May 2018

Analysis of Impacts of Electrical Architectures, Social-Economic Considerations and Regions, on Requirements for Residential Combined Solar and Battery Implementations

Swachala Veerapaneni
University of Wisconsin-Milwaukee

ANALYSIS OF IMPACTS OF ELECTRICAL ARCHITECTURES, SOCIAL-ECONOMIC CONSIDERATIONS AND REGIONS, ON REQUIREMENTS FOR RESIDENTIAL COMBINED SOLAR AND BATTERY IMPLEMENTATIONS

by

Swachala Veerapaneni

A Thesis Submitted in

Partial Fulfillment of the

Requirements for the Degree of

Master of Science

in Engineering

at

The University of Wisconsin-Milwaukee

May 2018

ABSTRACT

ANALYSIS OF IMPACTS OF ELECTRICAL ARCHITECTURES, SOCIAL-ECONOMIC CONSIDERATIONS AND REGIONS, ON REQUIREMENTS FOR RESIDENTIAL COMBINED SOLAR AND BATTERY IMPLEMENTATIONS

by

Swachala Veerapaneni

The University of Wisconsin-Milwaukee, 2018
Under the Supervision of Professor Robert Cuzner

A community DC MG in an urban environment is analyzed and aimed at driving down the utility costs in a low-income household. A typical home conventional AC loads is compared with smart technologies to prove that utility bills can be significantly reduced. The optimal installation and usage of solar and battery energy storage is determined for the entire integrated community aiming to achieve net zero energy community. This study revealed a need for better understanding of the loads in each house and load patterns across a wide range of regions nationally and more typical houses, as opposed to the specialized study of the Milwaukee DC microgrid. As a result, current research also incorporates analysis of different architectures, for the Residential Microgrid modeling, for different types of homes in five different locations to contemplate theoretical and statistical understanding of suitable architecture. Critical AC loads are identified, and came up with an equivalent replacement for the DC Loads. Loads which are continually in use are taken into consideration, such as DC LED lights, Electronic Loads, Air Conditioner’s/Heat Pumps. So, proposed methods and systems cost less for an average home owner, than the one proposed by NREL Study for Installed Cost Benchmarks for Residential Solar Photovoltaics with Energy Storage.

Dedication Page

Firstly, I would like to thank my professor Robert Cuzner for giving me opportunity to work with DC Community Micro Grid project. He guided me in every walk of the entire research. He provided me with different exposures in the trending in the current Microgrid industry

Also, I am very much thankful to Steve Schmalz from Eaton for giving me opportunity to work with Residential Microgrid modeling. He guided me in increasing my awareness in new technologies of residential microgrid modeling and optimization.

I am thankful to my fellow colleague Karthik Palaniappan helped me throughout the research.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.Introduction

Installation of Solar and battery is gaining its huge popularity across the world. Everyone has their own intent behind deployment of the setup. Presently in United States from below average to an above average income person, though they have the motivation, the installation pricing is alarming. This is since, majority of the population is still using inefficient loads. As a result, more power consumption with such a setup. So, if one wants to go green, then deployment of solar and battery will turn out to be expensive and oversized. According to NREL (National Laboratory of the U.S Department) building-integrated batteries currently have no sizing standards or broad application guidelines. Establishing practical guidance for sizing, using case expectations (cycling rates, depth of discharge), and economic outcomes could stimulate sales and competition in the home battery systems market, while accelerating energy storage into markets where it could provide immediate value for manufactures, utilities, and consumers [16].

The existing approach in today's world for providing electricity is expensive. More than 1.2 billion people around the world live without electricity and the world bank estimates that it will take a trillion dollars through 2030 to solve this energy poverty [18]. Low income households spend about 10-35% of their income on utility costs each month depending on the region and they have low access to energy efficiency program [19]. According to a report by the American Council for an Energy-Efficient Economy, the cost of heating or cooling for low-income households is also three times more expensive than for households at other income levels [19].

1.1 Why DC Micro Grid?

Energy industry is experiencing a growing revolution towards distributed energy resources (DER) such as solar photovoltaics and energy storage, end use loads are becoming more natively DC

(Direct Current) based, due to the proliferation of electronics, LED lighting, and DC plug in loads. Also, not just at the consumer end most of the meters, control, protection and sensors devices running at the conventional local generating power station, residential and commercial are exclusively are electronics, which natively run on DC. But electrical systems were not set up for direct current, so just about every device today must convert the grid supplied AC to DC. In addition to adding cost, size, weight, safety, and reliability issues, these converters exact a toll by wasting energy [21]. AC supplies would necessarily include their own AC to DC converters, which waste between 7-12% of the energy used [20]. The change to DC is more practical today than ever before because of the rapid development of modern power electronics. solid-state electronics can provide voltage conversion in DC circuits needed for typical applications [21]. Power distributed to devices in buildings should match the intrinsic form of power of both local sources and loads to minimize power conversion loss possible.

The generation of AC electricity is mostly with large rotating alternating current synchronous generators that provide significant system frequency inertia to keep frequency constant. Converting the DC generation sources such as solar panels to AC would introduce higher rates of frequency change. Since larger frequency deviations can be expected as they are considered as variable energy resources. So, most convention power system operators put a limit on the portion of generation from the variable energy sources that can be sent back to the grid which is about 15 percent of the total [21]. To attain frequency stability from DC power converted to AC adds cost, complexity, and reduced reliability and/or resiliency. The prospect of huge increase in the number of distributed site-based energy harvesting and generation systems that lack frequency inertia may result in unstable electric power grids or microgrids because frequency and phase synchronization are so critical in AC systems [21]. The logical solution is to eliminate the synchronous requirement by switching to a non-synchronous, non-frequency dependent power format, namely DC. As a result, more simple, reliable, resilient, efficient, convenient power [21].

1.2 Thesis Approach

In the abstract outline is stated about the current thesis, below is in detail explanation of approach.

1.2.1 Milwaukee Community DC Microgrid Project

Beginning of this project was taken into consideration Garden Homes District in Milwaukee, WI, USA. Milwaukee's Garden Homes neighborhood, the area consists of older homes with detached garages. This was a thriving industrial community until a lasting recession drove businesses out of this area [20]. So, the idea was to refurbish the vacated homes with a large part of their electrical system designed to directly deliver DC to household loads so that they are compatible with the DC microgrid concept. Within this neighborhood there are several vacant single-family homes that are being purchased and renovated by a non-profit community development corporation (CDC). The intent was to sell or lease these homes to owner-occupant buyers which will help to stabilize the community. Each detached garage will be equipped with combined solar PV and battery storage. Figure 1.1 shows the layout of the property with the 9 dwellings. The commercial building "hub" distributes 360Vdc to the connected homes, enabling a sharing of distributed solar power and battery energy storage among the homes [20]. The average dwelling size is 1200 ft^2. So, to begin with two types of analysis has been carried out. One of them is, if a typical home is considered and its average sized appliances being converted to DC appliances, and remaining running on smart AC, how much savings can be achieved on the utility bill. Another analysis is, if this arrangement is made for all the 9 dwellings and sourced by interconnected solar panels and storage, how much power would be generated, stored onsite and imported from the grid. So, with this study, we were aiming for net-zero energy community. That is, firstly converting most of the possible loads to DC (Direct Current) and remaining to smart AC (Alternating Current), so that the power consumption reduces quite a lot. Secondly preferred approach was to interconnect the homes to share the power produced within the community. For each group of interconnected homes is to have a designated lead dwelling (in this case the commercial property) that provides the interface to the utility for energy import and export while each of the homes has the DC portion of its loads fed independently from its own energy resources and the microgrid. This approach enables radially distributed feeds to each dwelling, which is advantageous from a protection standpoint [20]. Chapter 2 & 3 will cover the further analysis.

Figure 1.1 Milwaukee Non-Profit Community Development Corporation

The initial impetus for the project was to study the effectiveness of DC microgrid for a low income residential microgrid. This study revealed a need for better understanding of the loads in each house and load patterns across a wide range of regions nationally and more typical houses in more detail. So, this project was collaborated with EATON.

1.2.2 Study with EATON

So, the objective of the second half of research is to analyze different architectures, for the Residential Microgrid modeling, as this analysis aids in interpretation of in-depth analysis of DC appliances, optimal sizing of the PV panels, battery sizing, costs and converters ratings for different types of homes in different locations. This will aim in providing affordable systems to an average home owner and adapting to smart DC loads, on contradictory to the proposal put forth by NREL (National Regional Energy Laboratory) shown in the Figure 1.2.

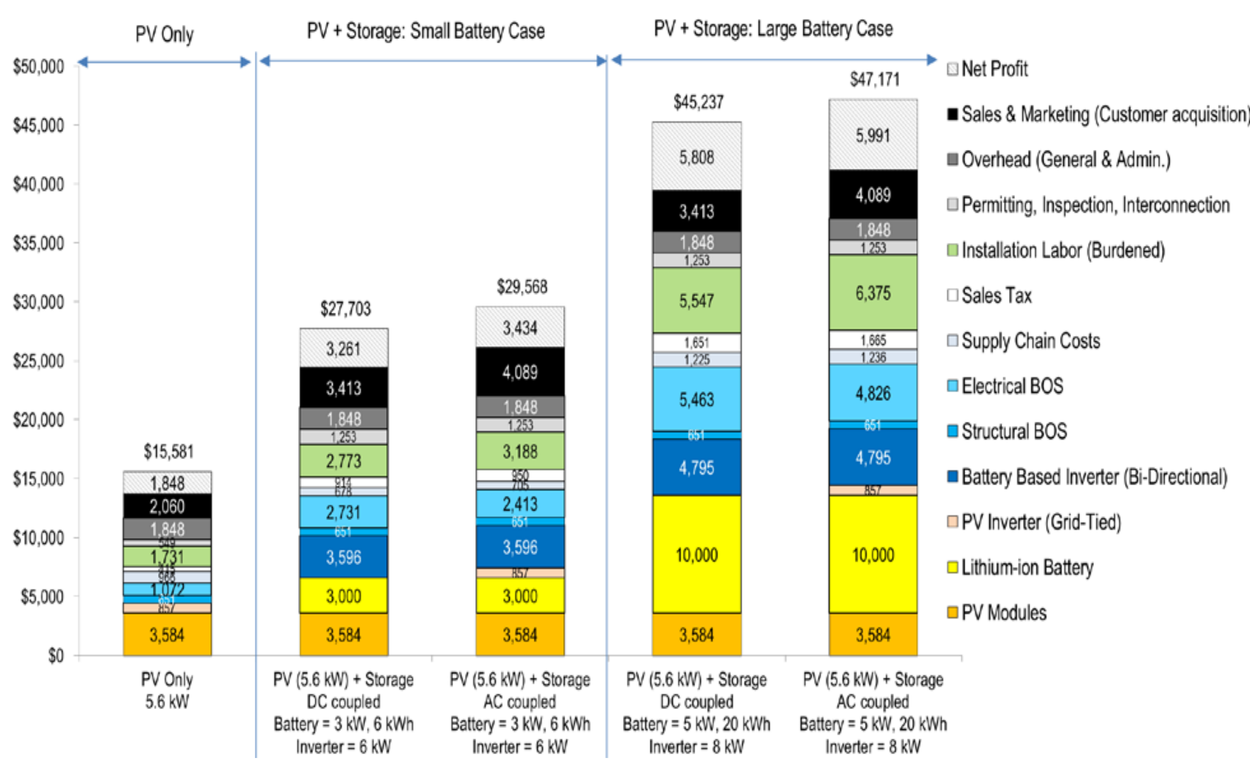

Figure 1.2 Proposed Costs by NREL

The analysis is carried out for typical 24-Hour Load consumption of the three types of houses based off Building America House Simulation Protocol for the entire year such as base, high, and low usage house. The types of houses are defined by the square footage, physical appearance like one story or two stories (maximum is two story), number of bedrooms and bathrooms and finish of the house such as highly insulated, medium insulation etc. The data is available for all the states spread across United Sates. For this analysis, five different regions are considered. Then a series of user profiles, intended to be an average over many homes of each type rather than the behavior of an individual set of typical occupants is considered from DOE (Department of Energy). Critical AC loads are identified and came up with an equivalent replacement for DC Loads. Chapter 4-8 cover the further analysis.

2.Analysis of Typical Home in Milwaukee Community Based DC Microgrid Power Consumption & Savings

The loads consuming more power in the average house in United States preferable cold places are taken into consideration and analyzed by comparing existing AC loads power consumption with Smart AC loads and DC loads. Many loads are still used as AC either because of their minimal power consumption or because there is no DC equivalent commercially available. But the AC loads used are converted to an energy efficient device, so that they consume less power.

Load	AC Load	DC Load	Appliance Factor	Human Usage Factor	Power Conversion Factor	Smart AC Home Load	DC Home Load
	(kW)	(kW)	h_a	h_u	h_h	(kW)	(kW)
Central A/C	3.450		1.000	0.500	1.100	1.898	
Blower Motor	0.187		1.000	1.000	1.100	0.205	
A/C 1	1.200	0.560	1.000	1.000	0.918	1.102	0.560
A/C 2	1.200	0.560	1.000	1.000	0.918	1.102	0.560
Ceiling Fan 1	0.750	0.014	1.000	1.000	0.918	0.689	0.014
Ceiling Fan 2	0.750	0.014	1.000	1.000	0.918	0.689	0.014
Range	6.000		0.600	0.500	1.100	1.980	1.980
Water Heater	5.500	2.525	1.000	0.500	0.918	3.025	2.525
Dryer	5.000		0.600	0.800	1.100	2.640	2.640
Washer	0.500		0.250	0.900	1.100	0.124	0.124
Heating (Gas)	0.322		1.000	1.000	1.000	0.322	0.322
Duct Fans		0.021	1.000	1.000	1.100	0.024	0.021
Dishwasher	1.100		1.000	1.000	1.100	1.210	1.210
Refrigerator	0.500		1.000	0.300	1.100	0.165	0.165
Freezer	0.350	0.170	1.000	1.000	0.918	0.385	0.170
Kitchen Loads	4.500		1.000	0.300	1.100	1.485	1.485
Electronic Loads	0.750		0.380	0.300	0.920	0.094	0.079
Lights (Kitchen)	0.080	0.040	1.000	0.500	1.000	0.040	0.020
Lights (Common Room)	0.340	0.018	1.000	0.500	1.100	0.187	0.009
Lights (Bath)	0.060	0.010	1.000	0.500	1.100	0.033	0.005
Lights (Bedroom 1+Bath)	0.180	0.024	1.000	0.500	1.100	0.099	0.012
Lights (Bedroom 2 & 3)	0.240	0.028	1.000	0.500	1.100	0.132	0.014
Lights (Basement)	0.080	0.014	1.000	0.500	1.100	0.044	0.007
Worst Case Peak Load						**17.350344**	**11.61409**

Table 1 Power Consumption of Various Loads

So, below is insight about DC loads and AC loads taken into consideration in Table 1

2.1 DC Loads

DC Air Conditioner makes the best use of solar power because there is no loss associated with converting DC power from solar panels into AC power to run a standard air conditioner. This avoids the inefficient addition of an "inverter" that converts solar DC current into AC current. A 48V DC brushless fan motors for both indoor and outdoor units of air conditioners using DC brushless fan motors can greatly reduce energy consumption. The use of a brushless permanent magnet motor driver provides a variable frequency drive that allows the system to dynamically adjust its capacity based on conditions [22]. DC Ceiling Fans a brushless DC (BLDC) motor is a synchronous electric Motor powered by direct-current (DC) electricity and having an electronic commutation system, rather than a mechanical commutator and brushes [23]. In BLDC motors, current to torque and voltage to rpm are linear relationships. This linearity provides an excellent opportunity to use the BLDC motor in the conventional ceiling fans [23]. Centralized heating systems with DC Duct fans will be used at the vents of the heat outlets, to circulate the heat in the house, it saves the gas usage. DC LED lights were considered which avoids the driver conversion in comparison with AC LED lights.

2.2 Smart AC Loads

AC Water Heater HPWH (Heat Pump Water Heaters) takes the heat from surrounding air and transfers it to water in an enclosed tank. During periods of high hot water demand, HPWHs switch to standard electric resistance heat (hence they are often referred to as “hybrid” hot water heaters) automatically [24]. AC clothe dryer or regular clothe dryers take air from outside which cold during winters, and heat it to remove the moisture from the clothes. If a dryer with heat pump technology is used, it reheats the air internally without taking the cold air from outside, which saves lot of energy as, dryer need not spend entire to warm it up again from very cold air. AC Refrigerator and Clothing Washers consume decent amount of power, there is no much saving converting them into DC. In fact, the size of the appliance is smaller, which does not serve the purpose of having it for a family. Most of the electronic appliance which are sold in the market are energy efficient, with bare minimum consumption of power, so as of now the trend continues to still AC power supply to them.

2.3 Factors

The smart AC loads used are converted to energy efficient devices by using additional factors which leads to reduction in power consumption. The Appliance Factor is selected to be an efficiency value associated with the AC appliance. Human Usage Factor is derived based on the human understanding of an appliance and how the human operates the equipment efficiently. Power Conversion Factor is to account for the losses in converters involved for a proper operation of the equipment. These factors are values between 0 and 1. The Appliance and Power Conversion Factors are derived from various studies online and published studies of smart AC and DC loads. The Human Usage Factor is assumed to be 0.5 for all appliances. As it can be seen in the Table 1 that if we use highly energy efficient AC System Vs DC and efficient AC combined, there is 66% reduction in energy consumption.

2.4 Utility Bill Savings

Each home was assumed to have an income based upon U.S. minimum wage ($7.25 USD/hour). The monthly utility costs for summer and winter are listed in Table 2. A typical day of summer and winter season hourly profiles are estimated and multiplied with the Kilowatt consumption from the Table 1 for total month. So, thus the kilowatt hour is obtained. The resultant Kilowatt hour (kwh) is multiplied with the 13 cents/ Kwh (Wisconsin energy charge).

Load	Summer Utility Home Monthly Cost			Winter Utility Home Monthly Cost		
	AC	Smart AC	DC Home	AC	Smart AC	DC Home
Central A/C	$ 136.62	$ 75.14	$ -	$ -	$ -	$ -
Blower Motor	$ 7.39	$ 8.12	$ -	$ 7.39	8.12	$ -
A/C 1	$ -	$ -	$ 22.18	$ -	$ -	$ -
A/C 2	$ -	$ -	$ 22.18	$ -	$ -	$ -
Ceiling Fan 1	$ -	$ -	$ 0.55	$ -	$ -	$ -
Ceiling Fan 2	$ -	$ -	$ 0.55	$ -	$ -	$ -
Range	$ 66.00	$ 21.78	$ 21.78	$ 105.60	$ 34.85	$ 34.85
Water Heater	$ 72.59	$ 39.93	$ 33.33	$ 72.59	$ 39.93	$ 33.33
Dryer	$ 11.00	$ 5.81	$ 5.81	$ 11.00	$ 5.81	$ 5.81
Washer	$ 0.55	$ 0.14	$ 0.14	$ 0.55	$ 0.14	$ 0.14
Heating (Gas)	$ -	$ -	$ -	$ 12.77	$ 12.77	$ 12.77
Duct Fans	$ -	$ -	$ -	$ -	$ 0.93	$ 0.85
Dishwasher	$ 1.21	$ 1.33	$ 1.33	$ 1.21	$ 1.33	$ 1.33
Refrigerator	$ 8.25	$ 2.72	$ 2.72	$ 8.25	$ 2.72	$ 2.72
Freezer	$ 2.31	$ 2.54	$ 1.12	$ 2.31	$ 2.54	$ 1.12
Kitchen Loads	$ 39.60	$ 13.07	$ 13.07	$ 49.50	$ 16.34	$ 16.34
Electronic Loads	$ 21.12	$ 2.65	$ 2.22	$ 24.75	$ 3.10	$ 2.60
Lights (Kitchen)	$ 0.79	$ 1.85	$ 0.09	$ 1.41	$ 3.29	$ 0.16
Lights (Common Room)	$ 4.49	$ 0.44	$ 0.07	$ 5.98	$ 0.58	$ 0.09
Lights (Bath)	$ 0.20	$ 0.33	$ 0.04	$ 0.20	$ 0.33	$ 0.04
Lights (Bedroom 1+Bath)	$ 1.19	$ 0.87	$ 0.09	$ 1.58	$ 1.16	$ 0.12
Lights (Bedroom 2 & 3)	$ 2.38	$ 0.44	$ 0.07	$ 3.17	$ 0.58	$ 0.09
Total Utility Bill	**$ 375.7**	**$ 177.1**	**$ 127.3**	**$ 308.3**	**$ 134.5**	**$ 112.3**
Average Savings per Month	**$ -**	**$ 198.5**	**$ 248.3**	**$ -**	**$ 173.7**	**$ 195.9**
% of Income	**18.8%**	**8.9%**	**6.4%**	**15.4%**	**6.7%**	**5.6%**

Table 2 Percentage of monthly income a home owner would pay for utilities

The monthly energy bill is expressed in the final row as a percentage of monthly income. It can be observed that the saving per month is substantial when using a house with DC loads compared to a house with AC loads and smart AC loads. The table 2 indicates the percentage of monthly income a family would pay for utilities. In summer the utility costs go from almost 19% to 6.4% if all DC loads are used. Adding solar and PV to this will yield a substantial benefit for the community as the DC CMG can enable a driving down of costs per household collectively.

3. Optimal Residential Solar And Battery Sizing

The typical load profile has been recorded for each house within the DC MG for four different seasons. There are total 9 dwellings and they are segregated based on the 4 different types of usage. Base usage house a typical 4 member sized working family, high usage house greater than 5 members and continuous usage of loads, minimal usage house is considered typically for a working single or a couple of members and an anomalous usage. An hourly usage is estimated for different seasons based on different user and, the Kilowatt consumption from the Table 1 is used to get the kilowatt hour. Also, solar irradiation data is obtained from the NREL website to obtain the production of Solar power.

3.1 The net loads profiles with different number of solar panels

So, the total energy consumed by all the 9 houses for that hour is used to obtain the aggregated load profile (ALP) for the overall DC MG. The ALP is defined as the total energy consumed by loads (in kWh) of all the houses in the DC MG vs. hour of day. The aggregated solar generation profile (ASGP) are obtained by installing solar panels on each house and its aggregated power generated for that hour. Considering the baseline case that a unit size solar panel, i.e., a 300 W solar panel, is installed on each house, the ASGP is then defined as the total energy generated by the unit size panel (USP) of all the houses in the DC MG vs. hour of day. Generation of solar power factored in the insolation levels (from NREL website) in that hour along with the number of solar panels on each house. Figure 3.1 which represents the case in summer, by varying the number of unit size panels installed on each house, the net load profile (NLP), i.e., ALP – ASGP*(# of the USP), can be plotted. The net loads consumption is reduced with the increasing of the number of USP installed per house. For instance, the purple profile with circle markers represent the NLP when 9 USP are installed on top of each house and the blue line represents without solar panel i.e zero. Between 8:00 am to 6:00 pm, the total energy generated by the solar panels are higher than the total energy consumed by the loads. If the extra energy can be stored in battery energy storage system and then utilized to supply the loads in other hours of the day, the total utility bill will be further reduced.

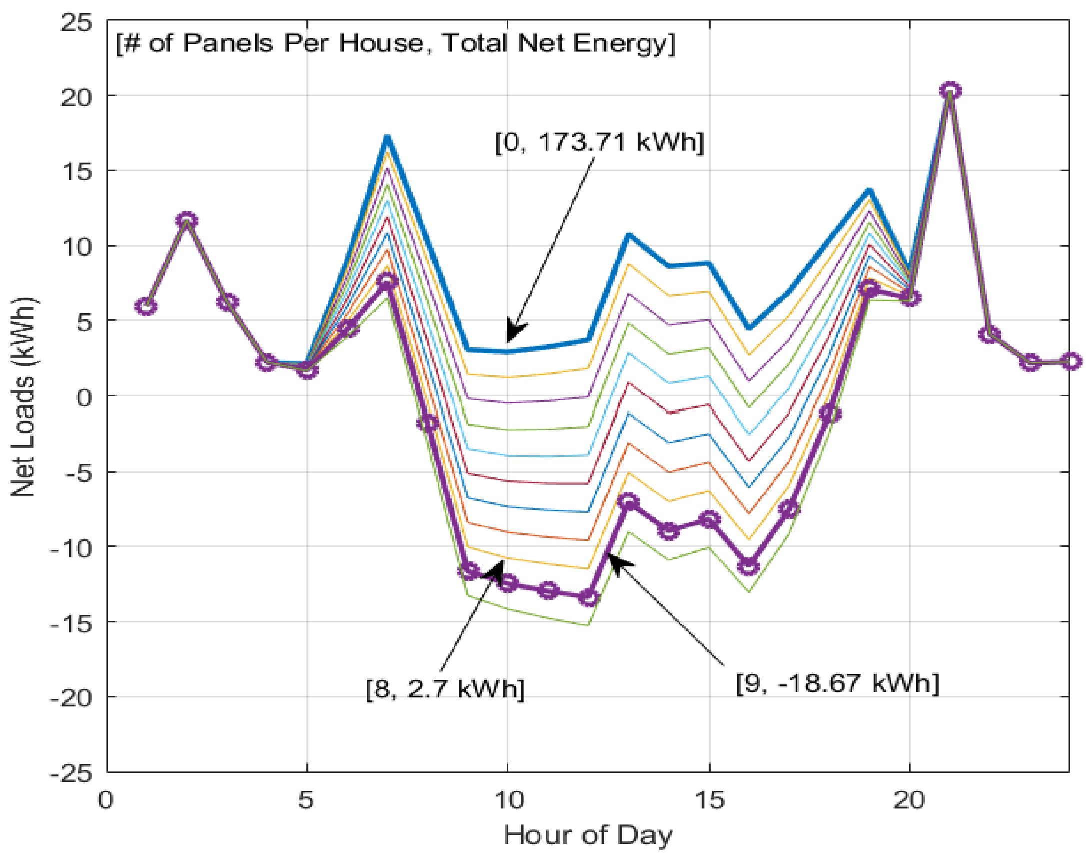

Figure 3.1 The net loads profiles with different number of solar panels

3.2 Sizing Solar panels and Battery for the Community

In this work, the unit cost of the residential solar PV installation is assumed to be $ 2.93 per watt dc, according to NREL's recent US solar PV system cost benchmark report [25]. This unit cost includes the costs related to modules, converter/charger, structural and electric balance of system, sales tax, installation labor etc. According to another NREL's report on residential solar PV with energy storage [26], the reported battery cost is \$471/kWh, which is selected to calculate the cost, including installation and permitting, for battery system in this work. In addition, the utility unit electricity cost is assumed to be \$ 0.11 per kWh. In this project, the specific constraints for the installation cost are: total installation cost, PV and battery, < \$10 K and total installation cost of the Hub (commercial property) < \$30K. The objective of this optimization is to minimize the utility bill for the DC MG.

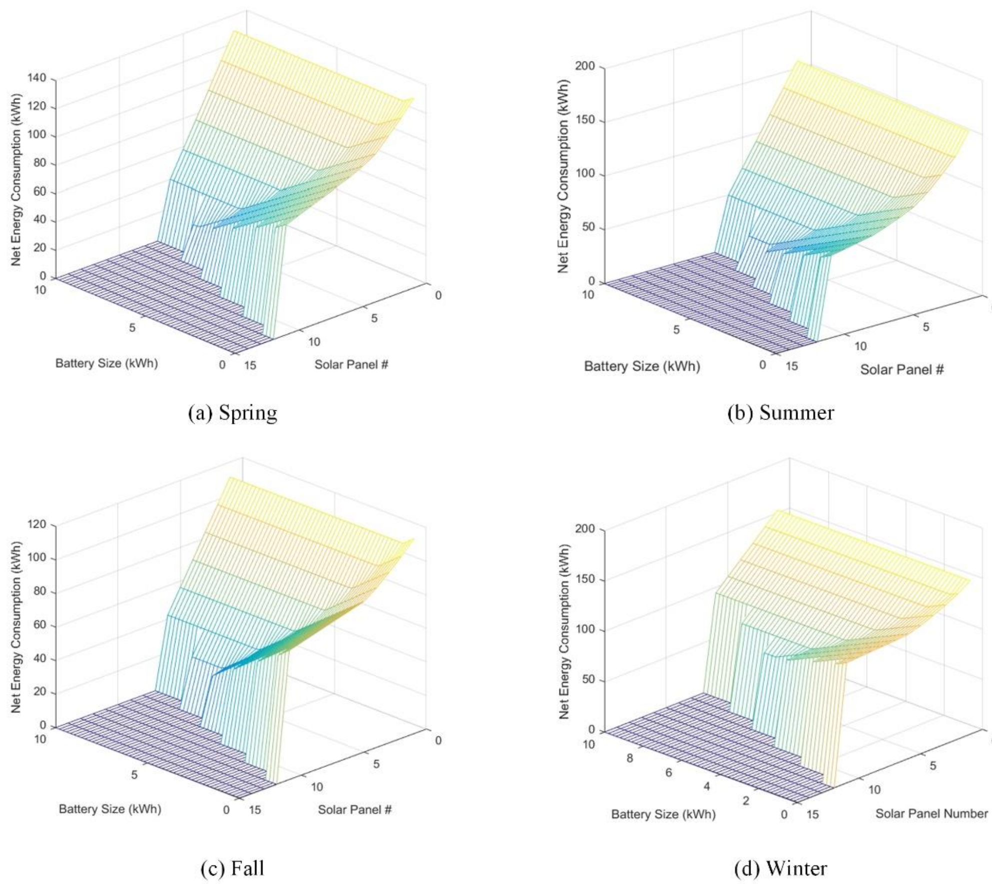

Figure 3.2 The net energy consumption versus the capacity of battery and the number of solar panels for different seasons.

By varying the number of USP, i.e., $P_{\#}$, and capacity of the batter energy storage, i.e., $B_{\#}$ (in kWh), installed in each house, the corresponding net energy consumed by the load can be obtained. Typical results for different seasons are shown in Fig. 3 and optimized solar and battery combination are summarized in Table 3. For the worst case, i.e., in winter with the least solar generation, by using optimized PV-battery combination, the total energy consumed by each home is 71.39/9*30 = 238 kWh, which corresponding to $ 26.18 on utility bill.

Season	$B_{\#}$ (kWh/home)	$P_{\#}$	Net Energy (kWh/day)
Spring	7.6	7	23.13
Summer	7.8	7	28.48
Fall	6.2	8	27.68
Winter	6.2	8	71.39

Table 3 Optimal results for different seasons.

So, far it is the idea of restructuring home with DC appliances and remaining loads to smart AC appliances and the houses will be sourced with Solar and battery on scale of community based. With Table 3 and rest of the analysis it can be concluded that though net energy zero is not achievable but, utility costs can be brought down bare minimum and it was probable because of interconnected community based homes So, to make the idea more practical for an average individual homeowner and as a result, this gave scope for digging deep into power consumption of load analysis by converting only appliances which are continually in use and available for reasonable prices in the market to be convertible to DC. Only these loads are sourced by Solar and Battery and the other way to put this is they are the critical loads of the house.

4. Analyzing different architectures, for the Residential Microgrid modeling

So, the objective of the current research is to analyze different architectures, for the Residential Microgrid modeling. For the current study three different micro grid architectures are considered,

Low power DC Distribution

- All lighting and plug-in loads (Electronic Loads) < 100W run off the distributed DC
- Plug-in loads > 100W run off traditional 120VAC

High Power DC Distribution,

- All lighting and plug-in loads < 100W run off the distributed DC
- Air conditioning, Heat Pump run off DC
- All other loads (e.g. resistive heating, kitchen appliances) run on AC

AC Distribution.

All the loads are connected to 120V AC.

The analysis is carried out for three different types of houses such as base usage house, high usage house, and low usage house. They are spread across five different regions in Unites States Tampa FL, Milwaukee WI, Nashville TN, Portland OR, and Tucson AZ. This gave us theoretical and statistical understanding of adapting suitable architecture for the different types of houses in their corresponding regions.

4.1 Source of data

The typical 24-Hour Load consumption of the three types of houses are based off Building America House Simulation Protocol for the entire year. A series of user profiles, intended to be an average over many homes of each type rather than the behavior of an individual set of typical occupants is provided. Building America (BA) is an industry-driven research program sponsored by the U.S. Department of Energy (DOE) that applies systems engineering approaches to accelerate the development and adoption of advanced building energy technologies in new and existing residential buildings. The DOE-2 or Energy Plus are used as simulation engine for the hourly simulation tool [1]. An hourly simulation is used to evaluate the time dependent energy impacts of advanced systems used in BA houses. Thermal mass, solar heat gain, and wind-induced air infiltration are examples of time-dependent effects used for accurate modeling only by using a model that calculates heat transfer and temperature in short time intervals [1].

4.2 Types of Houses

The types of houses considered for the current analysis

4.2.1 Base House

This has been reference building called the "B10 Benchmark" or "Benchmark" because this reference building is generally consistent with the 2009 International Energy Conservation Code (ICC 2009), which was referred to as "IECC" [1]. The 2009 IECC is still the most widely used energy code in the United States, and is consistent with DOE's benchmark [1].

The Benchmark may be applied to either a single-family or a multifamily home.

A single-family attached home is defined as either:

1. A residence, that shares one or more walls with another unit, or
2. A residence in a building of two or three units stacked vertically. This definition includes but is not limited to, duplexes, row houses, townhomes, two-flats, and three-flats [1].

A multifamily building has at least five housing units, each of which shares a floor or a ceiling with another unit. Also, a given multifamily building may have no more than three full above-grade stories; otherwise, it is considered a commercial building. These definitions are based on those provided by the EIA (Energy Information Administration) Residential Energy Consumption Survey (DOE 2016) [1].

Figure 4.1 shows the characteristics of a base house it's a three bedroom, 1story, and its other minor construction details are, lightning is 66% incandescent 21% CFL 13% Fluorescent and air conditioner is SEER 13.

	Selected Building Structure Types				
	Very Cold/Cold	Mixed-Humid	Mixed-Dry/Hot-Dry	Hot-Humid	Marine
Total Size (sq. ft.)	2696	2546	2000	2023	2090
Urban and Rural	Urban	Urban	Urban	Urban	Urban
Metropolitan and Micropolitan	Metro	Metro	Metro	Metro	Metro
Number of Stories / Levels	1 Story	1 Story	1 Story	1 Story	1 Story
Major Outside Wall Construction	Siding (Aluminum, Vinyl, Steel)	Siding (Aluminum, Vinyl, Steel)	Stucco	Brick	Wood
Major Roofing Material	Ceramic or Clay Tiles	Ceramic or Clay Tiles	Ceramic or Clay Tiles	Ceramic or Clay Tiles	Ceramic or Clay Tiles
Foundation/Basement of Single-Family	Basement	Concrete Slab	Concrete Slab	Concrete Slab	Crawlspace
Bedrooms	3	3	3	3	3
Full Bathrooms	1	1	2	2	1
Half Bathrooms	None	None	None	None	None
Basement Single-Family Homes	Yes	No	No	No	No
Finished Basement	No	No Basement	No Basement	No Basement	No Basement
Type of Glass in Windows	Double-pane Glass	Double-pane Glass	Single-pane Glass	Single-pane Glass	Double-pane Glass
	Selected Building Design Type				
	ALL OTHER OPTIONS SET TO B10 BENCHMARK HOUSE				

Figure 4.1 Base House Characteristics

4.2.2 High Usage House

Figure 4.2 shows the characteristics of a High usage house it's a Four bedroom, 2story, its minor construction details such as leaky infiltration, lightning is 80% incandescent 20% Fluorescent and air conditioner is SEER 10.

	Selected Building Structure Types				
	Very Cold/Cold	Mixed-Humid	Mixed-Dry/Hot-Dry	Hot-Humid	Marine
Total Size (sq. ft.)	4044	3819	3000	3034	3135
Urban and Rural	Urban	Urban	Urban	Urban	Urban
Metropolitan and Micropolitan	Metro	Metro	Metro	Metro	Metro
Number of Stories / Levels	2 Story	2 Story	2 Story	2 Story	2 Story
Major Outside Wall Construction	Siding (Aluminum, Vinyl, Steel)	Siding (Aluminum, Vinyl, Steel)	Stucco	Brick	Wood
Major Roofing Material	Ceramic or Clay Tiles	Ceramic or Clay Tiles	Ceramic or Clay Tiles	Ceramic or Clay Tiles	Ceramic or Clay Tiles
Foundation/Basement of Single-Family	Basement /Cralwspace	Basement / Crawlspace	Crawlspace	Crawlspace	Crawlspace
Bedrooms	4	4	4	4	4
Full Bathrooms	2	2	2	2	2
Half Bathrooms	1	1	1	1	1
Basement Single-Family Homes	Yes	Yes	No	No	No
Finished Basement	Basement /Cralwspace	Basement / Crawlspace	Crawlspace	Crawlspace	Crawlspace
Type of Glass in Windows	Single-pane Glass	Single-pane Glass	Single-pane Glass	Single-pane Glass	Single-pane Glass

	Selected Building Design Type				
	Very Cold/Cold	Mixed-Humid	Mixed-Dry/Hot-Dry	Hot-Humid	Marine
Heating Set Point (degrees)	74	74	74	74	74
Cooling Set Point (degrees)	74	74	74	74	74
Water Flow Rate (Showers / Sinks)	Benchmark	Benchmark	Benchmark	Benchmark	Benchmark
Natural Ventilation	No natural ventilation	No natural ventilation	No natural ventilation	No natural ventilation	No natural ventilation
Wall Insulatation Type	R7	R7	R7	R7	R7
Unifinshed Attic Insulation Type	R19	R19	R19	R19	R19
Finshed Basement Wall Insulation	8ft R5 Rigid	8ft R5 Rigid	8ft R5 Rigid	8ft R5 Rigid	8ft R5 Rigid
Exposed Floor (%)	80	80	80	80	80
Infiltration	Leaky	Leaky	Leaky	Leaky	Leaky
Refrigerator	Standard Side-By-Side	Energy Star Side-By-Side	Energy Star Side-By-Side	Energy Star Side-By-Side	Energy Star Side-By-Side
Cooking Range	Electric Conventional	Electric Conventional	Electric Conventional	Electric Conventional	Electric Conventional
Dishwasher	Standard	Standard	Standard	Standard	Standard
Clothes Washer	Standard	Standard	Standard	Standard	Standard
Clothes Dryer	Electric	Electric	Electric	Electric	Electric
Lighting	20% Fluor. 80% Incan.	20% Fluor. 80% Incan.	20% Fluor. 80% Incan.	20% Fluor. 80% Incan.	20% Fluor. 80% Incan.
Air Conditiong Unit Type	SEER 10	SEER 10	SEER 10	SEER 10	SEER 10
Water Heater	Gas Standard	Electric Standard	Gas Standard	Electric Standard	Gas Standard
Furnace	Gas, AFUE 78%	Gas, AFUE 78%	Gas, AFUE 78%	Electric, AFUE 98%	Gas, AFUE 78%

Figure 4.2 High Usage House Characteristics

4.2.3 Low Usage House

Figure 4.3 shows the characteristics of a Low usage house it's a two bedroom, 1story, its minor construction details such as tight infiltration, lightning is 100% Fluorescent and air conditioner is SEER 16.

	Selected Building Structure Types				
	Very Cold/Cold	Mixed-Humid	Mixed-Dry/Hot-Dry	Hot-Humid	Marine
Total Size (sq. ft.)	1348	1273	1000	1011	1045
Urban and Rural	Urban	Urban	Urban	Urban	Urban
Metropolitan and Micropolitan	Metro	Metro	Metro	Metro	Metro
Number of Stories / Levels	1 Story	1 Story	1 Story	1 Story	1 Story
Major Outside Wall Construction	Siding (Aluminum, Vinyl, Steel)	Siding (Aluminum, Vinyl, Steel)	Stucco	Brick	Wood
Major Roofing Material	Ceramic or Clay Tiles	Ceramic or Clay Tiles	Ceramic or Clay Tiles	Ceramic or Clay Tiles	Ceramic or Clay Tiles
Foundation/Basement of Single-Family	Slab	Slab	Slab	Slab	Slab
Bedrooms	2	2	2	2	2
Full Bathrooms	1	1	1	1	1
Half Bathrooms	0	0	0	0	0
Basement Single-Family Homes	No	No	No	No	No
Finished Basement	No	No	No	No	No
Type of Glass in Windows	Double-Pane Glass	Double-Pane Glass	Double-Pane Glass	Double-Pane Glass	Double-Pane Glass

	Selected Building Design Type				
	Very Cold/Cold	Mixed-Humid	Mixed-Dry/Hot-Dry	Hot-Humid	Marine
Heating Set Point (degrees)	66	66	66	66	66
Cooling Set Point (degrees)	78	78	78	78	78
Water Flow Rate (Showers / Sinks)	Low Flow	Low Flow	Low Flow	Low Flow	Low Flow
Natural Ventilation	B10 Benchmark	B10 Benchmark	B10 Benchmark	B10 Benchmark	B10 Benchmark
Wall Insulatation Type	R21 Foam	R21 Foam	R21 Foam	R21 Foam	R21 Foam
Unifinshed Attic Insulation Type	R38	R38	R38	R38	R38
Finshed Basement Wall Insulation	N/A	N/A	N/A	N/A	N/A
Exposed Floor (%)	20	20	20	20	20
Infiltration	Tight	Tight	Tight	Tight	Tight
Refrigerator	Energy Star Top Mount	Energy Star Top Mount	Energy Star Top Mount	Energy Star Top Mount	Energy Star Top Mount
Cooking Range	Gas Conventional	Gas Conventional	Gas Conventional	Gas Conventional	Gas Conventional
Dishwasher	Energy Star	Energy Star	Energy Star	Energy Star	Energy Star
Clothes Washer	Energy Star	Energy Star	Energy Star	Energy Star	Energy Star
Clothes Dryer	None (Clothes Line)	None (Clothes Line)	None (Clothes Line)	None (Clothes Line)	None (Clothes Line)
Lighting	100% Fluor.	100% Fluor.	100% Fluor.	100% Fluor.	100% Fluor.
Air Conditiong Unit Type	SEER 16	SEER 16	SEER 16	SEER 16	SEER 16
Water Heater	Gas Premium	Electric Premium	Gas Premium	Electric Premium	Gas Premium
Furnace	Gas, AFUE 92.5%	Gas, AFUE 92.5%	Gas, AFUE 92.5%	Electric, AFUE 98%	Gas, AFUE 92.5%

Figure 4.3 Low Usage House Characteristic

5.Residential Hourly Load Profiles

There are hourly load profiles available for residential buildings for all three types of houses, and all TMY3 locations in United States (based of Building America House Simulation Protocols). These datasets also use the Residential Energy Consumption Survey (RECS) for statistical references of building types by location [3]. The locations considered for analysis in Unites States are Tampa FL, Milwaukee WI, Nashville TN, Portland OR, Tucson AZ, as these states are moderate and has averaged climatic conditions compared to other states of that zones.

Each datasheet consists of following columns, Date Time, Electricity Facility kWH, Gas Facility kWH, Heating kWH, Electricity kWH, Heating Gas kWH, Cooling Electricity kWH, HVAC Fan kWH, Electricity HVAC kWH, General Exterior Lights Electricity kWH, General Interior Lights Electricity kWH, Appliances, Miscellaneous Interior Equipment Electricity kWH, Water Heater Gas kWH. Electricity Facility, Gas Facility are sum of entire kWH consumed by entire house electrically and gas as fuel respectively. Loads powered by gas are excluded from current analysis which are heating gas, Range and water heater gas. The dataset is an open load source available in the link reference [3].

5.1 Factoring of Loads

The kWH consumed by all loads is available from DOE (Department of Energy). The current research, which involves micro grid architecture comparison, in which Kw consumption of DC loads must be analyzed to compare it with conventional AC loads. In the current market, the following appliances or plug in electrical loads are available which can be converted to DC. They are Air Conditioner, Heat Pumps, Lightning, Miscellaneous Loads. The houses where cooling and heating systems are facilitated by gas is not converted to DC. Below is the detailed description of the loads which are converted to DC.

5.1.1 Air Conditioner

Below Figures 5.1 & 5.2 analysis is from DC Airco shows there is 21% more energy is needed for AC in comparison with a DC air conditioner. There is requirement of 21% more fuel, solar power, batteries, which are wasted using an AC air conditioner over DC installation. The first row of the Table 4 values are derived from following analysis.

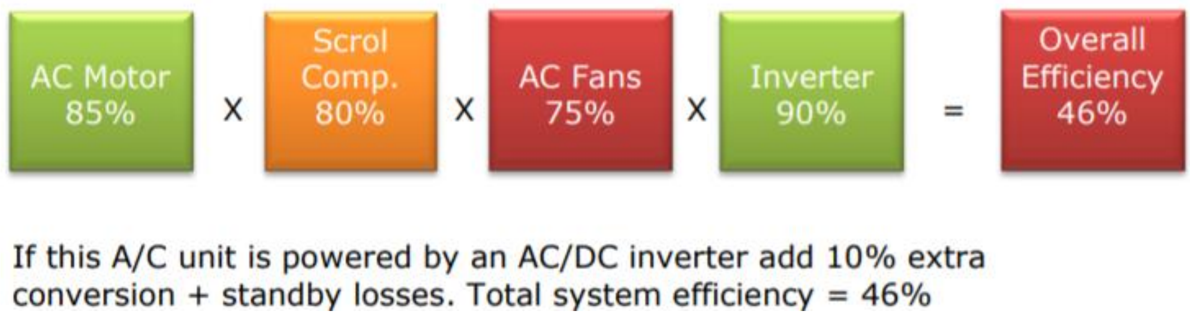

Figure 5.1 Effciency of AC Air Conditioner

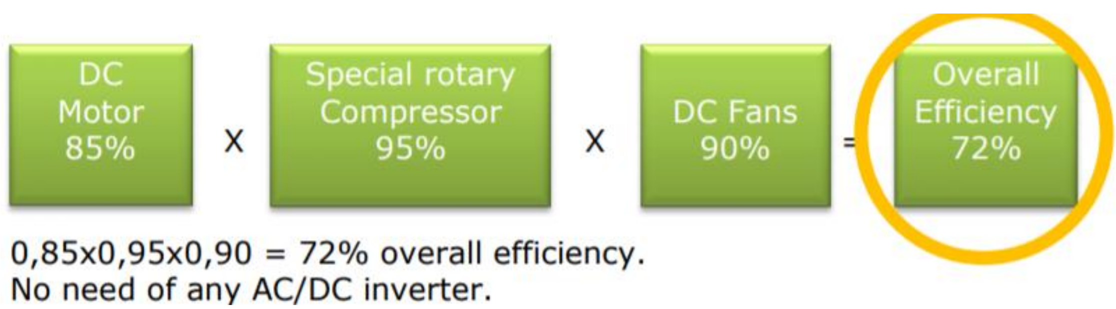

Figure 5.2 Effciency of DC Air Conditioner

Further analysis is done to verify the efficiency percentage. SEER 10, 13, 16 are the standard air conditioners used in High, Base and Low Usage Houses respectively. The efficiency of central air conditioning units is governed by U.S. law and regulated by the U.S. Department of Energy (DOE).

Every air conditioning unit is assigned an efficiency rating known as its "seasonal energy efficiency ratio" (SEER). The SEER is defined as the total cooling output (in British thermal units or Btu) provided by the unit during its normal annual usage period divided by its total energy input (in watt-hours) during the same period [5].

The energy efficiency ratio (EER) of a cooling device is the ratio of output cooling energy (in BTU) to input electrical energy (in Wh) at a given operating point. EER is generally calculated using a 95 °F outside temp and an inside (return air) temp of 80 °F and 50% relative humidity[6].The EER is related to the coefficient of performance (COP) commonly used in thermodynamics, with the primary difference being that the COP of a cooling device is unit-less, because the numerator and denominator are expressed in the same units. The EER uses mixed units, so it doesn't have an immediate physical sense and is obtained by multiplying the COP (or EER) by the conversion factor from BTU/h to Watts: EER = 3.41214 × COP (British thermal unit) [6].

The seasonal energy efficiency ratio (SEER) is also the COP (or EER) expressed in BTU/W·hr, but instead of being evaluated at a single operating condition, it represents the expected overall performance for a typical year's weather in each location [6]. The SEER is thus calculated with the same indoor temperature, but over a range of outside temperatures from 65 °F (18 °C) to 104 °F (40 °C), with a certain specified percentage of time in each of 8 bins spanning 5 °F (2.8 °C). There is no allowance for different climates in this rating, which is intended to give an indication of how the EER is affected by a range of outside temperatures over the course of a cooling season [6]. A SEER of 13 is approximately equivalent to an EER of 11, and a COP of 3.2, which means that 3.2 units of heat are removed from indoors per unit of energy used to run the air conditioner [6]. Heat pumps, work both ways. If there is an air conditioner with a reversing valve that lets it run backwards in winter. The cooling in summer and heating in winter, each function with its own rating. HSPF stands for Heating Season Performance Factor and is the SEER rating for winter [13].

Heat pumps don't work so well when it's cold outside, because they pump heat from the outside air into the house. (Ground source heat pumps, sometimes misleadingly called geothermal heat pumps, don't have this limitation because the ground doesn't get so cold.) The colder the outside air is, the less heat they can pump inside. For this reason, we don't see many heat pumps in cold climates [13]. But DC Heat Pumps offer better efficiency. One of the products available in the market are Green Energy, their name plate ratings show promising results converting to DC.

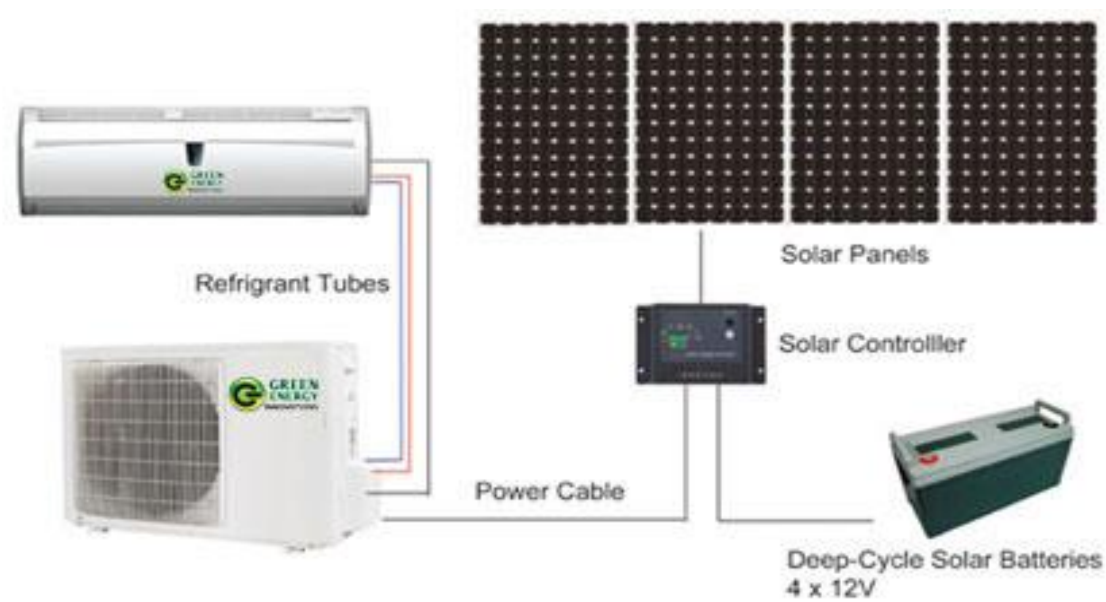

Figure 5.3 DC Air Conditioner setup

The average power of SEER 13 & 16 is calculated using

Average power = (BTU/h) / (SEER)

The resultant Average Power of AC and DC air conditioner is factored for calculating efficiency. Table 4 shows the calculations.

Ref 8-12	Capacity BTU	AC	DC	% Effciency
% Effciency		46	72	
EER(Btu/h/w) of SEER 13 12,000 Btu 1061W	12000	11.3	21	
EER((Btu/h/w)of SEER 16	12000	15	21	
Average Power SEER 13	12000	1061.9	571.43	
Average Power SEER 16	12000	800	571.43	0.7143

Table 4 Air Conditioner AC and DC Efficiency Factors

5.1.2 Lighting

Since each type of house has different types of certain percentage of lightning such as Base usage House 66% incandescent 21% CFL 13% Fluorescent, High usage House has 80% incandescent 20% Fluorescent, Low usage House has 100% Fluorescent. The efficiency of DC LED lights is analyzed over incandescent, fluorescent, and CFL. Below Table II shows the efficiency of DC LED Factors.

The total lighting interior and exterior kWH data for each house and, different locations from the DOE sheets are converted to their respective percentages of type of lighting such as incandescent, fluorescent, and CFL. The efficiency factor of DC LED over types of lighting is multiplied with them. The resultant is considered as total kWH consumption if the lighting is converted to DC. To make it a fair comparison the resultant DC LED kWH is converted to AC LED kWH by multiplying AC LED efficiency factor with DC LED kWH. The resultant AC LED kWH is compared with DC LED Kwh. A well-designed AC/DC driver at 18W has power conversion efficiency of 85% and has a wide operating range of 90V to 270V [8]. Typical commercially available drivers operate at 65-85% efficiency over a narrower voltage range of 150-260V. On the other hand, a well-designed DC-driver (possibly at 48V LVDC) can provide conversion efficiency of about 95%. The DC driver efficiency (taken as 90%) on an average will be about 15% better than the AC drivers (taken as 75%) [8].

Light Intensity	DC LED (W)	Incandescent (W)	Flourscent (W)	CFL(W)		Incandescent	Flourscent	CFL	AC LED Ref 7
(950Lumens) Blub	10	85		20	DC LED Factor	0.11765		0.5	
(500 Lumens) Bulb	5	50		12		0.1		0.4167	
850 Lumens Tube	9		35				0.25714		
(950Lumens) Tube	10		40				0.25		
Ref 6					Final Factor	0.2	0.5	0.6	0.83

Table 5 Lighting DC LED and AC LED Factors

5.1.3 Miscellaneous Loads

Miscellaneous electric loads (MELs) are the loads outside of a building's core functions of heating, ventilating, air conditioning, lighting, and water heating [9]. EIA Identified 15 loads are Miscellaneous category they are listed in Table 6

There are three sections in the Table 6 the one coloured in blue data is the directly derived from B10 Benchmark sheet. The one coloured in yellow is typical watts cosumed by the miscellaneous loads collected from various sources. There are three reasons to carry out this analysis, one is given that to calculate what percentage of Miscellaneous loads can be converted to DC. Secondly the analysis of B10 Benchmark sheet was carried out in the year 2010 and number of units is fractional since the data was averaged. Thirdly to calculate the factor. The following miscellaneous can be converted to DC television,ceiling fans,settop box, modem & routers, rechargeable electronics, DVDs/ VCR, tablets & laptops, desktop, monitors, and external power supplies. These loads contribute to 61% of the total miscellaneous loads. Typical wattage & Idle or standby wattage of all the loads is collected from various sources of present day and number of units is taken from 2015 EIA'S Residendianl Energy Consumption Survey.

Total Kw consumption of the loads which are able to be converted to DC, from B10 Benchmark and the one from different sources is calculated as, a resultant 61% of the total kw Miscellaneous is factored out and average of these two is used as multiplication factor which is 61.9% of the Miscellaneous Interior Equipment Electricity kWH (Miscellaneous Required). The one highlighted in green in left side of the Table III data is for same loads if they were converted to DC. Televison and ceiling fans in DC are readily available in the market, and remaining loads from set top box coloumn to External power supplies coloumn is mentioned as combined electronics in the Table 6 .The total required miscellaneous of DC is divided over total of required miscellaneous of various sources, to get the DC factor. (reference for future work-This factor in used as mutiplication factor to the Miscellaneous required coloumn in the Factoring sheet)

	Television	Ceiling fans	Set-topBox	Modem & Routers	Rechargeable Electronics	DVDs/ VCR	Tablets, Laptops	Deskt	Monito	External Power Supplies	Audio Equipment	security systems	Dehumidifiers	Portable Electric spas	Pool Pumps	Total Kw	Total of Required Miscellaneous	Factotin	Avg
TypicalWatts	150	40	35	15	6	15	100	100	45	0.8	42.5	5.1	274	4480	1050		6.162298	0.5651	0.619
No. of Units	2	2	1	1	3	1	1	1	1	4	2	1	1	1	1				
Hours/day	7.1	6.58	7.48	24	3.1	1.17	6.5	8.1	5.1	0.03	6	13.7	8.49	0.068	0.5				
KWH=(W*H)/1000	2.13	0.526	0.262	0.36	0.0558	0.0176	0.65	0.81	0.2295	1E-04	0.51	0.0699	2.326	0.3046	0.525				
Idle or Other Stdby Power (W)	13		16	8	2.2		7.1	9.5			7.5	5.1	2	222					
Hours/day in Lowest Standby Power Mode	16.9	17.42	16.52	0	25.52	20.37	15	15	16.1		34	10.3		2	0				
StandbyKWh per House Hold	0.439	0	0.264	0	0.168432	0	0.1065	0.143	0	0	0.51	0.0525	0	0.444	0				
Operating KWh per Household	2.569	0.526	0.526	0.36	0.224232	0.0176	0.7565	0.953	0.2295	1E-04	1.02	0.1224	2.326	0.7486	0.525	10.9047			
Referance	1&2	2,4	2,3	2,3	1,3	1,2,3	1,3	2	2	5	5	5	5	5					
TypicalWatts	110	35	16	6	6.8	15	25	75	42		51	7	274	3039	1050		3.45831	0.6727	
No. of Units	1.84	0.89	0.574	0.359	3.2	0.333	0.287	0.96	0.906		0.73	0.235	0.128	0.048	0.075				
Hours/day	7.1	6.58	7.48	24	3.1	1.17	6.5	8.1	5.1		6	13.7	8.49	0.068	6				
Lowest Standby Power (Off) (W)	4	0.0	15	0	2.8	4.5	2	2	1		5	7			0				
Hours/day in Lowest Standby Power Mode	16.9	17.42	16.52	0	25.52	20.37	15	15	16.1		34	10.3			0				
Idle or Other Stdby Power (W)	0	0	0	0	4	11	2	4	1		47			225					
Hours/day in Other Standby Power Mode	0		0	0	16	2.47	2.52	0.9	2.38		7.5			23.93					
StandbyKWh per House Hold	0.124	0	0.142	0	0.433459	0.0396	0.0101	0.032	0.0167	0	0.381	0.0169	0	0.2584	0				
Operating KWH=(W*H)/1000 p	1.437	0.205	0.069	0.052	0.067456	0.0058	0.0466	0.583	0.1941	0	0.223	0.0225	0.298	0.0099	0.473				
Operating KWh per Household	1.561	0.205	0.211	0.052	0.500915	0.0454	0.0567	0.615	0.2108	0	0.605	0.0395	0.298	0.2684	0.473	5.14131			
Referance	13																		
TypicalWatts	60	14	Combined Elecctronics														3.8455633		0.624
No. of Units	2	2																	
Hours/day	7.1	6.58																	
KWH=(W*H)/1000	0.852	0.184																	
Idle or Other Stdby Power (W)	6																		
Hours/day in Lowest Standby Power Mode	16.9	17.42																	
StandbyKWh per House Hold	0.203																		
Operating KWh per Household	1.055	0.184	2.6065233																
Referance	14	15																	

Table 6 Miscellaneous Load Factors

5.1.4 AC Loads

The loads which cannot be converted into DC such as heating in Wisconsin, Tennessee, Arizona and Oregon and water heater, since they are powered by gas and, all appliances such as washer, dryer, range and refrigerator. There are two loads which is not worth converting to DC. They are washer and refrigerator because of following reasons.

Washing machines consume widely varying amounts of power from less than 20 watts, to than 500Wdepending on what it is doing [10]. Because of less power consumption and typical usage of washer is only for thirty minutes and, operated only for few days of week, it's not worth converting into DC.

The working principle of a refrigerator is based on a vapor compression cycle used in most domestic refrigerators. Refrigerant fluid with low boiling temperatures and good heat exchange characteristics changes state to remove heat from the inside of the chamber. It then loses the gained heat through the condenser pipes to its surrounding environment in the room [11]. According to energy star data on refrigerators the bench mark in energy efficient refrigerators is a Fischer and Paykel refrigerator only unit consuming 145 kWh/year [11]. According to published Samsung data their side-by-side units range between 398-621 kWh/year. Other non-side-by-side units with top or bottom freezer units use approximately 13%-16% less energy than an average side-by-side unit [11].

For a freezer to maintain a desired temperature of 0 degrees F or a combination refrigerator-freezer to maintain a -5 to +8 degrees F freezer and 34 to 42 degrees fresh food temperature, the compressor will usually run much of the time [12]. Newer refrigerators have smaller, more powerful, high-speed compressors that generally cost less to operate than those in older refrigerators. These compressors are designed to run 80 % to 90% of the time. This makes them more energy efficient because the greatest amount of energy used when the compressor cycles on [12]. Since, temperature difference is minimal most of the time with the surroundings, compressor uses very minimal power to maintain the set temperatures. DC refrigerators of very small capacity are available in market, but there isn't any significant amount of difference in power consumption compared to AC.

6.Statistical Micro Grid Architecture Analysis

6.1 Microgrid Architecture Comparison

All the factors derived from the Tables 4, 5, 6 are used to calculate power consumption of Cooling DC, Heating DC (only for houses in Florida) Total DC lightning Interior & Exterior, AC LED Lightning, DC Miscellaneous, and AC Remaining (remaining 32% of Miscellaneous loads) for three types of houses in five different locations as mentioned. These additional columns are derived to get below architecture total power consumption, so that different architectures can be compared using MATLAB graphical representation. Based on typical weighted-average inverter efficiency from the California Energy Commission (CEC) Database, conversion losses for battery charging with AC-coupled systems can be up to 10% higher compared to DC-coupled systems [15].

6.1.1 AC and Low Power DC (Low power DC Distribution)

Only low powered loads run of DC and remaining High power loads and the one's, which cannot be converted to DC run off AC.

Low powered loads will be running 48V DC

At 48 Volts DC the power transmitted was strong enough to meet the needs of most applications. Some appliances like fans would have to be modified to become brushless fans and could then be run on DC motors.

Since most electronic appliances use DC power, as do LED lights, there was no sense in converting AC into DC. Even solar power is normally captured as DC, and is then converted to AC to be fed into grids. It would therefore be better to transmit DC power directly. Even when it comes to common desktops, AC power is used only for the SMPS (the fan which is meant to cool the system). The motherboard uses DC. If the SMPS could be dispensed with the AC power input would no longer be required. Most crucially, 48 Volts DC is an energy level that the human body can tolerate. It will not cause death.

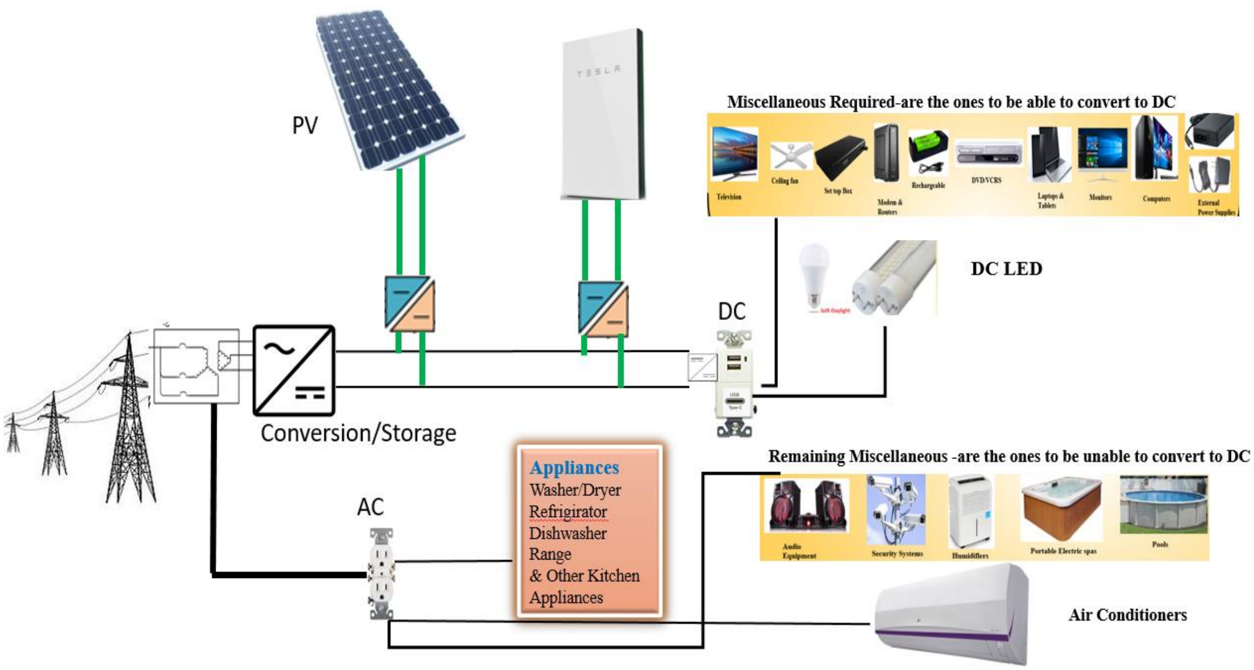

Figure 6.1 AC and Low Power DC (Low power DC Distribution)

6.1.2 **AC Low & High-power DC** (High Power DC Distribution)

Low & High-powered loads run of DC and remaining the one's, which cannot be converted to DC run off AC.

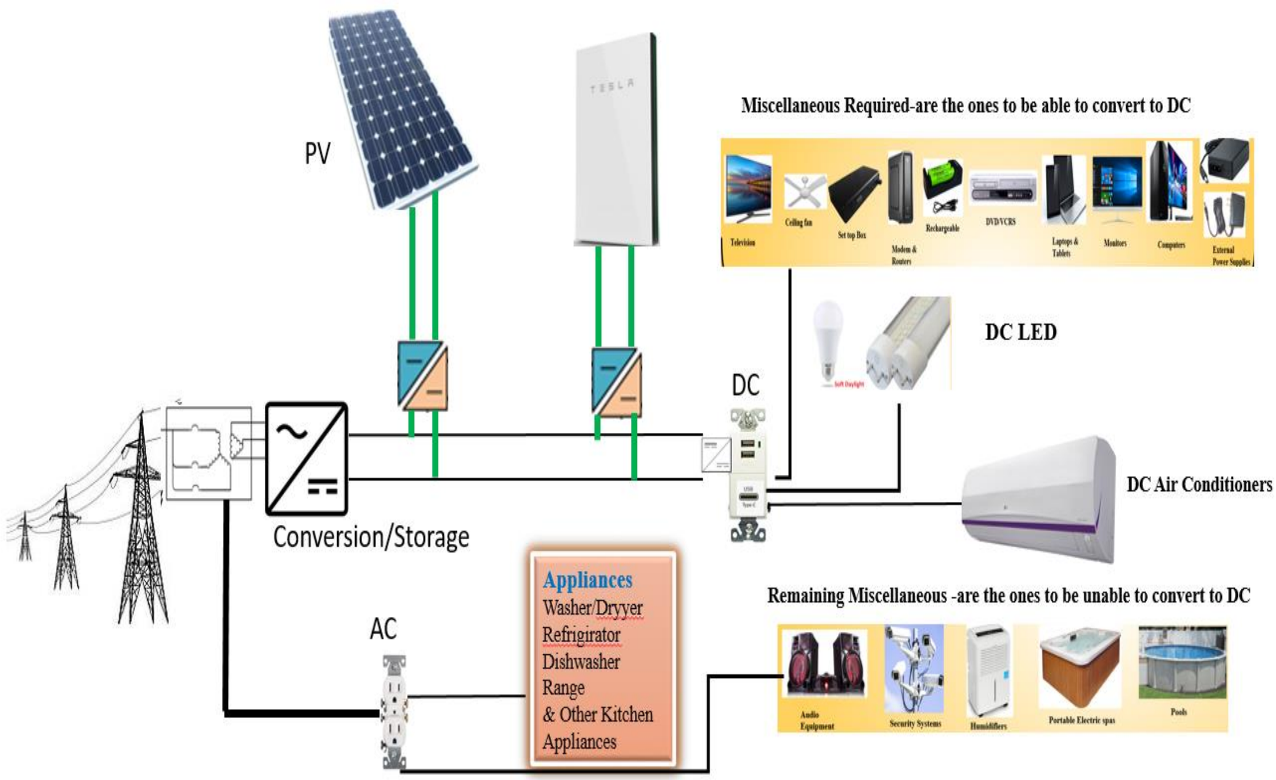

Figure 6.2 AC, Low & High-power DC (High Power DC Distribution)

6.1.3 AC Loads (AC Distribution)

AC-Cooling+Heating+LEDLightning+ Miscellaneous required. All the data of loads remain intact except lightning is converted to AC LED(reference for future work- refer factoring of load sheets).

Below is the Graphical analysis using MATLAB. A typical day from one of the peak month seasons is taken as reference and has been compared among total Kw of three architectures AC Loads, AC & Low power DC, and AC, Low and High-Power DC for graphical representation.

This analysis is done to analyze which micro grid architecture is suitable for type of house and location. Also, total net energy or area under curve gives visual analysis and reduction in energy consumption by adapting suitable architecture. Below figures also portray that majority of the type of houses, with their respective locations, sizing of the battery should be greater than the solar panels. As the 24-hour profile clearly shows the duck of the curves is mostly situated in the other half of the day. Similar analysis is done for peak case scenario such as peak season and peak month,

6.2 Simulation Plots

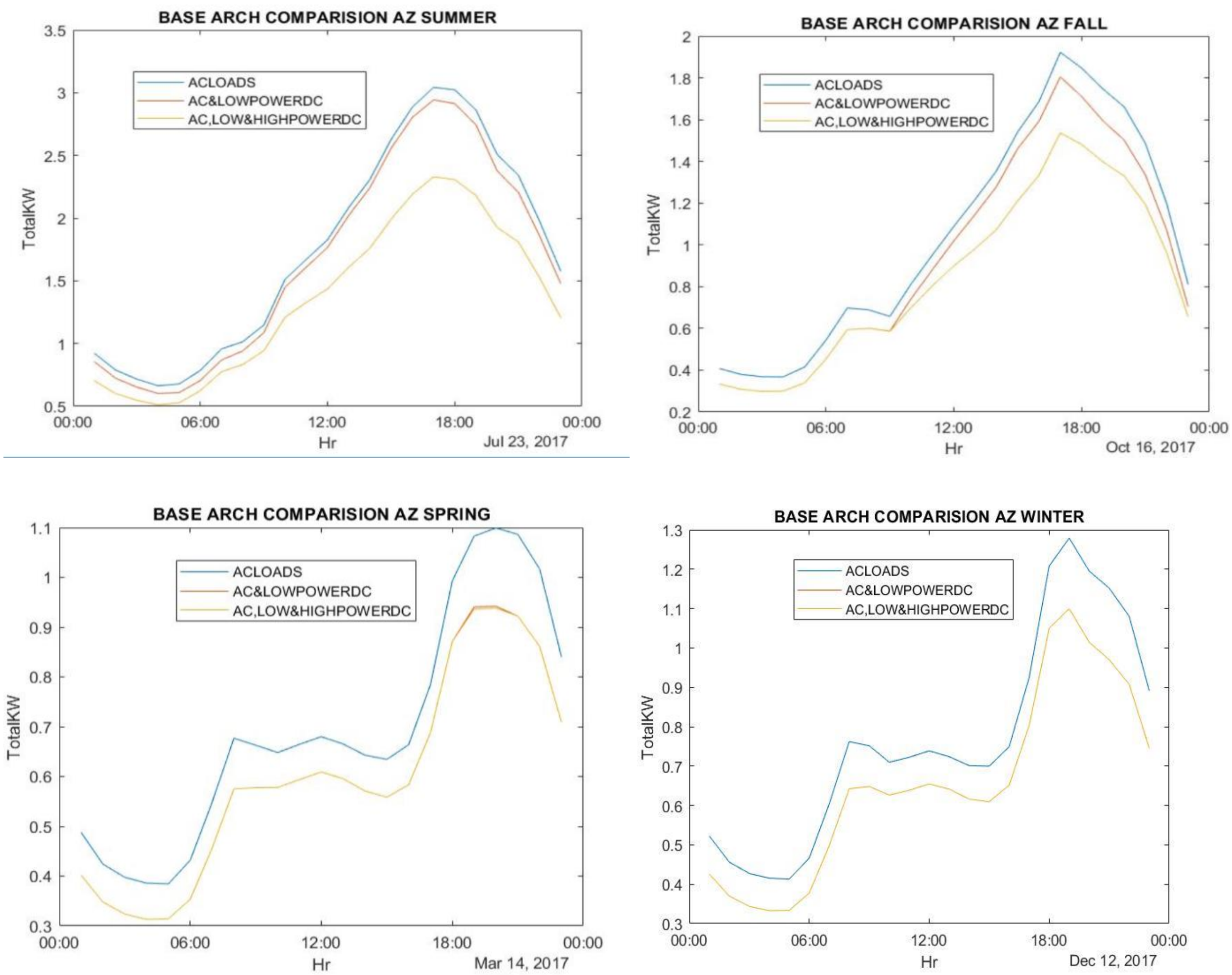

Figure 6.2.1 Base House AC Loads, AC & Low power DC, and AC, Low and High-Power DC Architecture Comparison

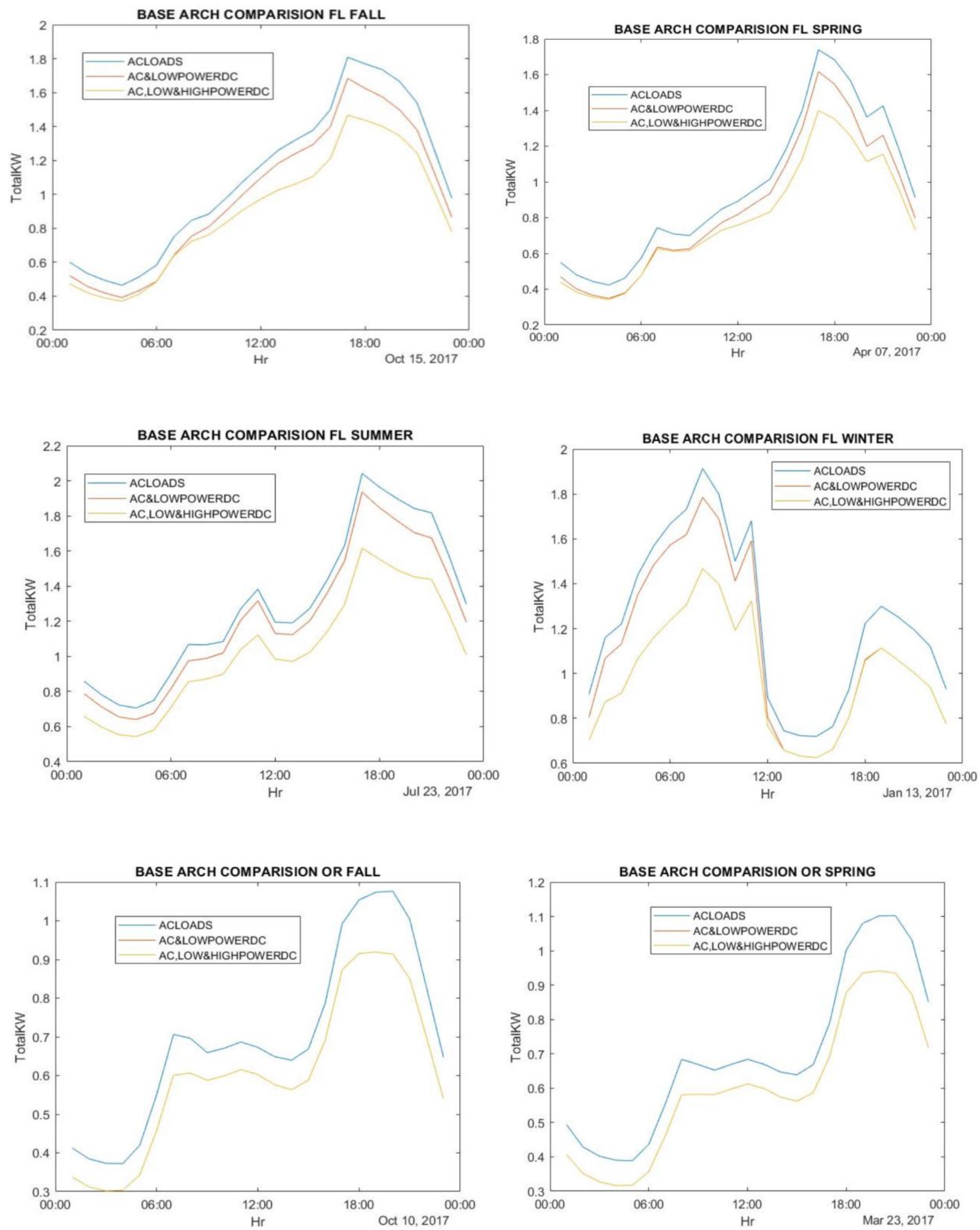

Figure 6.2.1 Base House AC Loads, AC & Low power DC, and AC, Low and High-Power DC Architecture Comparison

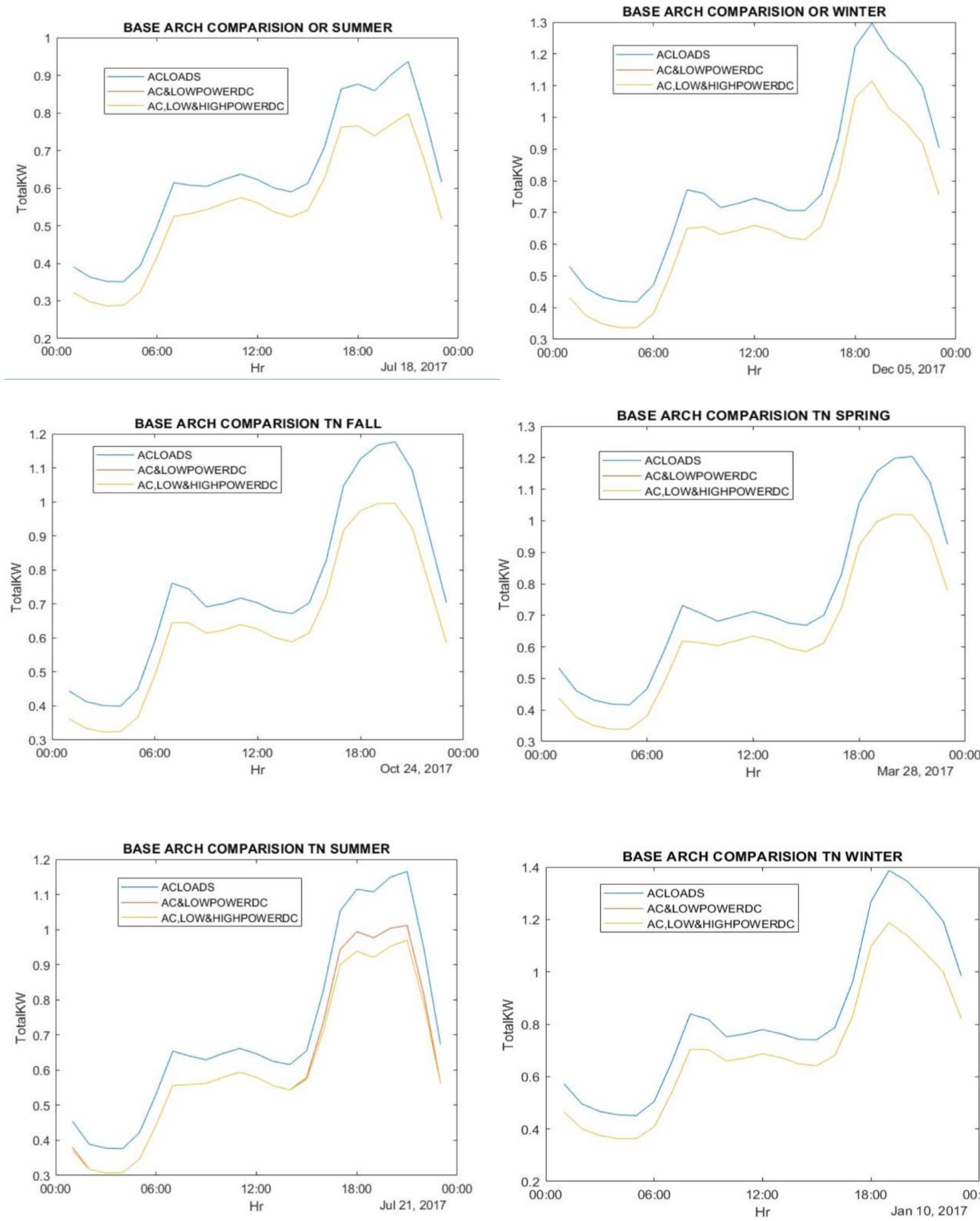

Figure 6.2.1 Base House AC Loads, AC & Low power DC, and AC, Low and High-Power DC Architecture Comparison

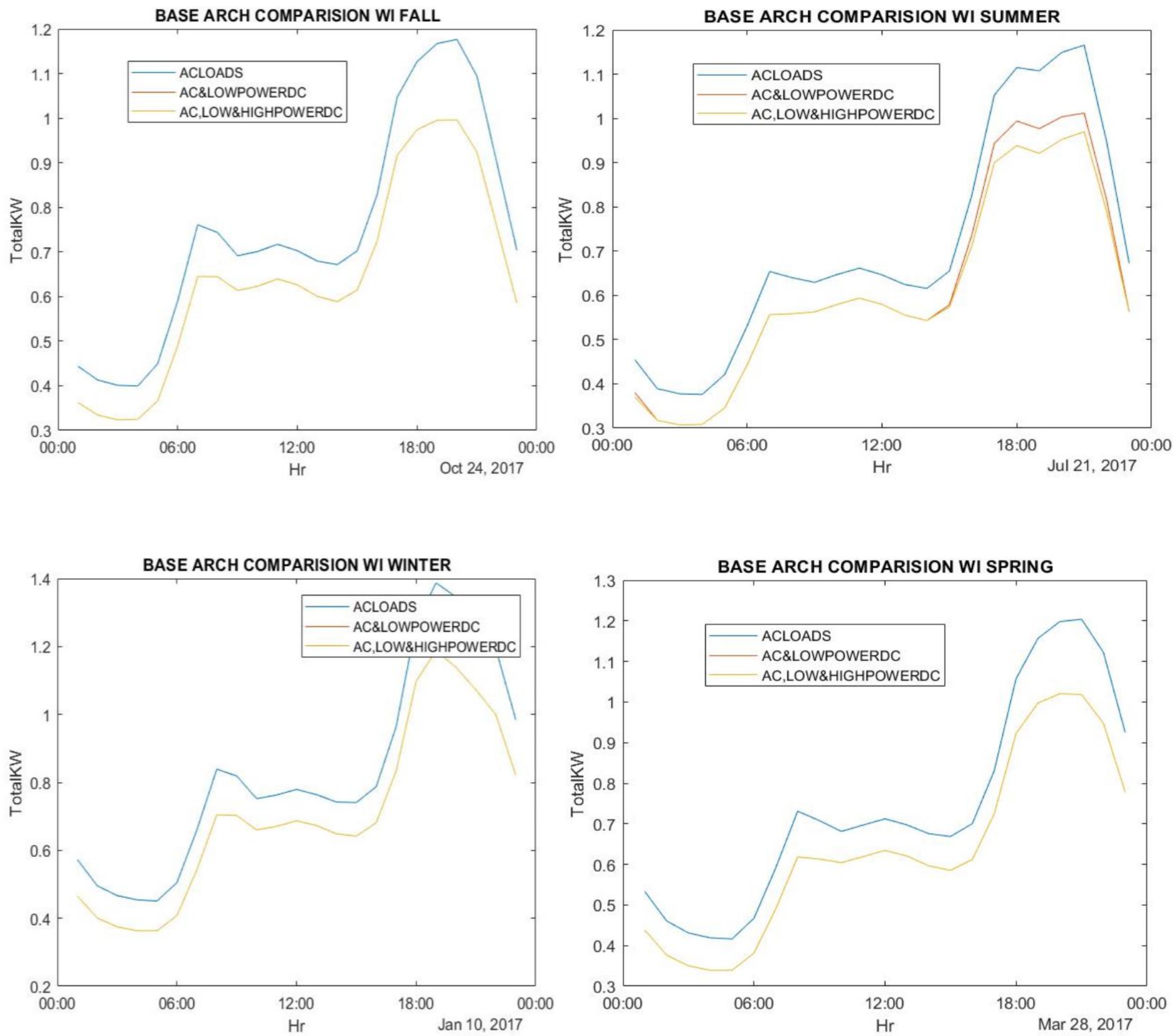

Figure 6.2.1 Base House AC Loads, AC & Low power DC, and AC, Low and High-Power DC Architecture Comparison

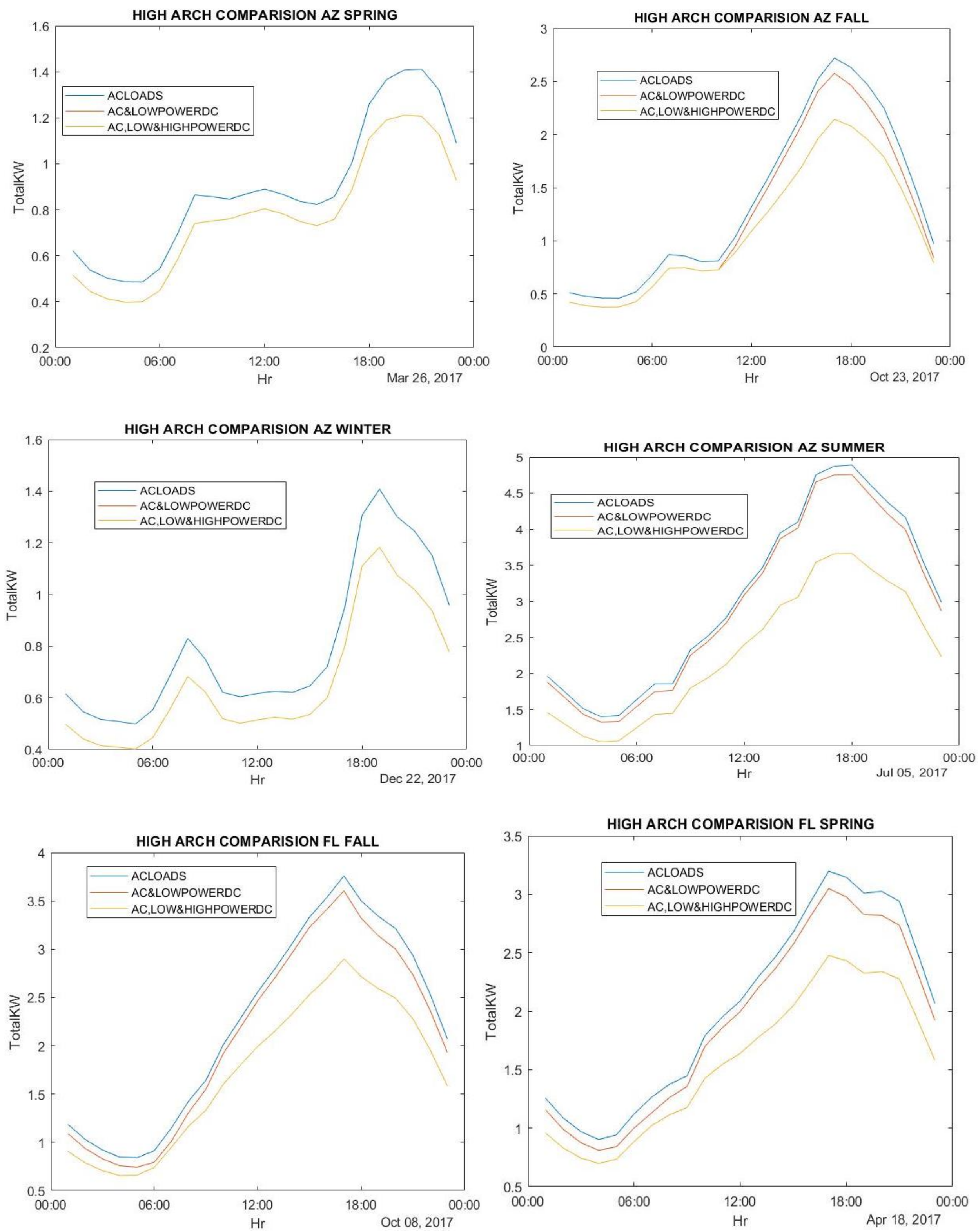

Figure 6.2.2 High Usage House AC Loads, AC & Low power DC, and AC, Low and High-Power DC Architecture Comparison

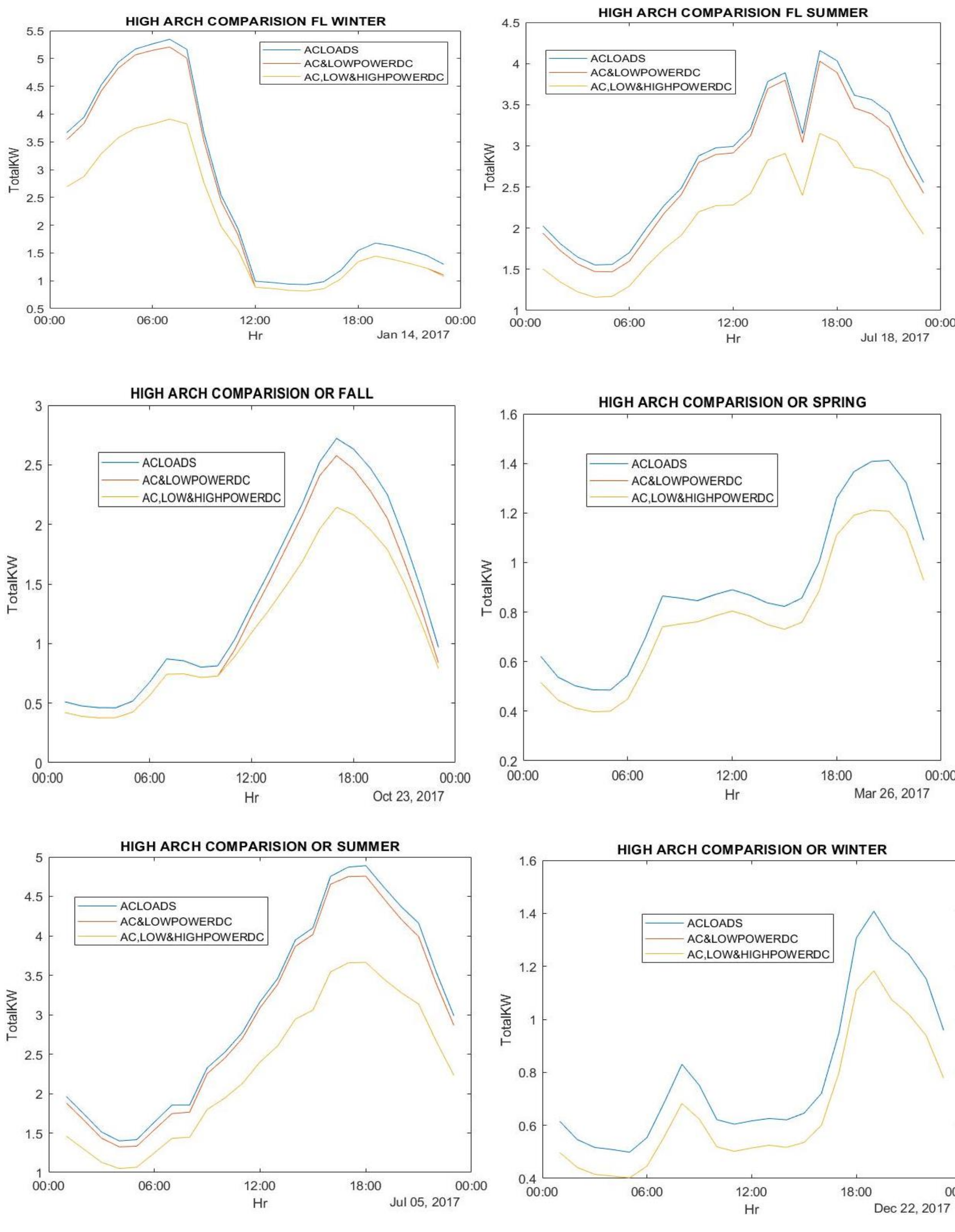

Figure 6.2.2 High Usage House AC Loads, AC & Low power DC, and AC, Low and High-Power DC Architecture Comparison

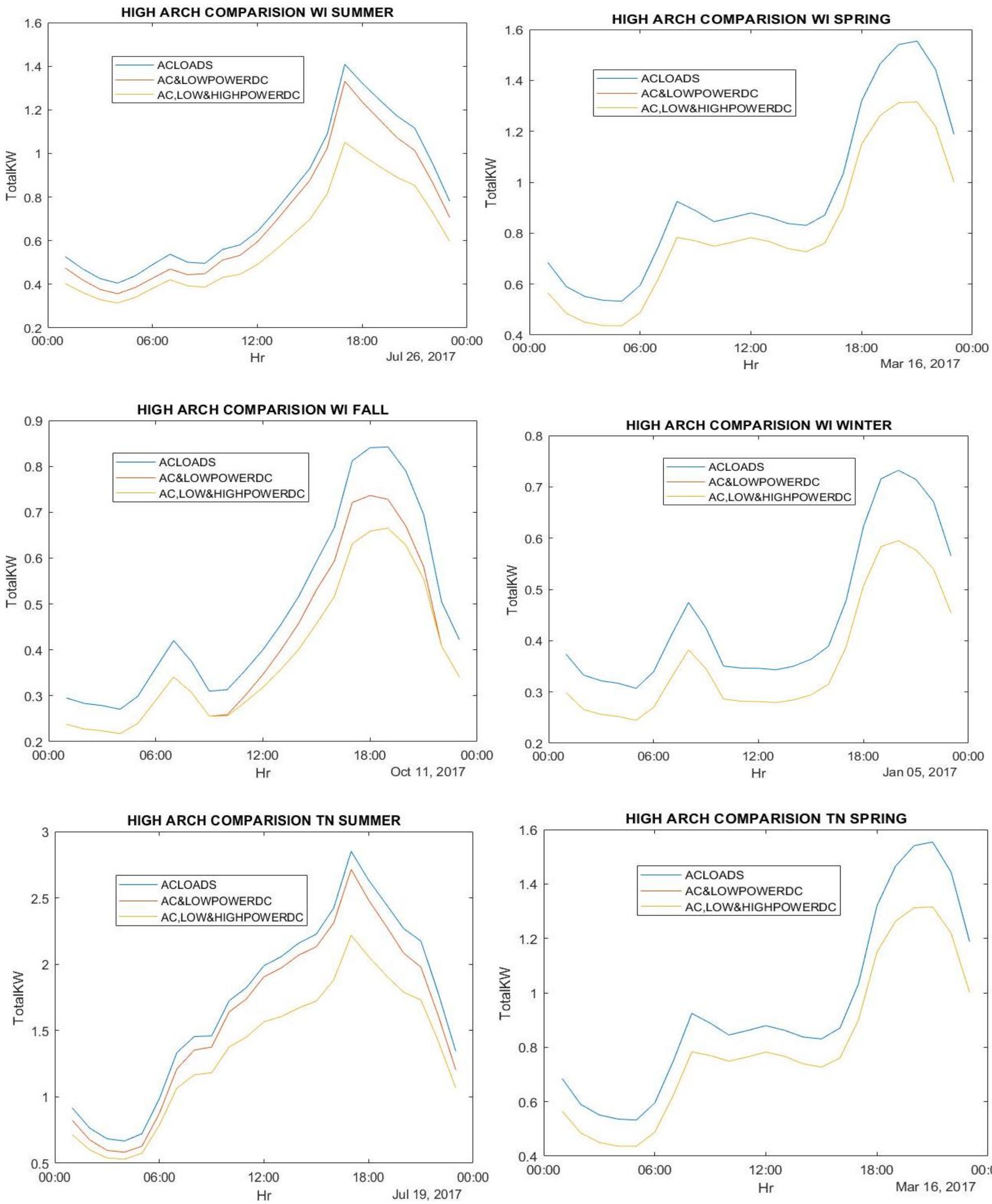

Figure 6.2.2 High Usage House AC Loads, AC & Low power DC, and AC, Low and High-Power DC Architecture Comparison

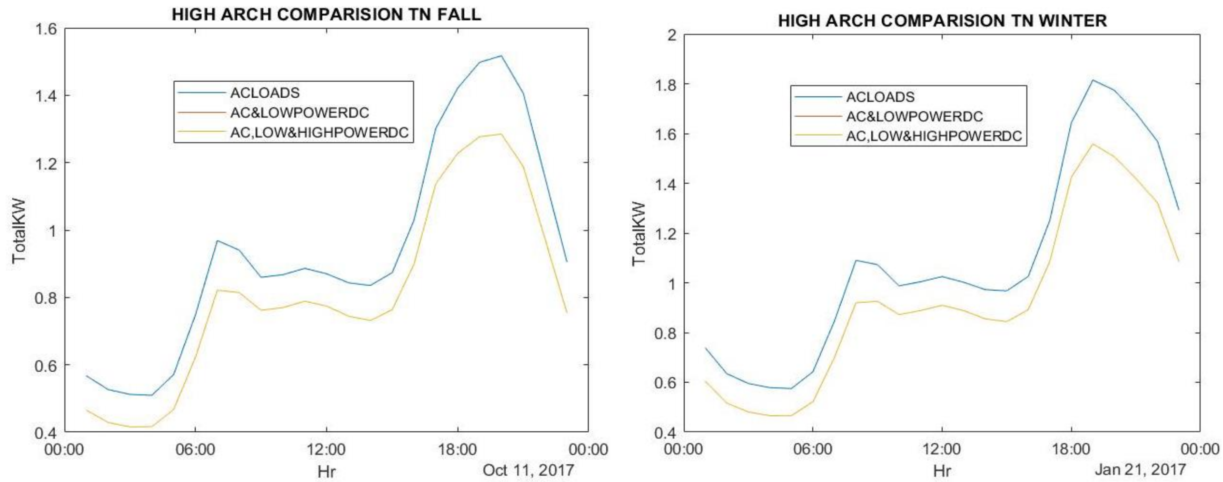

Figure 6.2.2 High House AC Loads, AC & Low power DC, and AC, Low and High-Power DC Architecture Comparison

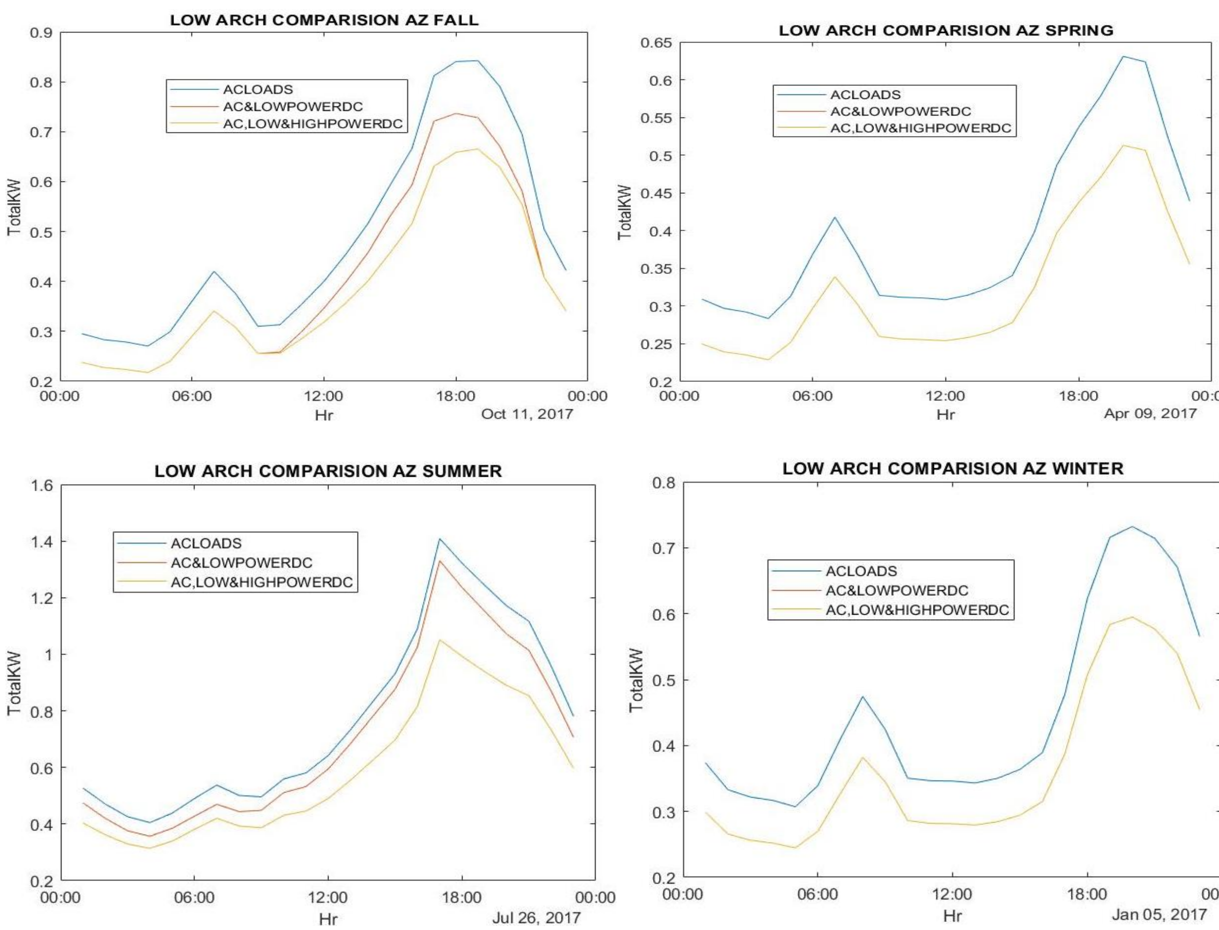

Figure 6.2.3 Low Usage House AC Loads, AC & Low power DC, and AC, Low and High-Power DC Architecture Comparison

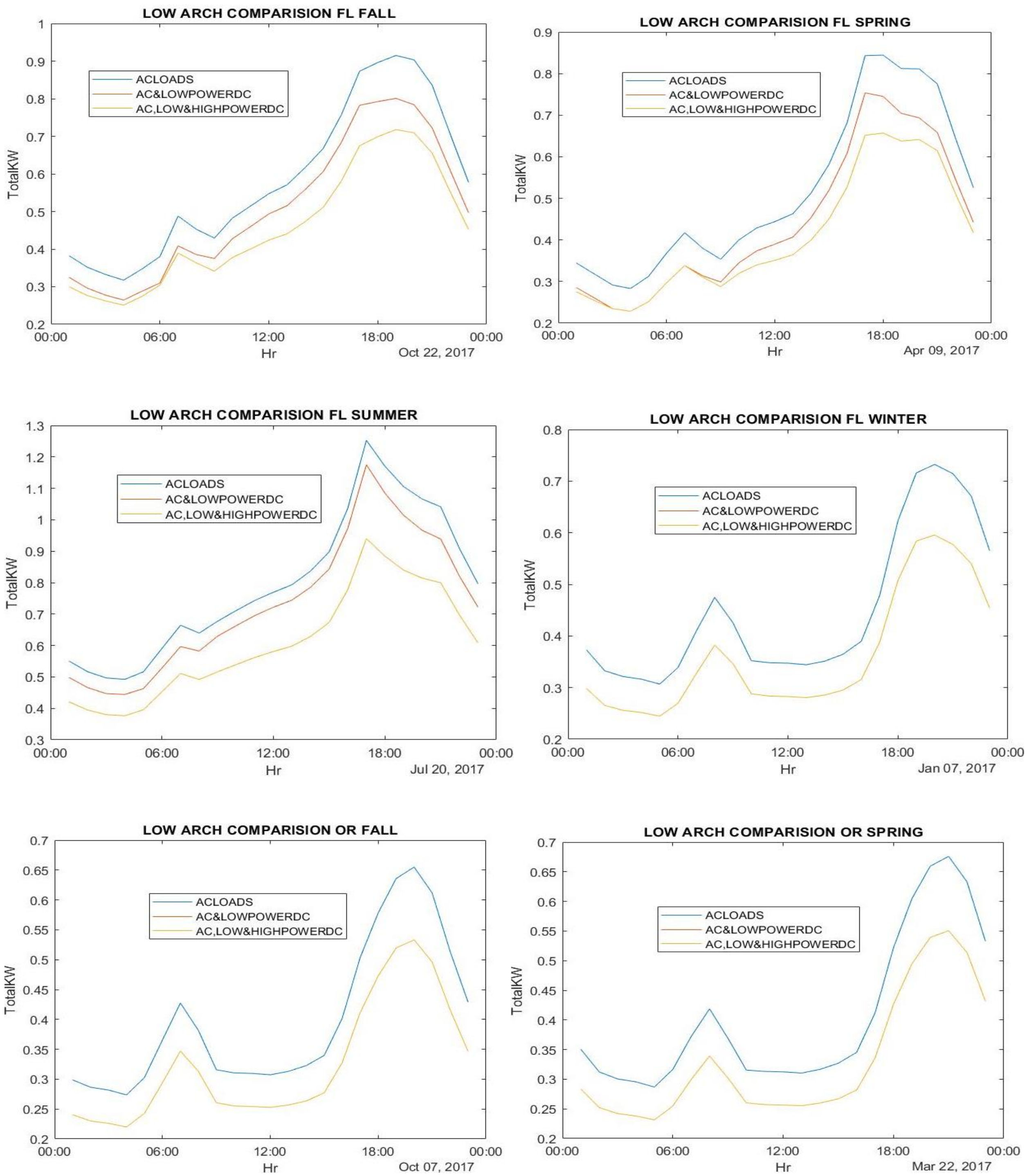

Figure 6.2.3 Low Usage House AC Loads, AC & Low power DC, and AC, Low and High-Power DC Architecture Comparison

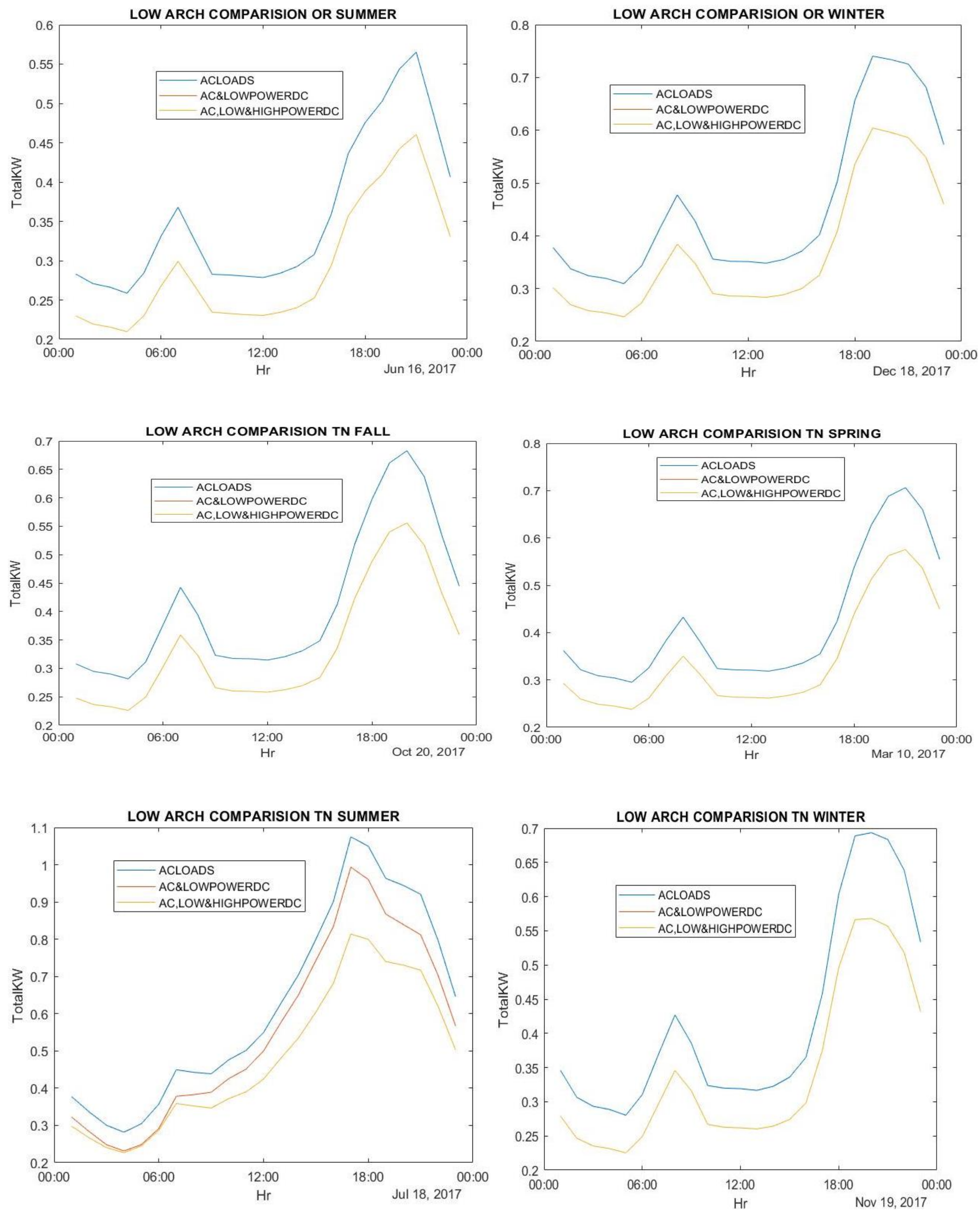

Figure 6.2.3 Low Usage House AC Loads, AC & Low power DC, and AC, Low and High-Power DC Architecture Comparison

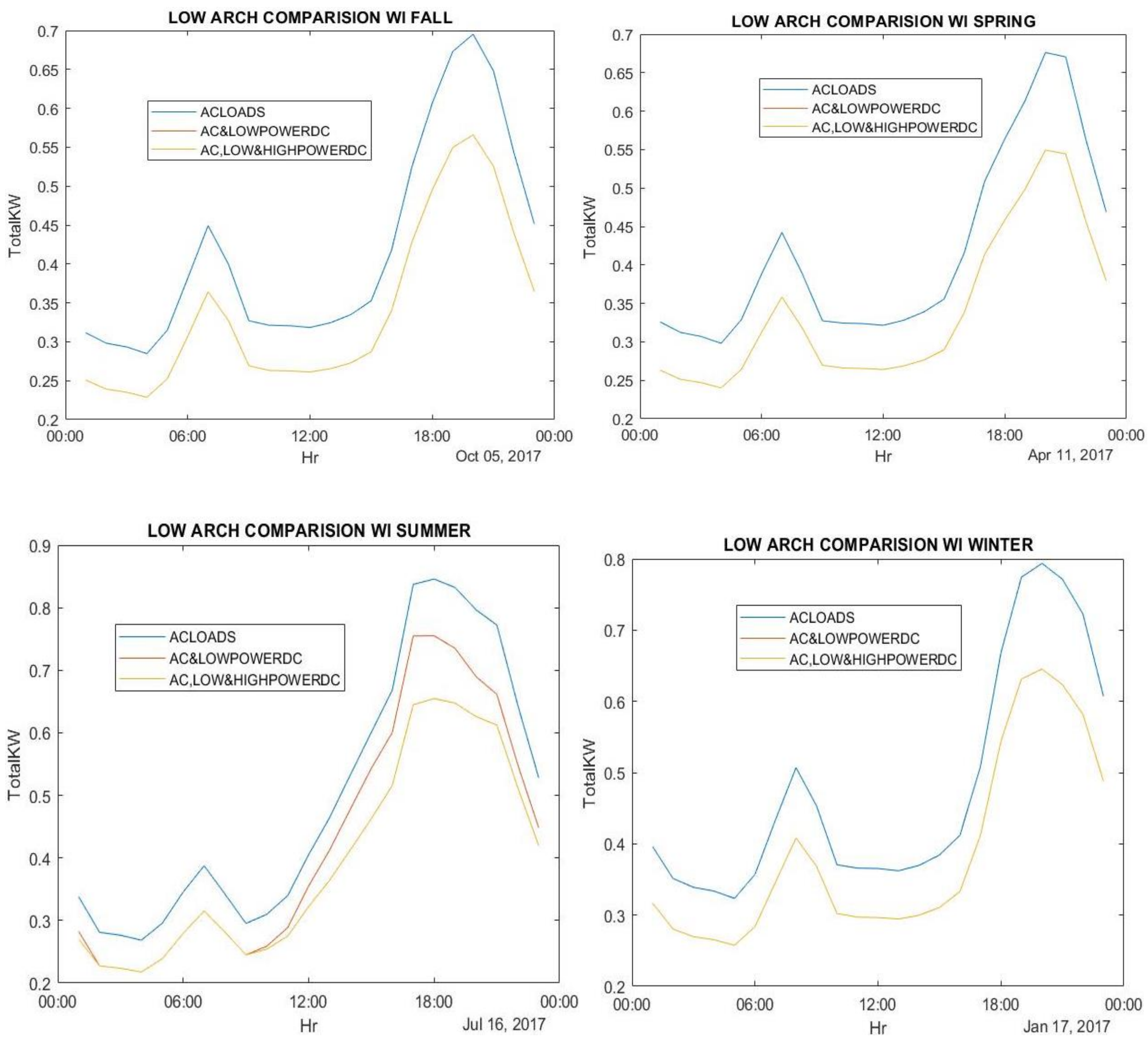

Figure 6.2.3 Low Usage House AC Loads, AC & Low power DC, and AC, Low and High-Power DC Architecture Comparison

6.3 AC Vs DC

Another type of analysis is done statistically and graphically to compare the total energy savings by converting certain number of loads (already stated in the above tables 4,5&6) from AC to DC. So, if all the converted DC loads Kilowatt consumption is compared with their respective AC loads power consumption. The days chosen are same as the one for architecture comparison. The results state quite a reduction in conversion to DC, additionally when compared to fall and spring, peak months summer and winter shows more reduction in the power consumption especially Arizona and Florida. Also, between Base Usage house and High Usage House, high usage house shows more reduction in the power.

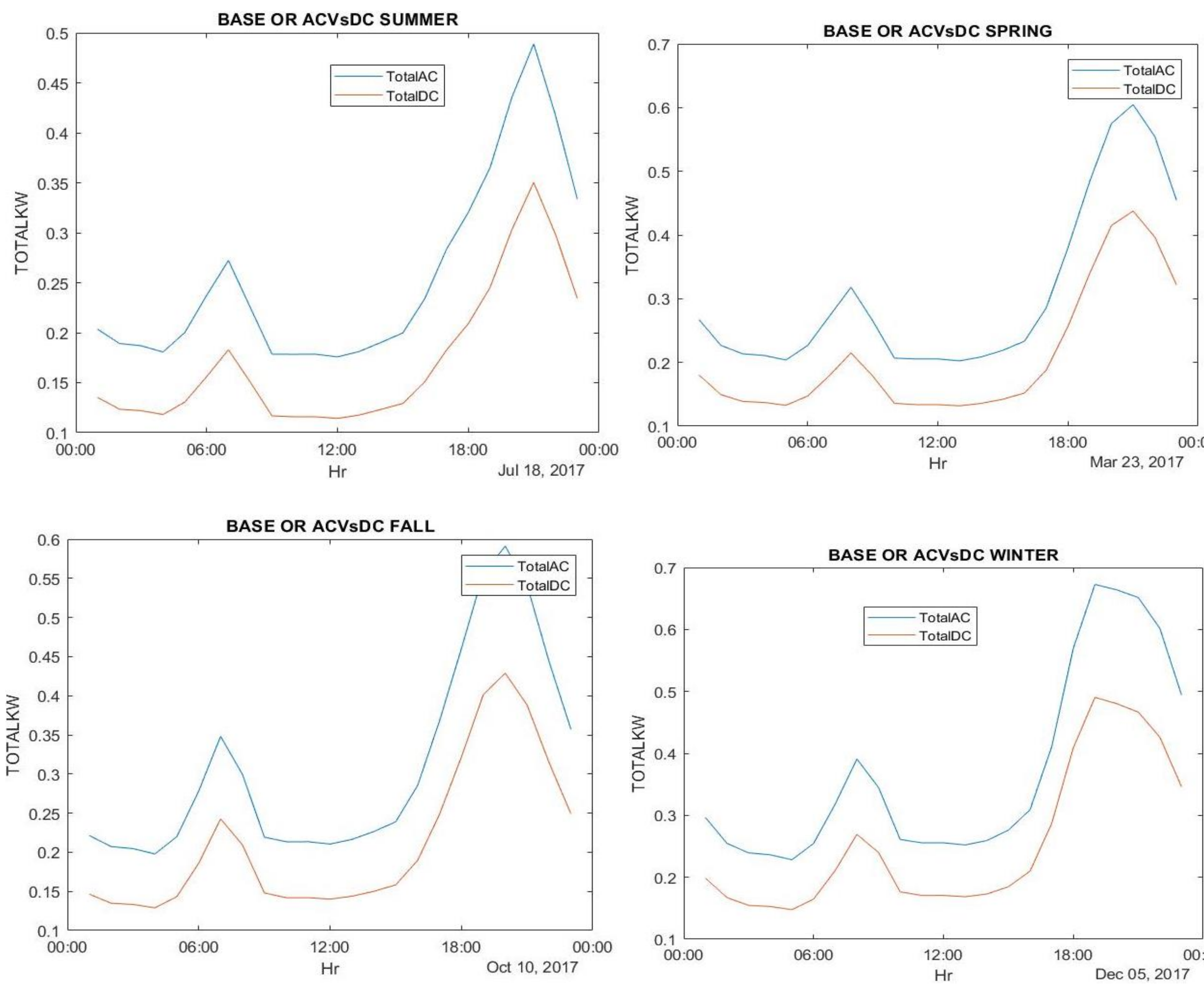

Figure 6.3.1 AC Vs DC Base House

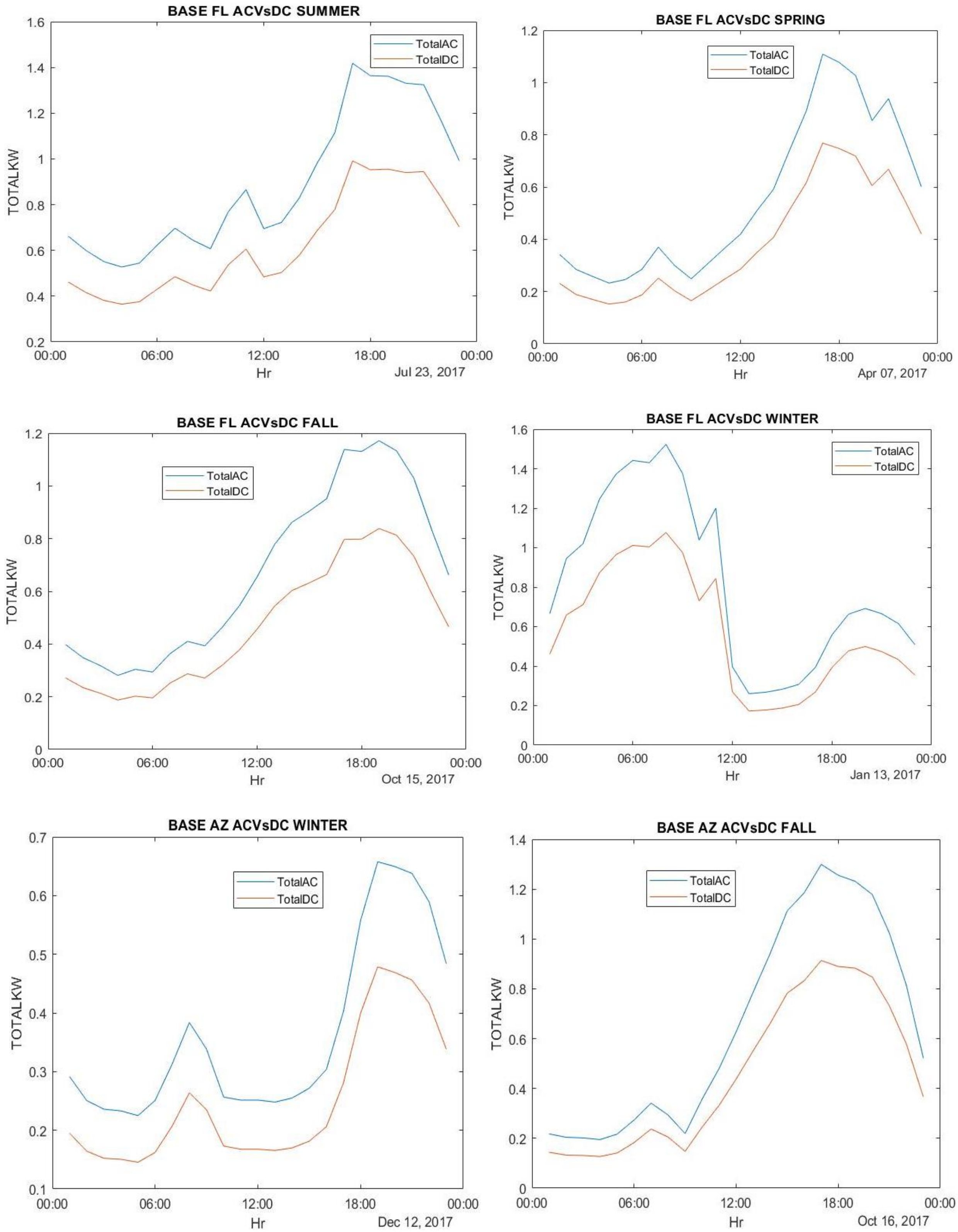

Figure 6.3.1 AC Vs DC Base House

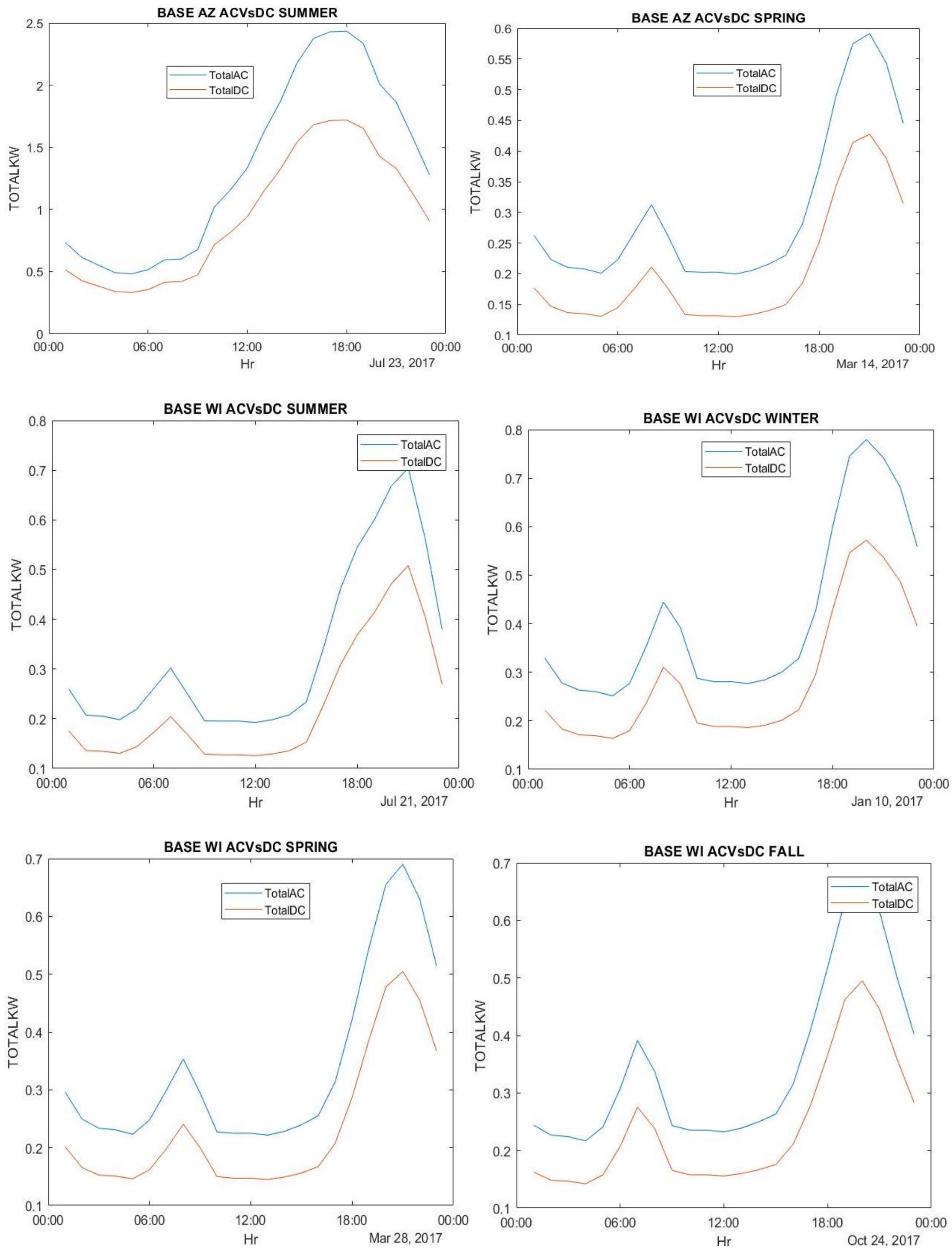

Figure 6.3.1 AC Vs DC Base House

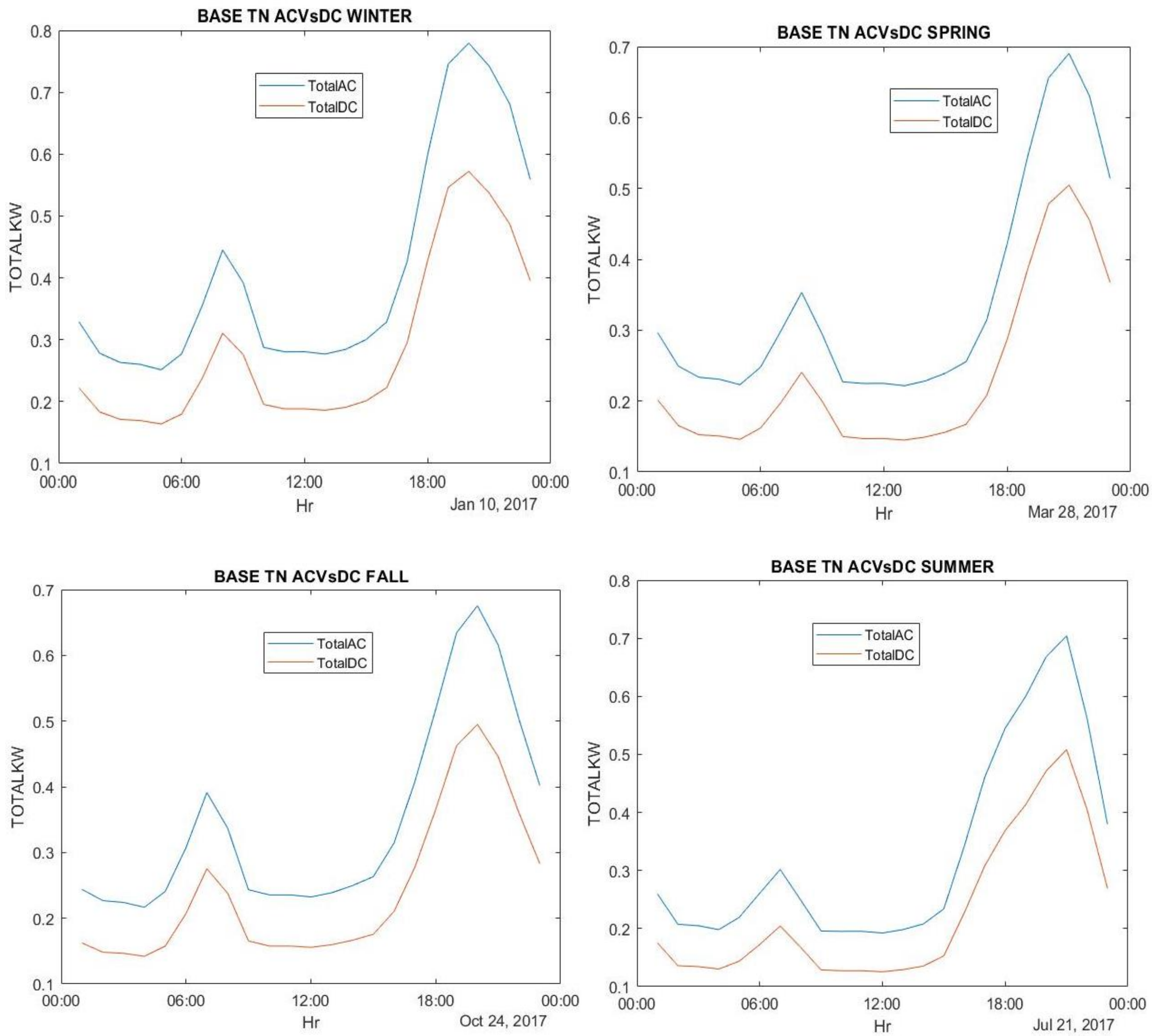

Figure 6.3.1 AC Vs DC Base House

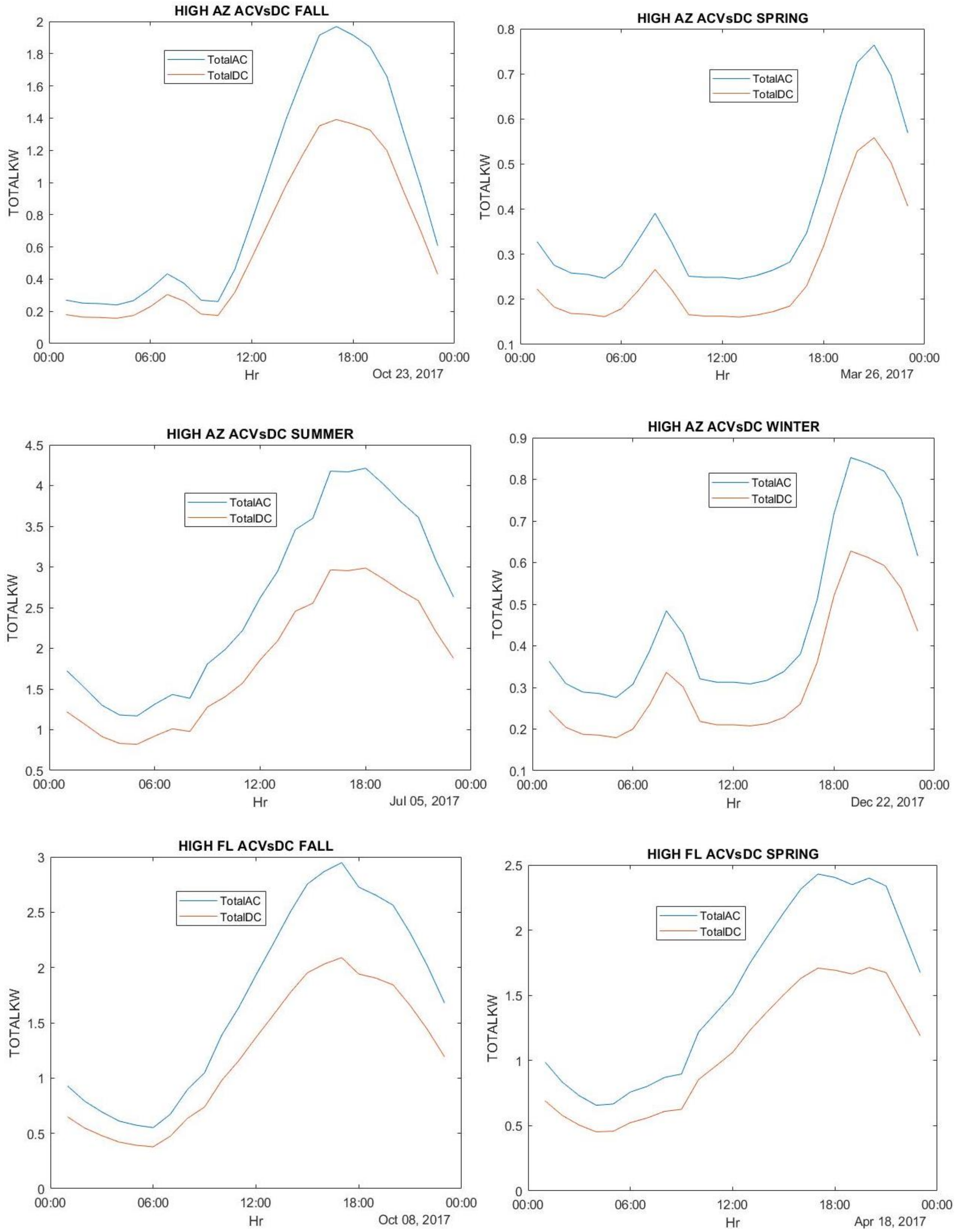

Figure 6.3.2 AC Vs DC High Usage House

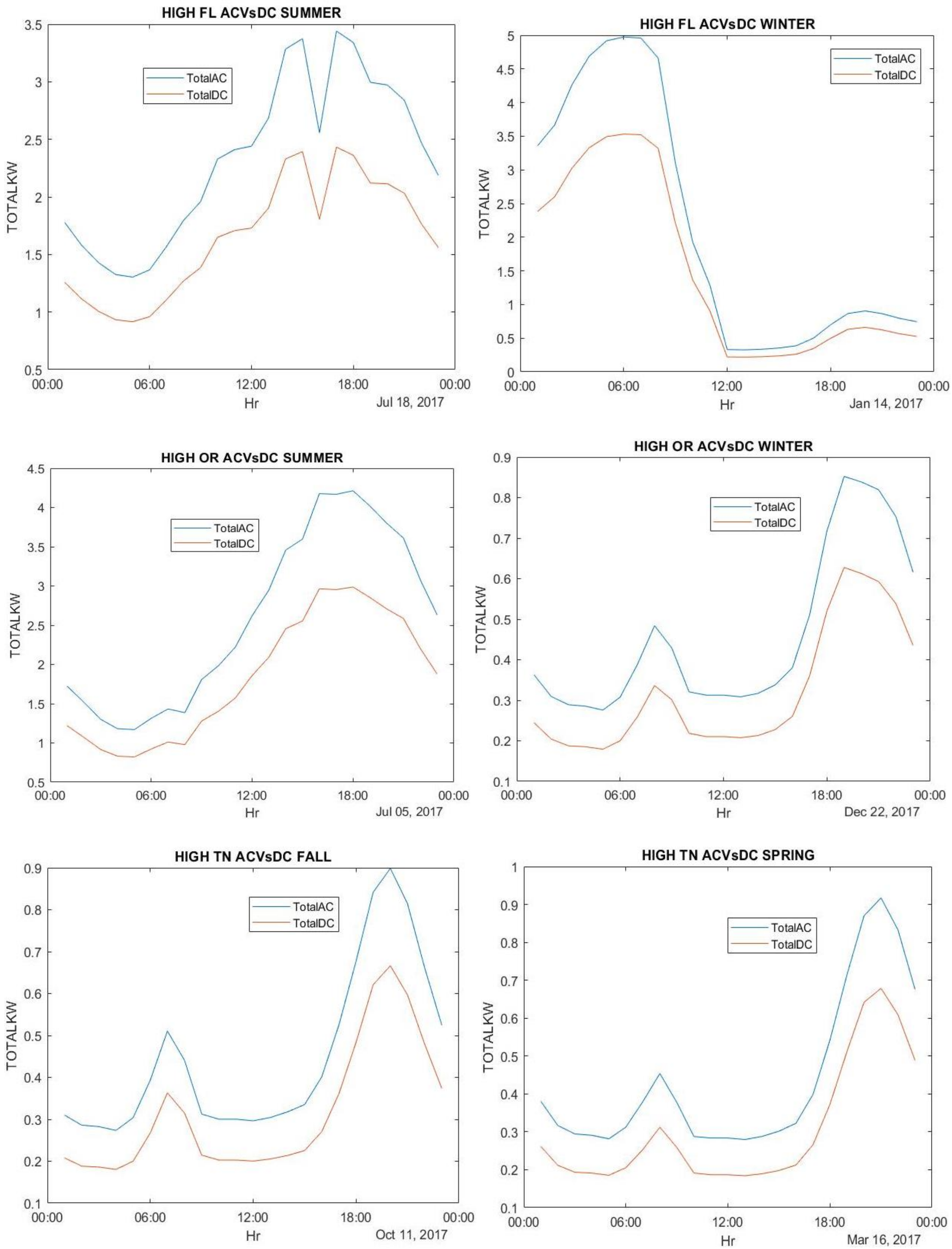

Figure 6.3.2 AC Vs DC High Usage House

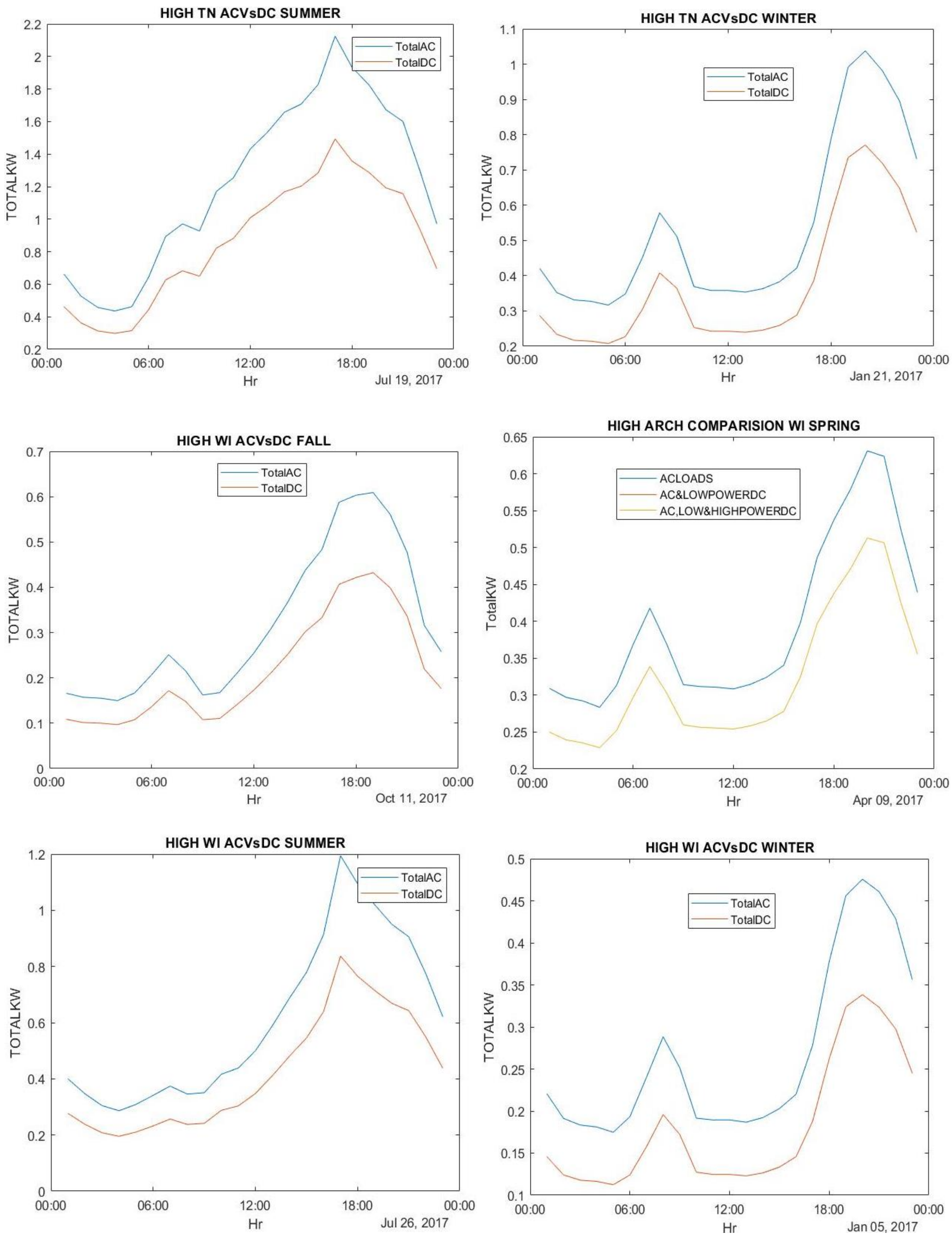

Figure 6.3.2 AC Vs DC High Usage House

7.Percentages of Loads Converted from AC to DC

All data provided in the DOE sheets is not completely taken into current analysis. The total electrical facility KWH column (directly taken from DOE data sheets) is sum of all the electrical loads in the facility which is sum of Heating Electric, cooling Electric, General Interior & Exterior Lightning, HVAC Fan:Fans:Electricity, Electricity:HVAC, General Lightning Interior, General Lightning Exterior, Miscellaneous Loads, Appliances, Water Heater Electric.

AC Loads (From factoring of loads sheet) the loads taken into consideration for analysis is sum of facility is sum Heating Electric, cooling Electric, Total AC LED Lightning Interior & Exterior, Miscellaneous Loads, Appliances.

This analysis is done to see what percentage of loads in AC (only which are plausible to be converted to DC), contribute to the above stated AC Loads and Total electrical facility KWH. In the Low power category AC Low Power is AC LED Interior & Exterior Lightning and Miscellaneous required. In AC High Power AC- Heating, cooling, Lightning LED Interior & Exterior and Miscellaneous required. These percentages state, if it's viable converting loads to DC in different types of homes in different locations. So, the percentages are averaged on monthly basis for AC Low Power Loads for all types of houses in different zones is calculated over Electrical Facility and AC Load. Similarly, AC High Power Loads for all types of houses in different zones is calculated over Electrical Facility and AC Load.

Refer Factoring of loads sheet the corresponding columns are addressed as AC LOW POWER% ELCETRICAL FACILITY, AC LOW POWER%AC LOADS, AC HIGH POWER % ELECTRICAL FACILITY and AC HIGH POWER % AC LOADS. As a result, refer Table IV the percentages of AC LOW POWER% ELCETRICAL FACILITY range from 10%-55%, AC

LOW POWER%AC LOADS 18%-60%, AC HIGH POWER % ELCETRICAL FACILITY 24%-60%, AC HIGH POWER % AC LOADS 40%-77%. From the range of percentages of percentage of loads converted to DC is significant and its worth adapting High power over Low power.

Brief explanation for Table 7,8 & 9

	BASE																			
	AZ				FL				OR				TN				WI			
	ACLOW POWER% ELECTRICA LFACILITY	ACLOW POWER % ACLOADS	ACHIGH POWER % ELECTRICAL FACILITY	ACHIGH POWER % ACLOADS	ACLOW POWER% ELECTRICAL FACILITY	ACLOW POWER % ACLOADS	ACHIGH POWER % ELECTRICAL FACILITY	ACHIGH POWER % ACLOADS	ACLOW POWER% ELECTRICAL FACILITY	ACLOW POWER % ACLOADS	ACHIGH POWER % ELECTRICAL FACILITY	ACHIGH POWER % ACLOADS	ACLOW POWER% ELECTRICAL FACILITY	ACLOW POWER % ACLOADS	ACHIGH POWER % ELECTRICAL FACILITY	ACHIGH POWER % ACLOADS	ACLOW POWER% ELECTRICAL FACILITY	ACLOW POWER % ACLOADS	ACHIGH POWER % ELECTRICAL FACILITY	ACHIGH POWER % ACLOADS
Jan	37.12	47.37	37.12	47.37	27.40	42.63	35.67	53.07	34.24	47.67	34.24	47.67	25.52	49.01	25.52	49.01	30.69	49.46	30.69	49.46
Feb	37.41	46.60	37.41	46.60	27.25	41.87	35.38	52.86	34.58	46.88	34.58	46.88	25.20	48.14	25.20	48.14	30.81	48.57	30.81	48.57
March	35.80	43.85	35.84	43.90	25.39	39.25	33.54	51.22	33.06	44.16	33.06	44.16	24.99	45.43	24.99	45.43	30.47	45.87	30.47	45.87
April	34.54	41.16	38.34	45.76	23.60	35.40	37.06	54.81	34.21	43.30	34.21	43.30	25.66	44.01	26.47	45.25	31.94	44.94	31.94	44.94
May	29.03	34.44	47.18	56.55	20.08	28.46	46.39	64.86	35.87	43.77	35.87	43.77	27.32	41.88	32.46	49.42	34.81	45.30	34.81	45.30
June	18.09	22.19	56.88	69.96	15.60	22.11	50.10	69.98	35.12	41.48	35.12	41.48	20.76	31.61	40.42	59.63	34.59	42.62	35.52	43.75
July	15.08	18.84	59.71	74.14	14.39	20.13	52.50	72.50	35.31	41.46	35.31	41.46	17.08	24.96	47.98	68.39	33.88	40.70	38.62	46.50
August	17.22	21.64	58.69	73.47	15.71	21.66	53.97	73.67	37.16	44.26	37.16	44.26	18.70	26.60	50.04	69.80	35.34	43.06	40.51	49.48
Sept	20.60	25.75	53.51	66.90	15.35	22.06	50.53	71.53	35.26	42.90	35.26	42.90	22.42	34.75	38.21	57.77	35.60	44.40	36.16	45.09
Oct	30.20	37.05	44.69	55.21	20.57	30.77	43.13	63.36	35.06	44.86	35.06	44.86	27.09	44.25	30.09	48.81	34.60	46.68	34.60	46.68
Nov	36.59	45.44	36.59	45.44	24.05	37.41	36.92	56.77	33.40	45.76	33.40	45.76	26.60	47.19	26.60	47.19	32.29	47.67	32.29	47.67
Dec	38.44	48.74	38.44	48.74	28.54	42.82	38.15	55.61	34.45	49.04	34.45	49.04	28.23	50.36	28.23	50.36	32.32	50.80	32.32	50.80

Table 7 Percentage of Loads converted to DC Base House

	HIGH																			
	AZ				FL				OR				TN				WI			
	ACLOW POWER% ELECTRICA LFACILITY	ACLOW POWER % ACLOADS	ACHIGH POWER % ELECTRICAL FACILITY	ACHIGH POWER % ACLOADS	ACLOW POWER% ELECTRICAL FACILITY	ACLOW POWER % ACLOADS	ACHIGH POWER % ELECTRICAL FACILITY	ACHIGH POWER % ACLOADS	ACLOW POWER% ELECTRICAL FACILITY	ACLOW POWER % ACLOADS	ACHIGH POWER % ELECTRICAL FACILITY	ACHIGH POWER % ACLOADS	ACLOW POWER% ELECTRICAL FACILITY	ACLOW POWER % ACLOADS	ACHIGH POWER % ELECTRICAL FACILITY	ACHIGH POWER % ACLOADS	ACLOW POWER% ELECTRICAL FACILITY	ACLOW POWER % ACLOADS	ACHIGH POWER % ELECTRICAL FACILITY	ACHIGH POWER % ACLOADS
Jan	33.61	47.78	33.61	47.78	22.46	35.25	44.28	61.65	31.19	48.18	31.19	48.18	24.27	49.82	24.27	49.82	27.63	50.28	27.63	50.28
Feb	34.53	46.91	34.53	46.91	18.20	26.62	51.82	70.28	31.63	47.30	31.63	47.30	24.06	48.85	24.06	48.85	28.15	49.29	28.15	49.29
March	29.71	40.35	36.98	49.38	18.04	26.50	48.05	67.32	30.36	44.29	30.36	44.29	24.33	45.88	24.33	45.88	28.64	46.33	28.64	46.33
April	27.03	34.98	43.42	55.12	18.69	27.45	46.54	65.67	31.77	43.37	31.77	43.37	22.90	40.28	30.87	51.89	30.71	45.33	30.71	45.33
May	23.00	27.93	53.66	65.17	14.79	20.16	56.78	75.38	33.48	43.70	33.48	43.70	22.44	34.76	40.72	60.19	33.63	45.55	33.63	45.55
June	13.09	16.04	64.80	78.49	11.20	14.97	60.90	79.87	33.02	41.43	33.02	41.43	16.58	24.51	50.21	70.17	27.26	35.79	43.12	55.16
July	11.05	13.58	67.22	81.55	10.37	13.67	62.82	81.50	33.56	41.44	33.56	41.44	13.34	18.63	57.30	77.29	23.90	30.67	49.76	62.49
August	13.02	16.20	65.45	80.30	11.32	14.85	63.53	82.07	35.09	44.13	35.09	44.13	14.77	20.40	58.10	77.58	25.97	33.25	49.02	62.07
Sept	16.07	20.22	60.14	74.62	11.36	15.43	60.48	80.49	32.92	43.02	32.92	43.02	19.50	29.96	44.89	65.30	28.86	39.18	41.06	54.42
Oct	24.36	31.74	49.34	63.11	16.50	24.02	51.56	72.31	32.29	45.23	32.29	45.23	23.66	40.37	34.50	56.10	32.27	47.37	32.27	47.37
Nov	33.36	45.78	33.36	45.78	20.64	31.89	43.16	64.27	30.40	46.22	30.40	46.22	25.47	47.97	25.47	47.97	29.61	48.46	29.61	48.46
Dec	34.65	49.10	34.65	49.10	18.23	26.34	54.67	72.69	31.17	49.50	31.17	49.50	26.64	51.12	26.64	51.12	29.05	51.57	29.05	51.57

Table 8 Percentage of Loads Converted to DC High Usage House

	LOW																			
	AZ				FL				OR				TN				WI			
	ACLOW POWER% ELECTRICA LFACILITY	ACLOW POWER % ACLOADS	ACHIGH POWER % ELECTRICAL FACILITY	ACHIGH POWER % ACLOADS	ACLOW POWER% ELECTRICAL FACILITY	ACLOW POWER % ACLOADS	ACHIGH POWER % ELECTRICAL FACILITY	ACHIGH POWER % ACLOADS	ACLOW POWER% ELECTRICAL FACILITY	ACLOW POWER % ACLOADS	ACHIGH POWER % ELECTRICAL FACILITY	ACHIGH POWER % ACLOADS	ACLOW POWER% ELECTRICAL FACILITY	ACLOW POWER % ACLOADS	ACHIGH POWER % ELECTRICAL FACILITY	ACHIGH POWER % ACLOADS	ACLOW POWER% ELECTRICAL FACILITY	ACLOW POWER % ACLOADS	ACHIGH POWER % ELECTRICAL FACILITY	ACHIGH POWER % ACLOADS
Jan	52.61	58.70	52.61	58.70	36.12	58.30	36.61	58.92	49.13	58.92	49.13	58.92	32.85	59.49	32.85	59.49	45.96	59.72	45.96	59.72
Feb	52.44	58.03	52.44	58.03	35.04	55.73	37.63	59.66	49.61	58.24	49.61	58.24	32.40	58.77	32.40	58.77	46.32	58.98	46.32	58.98
March	50.29	55.29	50.29	55.29	31.93	50.75	37.27	58.98	47.85	55.51	47.85	55.51	31.29	56.08	31.29	56.08	45.87	56.30	45.87	56.30
April	49.48	54.04	50.49	55.17	30.22	46.11	40.87	61.89	49.02	54.88	49.02	54.88	32.17	55.41	32.18	55.41	47.49	55.63	47.49	55.63
May	41.68	45.84	55.68	61.60	26.72	37.28	49.70	69.05	49.93	54.53	49.93	54.53	34.26	53.06	36.62	56.67	49.24	55.23	49.24	55.23
June	27.55	31.20	64.10	72.94	21.62	30.14	53.26	73.92	48.97	53.42	48.97	53.42	27.28	41.69	43.19	64.76	49.15	53.98	49.46	54.33
July	23.31	26.79	66.98	76.91	20.21	27.67	55.87	76.14	48.95	53.49	48.95	53.49	23.11	33.07	51.05	72.36	46.26	51.09	51.40	56.93
August	25.65	29.46	65.53	75.35	21.81	28.83	57.47	75.92	49.37	54.23	49.37	54.23	25.18	34.21	53.38	72.24	46.20	51.37	52.05	58.04
Sept	30.70	35.08	61.90	71.02	21.12	29.68	54.12	75.56	49.36	54.67	49.36	54.67	28.87	44.39	42.44	64.39	49.64	55.39	49.86	55.63
Oct	43.45	48.80	55.59	62.75	26.84	39.69	47.73	69.90	50.72	56.87	50.72	56.87	33.96	55.59	36.10	58.87	50.77	57.71	50.77	57.71
Nov	51.19	57.38	51.19	57.38	30.43	47.52	41.83	64.86	48.87	57.63	48.87	57.63	33.53	58.28	33.53	58.28	48.52	58.53	48.52	58.53
Dec	52.93	59.02	52.93	59.02	37.48	56.62	40.11	60.64	48.80	59.24	48.80	59.24	36.16	59.82	36.16	59.82	47.58	60.05	47.58	60.05

Table 9 Percentage of Loads Converted to DC Low Usage House

8.System component sizing and PV utilization from MATLAB Simulations

Other factor which decides system component sizing is solar irridiance throughout the year. All the respective data from DOE sheets is loaded to MATLAB. Factors derived are used inorder to get the required data for different types of micro grid architectures, types of houses as above stated. PV gain is normalized at 1000W/m^2, typical temp coefficient -1.07, Nominal temp at which PV panels are rated 25. So, solar irradiance data for all locations is collected from NREL website. To calculate system cost PV cost is considered as 640$ / Kw battery cost is 500$ / kWh [15].

Simulation optimization is based on following algorithm. If PV generation is greater than load consumption the difference is stored in the battery, if PV generation is less than load consumption and the battery can supply the difference there is no necessity to import from grid otherwise. If PV generation is greater than load consumption and battery can store remaining PV generated and the rest goes to grid. If PV generation is less than load consumption and battery can source only part, rest is imported from the grid.

Based on total KWH consumption range of battery and size of PV panel are set so, that the loci point minima of simulation curves are used as point of reference to decide optimum PV and Battery sizes as shown in the Table 10,11,13

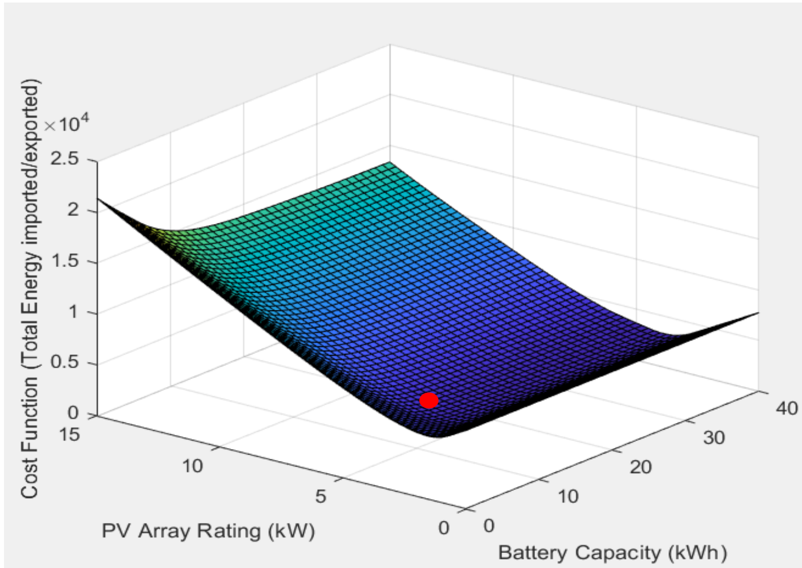

Figure 8.1 Loci point for minimizing size of PV, Battery and cost for, Milwaukee Base House ALL AC Loads

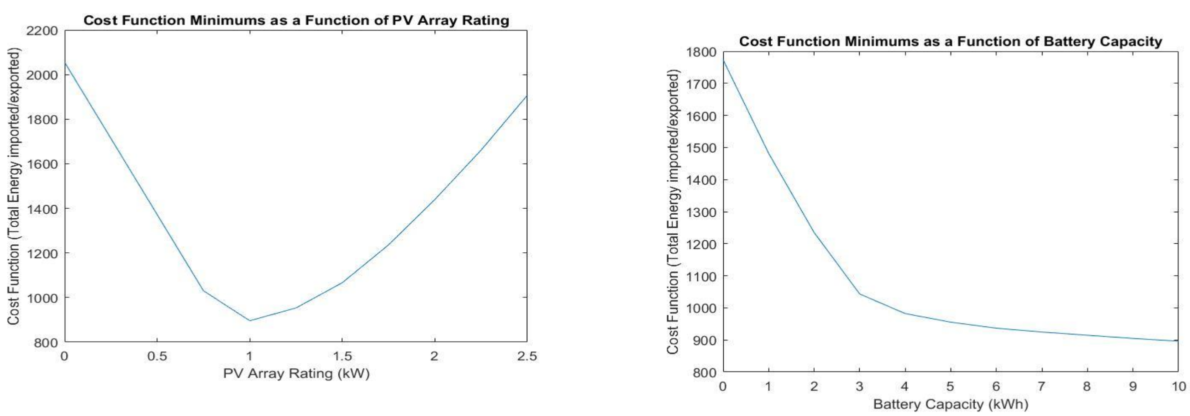

Figure 8.2 True Cost Loci point for minimizing size of PV, Battery and cost for Milwaukee Base House

Similarly, yearlong analysis is carried out on Milwaukee based Low power DC to see how much is imported and exported from the grid based on the size of PV and battery concluded from the Loci point analysis

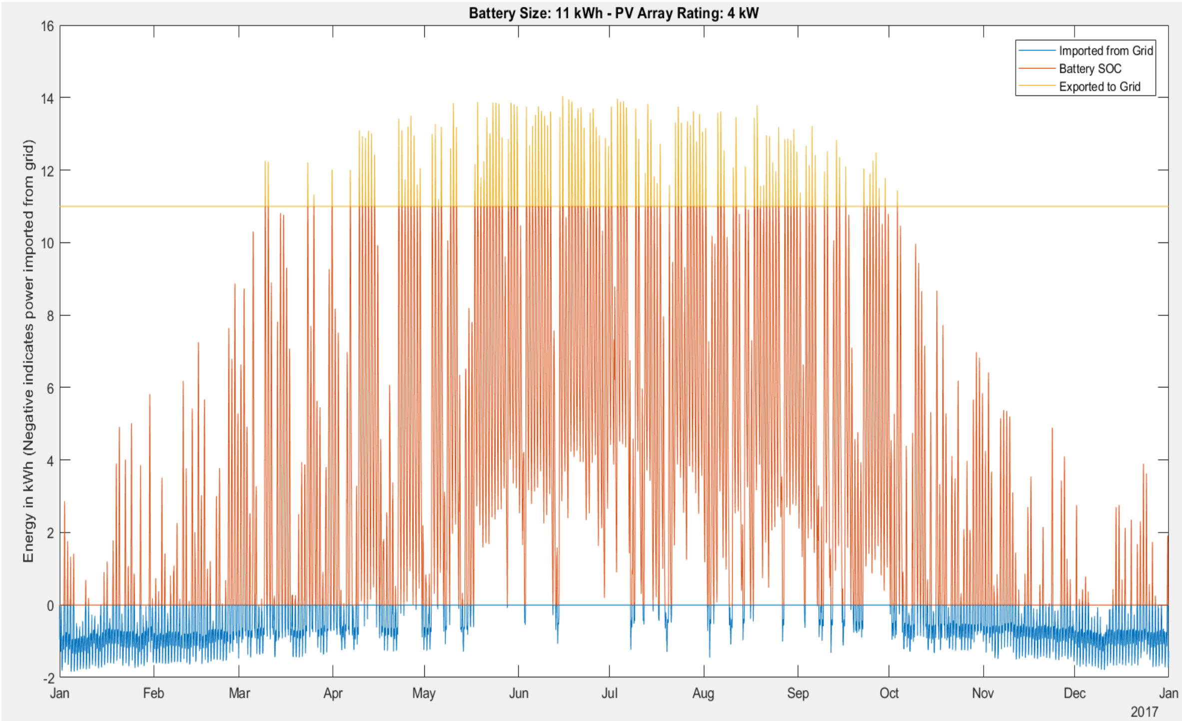

Figure 8.3 Milwaukee Base (Typical Home), servicing all AC loads

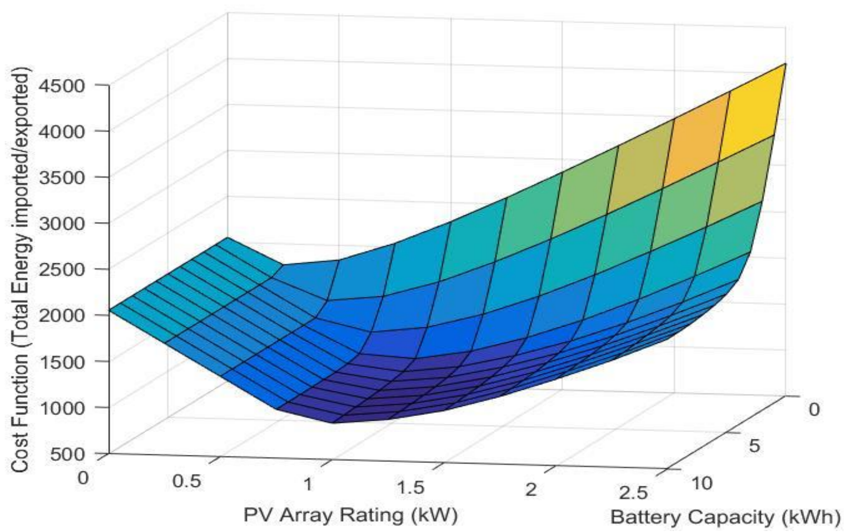

Figure 8.4 Loci point for minimizing size of PV, Battery and cost for Low Powered DC, Milwaukee

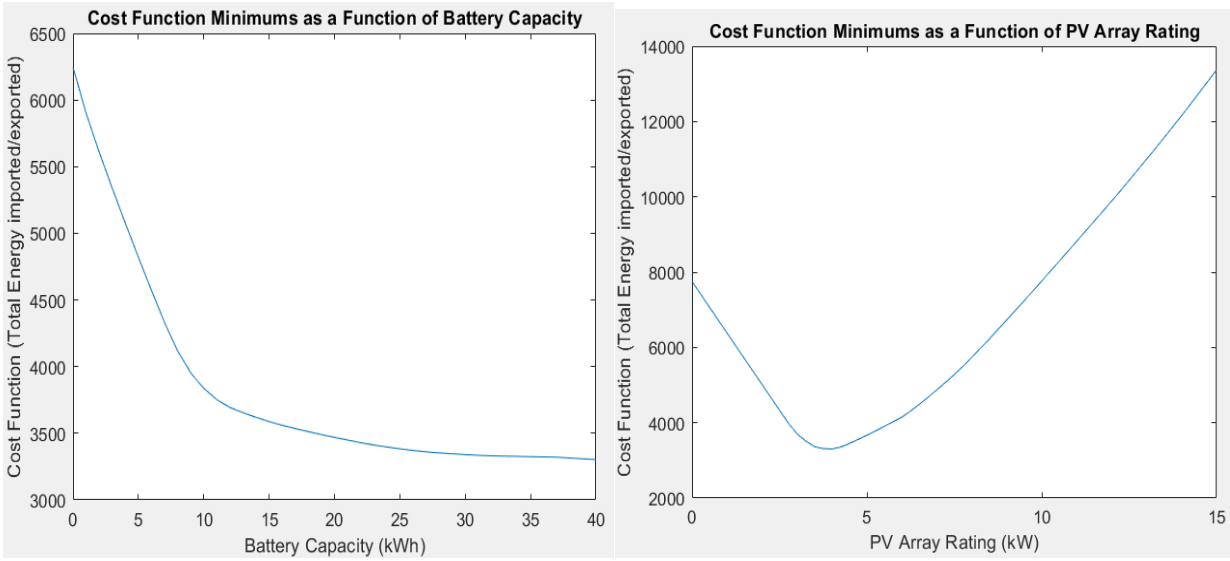

Figure 8.5 True Cost Loci point for minimizing size of PV, Battery and cost for Low Powered DC, Milwaukee Base House

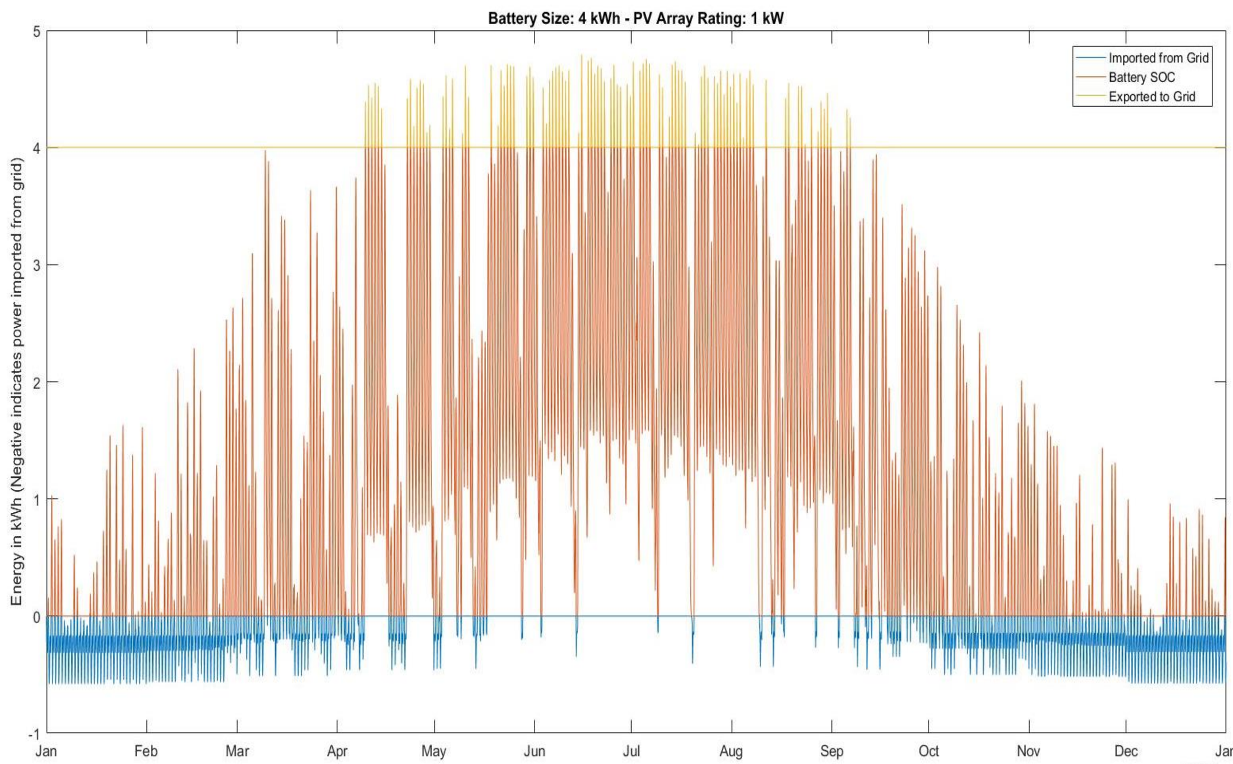

Figure 8.6 Milwaukee Base (Typical Home), Distributed 48VDC servicing Low powered DC loads

From analysis in table 10, the PV utilization is on an average above 0.8, which is a good utilization. Total PV sizing for base house and Low house for all regions is around the estimation of US average system size which is 5Kw [14]. The sizing of the PV panels and battery for high usage house is higher than the average house, but the payback period for it is least compared to low and base usage houses.

Home	PV size (kW)	Battery size (kWh)	PV Utilization	New System Energy / All AC Home	Total Energy Consumed by AC House w/LEDS (kWh/yr)	kWh Saved per year	$ Saved per year on Electricity	Estimated System Cost
Tucson AZ Base	5.25	12	0.8506	0.1716	9826	8139.858	1058.182	22869
Tucson AZ High	7.5	18	0.8833	0.2308	16483	12678.72	1648.234	30570
Tucson AZ Low	3	8	0.7865	8.22000E-02	4920	4515.576	587.0249	17168
Tampa FL Base	8	18	0.8283	0.1364	13184	11385.7	1480.141	30948
Tampa FL High	13	32	0.8682	0.1879	23882	19394.57	2521.294	48728
Tampa FL Low	4.5	12	0.8261	8.78E-02	7001	6386.312	830.2206	22302
Portland OR Base	3.3	7	0.8579	0.4817	6641	3442.03	447.4639	16394.8
Portland OR High	4.5	10	0.8724	0.479	9161	4772.881	620.4745	17559.53
Portland OR Low	2	5	0.8448	0.4462	3709	2054.044	267.0257	13412
Nashville TN Base	7.2	16	0.851	0.2313	11828	9092.184	1181.984	28343.2
Nashville TN High	12	23	0.8196	0.1985	18207	14592.91	1897.078	38972
Nashville TN Low	4	11	0.8697	0.2327	6727	876.5281	113.9487	20924
Milwaukee WI Base	4	11	0.8619	0.392	7752	4713.216	612.7181	20924
Milwaukee WI High	7.5	16	0.8061	0.3304	12342	8264.203	1074.346	28570
Milwaukee WI Low	3	6	0.7044	0.2917	4078	2888.447	375.4982	15168

Table 10 System component sizing summary from MATLAB Simulations All AC LOADS

Assuming sizing of PV and battery only supporting these loads AC Loads

AC-Cooling+Heating+LEDLightning+Misc required+ Appliances. All the data of loads remain intact except lightning is converted to AC LED.

	Ignore Nov,Dec,Jan		Including Nov,Dec,Jan								
Home	PV size (kW)	Battery size (kWh)	PV size (kW)	Battery size (kWh)	PV Utilization	LowPower DCLoads as % of Total	New System Energy / All AC Home	Total Energy Consumed by AC House w/LEDS (kWh/yr)	kWh Saved per year	$ Saved per year on Electricity	Estimated System Cost
Tucson AZ Base	0.75	3	0.75	3	0.9159	0.2679	0.7807	9826	2154.8418	280.12943	10467
Tucson AZ High	1	4	1	4	0.9447	0.2342	0.8228	16483	2920.7876	379.70239	11656
Tucson AZ Low	0.5	2	0.5	2	0.9527	0.3975	0.6836	4920	1556.688	202.36944	9278
Tampa FL Base	0.75	3	1	3.5	0.8748	0.21	0.8184	13184	2394.2144	311.24787	11156
Tampa FL High	1.25	5	1.25	5	0.9486	0.1704	0.865	23882	3224.07	419.1291	12845
Tampa FL Low	0.5	2	0.75	3	0.8501	0.2787	0.7515	7001	1739.7485	226.16731	10467
Portland OR Base	0.75	3	0.75	3	0.9481	0.4036	0.7415	6641	1716.6985	223.17081	10467
Portland OR High	1.25	4	1.25	4	0.8969	0.433	0.7271	9161	2500.0369	325.0048	11845
Portland OR Low	0.5	3	0.5	3	0.9873	0.5363	0.662	3709	1253.642	162.97346	10278
Nashville TN Base	0.75	3	1	3	0.8763	0.2457	0.8103	11828	2243.7716	291.69031	10656
Nashville TN High	1.25	5	1.25	5	0.9672	0.2433	0.833	18207	3040.569	395.27397	12845
Nashville TN Low	0.5	3	0.5	3	0.9983	0.3091	0.7892	6727	1418.0516	184.34671	10278
Milwaukee WI Base	0.75	4	1	4	0.8926	0.3854	0.7223	7752	2152.7304	279.85495	11656
Milwaukee WI High	1.25	5	1.25	5	0.9548	0.3704	0.7641	12342	2911.4778	378.49211	12845
Milwaukee WI Low	0.5	3	0.75	3	0.8703	0.5191	0.6127	4078	1579.4094	205.32322	10467

Table 11 System component sizing summary from MATLAB Simulations LOW POWER DC LOADS

Assuming sizing of PV and battery only supporting these loads LOWPOWERDCLOADS DCLEDLightning+DCMiscellaneous.

Table 11 explanation

- Column PVutilization = (sum(PVpowergen) - sum(GridExportBucket))/sum(PVpowergen)
- Computing facility total AC power if all lighting was converted to LED is the column with title So, in the DOE datasheets as previously stated, the exterior & interior lightening loads power consumption is combination of CFL, fluorescent and incandescent and if this power consumption is subtracted from the entire electrical facility power consumed and add the

Lightening loads power consumption if they were converted to AC LED then the total power consumed is the "Total Energy Consumed by AC House w/LEDS (kWh/yr)"

FacilityACwLED=ElectricityFacilitykWHourly1-GeneralExteriorLightsElectricitykWHourly1-GeneralInteriorLightsElectricitykWHourly1+ TotalACLEDExterior + TotalACLEDInterior.

- Column New system energy/ All AC Homes

PV and battery are only supporting these loads LOWPOWERDCLOADS which are DCLEDLightning and DCMiscellaneous. So, total power consumed by the new house setup can be obtained subtracting these loads in AC from the total Electrical Facility and adding the power if being any imported from the grid, will give us

NewHousePowerConsumed = ElectricityFacilitykWHourly1 - GeneralExteriorLightsElectricitykWHourly1 - GeneralInteriorLightsElectricitykWHourly1 - MiscRequired + GridImportBucket this is divided over power consumption of All AC Loads

New system energy/ All AC Homes = sum(NewHousePowerConsumed)/sum(FacilityACwLED)

- Column Kwh saved per year

Total Energy Consumed by AC House w/LEDS (kWh/yr)- NewHousePowerConsumed

- Low power DC Loads, if they were considered in AC power consumption and as a percentage of total AC loads power consumption they contribute between 21%-40% vary the Base Usage house

- Estimated Sytems Costs

  PVcost = 640 in $ per kW

  Battcost = 500 in $ per kWh

Note- There are other values that can be chosen from the NREL Installed Cost Benchmarks and Deployment Barriers for Residential Solar Photovoltaics with Energy Storage: Q1 2016

Category	**Estimated Cost***
PV Modules	1Kw*640=640
Li-ion Battery	4Kwh*500=2000
AC/DC Converter	600
Structural BOS	116
Electrical BOS	1000
Supply Chain Costs	200
Sales Tax	200
Installation Labor	1600
Permitting, etc.	800
Overhead	500
Sales & Marketing + Net Profit	2000
Total	**$11,656**

Table 12 Breakdown of the all the costs, in this case Milwaukee base house

	Ignore Nov,Dec,Jan		Including Nov,Dec,Jan							
Home	PV size (kW)	Battery size (kWh)	PV size (kW)	Battery size (kWh)	PV Utilization	HighPowerDCLoads as % of Total	New System Energy / All AC Home	Total Energy Consumed by AC House w/LEDS (kWh/yr)	kWh Saved per year	$ Saved per year on Electricity
Tucson AZ Base	1.5	4	1.5	4	0.8715	0.5499	0.5794	9826	4132.82	537.26603
Tucson AZ High									0	0
Tucson AZ Low									0	0
Tampa FL Base	1.75	6	1.75	5	0.9356	0.4515	0.6501	13184	4613.08	599.70061
Tampa FL High									0	0
Tampa FL Low									0	0
Portland OR Base	0.75	3	0.75	3	0.9481	0.4036	0.7415	6641	1716.7	223.17081
Portland OR High									0	0
Portland OR Low									0	0
Nashville TN Base	1.5	5	1.5	5	0.9184	0.3793	0.712	11828	3406.46	442.84032
Nashville TN High									0	0
Nashville TN Low									0	0
Milwaukee WI Base	1	4	1	4	0.9149	0.4006	0.7141	7752	2216.3	288.11858
Milwaukee WI High									0	0
Milwaukee WI Low									0	0

Table 13 System component sizing summary from MATLAB Simulations High Power DC LOADS

High-power DC Loads

Assuming sizing of PV and battery only supporting these loads DC Cooloing+DC Heating+DC LEDLightning+DCMisc.

Since, target was an average individual home owner, only detail analysis is done on Base case.

- Column PVutilization = (sum(PVpowergen) - sum(GridExportBucket))/sum(PVpowergen)
- Computing facility total AC power if all lighting was converted to LED is the column with title So, in the DOE datasheets as previously stated, the exterior & interior lightening loads power consumption is combination of CFL, fluorescent and incandescent and if this power consumption is subtracted from the entire electrical facility power consumed and add the

Lightening loads power consumption if they were converted to AC LED then the total power consumed is the "Total Energy Consumed by AC House w/LEDS (kWh/yr)"

FacilityACwLED=ElectricityFacilitykWHourly1-GeneralExteriorLightsElectricitykWHourly1-GeneralInteriorLightsElectricitykWHourly1+ TotalACLEDExterior + TotalACLEDInterior.

- Column New system energy/ All AC Homes

PV and battery are only supporting these loads HIGHPOWERDCLOADS which are DCLEDLightning, DCMiscellaneous and Cooling DC. So, total power consumed by the new house setup can be obtained subtracting these loads in AC from the total Electrical Facility and adding the power if being any imported from the grid, will give us

NewHousePowerConsumed = ElectricityFacilitykWHourly1 - GeneralExteriorLightsElectricitykWHourly1 - GeneralInteriorLightsElectricitykWHourly1 - MiscRequired - CoolingElectricitykWHourly1+ GridImportBucket this is divided over power consumption of All AC Loads

New system energy/ All AC Homes = sum(NewHousePowerConsumed)/sum(FacilityACwLED)

- Column Kwh saved per year

Total Energy Consumed by AC House w/LEDS (kWh/yr)- NewHousePowerConsumed

- High power DC Loads, if they were considered in AC power consumption and as a percentage of total AC loads power consumption they contribute between 37%-55% for the base house

9.Conclusions

- Component size range for “typical” US homes for converting Low Powered Loads into DC cost between 10000-13000$ and percentage of Low powered DC loads as total power consumed by the entire loads range between 17%-51% based on the type of the House from Table 11.
- Lighting and electronics comprise **21 – 40%** of total home electrical energy consumed per year
- Homes equipped with this system achieve **87 – 91%** utilization of onsite generated energy
- Total home energy consumption from the grid for the Base Usage House with Low Power DC Micro grid architecture, can be reduced **18 – 28%** with this system **(1716 – 2394 kWh/year)**
- Reduction in Utility Bill by converting at least certain loads into DC as stated.
- A net-zero energy community is more likely plausible in comparison with the individual homes.
- From the community based as well individual homes it is observed that the major share of power generated by the solar panels installed is in excess between 9.00am to 5.00pm, this is because most of the demand is other than those hours. So, having properly sized battery is very crucial. More analysis must be done to reduce the Battery Management System cost.
- All the different types of analysis done in this document will serve as input to designing grids and estimating approximate sizing of converters, protection systems for community based houses as well individual home owner

10.Future Scope

So, far analysis was done to give a direction for designing optimal microgrid, for type of house and location and as well to verify how promising is to convert certain portion of loads into DC or what percentage of loads must be converted to DC based on the type of house, since, this is the base for KWH consumption. Also, a rough estimate of sizing of PV panels, battery is analyzed along with cost of installation. But for the future work, benchmark is to achieve minimum net energy usage cost. So, the following factors must be taken into consideration

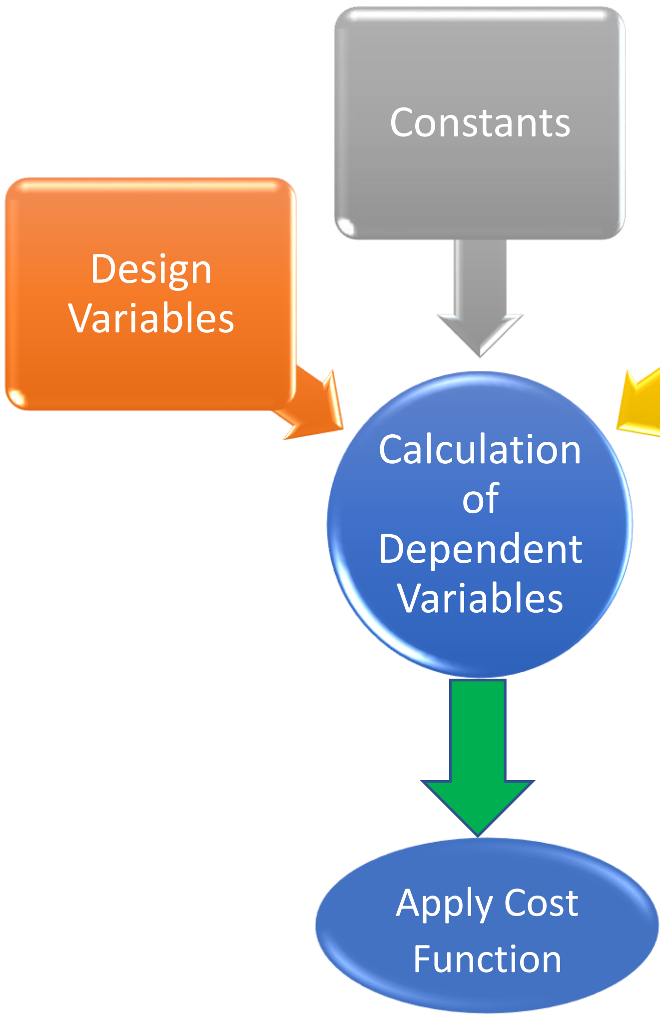

Figure 10.1 Flow Chart of Parameters

Any product or proposal depends on feasibility, viability and human factors. So, for future work all parameters in the above figure should be considered. Design variables such a season, region, types of houses, architectures were taken into consideration (human factors and viability), also constants such as appliances cost, material cost, PV installation cost, panel cost, and battery cost should be included (feasibility and viability).

Meeting cost requirements such as savings for the installation (human factors) is very crucial as all the factors are interdependent. Such as, designing of the different microgrid architectures for real time analysis and, sizing of converters inverters and in-depth working on protection systems. So, that one can propose of all the designs, which is best feasible, viable option for type of houses across the country.

References

1. https://www.nrel.gov/docs/fy14osti/60988.pdf

2. https://openei.org/doe-opendata/dataset/eadfbd10-67a2-4f64-a394-3176c7b686c1/resource/cd6704ba-3f53-4632-8d08-c9597842fde3/download/buildingcharacteristicsforresidentialhourlyloaddata.pdf

3. https://openei.org/datasets/dataset/commercial-and-residential-hourly-load-profiles-for-all-tmy3-locations-in-the-united-states

4. http://www.dcairco.com/uploads/consumption-20comparison-20ac-20vs-20dc-20air-20conditioners-20-20www.dcairco.pdf

5. http://www.eesi.org/papers/view/fact-sheet-air-conditioner-efficiency-standards-seer-13-vs.-seer-12

6. https://en.wikipedia.org/wiki/Seasonal_energy_efficiency_ratio

7. http://www.geinnovations.net/Specifications.html

8. A. Jhunjhunwala et al., "Energy efficiency in lighting: AC vs DC LED lights," 2016 First International Conference on Sustainable Green Buildings and Communities (SGBC), Chennai, 2016, pp. 1-4.

9. https://www.eia.gov/analysis/studies/demand/miscelectric/pdf/miscelectric.pdf

10. https://www.kompulsa.com/how-much-power-are-your-appliances-consuming/#refrigerators

11. https://deepblue.lib.umich.edu/bitstream/handle/2027.42/106035/me589f13section881project8_report.pdf

12. http://products.geappliances.com/appliance/gea-support-search-content?contentId=16932

13. https://www.energyvanguard.com/blog/29092/Know-Your-Terms-Heat-Pump-Efficiency-Ratings-SEER-HSPF

14. https://news.energysage.com/how-much-does-the-average-solar-panel-installation-cost-in-the-u-s/

15. https://www.nrel.gov/docs/fy17osti/67474.pdf

16. https://www.nrel.gov/docs/fy18osti/70196.pdf

17. NEMA Draft DC in building

18. Frank Sharp, Dennis Symanski, “Scalable DC Micro Grids Provide Cost Effective Electricity in Regions without Electric Infrastructure”, IEEE Global Humanitarian Technology Conference.

19. https://www.theatlantic.com/business/archive/2016/06/energy-povertylow-income-households/486197/

20. K. Palaniappan, S. Veerapeneni, R. Cuzner and Y. Zhao, "Assessment of the feasibility of interconnected smart DC homes in a DC microgrid to reduce utility costs of low income households," 2017 IEEE Second International Conference on DC Microgrids (ICDCM), Nuremburg, 2017, pp. 467-473.doi: 10.1109/ICDCM.2017.8001087

21. http://www.caba.org/CABA/DocumentLibrary/Public/AC-DC-Microgrids-Part-1.aspx?WebsiteKey=451e6c9e-f8f5-4af2-b355-ee1dbdd2c908

22. http://www.geinnovations.net/solar_air_conditioner.html

23. Dr. Mahesh Rao,Energy efficient Ceiling fans using BLDC motors- A practical implementation”.

24. https://www.energystar.gov/products/water_heaters/high_efficiency_electric_storage_water_heaters/how_it_works

25. R. Fu, D. Chung, T. Lowder, D. Feldman, K. Ardani, and R. Margolis, “U.S. Solar Photovoltaic System Cost Benchmark: Q1 2016”, National Renewable Energy Laboratory (NREL), Technical Report NREL/TP-6A20-66532, Sept. 2016.

26. K. Ardani, E. O’Shaughnessy, R. Fu, C. McClurg, J. Huneycutt, and R. Margolis, “Installed Cost Benchmarks and Deployment Barriers for Residential Solar Photovoltaics with Energy Storage: Q1 2016”, National Renewable Energy Laboratory (NREL), Technical Report NREL/TP-7A40-67474 February 2017.