,806	2001	5	3
NV 89138	1,882	2005	6	0
NV 89135	1,723	2001	5	3
NV 89148	1,743	2000	7	3

TABLE 12 - LIST OF HOMES BUILT UNDER IECC 2006 CODE

Location	Living Space Area sq-ft	Year Built	Sample Size requested	Sample Size received
NV 89148	2,021	2006	6	3
NV 89148	1,775	2006	6	2
NV 89135	1,791	2007 - 2009	5	0

Villa Trieste homes electrical consumption data

The data supplied by NV Energy for the Villa Trieste homes consists of 4 values for each house. The electrical energy generated by the photovoltaic sun tiles system, the electrical energy consumed by the sun tile system (inverter), the electrical energy provided by NV Energy to the house and the electrical energy that is returned back to the grid. The data supplied is in 5 minute intervals.

First, the missing data from the raw 5 minute electrical data consumption from the Vila Trieste homes were eliminated/filled with 0 values. These missing data constituted a small fraction of the data (mostly missing hours), and were deemed to insignificantly affect the average electrical consumption if they would be replaced by a null value. Next, the data were turned into hourly data using a Matlab code (Appendix A) that accepts an Excel spreadsheet which includes the electrical consumption of the Villa Trieste homes, then adds twelve consecutive 5-minute electrical energy values into one hourly electrical consumption in kWh. Next, the electrical energy produced by the sun tiles is added to the electrical consumption of the house that is supplied by NV Energy. Then the energy that is returned to the grid is subtracted from the latter summation. The result is the actual electrical consumption of the house which does not include photovoltaic generation. Finally the electrical consumption of the house is normalized to a livable floor area of 1,458 sq-ft.

Code Built homes electrical consumption data

Similarly to the Villa Trieste data, the missing data from the raw 15 minute data consumption from the code built homes were eliminated. Later, the data were turned into hourly data using a Matlab code (Appendix B) that accepts an Excel spreadsheet. This spreadsheet includes the electrical consumption of the code built homes, where 4 consecutive 15-minute electrical energy values were added into one hourly electrical consumption in kWh.

CHAPTER 4 – FINDINGS

Actual Measurements

Before getting into the results, a reminder of the difference between the IECC 2006 code built house and the Villa Trieste energy efficient house is shown below.

TABLE 13 - IECC 2006 VS VILLA TRIESTE COMPARISON

Climate Zone	Fenestration U-Factor	Skylight U-Factor	Glazed Fenestration SHGC	Ceiling R-Value	Wood Frame Wall R-Value	Floor R-Value	Slab R-Value & Depth
IECC 2006 Code	0.65	0.65	0.4	30	13	19	0
Villa Trieste	0.325 – 0.339	N/A	0.56	30	15 (2 x 4 frame Wall) 20 (2 x 6 frame Wall)	24	0

The energy efficient house also includes photovoltaic solar roof tiles, which is not in the IECC 2006 code built homes. The energy efficient house also includes an improved building envelope insulation system with blown-in cellulose which increases the insulation and decreases the infiltration compared with the IECC 2006 code built house. Moreover, the HVAC system installed in the Villa Trieste houses is a high efficiency 15 SEER-rated system which is an upgrade from the regular 13 or 14 SEER HVAC systems used in regular production homes. The gas furnace is also more efficient. Also, low-e, dual pane windows with vinyl frames are installed and are a significant improvement over the non-low-e dual pane windows installed in the IECC 2006 code built houses. In order to further reduce the electrical consumption, compact fluorescent light (CFL) bulbs are installed throughout the Villa Trieste homes which reduce the electrical energy consumption by up to 75% compared with incandescent light bulbs.

There were several concerns with the electric consumption data that was intended to be acquired by NV Energy. First, the NV Energy “Smart Meters” started being deployed in NV Energy's southern and northern Nevada service territories in 2010 and not all homes had the smart meters at the time when data was requested from NV Energy. Due to this fact, there is no possible way of knowing which homes have the smart meters installed and which do not. Thus, when a request is sent to NV Energy for the acquisition of electrical consumption data for identified homes that will be used as benchmark for certain periods of the year, not all homes’ data are returned for every time period requested. As an example, when the second batch data of homes built in 2006 were received from NV Energy for the months of June, July and August of 2011, only two of the 5 homes data were received for the month of June and July and the rest 3 homes’ data were for August 2011 only. As will be shown in the next few paragraphs, in order to reduce the effect of different human behavioral electric consumption and to better estimate the energy consumption of a residential building, an increase in sample size is preferred. Therefore, the month of August 2011 will be used to compare the actual electric consumption of energy efficient homes with non-energy efficient homes.

Comparison without taking photovoltaic power generation into account

As was mentioned earlier, the 5-minute electric consumption data for 30 energy efficient homes from Villa Trieste, which were provided by NV Energy, were processed, fixing missing data and converting the 5 minute data to hourly data. Also the result is the actual electrical consumption of the house which does not include photovoltaic generation. The data were also converted to daily data. The average daily consumption comparing the energy efficient homes with the non-energy efficient homes in June, July and August of 2011 is shown in Figure 14.

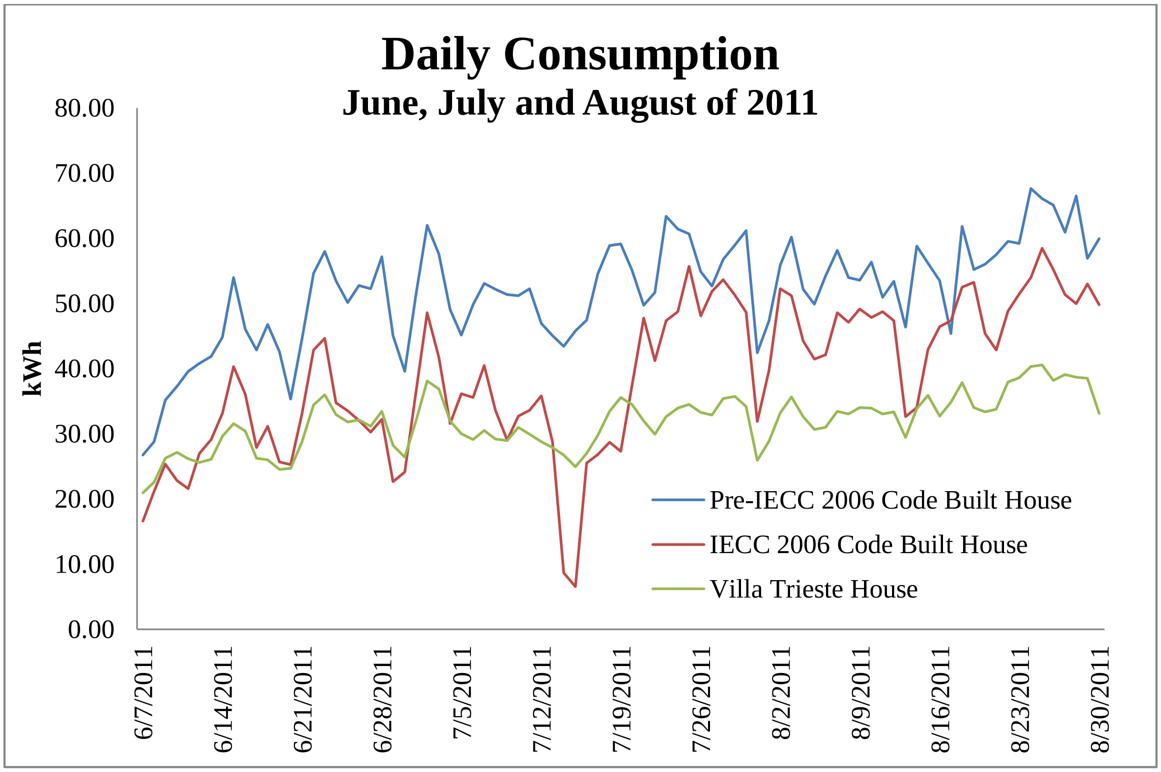


FIGURE 14 - AVERAGE TOTAL DAILY CONSUMPTION COMPARISON BETWEEN ENERGY EFFICIENT VS NON-ENERGY EFFICIENT HOMES IN JUNE, JULY AND AUGUST OF 2011

As can be seen in Figure 14, the non-energy efficient homes built from 1989 and 2001 consume the most electrical energy per day for the summer season. It is worth noting that the electric consumption data for these homes are continuous and are the average of 15 homes throughout the season. This is not the case for the non-energy efficient homes built in 2006. In fact, it is clear from the graph above that prior to 7/22/2011, the daily electric consumption of these homes was around the same as the Villa Trieste energy efficient homes. To better illustrate that fact, the reduction in daily consumption from non-efficient homes to the Villa Trieste homes is shown in Figure 15 for the three summer months.

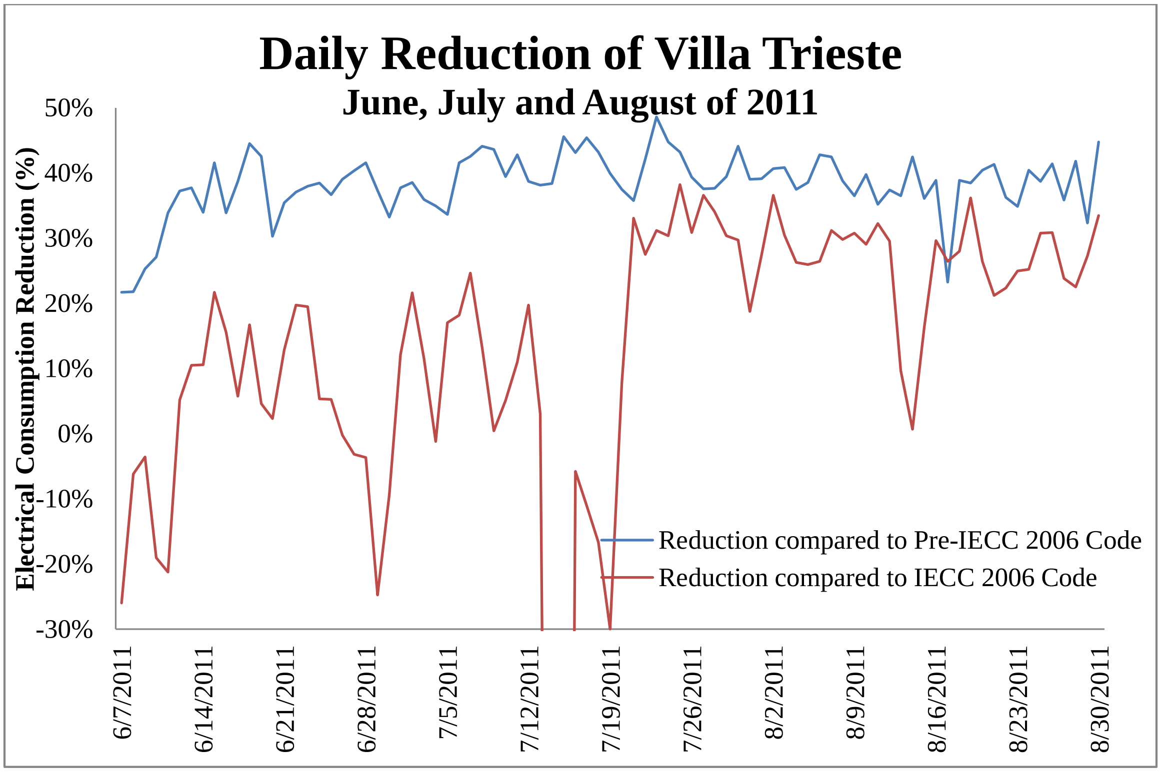


FIGURE 15 - THE REDUCTION IN TOTAL DAILY CONSUMPTION FROM NON-EFFICIENT HOMES TO THE VILLA TRIESTE

Figure 15 shows that the reduction (which is the electrical consumption reduction of the Villa Trieste house compared to the IECC 2006 code built house) is inconsistent before 7/22/2011. As can be seen in Figure 16, the daily electrical reduction fluctuates greatly between -20% to 20% before 7/22/2011. However, after this date the reduction becomes more stable fluctuating between 20% and 37%. This fact is perfectly explained by the sample number (number of homes being investigated). In fact, smart meters for three of the five homes that constitute the non-efficient 2006 homes weren't installed until that date. Therefore the data prior to 7/22/2011 constitute two homes, and after that date 3 more homes were added to the average. When the average of electrical power consumption is derived from only two homes, it is greatly affected by the individual electrical usage of a house. The average of the electrical consumption of a total of five homes (after 7/22/2011) is more reliable (in terms or accuracy) than the average of the electrical consumption of two homes (from 6/7/2011 to 7/21/2011). It can easily be seen that after 7/22/2011, the daily electrical consumption reduction of the Villa Trieste house compared with the IECC 2006 built house is almost stable at around 30%. For the purpose of increasing accuracy to the study, the data subsequent to 7/22/2011 will be used as the comparison period as is shown in Figure 16.

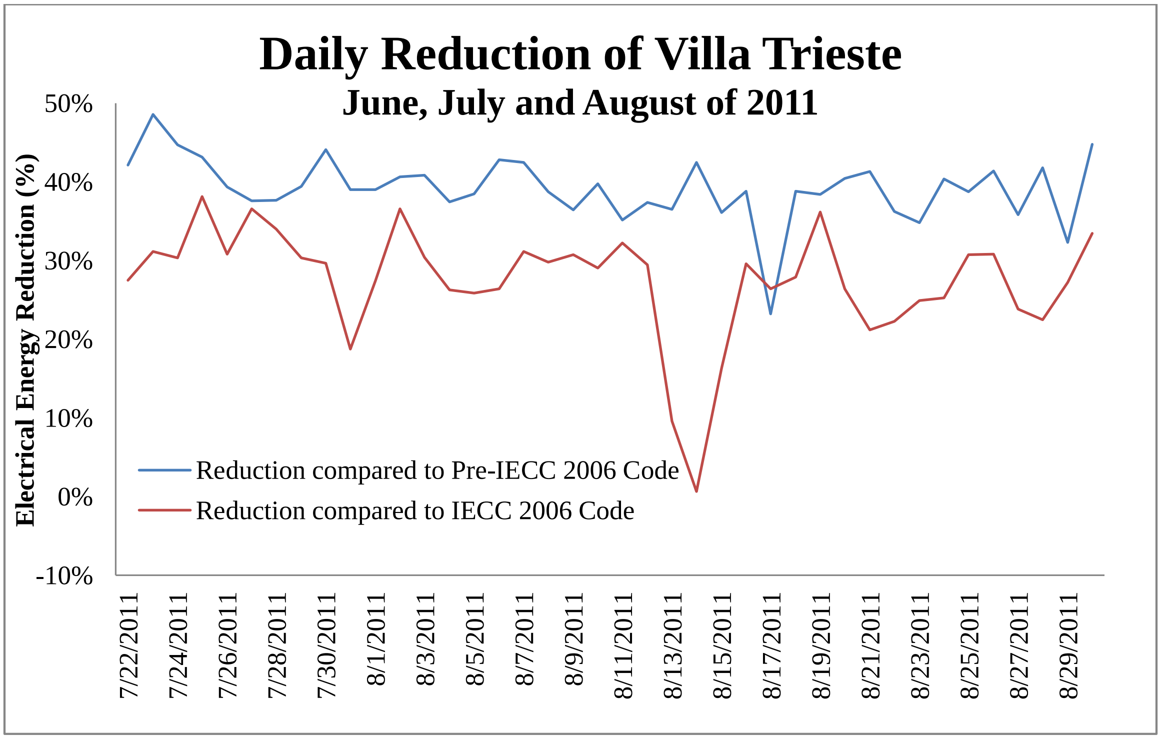


FIGURE 16 - THE REDUCTION IN DAILY CONSUMPTION FOR JUNE – JULY & AUGUST 2011

As illustrated in the Figure 16, it is clear that the daily reduction in electric consumption from the non-efficient homes built between 1989 and 2001 compared to Villa Trieste is around 40% and the reduction from the 2006 homes compared to Villa

Trieste is almost half the number and is estimated at 30%. To better view the electrical consumption, hourly data were processed, and the result is shown in Figure 17 for the first week of August.

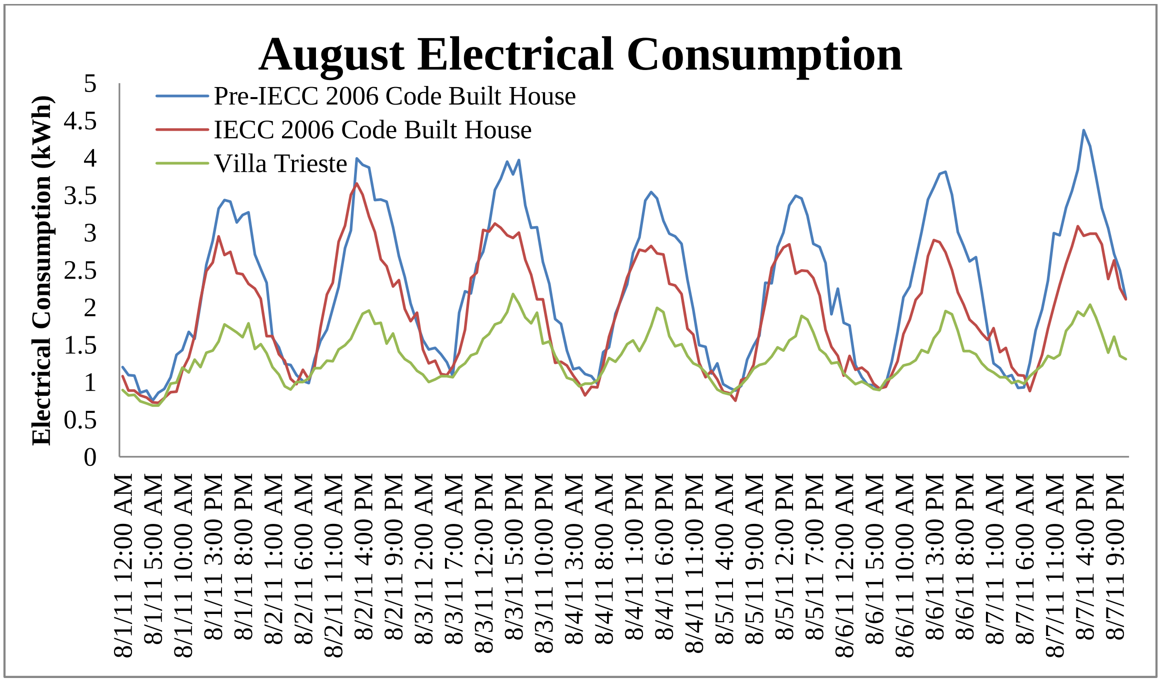


FIGURE 17 – FIRST WEEK OF AUGUST HOURLY ELECTRICAL CONSUMPTION

As expected, Figure 17 shows that the hourly electrical consumption is highest at times from 1:00 pm until 7:00 pm. To better illustrate the reduction, it is plotted below for the first week of August.

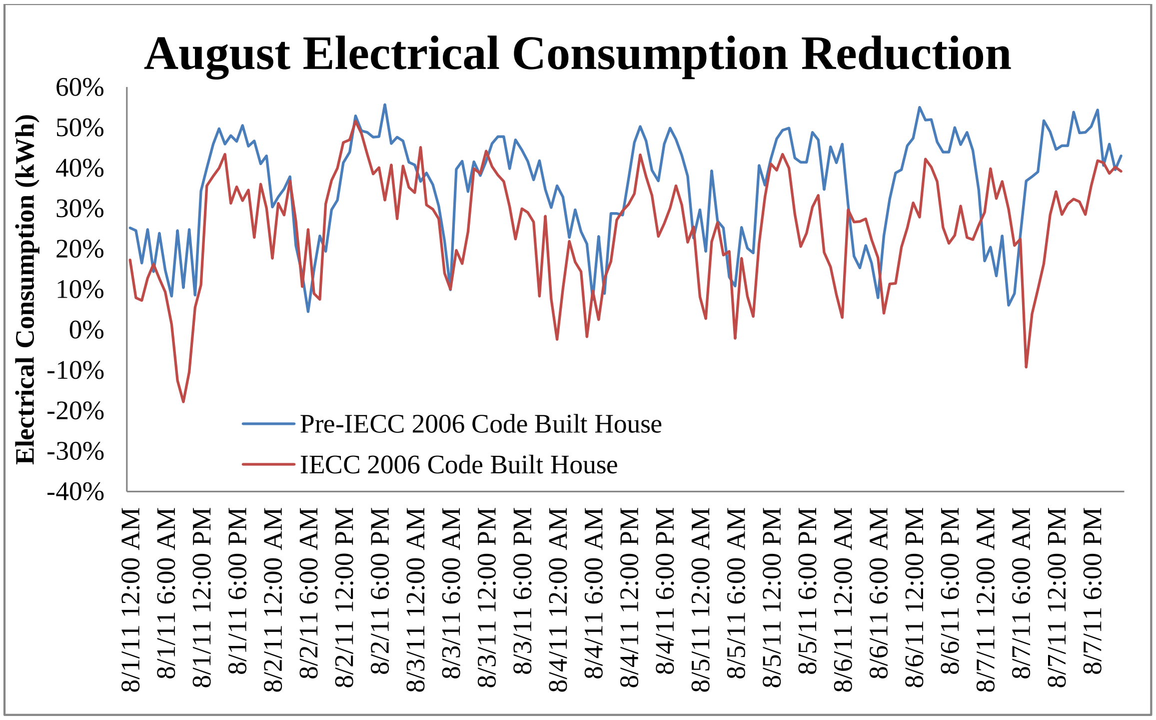


FIGURE 18 - AUGUST VILLA TRIESTE ELECTRICAL CONSUMPTION REDUCTION COMPARD WITH IECC 2006 CODE BUILT HOMES AND PRE-IECC 2006 CODE BUILT HOMES

Figure 18 shows that the reduction in electrical consumption is highest at those times from 10:00 am until 4:00 pm.

To better understand the effect of the energy efficient strategies implemented at Villa Trieste (without taking the PV panels into account yet) in terms of peak load reduction, the hours of interest which are the peak hours (from 1:00 PM until 7:00 PM) will be the main focus. Therefore Figure 19 shows the average of the peak reduction (which was found by averaging the electric consumption from 1:00 pm to 7:00 pm for the non-efficient homes, subtracting from the latter the average of electric consumption from 1:00 pm to 7:00 pm for Villa Trieste homes, and then dividing by the first value).

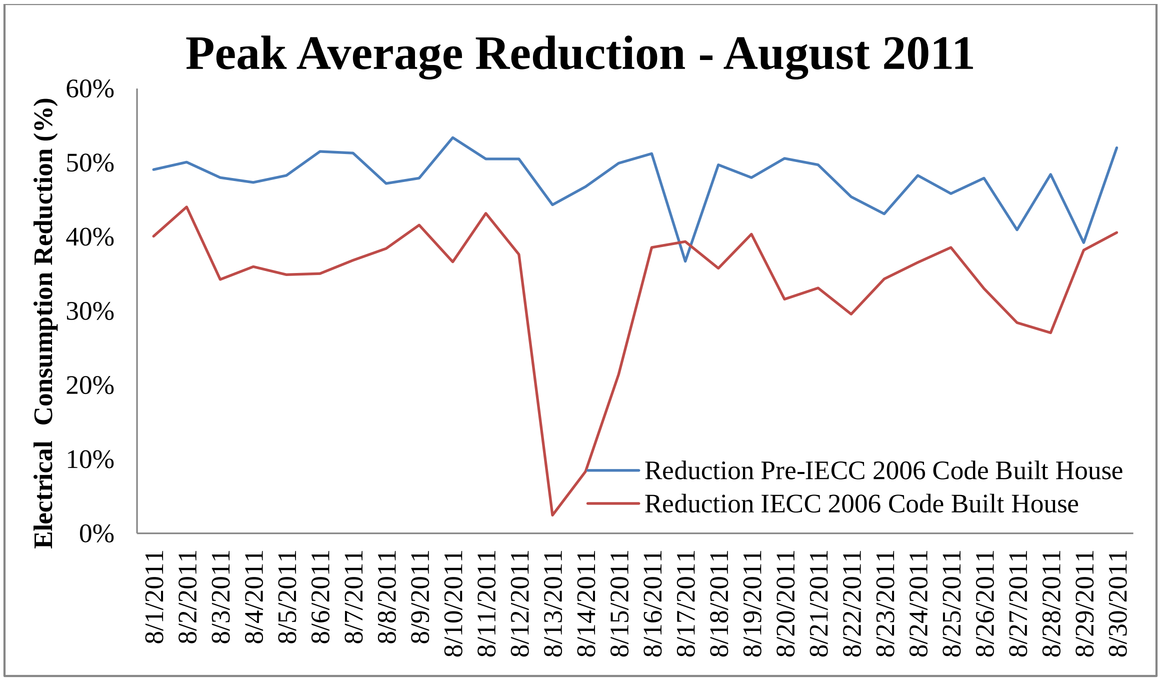


FIGURE 19 - PEAK AVERAGE REDUCTION FOR AUGUST 2011

As can be seen from Figure 19, the average peak reduction is around 35% to 40% from the 2006 built non-efficient homes (excluding the discrepancies on the 13th and 14th of August, which could be due to the small size of the sample), and around 45% from the non-efficient 1989 to 2001 built homes. If the maximum hourly reduction is taken for each day of August 2011, the result would be what is shown in Figure 20.

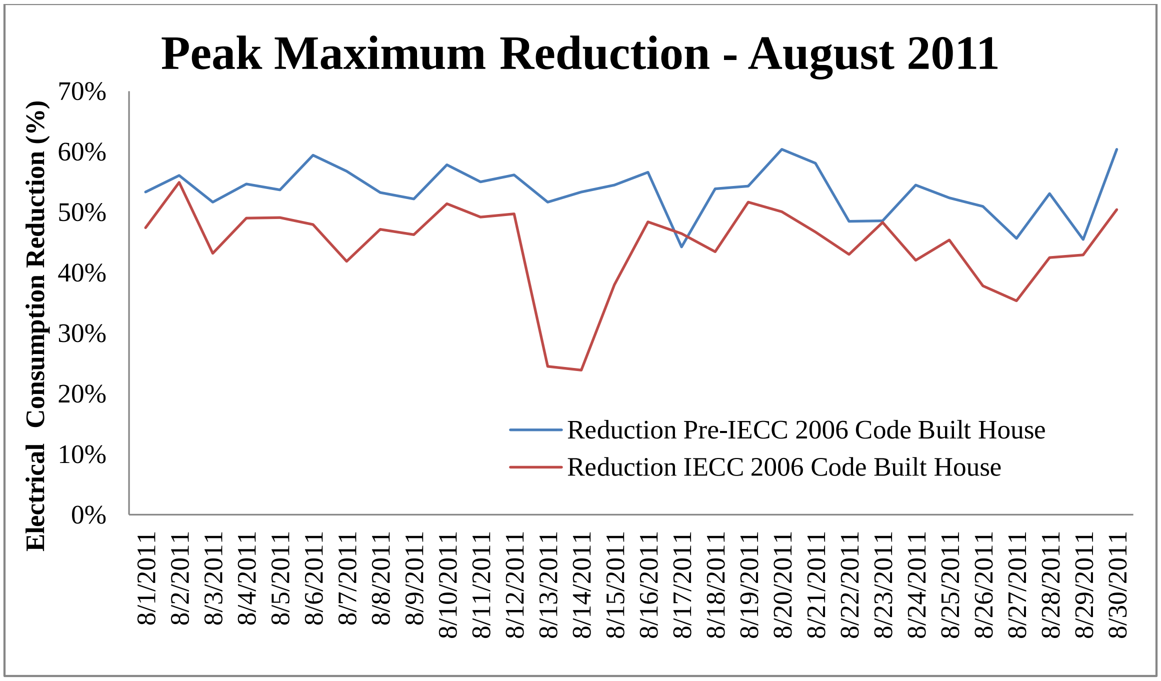


FIGURE 20 - PEAK MAXIMUM REDUCTION AUGUST 2011

As noted, taking the maximum hourly reduction, for each day of August 2011 would, as expected, yields a higher overall reduction which is around 45% to 50% from the IECC 2006 code built homes and around 55% reduction from the code build 1989 to 2001 built homes.

Taking the average of each hour for all August days yields the results shown in Figure 21. Figure 21 shows that the average peak reduction is highest at 41% at 2:00 PM from the IECC 2006 non-efficient homes. The average peak reduction from the 1989-2001 non-efficient homes is highest at 52% at 15:00.

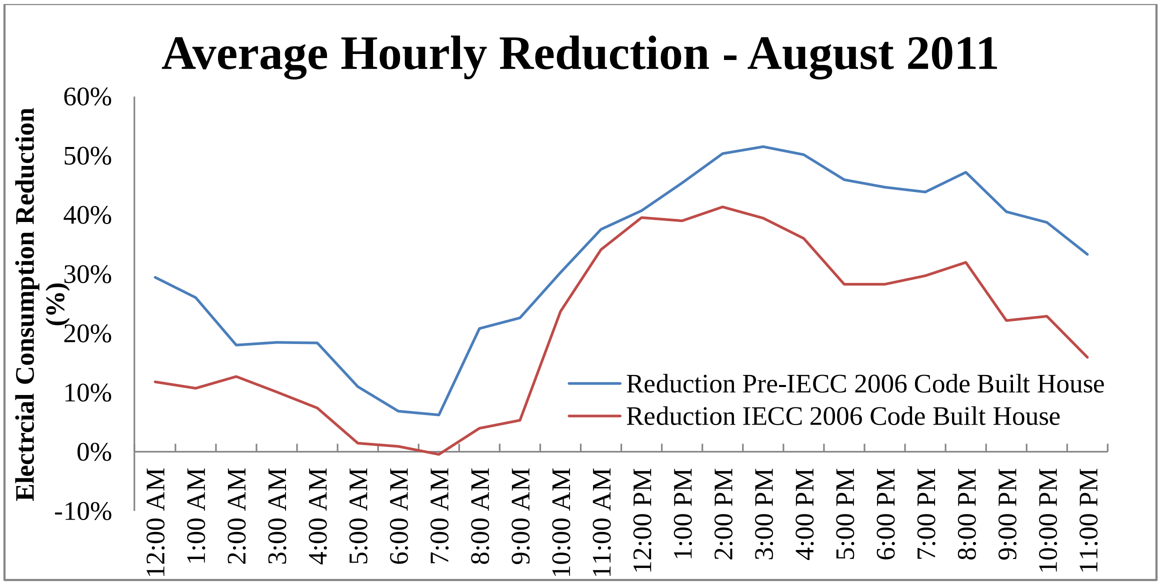


FIGURE 21 - AVERAGE HOURLY REDUCTION FOR AUGUST 2011

Taking the maximum of each hour for all August days yields the results shown in Figure 22.

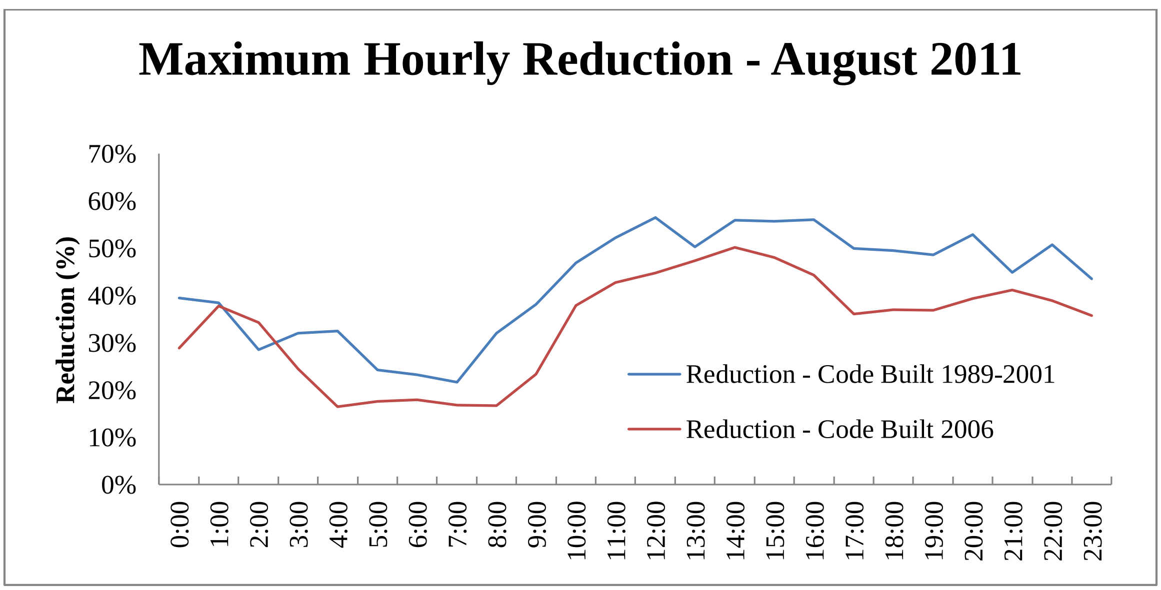


FIGURE 22 - MAXIMUM HOURLY REDUCTION FOR AUGUST 2011

Figure 22 shows that maximum peak reduction that occurred during the month of August 2011 is highest at 50% at 14:00 from the 2006 non-efficient homes, and it is at 56% for hours 14:00, 15:00 and 16:00 from the 1989-2001 non-efficient homes.

The average trend of the electrical consumption (without including the photovoltaic power generation) for the different groups of homes for August 2011 is shown in Figure 23.

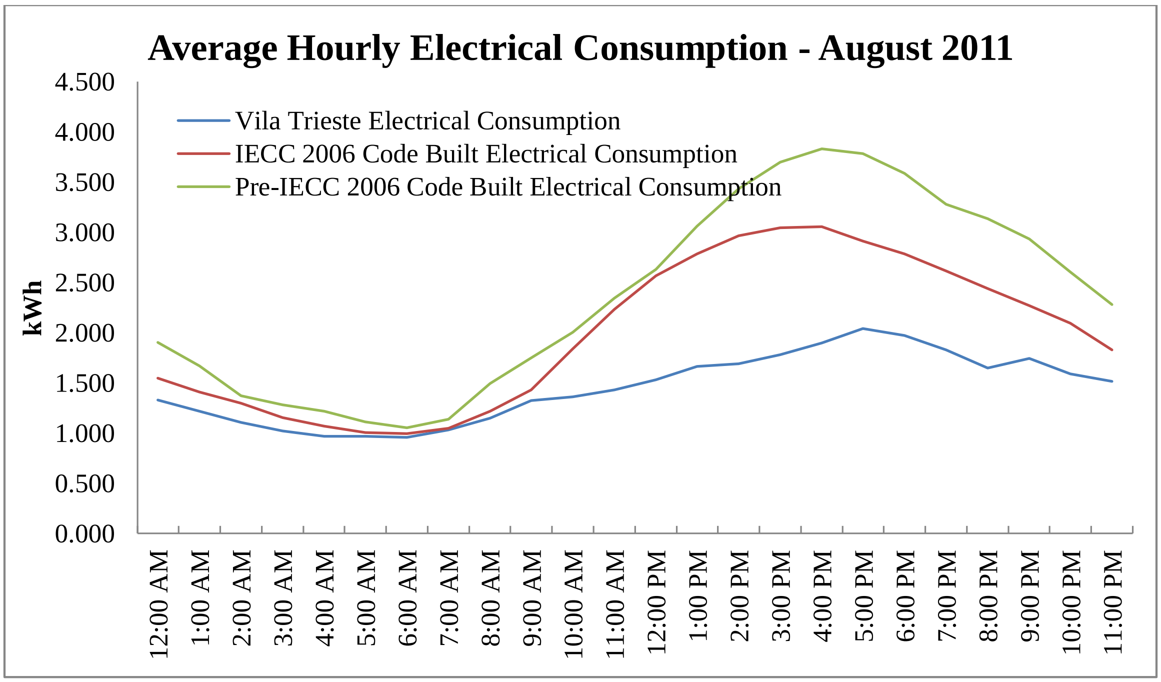


FIGURE 23 - AVERAGE HOURLY ELECTRICAL CONSUMPTION AUGUST 2011

As can be seen from Figure 23, the peak load for the energy efficient Villa Trieste house is at 5:00 PM whereas the peak load for the IECC 2006 code built house is at 3:00 PM to 4:00 PM.

Comparison taking photovoltaic power generation into account

This section will compare the Villa Trieste house including the photovoltaic power production. Therefore the actual electrical power consumption of the house (which is the electrical power used from the grid) minus the power going back to the grid, will be the actual electrical consumption of the house. The hourly processed data shows that at certain hours during the day, even if a house needs a total of 1.45 kWh for example as is shown in Figure 24 for the hour 12:00 PM and is generating 1.45 kWh though its photovoltaic panels, the electrical consumption from the grid is around 0.72 kWh and the rest energy which is needed for the operation of the house is consumed from the PV generation, and the remaining generated energy is returned to the grid. This fact is explained by remembering that the data shows the total energy spent during the hour. However during that hour the electrical components (including the HVAC system) turn on and off several times during that hour and actually consume the PV generated power as is shown in Figure 25 and 26. Also, the recordings of the electrical consumption, generation and return to grid are not done at the same instant of time in a synchronized manner.

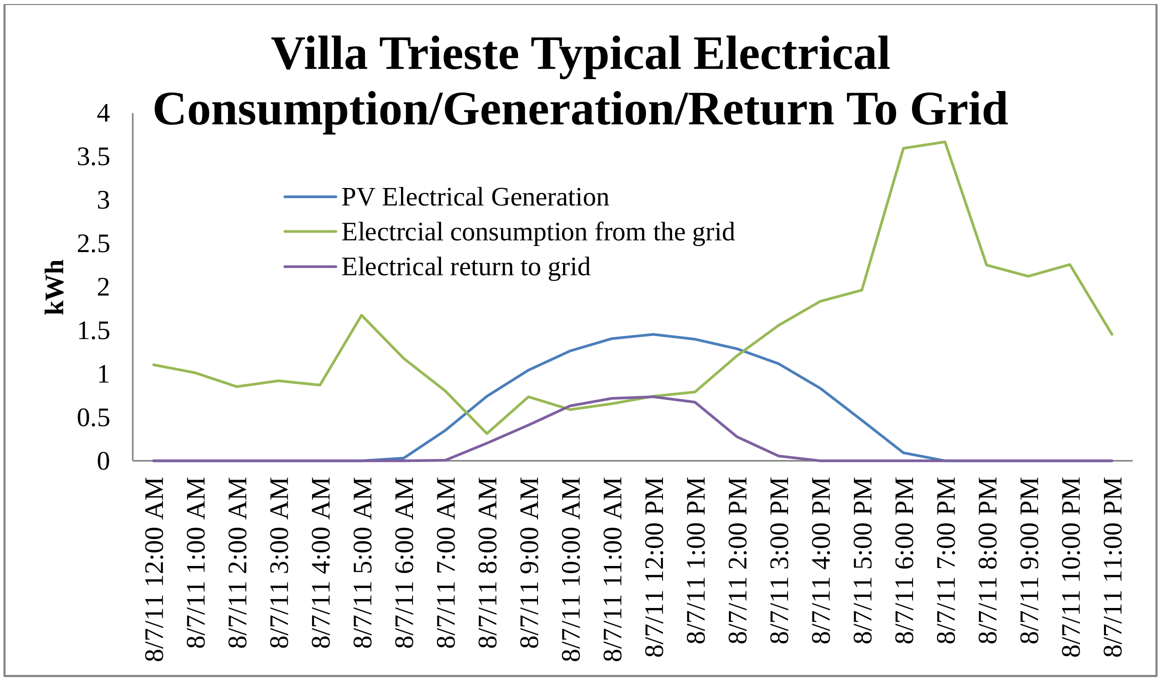


FIGURE 24 - VILLA TRIESTE TYPICAL ELECTRICAL CONSUMPTION AND PV POWER GENERATION

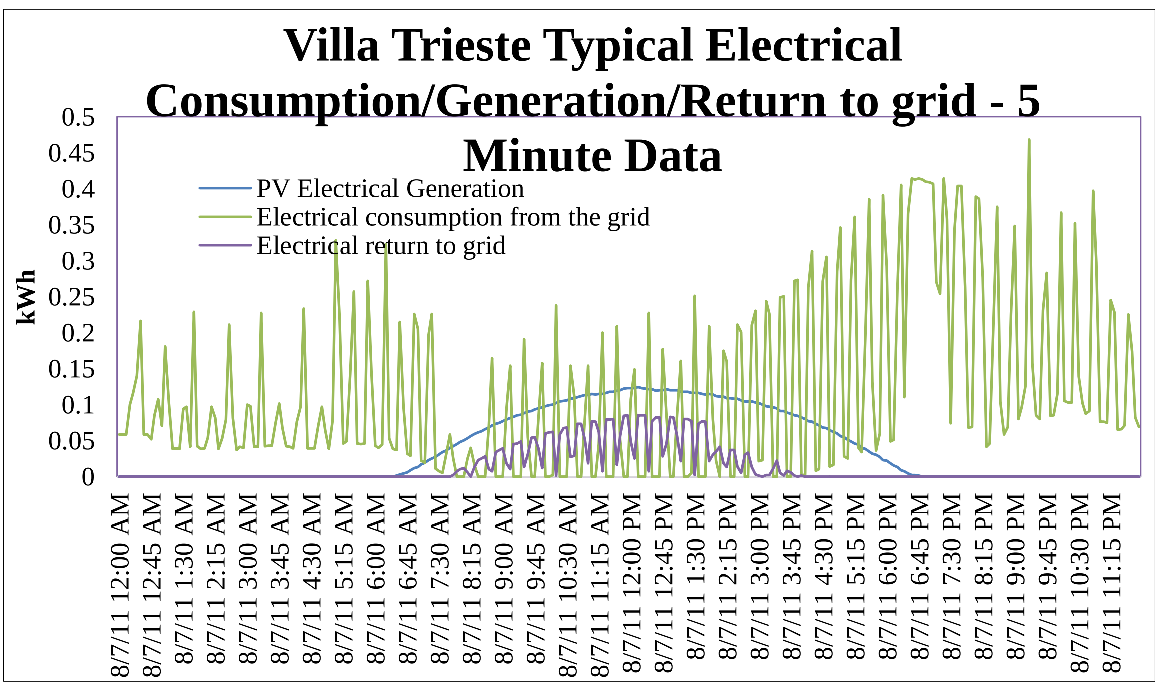


FIGURE 25 - VILLA TRIESTE TYPICAL ELECTRICAL CONSUMPTION AND PV POWER GENERATION – 5-MIN

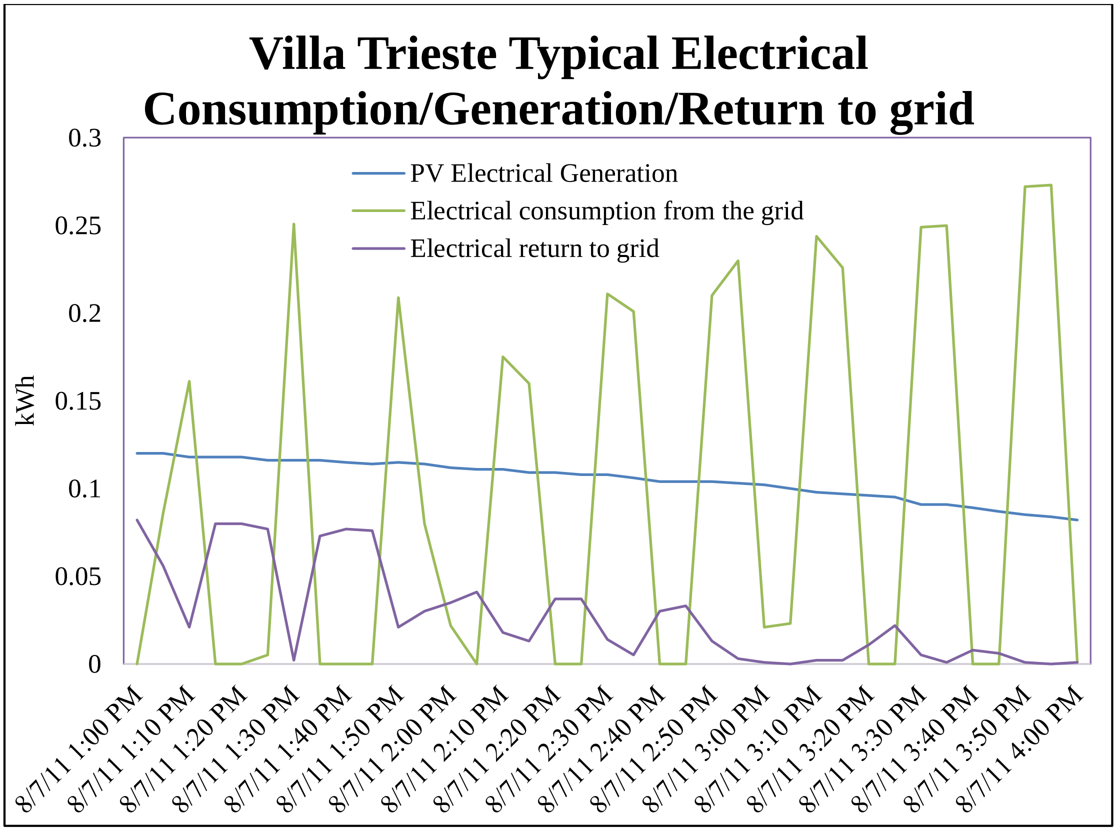


FIGURE 26 - VILLA TRIESTE TYPICAL ELECTRICAL CONSUMPTION AND PV POWER GENERATION – 5-MIN - ZOOM IN

Therefore, it is reasonable to assume that electrical consumption from the grid minus the electrical energy returned to the grid is in fact the actual energy consumed by the house.

Taking the photovoltaic power generation into account, the daily electrical consumption of the homes is shown in the graph below beginning 7/22/2011 until the end of the month of August.

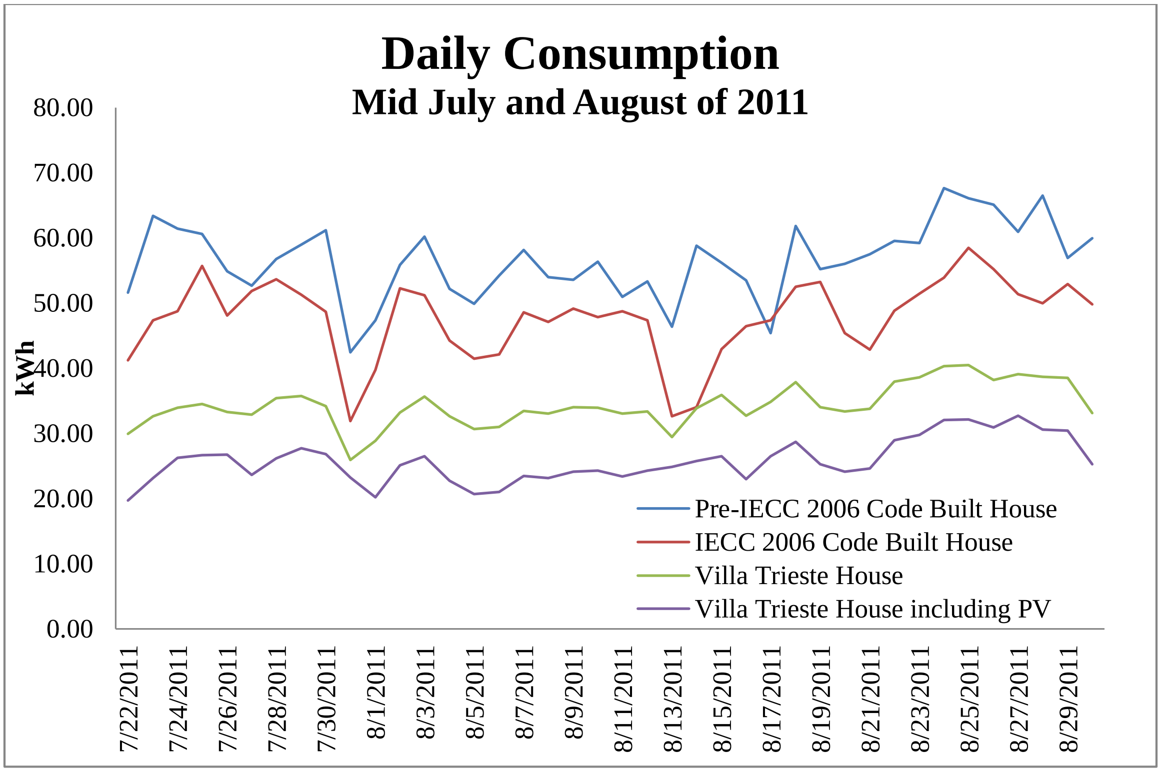


FIGURE 27 - DAILY CONSUMPTION FROM MID JULY UNTIL THE END OF AUGUST 2011

As expected and is shown in Figure 27, the Villa Trieste house which includes the PV panels, consumes the least amount of electrical energy per day. Figure 26 shows the daily electrical consumption reduction of Villa Trieste house compared with code built homes with and without including the PV panels' effect.

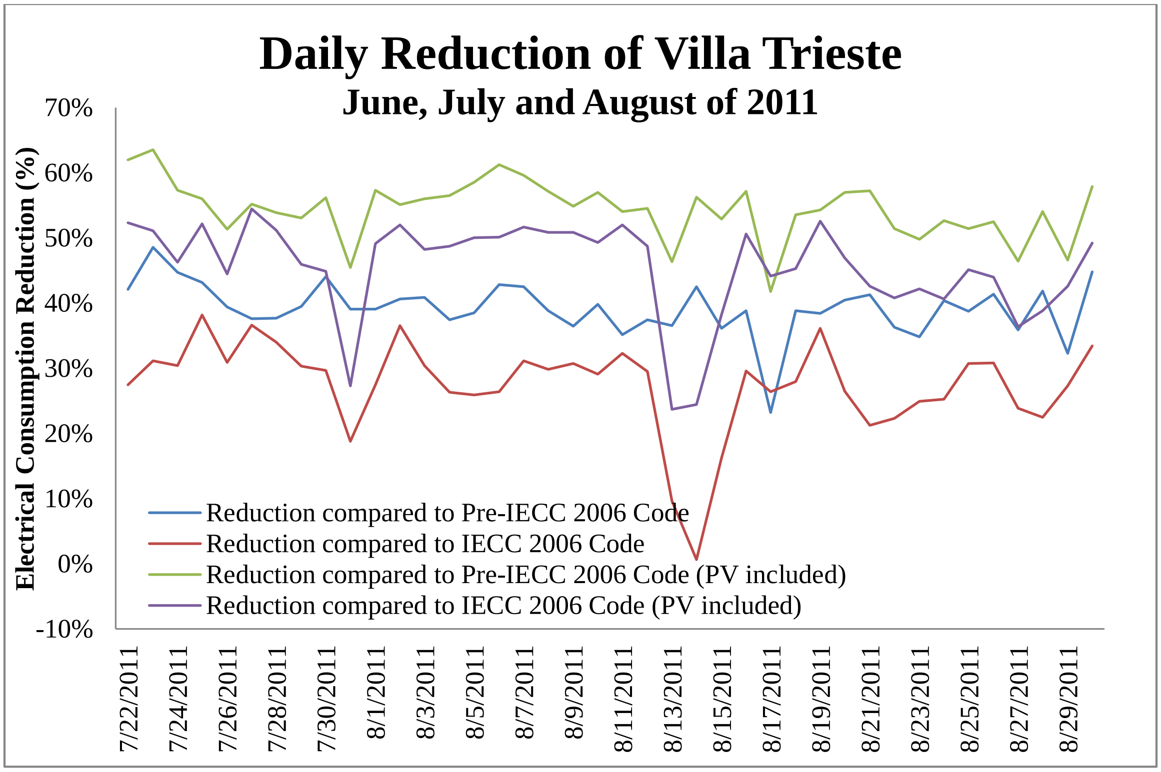


FIGURE 28 - DAILY REDUCTION ELECTRICAL CONSUMPTION OF VILLA TRIESTE

As is shown in Figure 28, the graph reveals a daily total energy reduction of 40% to 50% by Villa Trieste compared with the IECC 2006 Code built house.

The added benefit of the PV generation is further shown in Figure 29, which illustrates the hourly electrical consumption of the different group of studied homes for the first week of August.

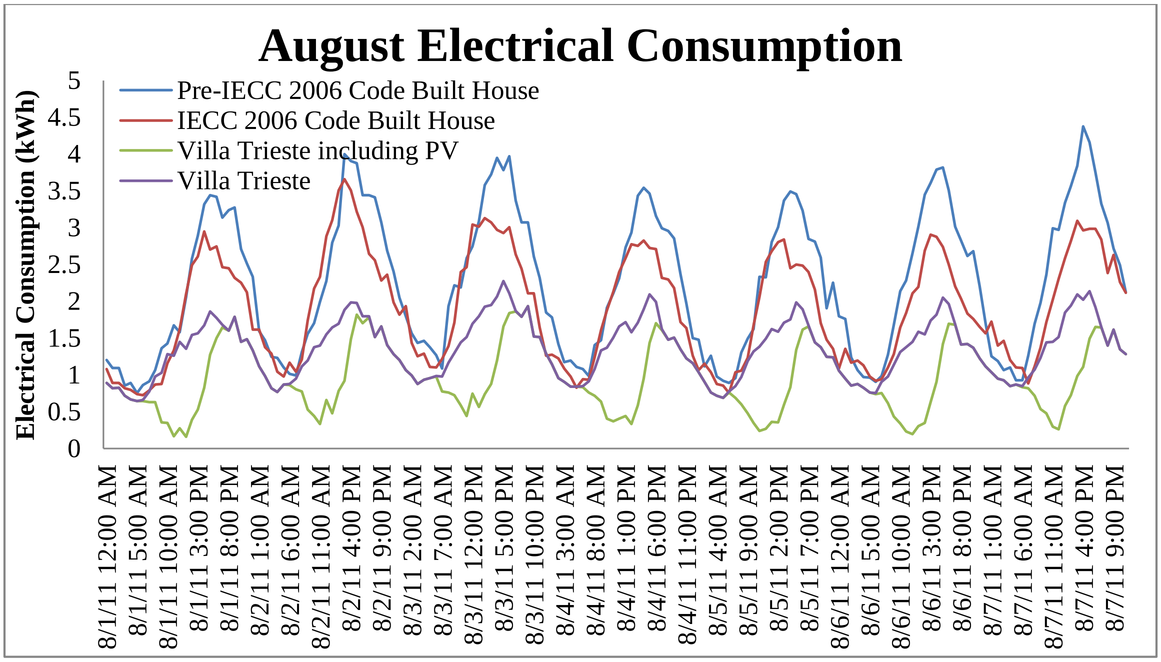


FIGURE 29 – FIRST WEEK OF AUGUST HOURLY ELECTRICAL CONSUMPTION

Figure 29 shows that the electrical consumption of the Villa Trieste house which includes PV panels is lower than the Villa Trieste house which doesn't include PV panels starting 7:00 AM and ending at 6:00 PM.

The next few figures illustrate in depth the electrical consumption reduction of the Villa Trieste house compared with the code built house where in one case the Villa Trieste house includes PV panels and the Villa Trieste house which does not include PV panels.

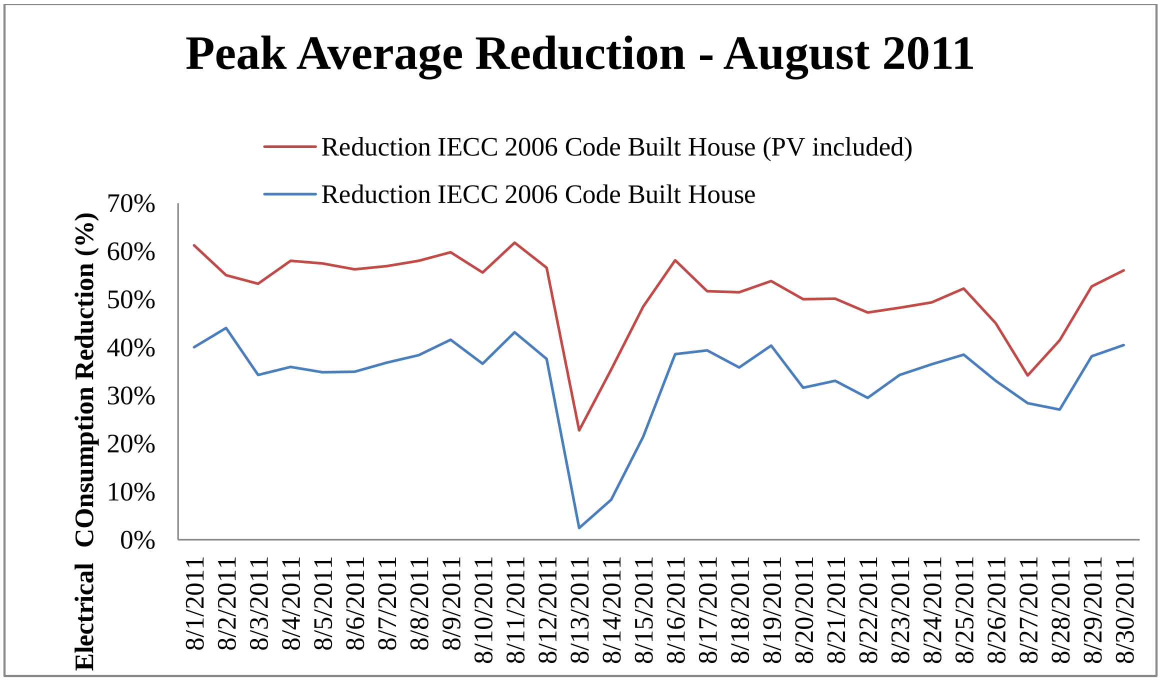


FIGURE 30 - PEAK AVERAGE REDUCTION COMPARED TO IECC 2006 CODE BUILT HOUSE – AUGUST 2011

Figure 30 shows the average of the peak reduction compared to IECC 2006 code built house (which was found by averaging the electric consumption reduction from 1:00 pm to 7:00 pm). It is clear that the PV panels have a significant effect on the average of peak load reduction increasing the latter by 15% to 20%, going from a reduction range of 35% - 40% to 50% – 55%.

Figure 31 shows the maximum peak hourly reduction for every day for the month of August 2011.

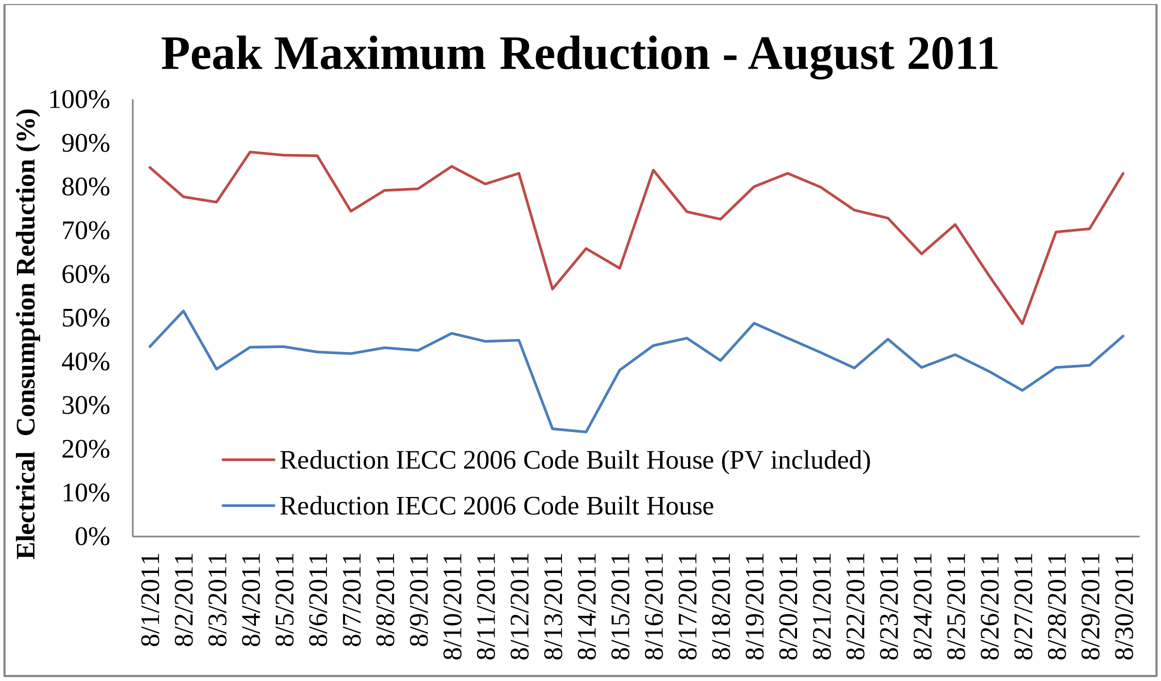


FIGURE 31 - PEAK MAXIMUM REDUCTION AUGUST 2011

Figure 31 shows that the maximum peak load reduction hour for every day in the month of August 2011 is increased by around 40% when photovoltaic panel power generation s taken into account.

Taking the average of electrical consumption reduction for each hour for all August days yields the results shown in Figure 32.

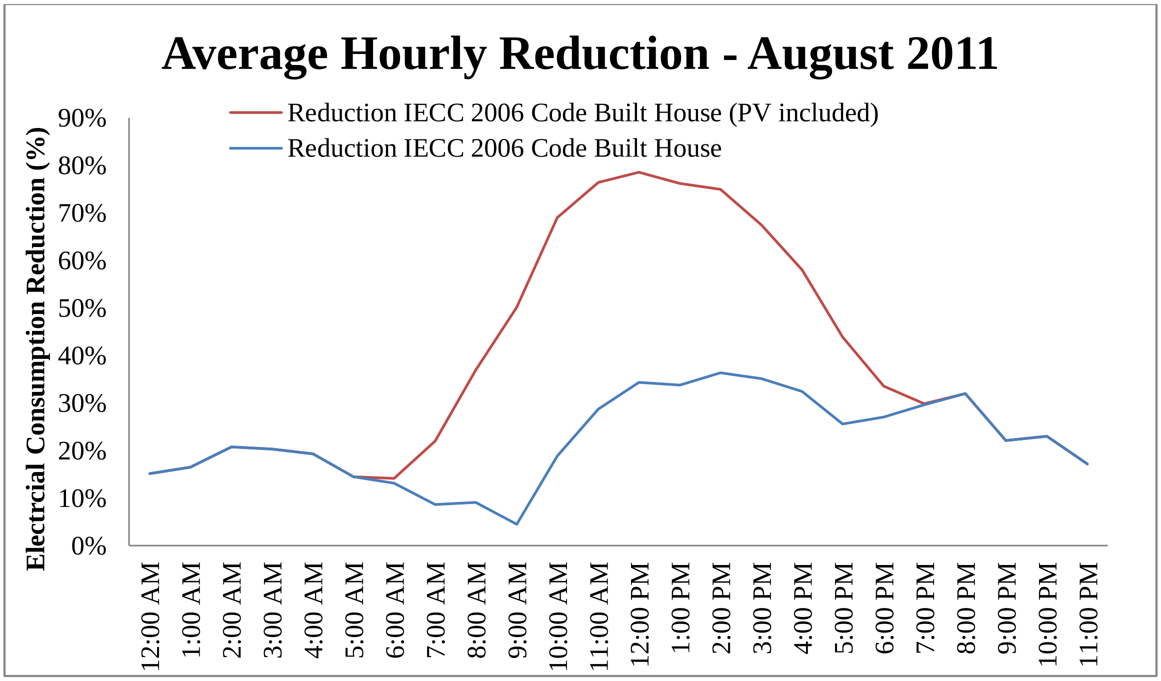


FIGURE 32 - AVERAGE HOURLY REDUCTION AUGUST 2011

Figure 32 shows that electrical consumption reduction of the Villa Trieste house which includes PV panels compared with the IECC 2006 code built house yields a reduction of around 80% at 12:00 PM, 76% at 1:00 PM, 75% at 2:00 PM, 67% at 3:00 PM, 58% at 4:00 PM, 44% at 5:00 PM and 34% at 6:00 PM. It is also noticeable that the photovoltaic panels' benefit is highest at noon and diminishes gradually during the next peak hours.

Figure 33 shows the maximum hourly reduction for any day in the month of August 2011.

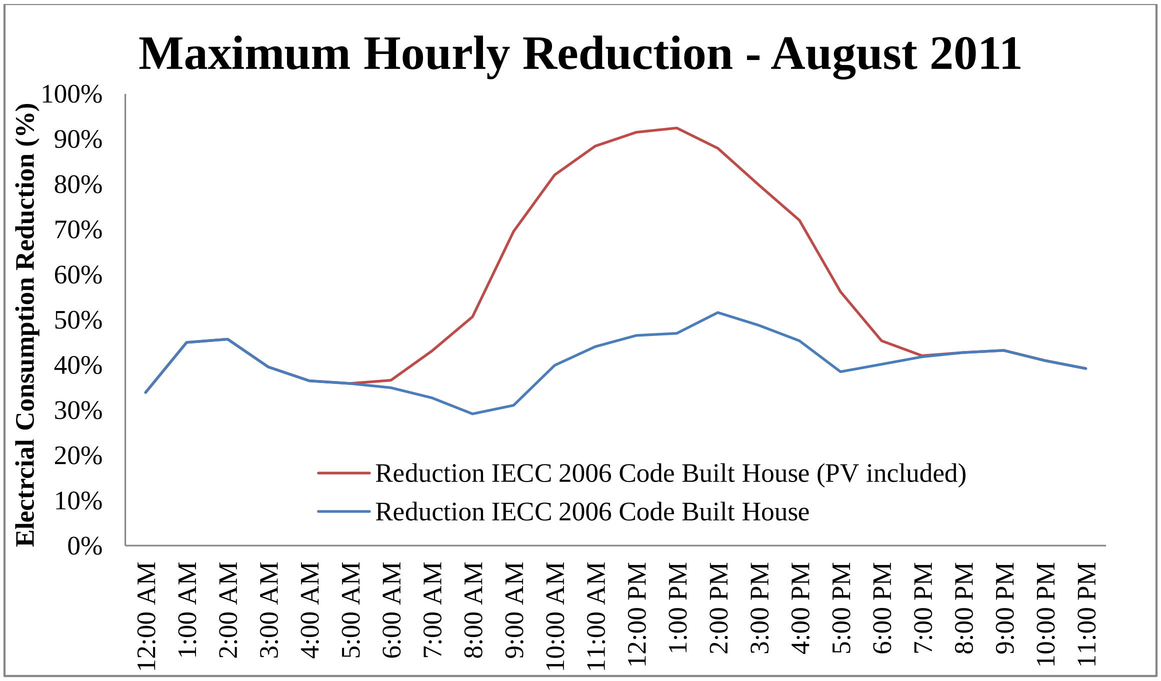


FIGURE 33 - MAXIMUM HOURLY REDUCTION AUGUST 2011

As can be seen in Figure 33, the maximum reduction reached in the month of August 2011 at 12:00 PM is around 92% which is also the case at 1:00 PM. At 2:00 PM it is around 88%, at 3:00 PM the reduction is around 80%, at 4:00 PM it is around 72%, at 5:00 PM it is around 56% and at 6:00 PM it is around 45%. Figure 33 also shows that at certain times the electric consumption reduction can reach significant values.

Figure 34, the final graph in the section that shows the average trend of the electrical consumption for the different groups of homes for August 2011, is shown below.

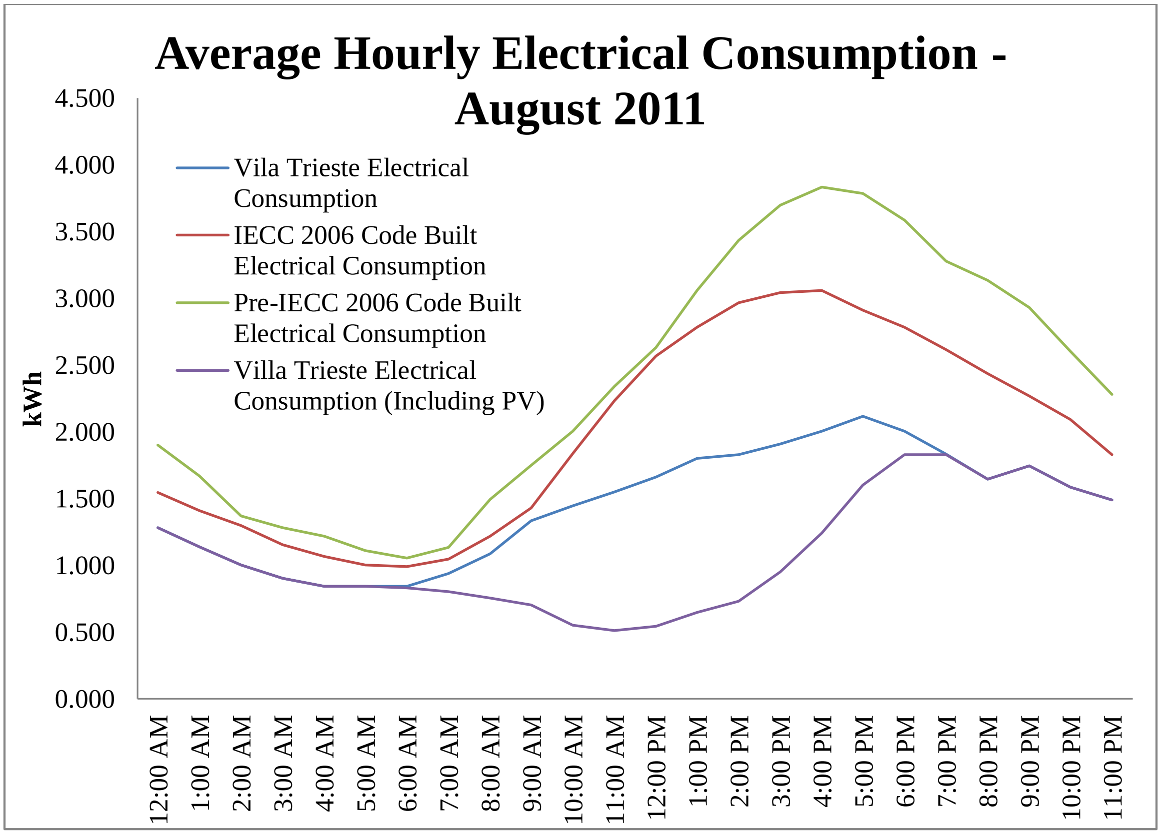


FIGURE 34 - AVERAGE HOURLY ELECTRICAL CONSUMPTION AUGUST 2011

As can be seen from Figure 34, the peak load for the energy efficient Villa Trieste house with PV is at 6:00/7:00 PM, and the peak load for the Villa Trieste house without including photovoltaic is at 5:00 PM whereas the peak load for the IECC 2006 code built house is at 3:00 PM to 4:00 PM. It is clear that the energy efficiency strategies implemented at Villa Trieste shave and shift the peak load 2 to 3 hours later than that for the code-built houses.

The results that were presented in this section illustrate the benefits of the energy efficient strategies implemented at the Villa Trieste community in Las Vegas, NV and specifically show how the peak load of the Villa Trieste homes are reduced and shifted compared with their IECC 2006 code built counterparts. The following section will show if the simulated energy consumption agrees with the real measured electrical consumption.

Comparing the Simulation Results with the Actual Measurements

In order to test the accuracy of the building energy simulation model of the Villa Trieste home compared with the IECC 2006 code built house, a graph illustrating the electrical energy consumption for the different group of houses for the month of August 2011 is shown in Figure 35.

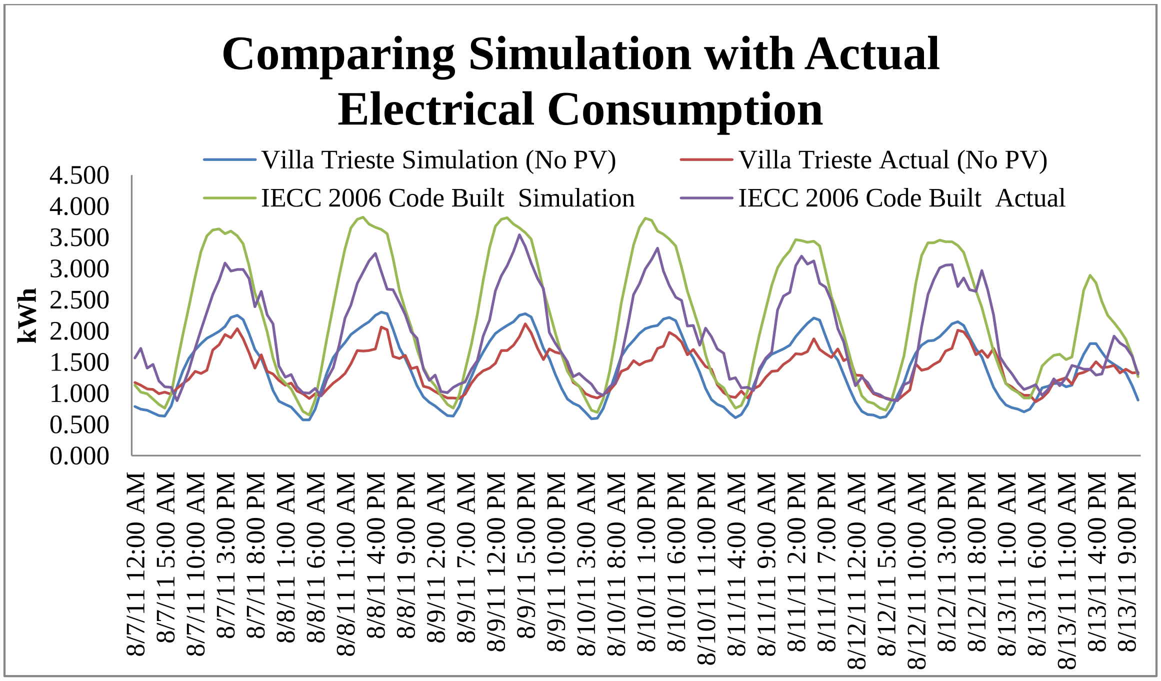


FIGURE 35 - COMPARISON BETWEEN SIMULATION & ELECTRICAL CONSUMPTION VARIATIONS

As can be seen in Figure 35, the electrical consumption of the simulated IECC 2006 code built house is higher than the actual electrical consumption. The same can also be said about the Villa Trieste house. In order to better match the actual houses electrical consumption, the model would have to be tuned.

The parameters that will be considered for tuning are the Energy Efficiency Ratio (EER) of the air conditioning unit and the schedule. In fact, these parameters could significantly affect the electrical consumption and are not accurately predictable.

EER Tuning

The EER for the air conditioning system used on the IECC 2006 code built home was originally set at 11. In order to decrease the electrical consumption of the model house the EER would have to be increased. The new value will be set at 12.5. On the other hand, the EER for the air conditioning system used on the Villa Trieste house was set at 12.5 and will be increased to 13. The result is shown in Figure 34.

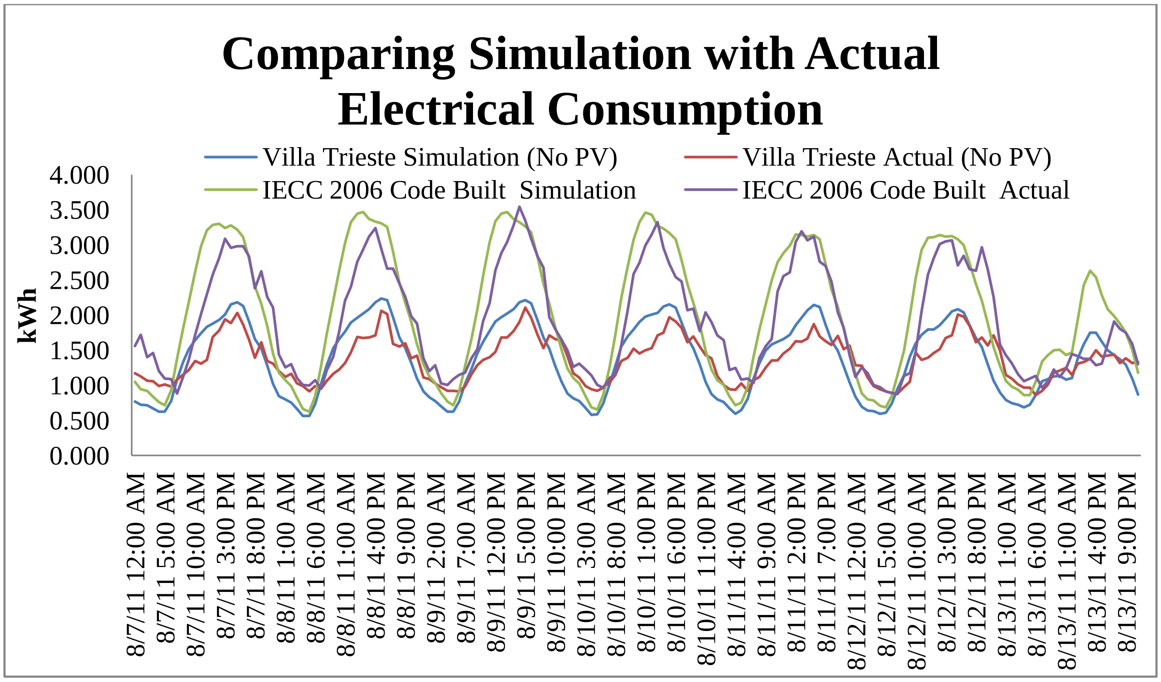


FIGURE 36 - COMPARISON OF SIMULATION VS ACTUAL ELECTRICAL CONSUMPTION

As can be seen in Figure 36, the electrical consumption of the simulated IECC 2006 code built house was reduced to closely match the actual electrical consumption. The same can also be said about the Villa Trieste house. However, one can notice that the electrical consumption of both simulation houses is lower than the actual homes from 12:00 AM to 6:00 AM.

Electrical Components Schedule Tuning

The most straightforward and intuitive way to counter the discrepancy in electrical consumption at this point would be to increase the electrical consumption of the "Other" electrical components in the house at these times. The reasoning is there could be an unaccounted electrical component which could be added.

The original schedule of the "Other" electrical components was as shown in Figure 37.

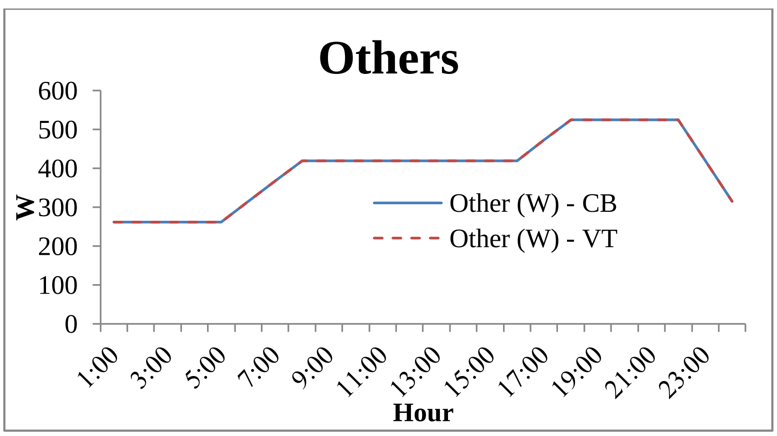


FIGURE 37 - ORIGINAL SCHEDULE

The new schedule which replaced the old one is the illustrated in Figure 38.

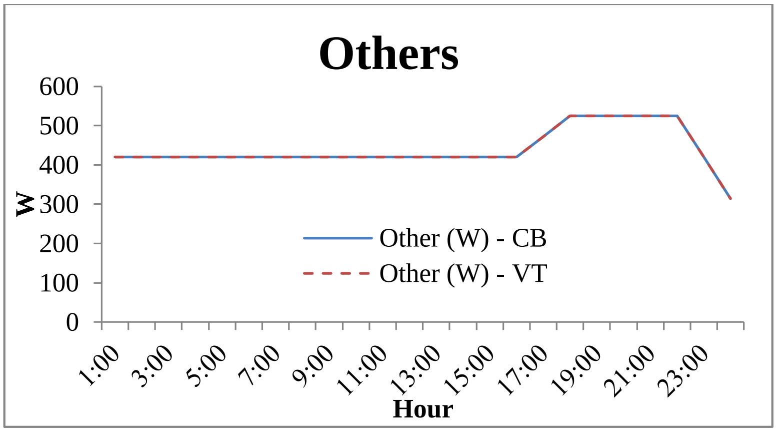


FIGURE 38 - NEW SCHEDULE

The result of the updated simulation is shown in Figure 39.

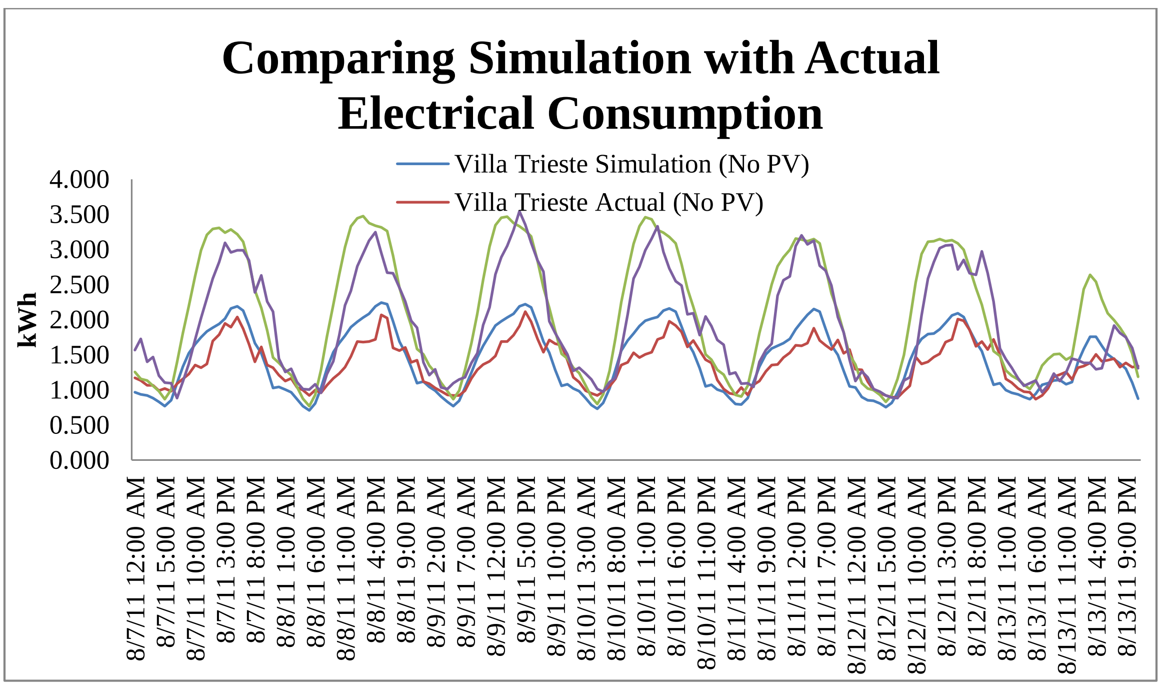


FIGURE 39 - SIMULATION VS ACTUAL ELECTRICAL CONSUMPTION COMPARISON

As can be seen from Figure 39, after all the tuning has been made, the simulation closely matches the actual measurements of the electrical consumption of the homes.

Figure 40 shows the electrical consumption comparison for the whole month of August.

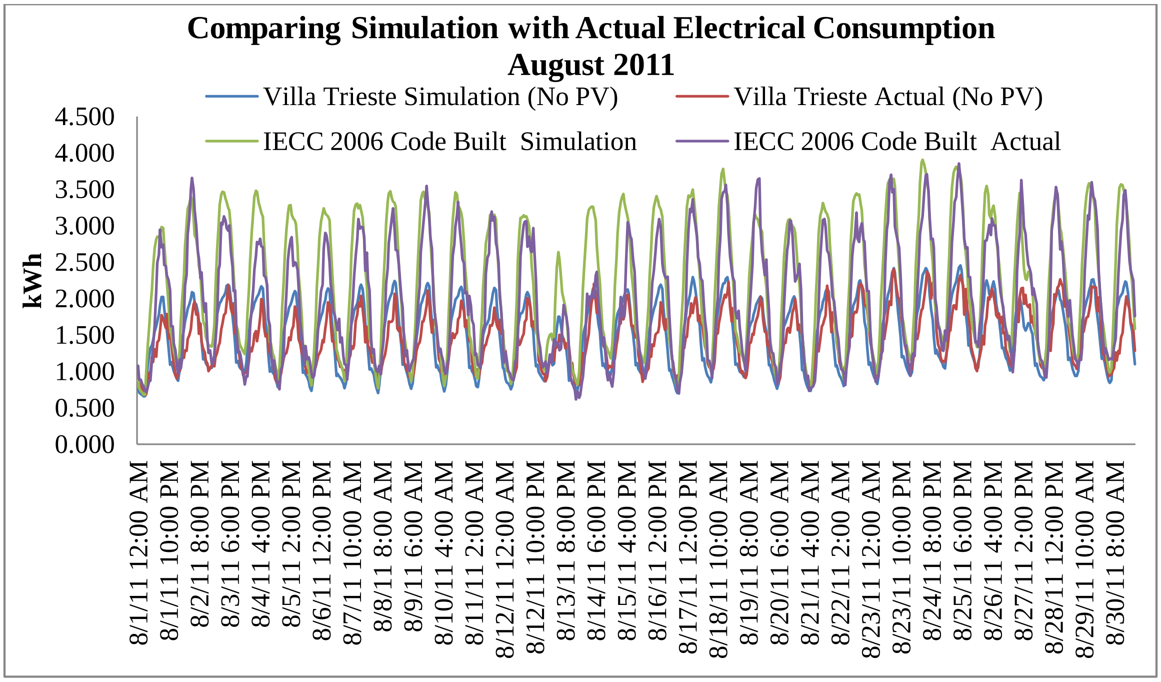


FIGURE 40 - SIMULATION VS ACTUAL ELECTRICAL CONSUMPTION COMPARISON

It is clearly shown that the computer models' performance agrees fairly well with the actual performance of the homes. One can notice that the Villa Trieste model performance agrees better with the actual Villa Trieste average performance than the Code built model performance to its actual counterpart average. This is most probably due to the sample size which is 28 homes for Villa Trieste compared to 5 code built homes.

PV Generation Modeling vs Actual

Also on the modeling list are the roof sun tiles photovoltaic panels. The actual photovoltaic power generation from the 30 Villa Trieste homes under investigation for the first week of August 2011 is shown in figure 39 below.

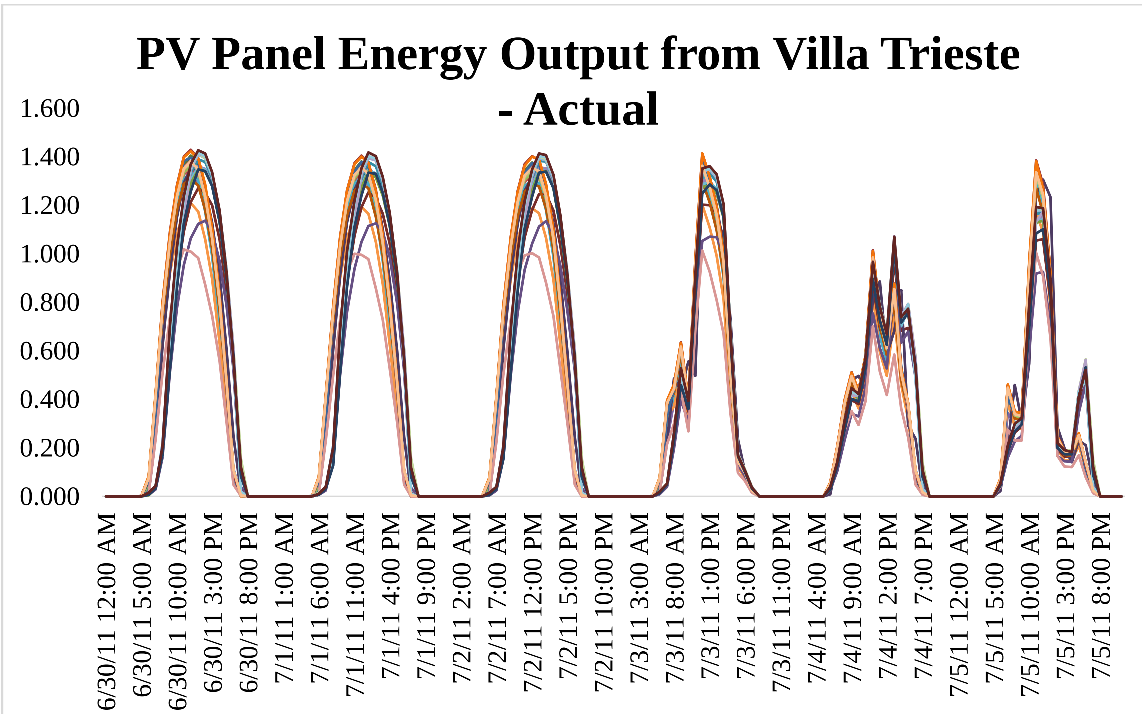


FIGURE 41 - ACTUAL PV GENERATION FROM ALL VILLA TRIESTE HOMES UNDER INVESTIGATION

As can be seen from Figure 41, the power generation from the photovoltaic panels differs for each house depending on the orientation of the PV panels (14 homes had west facing panels while the rest had south facing panels). A closer look at one day of PV generation is shown in Figure 42 below.

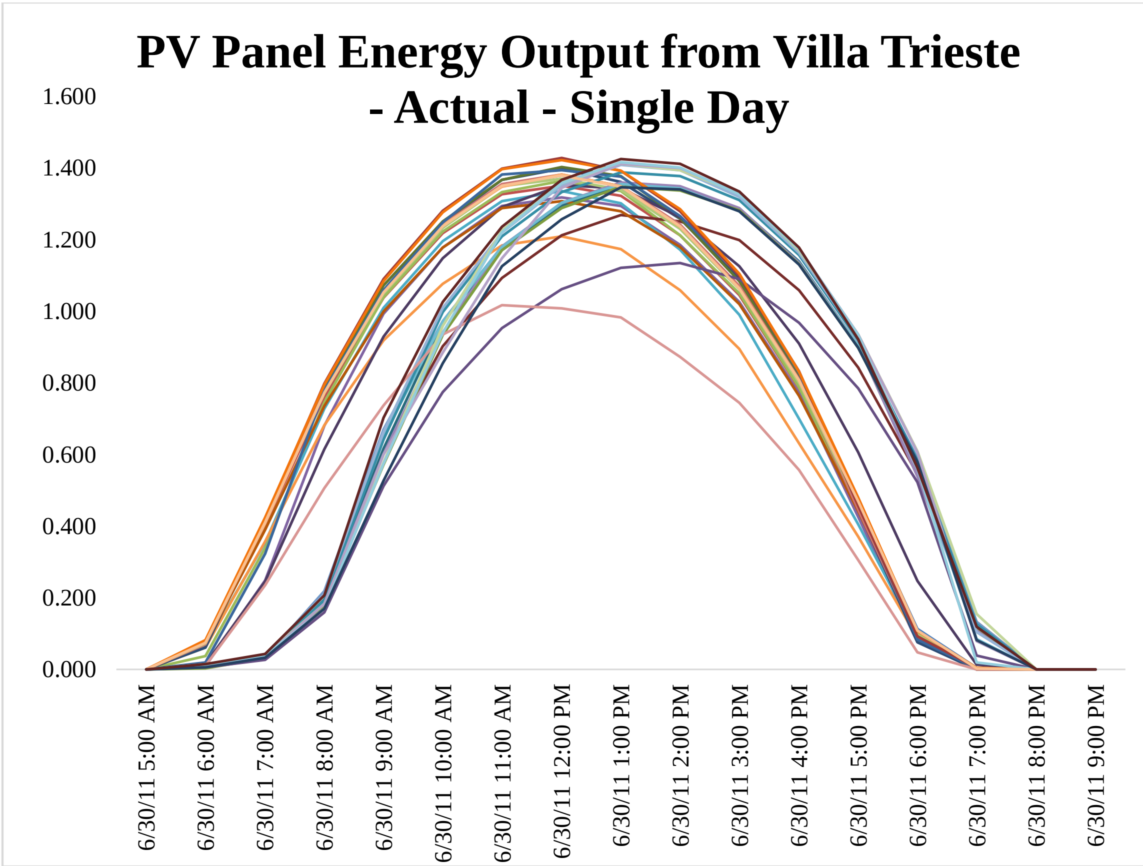


FIGURE 42 - ACTUAL PV GENERATION FROM ALL VILLA TRIESTE HOMES FOR ONE DAY UNDER INVESTIGATION

As can be seen from Figure 42, there are primarily two orientations for the PV panels at Villa Trieste. The south facing panel's PV electrical power generation peaks as expected at 12:00 PM, whereas the west facing panels' generation peaks between 1:00 PM and 2:00 PM. It is obvious that for peak load reduction purposes, it is beneficial to orient the PV panels west facing in order to generate more power at the peak hours (from 1:00 PM to 7:00 PM).

Comparing the model (PV panels facing South) and the actual PV electrical power generation average for the first week of August 2011 yields the results shown in Figure 43.

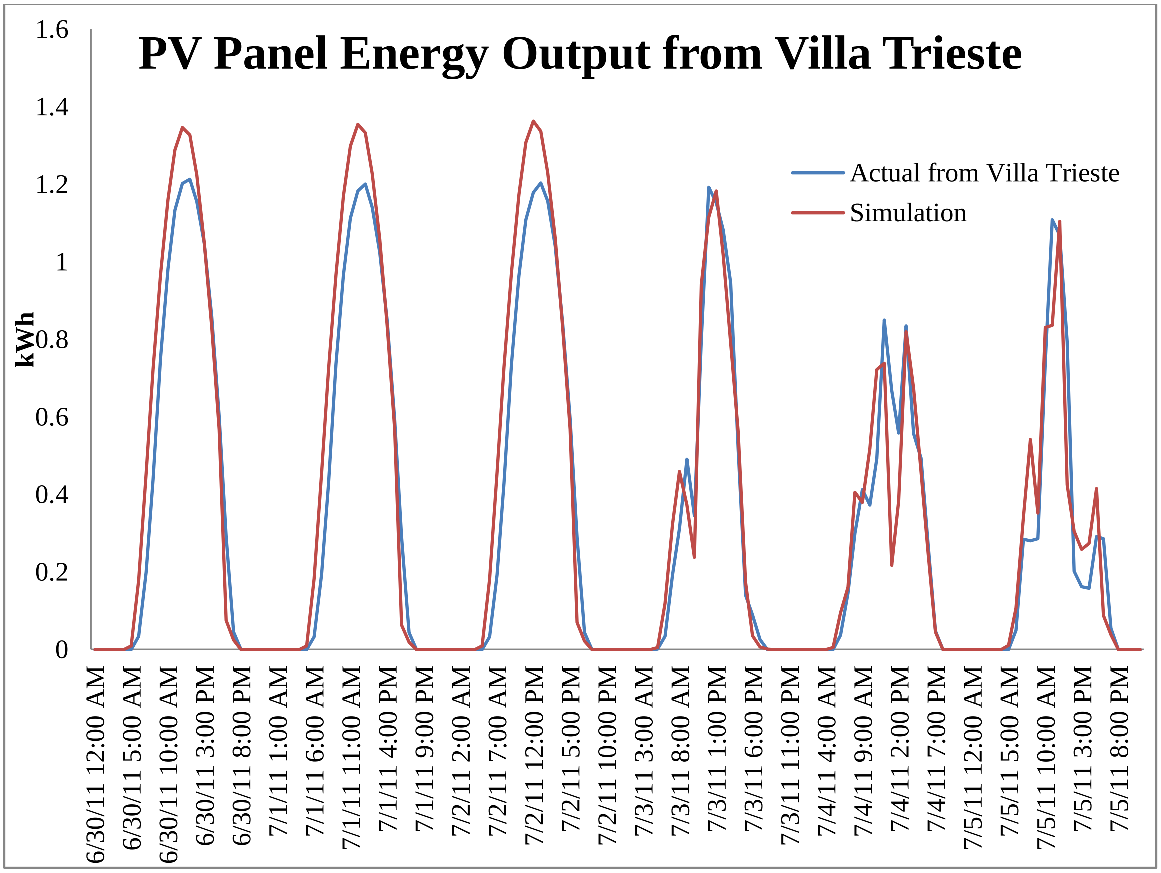


FIGURE 43 - FIRST WEEK OF AUGUST COMPARISON FOR MODEL AND ACTUAL PV ELECTRICAL POWER GEN

Figure 43 shows that actual electrical power generation from the PV panels is slightly lower than the modeled. This could be due to the averaging of west and south facing panel power generation which reduces the peak levels. Figure 41 also shows that the average of the Villa Trieste power production lags behind the simulated south facing PV generation which is due to the mix of south and west facing panels installed at Villa Trieste. The photovoltaic power generation for most of the three summer months is shown in Figure 44.

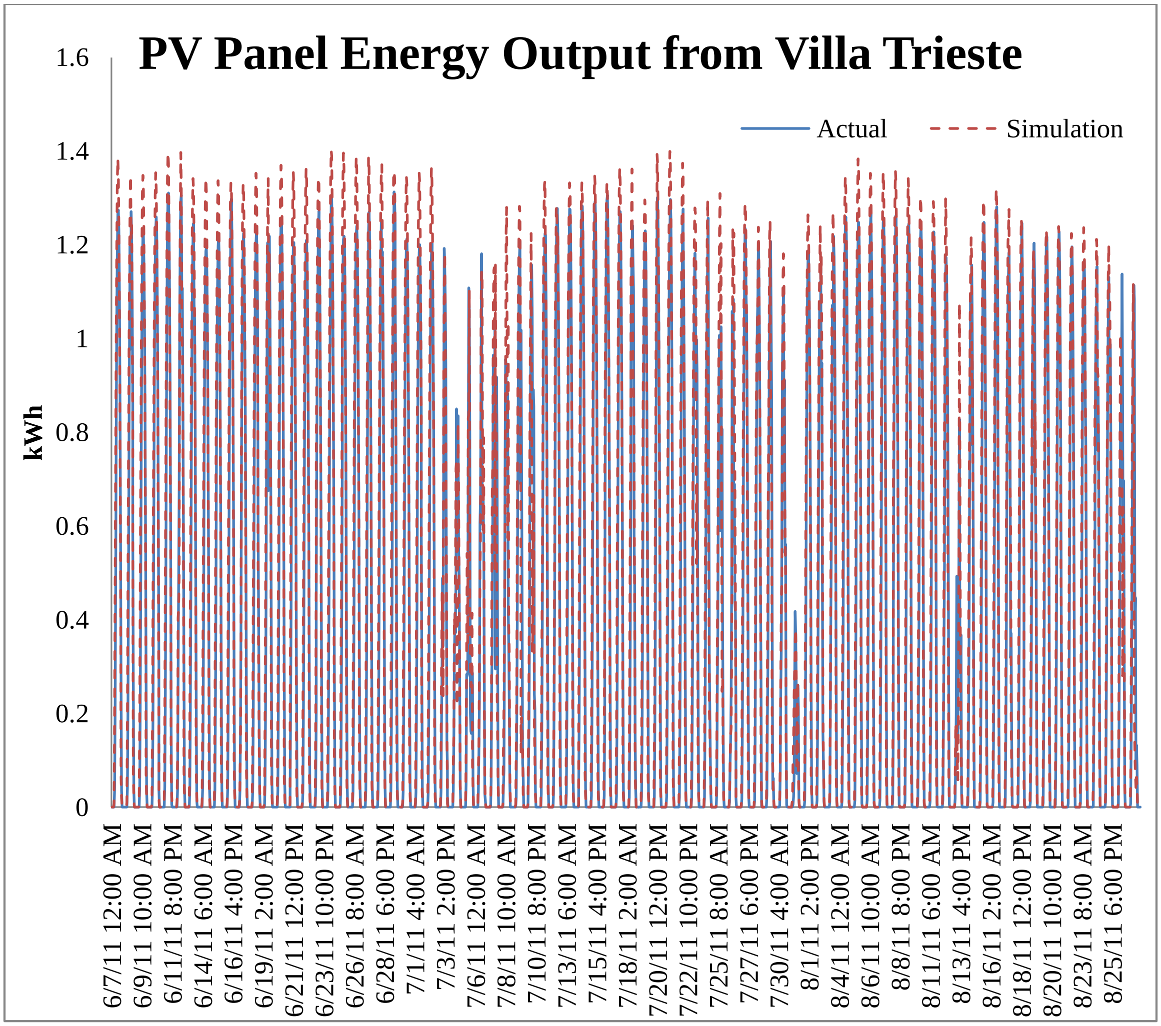


FIGURE 44 – PV PANEL ENERGY OUTPUT FROM VILLA TRIESTE FOR 3 SUMMER MONTHS

It is clear from Figure 44 that the model agrees well with the actual PV generation except for the slight increase in performance from the model.

CHAPTER 5 – DISCUSSION

Outcomes

As was seen in the previous chapter, the energy efficiency strategies presented in the study, notably energy efficient building envelope including improved wall insulation, low emissivity fenestration, tighter built homes with lower infiltration, higher efficiency cooling and heating systems, CFL lighting and power generation though photovoltaic panels contributed to substantial peak load reduction. The goal of the Villa Trieste project was to reduce the peak load by 65% compared with the IECC 2006 code built house, and as was seen in the previous section, this reduction was met. It is worth noting that the reduction in power production is not constant for every hour at 65%. In fact, as was seen in Figure 32, the monthly average of August's electrical consumption reduction of the Villa Trieste house which includes PV panels compared with the IECC 2006 code built house yields a reduction of around 80% at 12:00 PM, 76% at 1:00 PM, 75% at 2:00 PM, 67% at 3:00 PM, 58% at 4:00 PM, 44% at 5:00 PM, 34% at 6:00 PM and 30% at 7:00 PM. It is clear that the reduction is higher than 65% at certain times and lower at others due to the varying house loads and varying PV power generation.

A strategy under investigation is homes-installed batteries that would save the solar energy for peak load reduction use. To illustrate the benefits of the strategy, Figure 43 shows the energy needed for each peak hour to reach the 65% reduction in electrical consumption comparing a Villa Trieste house without PV panels and an IECC 2006 code built house.

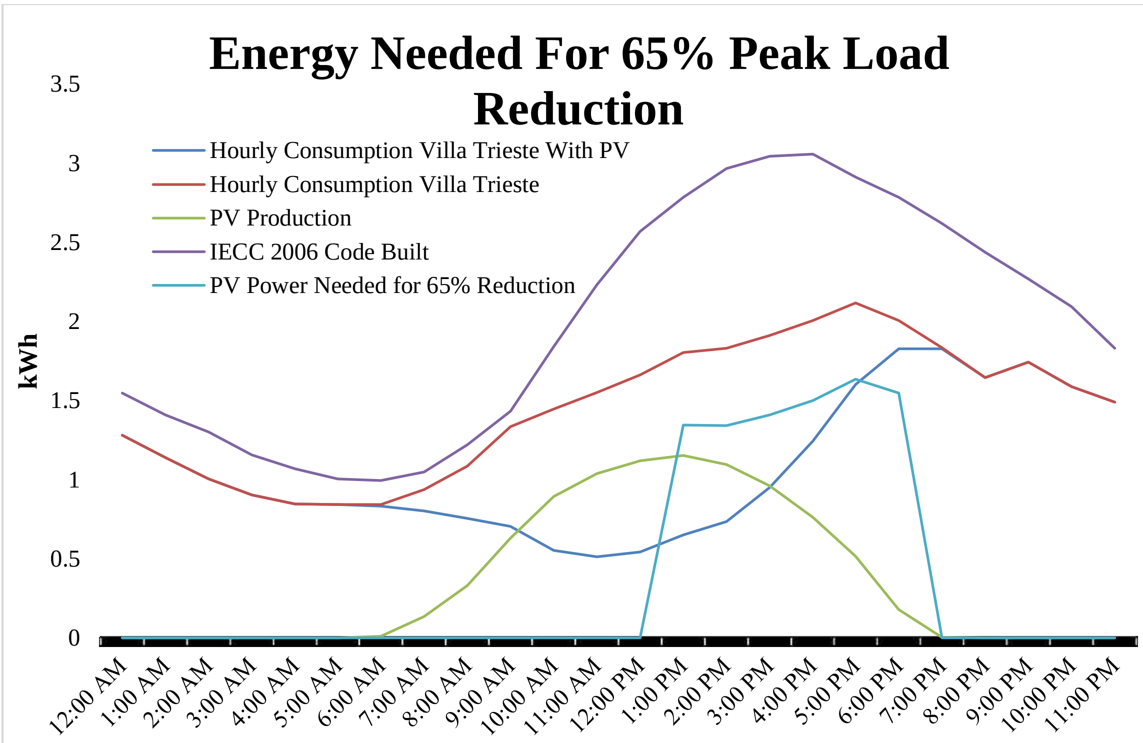


FIGURE 45 - ENERGY NEEDED FOR 65% PEAK LOAD REDUCTION - AUGUST 2011 AVERAGE

As can be seen in Figure 45, if the energy generated from the photovoltaic panels is shifted to be used later during the day, the 65% peak load reduction would be easily met with a 3.3 kWh excess PV electrical energy produced during the day that could be used at a later time. Moreover, if all the photovoltaic energy is used during the 6 hour peak time, the peak load reduction would reach 84% at peak times which greatly exceeds the 65% reduction goal.

This study was able to develop an accurate building energy model of the Villa Trieste community energy efficient house and another model of the IECC 2006 code built house located in Las Vegas, Nevada. The models proved to be accurate by matching the electrical energy consumption of the actual homes with their respective models using the weather data provided by NREL. Using these models, new peak load reduction strategies could be implemented to these models to simulate their effect on electrical energy consumption. Also, a methodology was created to develop current meteorological weather data files.

It is also clear from this study that it is beneficial for the PV panels to face the west in order to generate more electrical power during the peak load hours.

Appendix A

Matlab Code – Villa Trieste 5 minute to hourly & multiple file to one file

```
clear all
clc

data1   =xlsread('HomeID=2171881.xlsx','L1:Q24960');
data2   =xlsread('HomeID=2171882.xlsx','L1:Q24960');
data3   =xlsread('HomeID=2171883.xlsx','L1:Q24960');
data4   =xlsread('HomeID=2171884.xlsx','L1:Q24960');
data5   =xlsread('HomeID=2171885.xlsx','L1:Q24960');
data6   =xlsread('HomeID=2203353.xlsx','L1:Q24960');
data7   =xlsread('HomeID=2220448.xlsx','L1:Q24960');
data8   =xlsread('HomeID=2220449.xlsx','L1:Q24960');
data9   =xlsread('HomeID=2224974.xlsx','L1:Q24960');
data10  =xlsread('HomeID=2224975.xlsx','L1:Q24960');
data11  =xlsread('HomeID=2225008.xlsx','L1:Q24960');
data12  =xlsread('HomeID=2225009.xlsx','L1:Q24960');
data13  =xlsread('HomeID=2225010.xlsx','L1:Q24960');
data14  =xlsread('HomeID=2228533.xlsx','L1:Q24960');
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data29  =xlsread('HomeID=2238447.xlsx','L1:Q24960');
data30  =xlsread('HomeID=2238448.xlsx','L1:Q24960');
data31  =xlsread('HomeID=2238449.xlsx','L1:Q24960');
data32  =xlsread('HomeID=2240057.xlsx','L1:Q24960');

h1  =   data1   (:, 1   );
h2  =   data1   (:, 2   );
h3  =   data1   (:, 4   );
h4  =   data1   (:, 5   );
h5  =   data2   (:, 1   );
h6  =   data2   (:, 2   );
```

```
h7  =   data2   (:, 4   );
h8  =   data2   (:, 5   );
h9  =   data3   (:, 1   );
h10 =   data3   (:, 2   );
h11 =   data3   (:, 4   );
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h13 =   data4   (:, 1   );
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h50 =   data13  (:, 2   );
h51 =   data13  (:, 4   );
h52 =   data13  (:, 5   );
```

```
h53 =   data14  (:, 1   );
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h66 =   data17  (:, 2   );
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h68 =   data17  (:, 5   );
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h75 =   data19  (:, 4   );
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h80 =   data20  (:, 5   );
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h83 =   data21  (:, 4   );
h84 =   data21  (:, 5   );
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h95 =   data24  (:, 4   );
h96 =   data24  (:, 5   );
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h98 =   data25  (:, 2   );
```

```
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h100    =   data25  (:, 5   );
h101    =   data26  (:, 1   );
h102    =   data26  (:, 2   );
h103    =   data26  (:, 4   );
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h106    =   data27  (:, 2   );
h107    =   data27  (:, 4   );
h108    =   data27  (:, 5   );
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h110    =   data28  (:, 2   );
h111    =   data28  (:, 4   );
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h113    =   data29  (:, 1   );
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h115    =   data29  (:, 4   );
h116    =   data29  (:, 5   );
h117    =   data30  (:, 1   );
h118    =   data30  (:, 2   );
h119    =   data30  (:, 4   );
h120    =   data30  (:, 5   );
h121    =   data31  (:, 1   );
h122    =   data31  (:, 2   );
h123    =   data31  (:, 4   );
h124    =   data31  (:, 5   );
h125    =   data32  (:, 1   );
h126    =   data32  (:, 2   );
h127    =   data32  (:, 4   );
h128    =   data32  (:, 5   );



hf = zeros(2080,128);


for i=1:2080
   for j=1:12

      hf(i,   1   )=  h1  (12*(i-1)+j)+hf(i,  1   );
      hf(i,   2   )=  h2  (12*(i-1)+j)+hf(i,  2   );
      hf(i,   3   )=  h3  (12*(i-1)+j)+hf(i,  3   );
      hf(i,   4   )=  h4  (12*(i-1)+j)+hf(i,  4   );
      hf(i,   5   )=  h5  (12*(i-1)+j)+hf(i,  5   );
      hf(i,   6   )=  h6  (12*(i-1)+j)+hf(i,  6   );
      hf(i,   7   )=  h7  (12*(i-1)+j)+hf(i,  7   );
```

```
hf(i,   8   )=  h8  (12*(i-1)+j)+hf(i,  8   );
hf(i,   9   )=  h9  (12*(i-1)+j)+hf(i,  9   );
hf(i,   10  )=  h10 (12*(i-1)+j)+hf(i,  10  );
hf(i,   11  )=  h11 (12*(i-1)+j)+hf(i,  11  );
hf(i,   12  )=  h12 (12*(i-1)+j)+hf(i,  12  );
hf(i,   13  )=  h13 (12*(i-1)+j)+hf(i,  13  );
hf(i,   14  )=  h14 (12*(i-1)+j)+hf(i,  14  );
hf(i,   15  )=  h15 (12*(i-1)+j)+hf(i,  15  );
hf(i,   16  )=  h16 (12*(i-1)+j)+hf(i,  16  );
hf(i,   17  )=  h17 (12*(i-1)+j)+hf(i,  17  );
hf(i,   18  )=  h18 (12*(i-1)+j)+hf(i,  18  );
hf(i,   19  )=  h19 (12*(i-1)+j)+hf(i,  19  );
hf(i,   20  )=  h20 (12*(i-1)+j)+hf(i,  20  );
hf(i,   21  )=  h21 (12*(i-1)+j)+hf(i,  21  );
hf(i,   22  )=  h22 (12*(i-1)+j)+hf(i,  22  );
hf(i,   23  )=  h23 (12*(i-1)+j)+hf(i,  23  );
hf(i,   24  )=  h24 (12*(i-1)+j)+hf(i,  24  );
hf(i,   25  )=  h25 (12*(i-1)+j)+hf(i,  25  );
hf(i,   26  )=  h26 (12*(i-1)+j)+hf(i,  26  );
hf(i,   27  )=  h27 (12*(i-1)+j)+hf(i,  27  );
hf(i,   28  )=  h28 (12*(i-1)+j)+hf(i,  28  );
hf(i,   29  )=  h29 (12*(i-1)+j)+hf(i,  29  );
hf(i,   30  )=  h30 (12*(i-1)+j)+hf(i,  30  );
hf(i,   31  )=  h31 (12*(i-1)+j)+hf(i,  31  );
hf(i,   32  )=  h32 (12*(i-1)+j)+hf(i,  32  );
hf(i,   33  )=  h33 (12*(i-1)+j)+hf(i,  33  );
hf(i,   34  )=  h34 (12*(i-1)+j)+hf(i,  34  );
hf(i,   35  )=  h35 (12*(i-1)+j)+hf(i,  35  );
hf(i,   36  )=  h36 (12*(i-1)+j)+hf(i,  36  );
hf(i,   37  )=  h37 (12*(i-1)+j)+hf(i,  37  );
hf(i,   38  )=  h38 (12*(i-1)+j)+hf(i,  38  );
hf(i,   39  )=  h39 (12*(i-1)+j)+hf(i,  39  );
hf(i,   40  )=  h40 (12*(i-1)+j)+hf(i,  40  );
hf(i,   41  )=  h41 (12*(i-1)+j)+hf(i,  41  );
hf(i,   42  )=  h42 (12*(i-1)+j)+hf(i,  42  );
hf(i,   43  )=  h43 (12*(i-1)+j)+hf(i,  43  );
hf(i,   44  )=  h44 (12*(i-1)+j)+hf(i,  44  );
hf(i,   45  )=  h45 (12*(i-1)+j)+hf(i,  45  );
hf(i,   46  )=  h46 (12*(i-1)+j)+hf(i,  46  );
hf(i,   47  )=  h47 (12*(i-1)+j)+hf(i,  47  );
hf(i,   48  )=  h48 (12*(i-1)+j)+hf(i,  48  );
hf(i,   49  )=  h49 (12*(i-1)+j)+hf(i,  49  );
hf(i,   50  )=  h50 (12*(i-1)+j)+hf(i,  50  );
hf(i,   51  )=  h51 (12*(i-1)+j)+hf(i,  51  );
hf(i,   52  )=  h52 (12*(i-1)+j)+hf(i,  52  );
hf(i,   53  )=  h53 (12*(i-1)+j)+hf(i,  53  );
```

```
hf(i,   54  )=  h54 (12*(i-1)+j)+hf(i,  54  );
hf(i,   55  )=  h55 (12*(i-1)+j)+hf(i,  55  );
hf(i,   56  )=  h56 (12*(i-1)+j)+hf(i,  56  );
hf(i,   57  )=  h57 (12*(i-1)+j)+hf(i,  57  );
hf(i,   58  )=  h58 (12*(i-1)+j)+hf(i,  58  );
hf(i,   59  )=  h59 (12*(i-1)+j)+hf(i,  59  );
hf(i,   60  )=  h60 (12*(i-1)+j)+hf(i,  60  );
hf(i,   61  )=  h61 (12*(i-1)+j)+hf(i,  61  );
hf(i,   62  )=  h62 (12*(i-1)+j)+hf(i,  62  );
hf(i,   63  )=  h63 (12*(i-1)+j)+hf(i,  63  );
hf(i,   64  )=  h64 (12*(i-1)+j)+hf(i,  64  );
hf(i,   65  )=  h65 (12*(i-1)+j)+hf(i,  65  );
hf(i,   66  )=  h66 (12*(i-1)+j)+hf(i,  66  );
hf(i,   67  )=  h67 (12*(i-1)+j)+hf(i,  67  );
hf(i,   68  )=  h68 (12*(i-1)+j)+hf(i,  68  );
hf(i,   69  )=  h69 (12*(i-1)+j)+hf(i,  69  );
hf(i,   70  )=  h70 (12*(i-1)+j)+hf(i,  70  );
hf(i,   71  )=  h71 (12*(i-1)+j)+hf(i,  71  );
hf(i,   72  )=  h72 (12*(i-1)+j)+hf(i,  72  );
hf(i,   73  )=  h73 (12*(i-1)+j)+hf(i,  73  );
hf(i,   74  )=  h74 (12*(i-1)+j)+hf(i,  74  );
hf(i,   75  )=  h75 (12*(i-1)+j)+hf(i,  75  );
hf(i,   76  )=  h76 (12*(i-1)+j)+hf(i,  76  );
hf(i,   77  )=  h77 (12*(i-1)+j)+hf(i,  77  );
hf(i,   78  )=  h78 (12*(i-1)+j)+hf(i,  78  );
hf(i,   79  )=  h79 (12*(i-1)+j)+hf(i,  79  );
hf(i,   80  )=  h80 (12*(i-1)+j)+hf(i,  80  );
hf(i,   81  )=  h81 (12*(i-1)+j)+hf(i,  81  );
hf(i,   82  )=  h82 (12*(i-1)+j)+hf(i,  82  );
hf(i,   83  )=  h83 (12*(i-1)+j)+hf(i,  83  );
hf(i,   84  )=  h84 (12*(i-1)+j)+hf(i,  84  );
hf(i,   85  )=  h85 (12*(i-1)+j)+hf(i,  85  );
hf(i,   86  )=  h86 (12*(i-1)+j)+hf(i,  86  );
hf(i,   87  )=  h87 (12*(i-1)+j)+hf(i,  87  );
hf(i,   88  )=  h88 (12*(i-1)+j)+hf(i,  88  );
hf(i,   89  )=  h89 (12*(i-1)+j)+hf(i,  89  );
hf(i,   90  )=  h90 (12*(i-1)+j)+hf(i,  90  );
hf(i,   91  )=  h91 (12*(i-1)+j)+hf(i,  91  );
hf(i,   92  )=  h92 (12*(i-1)+j)+hf(i,  92  );
hf(i,   93  )=  h93 (12*(i-1)+j)+hf(i,  93  );
hf(i,   94  )=  h94 (12*(i-1)+j)+hf(i,  94  );
hf(i,   95  )=  h95 (12*(i-1)+j)+hf(i,  95  );
hf(i,   96  )=  h96 (12*(i-1)+j)+hf(i,  96  );
hf(i,   97  )=  h97 (12*(i-1)+j)+hf(i,  97  );
hf(i,   98  )=  h98 (12*(i-1)+j)+hf(i,  98  );
hf(i,   99  )=  h99 (12*(i-1)+j)+hf(i,  99  );
```

```
        hf(i,   100 )=  h100    (12*(i-1)+j)+hf(i,  100 );
        hf(i,   101 )=  h101    (12*(i-1)+j)+hf(i,  101 );
        hf(i,   102 )=  h102    (12*(i-1)+j)+hf(i,  102 );
        hf(i,   103 )=  h103    (12*(i-1)+j)+hf(i,  103 );
        hf(i,   104 )=  h104    (12*(i-1)+j)+hf(i,  104 );
        hf(i,   105 )=  h105    (12*(i-1)+j)+hf(i,  105 );
        hf(i,   106 )=  h106    (12*(i-1)+j)+hf(i,  106 );
        hf(i,   107 )=  h107    (12*(i-1)+j)+hf(i,  107 );
        hf(i,   108 )=  h108    (12*(i-1)+j)+hf(i,  108 );
        hf(i,   109 )=  h109    (12*(i-1)+j)+hf(i,  109 );
        hf(i,   110 )=  h110    (12*(i-1)+j)+hf(i,  110 );
        hf(i,   111 )=  h111    (12*(i-1)+j)+hf(i,  111 );
        hf(i,   112 )=  h112    (12*(i-1)+j)+hf(i,  112 );
        hf(i,   113 )=  h113    (12*(i-1)+j)+hf(i,  113 );
        hf(i,   114 )=  h114    (12*(i-1)+j)+hf(i,  114 );
        hf(i,   115 )=  h115    (12*(i-1)+j)+hf(i,  115 );
        hf(i,   116 )=  h116    (12*(i-1)+j)+hf(i,  116 );
        hf(i,   117 )=  h117    (12*(i-1)+j)+hf(i,  117 );
        hf(i,   118 )=  h118    (12*(i-1)+j)+hf(i,  118 );
        hf(i,   119 )=  h119    (12*(i-1)+j)+hf(i,  119 );
        hf(i,   120 )=  h120    (12*(i-1)+j)+hf(i,  120 );
        hf(i,   121 )=  h121    (12*(i-1)+j)+hf(i,  121 );
        hf(i,   122 )=  h122    (12*(i-1)+j)+hf(i,  122 );
        hf(i,   123 )=  h123    (12*(i-1)+j)+hf(i,  123 );
        hf(i,   124 )=  h124    (12*(i-1)+j)+hf(i,  124 );
        hf(i,   125 )=  h125    (12*(i-1)+j)+hf(i,  125 );
        hf(i,   126 )=  h126    (12*(i-1)+j)+hf(i,  126 );
        hf(i,   127 )=  h127    (12*(i-1)+j)+hf(i,  127 );
        hf(i,   128 )=  h128    (12*(i-1)+j)+hf(i,  128 );


    end
end
xlswrite('VillatriesteAll.xls',hf);
```

Appendix B

Matlab Code – Code Built 15 minute to hourly

```
clear all
clc

data1 = xlsread('Data combined - FA - 1.0.xlsx','Data','A2:T8833');
h1 = data1(:,3);
h2 = data1(:,7);
h3 = data1(:,11);
h4 = data1(:,15);
h5 = data1(:,19);

for i1=1:2208

    hf(i1,1) = 0;
    hf(i1,2) = 0;
    hf(i1,3) = 0;
    hf(i1,4) = 0;
    hf(i1,5) = 0;

end

for i=1:2208
  for j=1:4

    hf(i,1) = h1(4*(i-1)+j) + hf(i,1);
    hf(i,2) = h2(4*(i-1)+j) + hf(i,2);
    hf(i,3) = h3(4*(i-1)+j) + hf(i,3);
    hf(i,4) = h4(4*(i-1)+j) + hf(i,4);
    hf(i,5) = h5(4*(i-1)+j) + hf(i,5);

  end
end
xlswrite('Data.xls',hf);
```

Appendix C

Matlab Code – PV Panel Output

```
clear all
clc

%-----------------------------------------------------
%Days of the Year
%-----------------------------------------------------
january=0;              % January     31 days
february=january+31;    % February     28 days
march=february+28;      % March     31 days
april=march+31;         % April     30 days
may=april+30;           % May       31 days
june=may+31;            % June      30 days
july=june+30;           % July      31 days
august=july+31;         % August     31 days
september=august+31;    % September 30 days
october=september+30;   % October     31 days
november=october+31;    % November     30 days
december=november+30;   % December     31 days
yearend=december+31;
%-----------------------------------------------------

%-----------------------------------------------------
% Design period
%-----------------------------------------------------
% Start
x=january*24;

% End
y=yearend*24-1;
%-----------------------------------------------------

%-----------------------------------------------------
% Begin program
%-----------------------------------------------------
% Read and save values from modified the actual data.
Data = xlsread('Convert to et1.xlsx','D2:F8761');

% Lattitude
lat = 36.083; %las vegas

% Longitude
long = 115.15;
```

```
% Global Horizontal Irradiation GHI (W/m^2)
GHI = Data(:,1)';

% Diffuse horizontal irradiance DHI (W/m^2)
DHI = Data(:,3)';

% Albedo (ground reflectivity)
albedo = 0.1; %0.2

% Standard Meridian
Lst = ceil(long/15)*15;

% Collector tilt Beta (degree)
B = 22.5;

for i = 1:8760
   % day number nday
   nday(i) = ceil(i/24);

   % Solar time Correction B in degees
   B_st(i) = (nday(i)-1)*360/365;
   % E in minutes
   E(i) = 229.2*(0.000075+0.001868*cosd(B_st(i))-0.032077*sind(B_st(i))-
0.014615*cosd(2*B_st(i))-0.04089*sind(2*B_st(i)));
   % solar time in hours
   solar_time(i) = (4*(Lst-long) + E(i) + rem(i,24)*60)/60;

   % Hour angle w (degrees)
   w(i) = -15*(12-solar_time(i));

   % Declination Page 14 Eq. 1.6.1b
   dec(i) = 0.006918-0.399912*cosd(B_st(i))+0.070257*sind(B_st(i))-
0.006758*cosd(2*B_st(i))+0.00097*sind(2*B_st(i))-
0.002697*cosd(3*B_st(i))+0.00148*sind(3*B_st(i));

   % Zenith angle (theta_z degree)
   zenith(i) = acosd(cosd(lat)*cosd(dec(i))*cosd(w(i))+sind(lat)*sind(dec(i)));

   % Angle of incidence (theta degrees) (Eq. 1.6.7a)
   theta(i) = acosd(cosd(lat-B)*cosd(dec(i))*cosd(w(i))+sind(lat-B)*sind(dec(i)));

   % Rb Ratio of beam radiation on tilted surface to that of horizontal
   % surface
   Rb(i) = cosd(theta(i))/cosd(zenith(i));
```

```
    % Sunrise Sunset hour angle (degrees)
    ws(i) = acosd(-tand(lat)*tand(dec(i)));

    if (abs(w(i)) >= abs(ws(i)))
        Rb(i) = 0;
    end

    % Beam Radiation Ib W/m^2
    Ib(i) = GHI(i) - DHI(i);

    % Beam on tilted Plate Ibtilt (W/m^2)
    Ibtilt(i) = Rb(i)*Ib(i);

    % Global Tilt Eq. 2.15.1
    Gtot_tilt(i) = Ibtilt(i) + DHI(i)*((1+cosd(B))/2) + GHI(i)*albedo*((1-cos(B))/2);

end

array = [Gtot_tilt'];
xlswrite('PV2011.xls',array);
```

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Curriculum Vitae

Fady Atallah

OBJECTIVE

To use my acquired work, academic and personal skills, especially the skills related to HVAC and Natural Gas during my work at IntelliChoice Energy, to gain valuable work experience in a dynamic and stable workplace, and to potentially build a long-term career in Engineering with opportunities for career growth

EXPERIENCE

June 2011 – Present

<u>Mechanical Engineer, IntelliChoice Energy</u>

- Natural Gas Driven Heat Pump Development
    - Condenser fan motor & blade selection
    - Indoor blower motor & wheel selection
    - Condenser Coil Selection
    - Engine Radiator Selection
    - Coolant Pump investigation (pressure drop estimation)
    - Bill of Material management
- Investigation of Natural Gas Flow meters including Coriolis Micro Motion flow meters
- Selection & Procurement of Top-track Flow Natural Gas flow meters
- Selection & Procurement of Natural Gas Sub Meters for the residential gas heat pumps
- Cost estimation and Procurement of refrigeration, electrical and mechanical components and data logging components
- Measured and calculated variables uncertainty analysis
- HVAC Performance Analysis
- COP, EER, SEER, IEER and IPLV per ANSI AHRI 1230 and per ANSI Z21 40.4 calculation
- Life Cycle Cost Analysis/Annual Operation Costs estimation
- Develop testing plans
- Cost Reduction Design
- Troubleshoot problems including , Natural Gas Regulators, pressure transducers, high/low discharge/suction pressures, fan motor failures, hygrometers
- Project planning/project management
    - Developed man-hour schedules/Gantt charts
- Weekly team reporting and annual reporting
- Piping and instrumentation diagram
- EPA/ETL certification
- Data logging using Datataker and Arduino Board

- Natural Gas Flow rate
- Engine speed (optical sensor/tachometer)
- Air flow rate
- Relative humidity (hygrometers)
- Refrigerant pressures and temperatures at strategic locations
- Electrical power consumption (watt transducers)
- Power supplies

January 2010 – June 2011

Graduate Research Assistant, University of Nevada, Las Vegas

- Research on Energy efficient strategies in residential buildings
- Investigation of peak load reduction strategies
- Building energy modeling using EnergyPlus and Energy-10
- Analysis/Optimization of a coupled absorption refrigeration system with a vapor compression refrigeration system
- Measurement database management which includes meteorological data and energy consumption measurements in energy efficient residential buildings
- Contributed to the analysis of economic feasibility of typical and advanced upgrades which would increase the energy efficiency of a typical residential building in Las Vegas
- Worked on the analysis/optimization of absorption refrigeration systems
- Design, installation and testing of photovoltaic panels including 1-axis tracking
- Exhibitor at GlassBuild America 2010 exhibition

July 2008 – October 2008 (4 months)

Mechanical Engineer Intern, Midmac Contracting, Doha, Qatar

- Worked on pump selection (pressure loss in fresh air ducts, extract air ducts and chilled water pipes)
- Worked on sound control (sound attenuator design and procurement)
- Familiarized with the installation of AHUs and FCUs
- Familiarized with the firefighting system (pump sizing, pressure loss, etc…)
- Familiarized with the procurement process of various products such as sound dampers for HVAC ducts
- Performed an initial research for starting an HVAC Duct shop which included searching and cataloging the best manufacturers and suppliers of various machines including hydraulic press brakes, duct formers (Coil Line), plasma cutters, folding machines, duct Zippers and Pittsburg Lock seams

SKILLS & EXPERTISE

Proficient/familiar with a vast array of engineering computer programs including

- MatLab, Mathematica
- National Instruments Labview
- Solidworks, AutoCAD, Google Sketchup
- Energy-10, eQuest, EnergyPlus, DesignBuilder
- Metatrader/MQL4
- HVAC/HPDM
- C++
- HVAC
- Energy Efficiency

EDUCATION

January 2010 – May 2013

<u>University of Nevada, Las Vegas UNLV, M.S. Mechanical Engineering</u>

- GPA 3.81
- Tau Beta Pi (top 5%)
- Golden Key International Honour Society (top 15%)

2009 – 2009

<u>University of Tennessee Space Institute UTSI, Tullahoma, TN 37388, M.S. Aerospace Engineering</u>

- GPA 4.00

2004 – 2009

<u>Notre Dame University, Zouk Mosbeh, Lebanon, B.E. Mechanical Engineering</u>

- GPA 3.70
- ASME (Secretary), AHSRAE

2003 - 2004

Collège des Soeurs des Saints Coeurs, Kfarhbab, Lebanon, French Baccalaureate (Terminale Scientifique option Mathematiques)

HONORS, AWARDS, INTERESTS

- Awarded the Morris Simon Fellowship (Fall 2009 at UTSI)
- Awarded the Jordan G. Ennis Fellowship (Fall 2009 at UTSI)
- Distinguished graduate and on the honorary Dean's List at Notre Dame university (NDU) all semesters spent at NDU with a 3.70/4.0 GPA
- GRE Score: Quantitative 790/800 (92%)
- Senior Undergraduate Project: Stationary 2R axis tracking camera (PID controlled rotation around the x and y axis in order to follow a predetermined target using NI Labview)
- Passion in Sports cars (Supercars), Racing
- Advanced knowledge in computers and hi-tech gadgets

LANGUAGES

English, French, Arabic

REFERENCES

References are available upon request.