ELECTRIC POWER RESEARCH INSTITUTE

Variable Capacity Residential Heat Pumps

Evaluation of Field Performance for SDG&E

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Technical Update, February 2016

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ABSTRACT

Variable capacity heat pumps (VCHPs) have the ability to deliver capacity below and above their nominal rated capacity by changing the speed of the compressor and modulating ancillary components like fans and expansion valves. This flexibility allows for similar component sizes to provide a wider range of delivered capacity. Variable capacity is a promising technology for addressing the imbalance between heating and cooling load demands, while maintaining proper cooling and dehumidifying ability under part-load.

This report examines variable capacity technology for a common U.S. residential application, the ducted, split configuration. The site selected for this demonstration of VCHP technology is a condominium building in Escondido, California. The selected site is in California climate zone 10 (CZ 10), which encompasses the interior hills and valleys of Southern California. The existing heating, ventilation, and air conditioning (HVAC) system, consisting of a single speed split heat pump system, was replaced in two of four units with VCHPs from Carrier's Greenspeed line of heat pumps. Instrumentation was installed to monitor electrical and thermal characteristics of the baseline and VCHP systems. The baseline and treatment systems were monitored for a period of one full year, from April 2014 to March 2015.

The data shows a demand reduction on the order of 1.2 kW can be achieved by using a VCHP unit. This reduction aggregated over a large population can provide significant demand reduction. Estimating energy savings was difficult with the given data set since neither the occupancy data nor the set points on thermostats were available. To estimate occupancy an averaging methodology was used to determine heat pump operating hours. A conservative estimate of 30% energy savings over code minimum system was observed for the condos that were monitored. The energy savings and demand reduction demonstrated in this study can be achieved at other similar installations.

Keywords
Variable capacity heat pumps
Energy efficiency
Residential heating, ventilation, and air conditioning (HVAC)

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1 INTRODUCTION

Variable Capacity Split Heat Pump

Variable capacity heat pumps have the ability to modulate capacity delivered below and often above their nominal rated capacity by changing the speed of the compressor and modulating ancillary components like fans and expansion valves. This flexibility allows for similar component sizes to provide a wider range of delivered capacity. Where traditional air-source heat pumps often rely on backup heat in the winter, variable capacity heat pumps may be able to provide the required heating capacity with no or less backup heat by running at high compressor speed. Variable capacity systems can also run at reduced capacity during lower load conditions, eliminating the losses associated with system cycling. Variable capacity is a promising technology for addressing the imbalance between heating and cooling load demands, while maintaining proper cooling & dehumidifying ability under part-load. In the context of this work, the air-to-air, split systems will be called variable capacity heat pumps (VCHPs) though the variable capacity descriptor could apply to other systems as well.

VC technology offers numerous benefits to the electric utility industry, including: efficiency improvement, power demand reduction, improved demand response capability, and the ability to satisfy heating loads in traditional fossil-fuel heating territories. For further details on the applicability of VC technology to the electric utility industry, refer to *Thermal Resources for Load Management: Understanding Variable Capacity HVAC Systems as a Load Management Resource* [1]. This report examines VC technology for a common U.S. residential application, the ducted, split configuration. For information on VC for the most common U.S. commercial application, refer to *Assessment of Commercial Space Conditioning Technologies: Variable Capacity Rooftop Units* [2].

U.S. Residential Variable Capacity Market

A common U.S. residential, space conditioning configuration is the ducted, split system. Split refers to the system including both an indoor unit and an outdoor unit. Ducted refers to a network of ductwork which supplies the conditioned air into the conditioned space. Recently, the number of available VC products in the ducted, split configuration has significantly increased for the U.S. market. Table 1-1 provides a list of HVAC manufacturers which make up approximately 97% of the U.S. market, according to a 2008 Department of Energy survey [3]. In 2012, two of these HVAC manufacturers were producing VC systems with an overall total of two to three available product lines. In 2015, eight manufacturers are producing VC products with an overall total of over ten available product lines. Other manufacturers not shown in the table are producing VC equipment for residential and commercial applications.

Table 1-1
Commercially Available Variable Capacity Heat Pumps

Manufacturer	Series	AC	HP	SEER[1]	HSPF[1]	Size (tons)
American Standard	Platinum ZV	-		21		2-5
	Platinum ZV		-	20	10	2-5
	Platinum XV	-		18		2-5
	Platinum XV		-	18	10	2-5
Bryant	Evolution Extreme		-	20.5	13	2-5
	Evolution		-	18	11	2-3
	Evolution	-		19		2-3
Carrier	Infinity 20 Greenspeed		-	20.5	13	2-5
	Infinity 18VS		-	18	11	2-5
	Infinity 19VS	-		19		2-3
Daikin	SkyAir		-	20	12	1.5-3.5
Goodman	DX20VC	-		24.5		2-5
Lennox	XC25	-		25		2-5
	XP25		-	23.5	10.2	2-5
Nordyne[2] (iQ Drive)	FS4BI	-		24.5		2-4
	FT4BI		-	21	9.6	2-4
	FT4BG		-	19	10	2-5
Trane	XV20i	-		21		2-5
			-	19.75	10	2-5
	XV18	-		18		2-5
			-	18	10	2-5

The Seasonal Energy Efficiency Ratio (SEER) and the Heating Seasonal Performance Factor (HSPF) are efficiency metrics for cooling and heating seasons, respectively. For residential size unitary systems, SEER and HSPF are determined by procedures outlined in AHRI Standard 210/240 [4]. The nominal efficiency of the available VC, ducted split products range from 17 to ~24 SEER and 10 to 13 HSPF. The nominal cooling efficiency typically decreases slightly in heat pump models for manufacturers which produce both air conditioner and heat pump equipment. SEER is significantly increased when adding VC technology to a system, but Energy Efficiency Ratio (EER) is relatively unaffected. EER is a single point cooling efficiency at maximum cooling output at an outdoor temperature of 95°F. EER values vary as well within the

[1] SEER = Seasonal Energy Efficiency Ratio; HSPF = Heating Seasonal Performance Factor.

[2] Nordyne products sold under brands: Maytag, Broan, Frigidaire, NuTone, Tappan, and Westinghouse.

available VC capacity products. The typical EER for an available ducted split, VC product is between 12.5 and 15. For further details on SEER, HSPF, and EER and their applicability to utility programs refer to SEER Investigation for Residential and Small Commercial Split Air-Source Heat Pumps [5].

One of the potential efficiency advantages of VC equipment is their ability to offer higher heating output at lower outdoor temperatures than standard, fixed speed heat pump equipment. However, the implementation of VC technology into a system does not ensure that a system is designed to supply high heating output at low outdoor temperatures. For example, one specific two ton VC product may supply two tons of heating at any outdoor temperature above 17°F, while another two ton VC product may only supply two tons of heating above the rating outdoor temperature of 47°F. Of the numerous systems listed in Table 1-1, only a few have the ability to provide increased heating output at lower outdoor temperatures when compared to a similarly sized baseline product. Although few products are currently designed to output nominal capacity at low outdoor temperatures, VC systems are flexible such that a system may be sized for the heating load in significant cooling climates, instead of the traditional sizing method which sizes for the cooling load in significant cooling territories.

The majority of the VC products listed in the Table 1-1 contain inverter driven compressors and are able to achieve a broad range of capacity values from ~40 to 100% nominal output. Some of the available VC equipment contain multi-stage compressors (e.g. five-stage compressors), which allow for similar capacity ranges (~40 to 100%) with significantly decreased incremental steps. The capacity control for a given VC system may vary depending upon the outdoor temperature, mode of operation, and thermal load on the system. Most VC products are designed to match the load of the conditioned space, and the control strategy may involve elapsed time and learning capabilities.

The majority of available VC products have humidity control options within the system. Humidity control may include a humidity setpoint, overcool options, and specific dehumidification modes of operation. A VC system can provide an increased level of dehumidification or latent cooling in response to humidity setpoints or the needs of the conditioned space.

The available VC systems are designed to be a flexible technology which could respond in numerous manners to a demand response (DR) signal. Currently there is no specific industry protocol for demand response with VC equipment, and therefore the DR functionality within the available VC systems is limited. The DR control signal for the systems which currently have a DR mode is a contactor at either the unit controller or outdoor unit. Two manufacturers have the ability to cycle the unit OFF in response to a DR signal, while another manufacturer has the option to either cycle OFF or to not allow operation above the minimum output level.

All of the available VC products must be operated with a specific unit controller designed for that specific system. Manufacturers prefer the approach of a proprietary controller, because it ensures that the system is operated appropriately under a specific condition. Most VC unit controllers offer high end features, such as programming, connectivity, and detailed modes of operation. The available VC products are suitable with either retrofit replacement or new construction applications. The current standard refrigerant used in residential VC products is R410a. The refrigerant piping size for the available VC products is usually similar to comparable fixed speed equipment.

2
SITE DESCRIPTION

The site selected for demonstration of variable capacity heat pump technology is a condominium building at a time-share resorts in Escondido, California. The selected site is in California climate zone 10 (CZ 10). Two side by side buildings were selected for this evaluation. Condo number 357 and 352 are similar condos (outside units) and condo 358 and 359 are similar (interior units). Condo 352 and condo 359 are baseline units whereas condo number 357 and 358 have new variable capacity heat pumps. Figure 2-1 shows bird's-eye view of the selected site.

Figure 2-1
Selected Site (From Google Earth)

California Climate Zone 10

California CZ 10 encompasses the interior hills and valleys of Southern California. This inland region is not affected by the ocean as much as some other zones like CZ 7. As such, this hilly region experiences greater seasonal temperature extremes and can get cold in winter months with temperatures reaching freezing or below in some areas. Most of the cities in CZ 10 have equal cooling and heating requirements over the course of the year.

3
INSTALLED EQUIPMENT

The existing HVAC system for the condo units consisted of a single speed split heat pump system shown in Figure 3-1. Table 3-1 provides the specifications of these existing units. The units were 13 SEER (Seasonal Energy Efficiency Ratio) units using R410a refrigerant with a nominal cooling and heating capacity of 34,000 BTU/hr.

Figure 3-1
Existing heat pumps

Table 3-1
Existing Heat Pump System (Baseline)

<table>
<tr><td colspan="2">AHRI Ref. No.</td><td>3699488</td></tr>
<tr><td colspan="2">Model Number</td><td>25HBC336(A,W)**30</td></tr>
<tr><td colspan="2">Coil Model Number</td><td>FB4CNF036</td></tr>
<tr><td colspan="2">Furnace</td><td></td></tr>
<tr><td colspan="2">Cooling Capacity (BTU/hr)</td><td>34,000</td></tr>
<tr><td colspan="2">EER</td><td>11.0</td></tr>
<tr><td colspan="2">SEER</td><td>13.0</td></tr>
<tr><td rowspan="2">Heating High Temp</td><td>Capacity (BTU/hr)</td><td>34,000</td></tr>
<tr><td>COP</td><td>3.62</td></tr>
<tr><td colspan="2">HSPF</td><td>8.0</td></tr>
<tr><td rowspan="2">Heating Low Temp</td><td>Capacity (BTU/hr)</td><td>21,400</td></tr>
<tr><td>COP</td><td>2.50</td></tr>
</table>

The treatment units (new installed units) are variable capacity units from Carrier's Greenspeed line of heat pumps. The treatment units were sized similar to the baseline units to gurantee occupant comfort. Oversizing the units was not considered since the property's Chief Engineer stated that they never had any HVAC related complaints from the occupants. The treatment units have nominal cooling capacity of 35,000 BTU/hr and nominal heating capacity of 33,400 BTU/hr. The SEER rating of these units is 20.0 which is significantly higher than the baseline units (SEER 13). Table 3-2 provides details on the treatment units. The efficiency improvement is due to the variable speed compressor and fans and also because of the increased heat transfer area possible due to large outdoor heat exchange. Figure 3-2 shows size difference between the two units which are installed side by side (while maintaining manufacturer recommended minimum clearances).

Table 3-2
Variable Capacity Heat Pump

AHRI Ref. No.		4616934
Model Number		25VNA036A0030
Coil Model Number		FE4ANF005000
Furnace		
Cooling Capacity (High) (BTU/hr)		35,000
Cooling Capacity (Low) (BTU/hr)		23,000
EER		14.0
SEER		20.0
Indoor CFM	High	1,200
	Low	875
Heating High Temp	Capacity (BTU/hr)	33,400
	COP	4.28
HSPF		12.4
Heating Low Temp	Capacity (BTU/hr)	31,000
	COP	2.48

Figure 3-2
Size difference between treatment (left) and baseline (right) units

Instrumentation

The instrumentation plan involves monitoring two important characteristics of the VCHP system – electrical, and thermal. Electrical measurements include monitoring the following parameters for the VCHP and the baseline unit:

1. Power draw (kW)
2. Energy (kWh)
3. Current (A)
4. Power factor

Thermal measurements include temperature and relative humidity measurements at various points in the system.

Figure 3-3 and Figure 3-4 show the indoor unit and outdoor unit instrumentation. Temperature and relative humidity are measured at the return and supply side of the indoor unit. Indoor unit power and energy measurements are also recorded to determine energy consumption of the indoor unit.

Figure 3-3
Indoor unit instrumentation

The outdoor unit measurements include electrical characteristics as well as ambient temperature and relative humidity measurements.

Figure 3-4
Outdoor Unit Instrumentation

Data Monitoring

Data monitoring is accomplished by using the following sensors:

Table 3-3
Monitoring Equipment Used

Measurement	Device / Instrument	Accuracy
Power	Elkor WattsOn	Within 0.2% @ 25°C
Energy		
Power Factor		
Current	Accu-CT	±0.75%
Air Temperature	Dwyer RHT-R016 Temperature	±2% @ 10-90%RH
Air Relative Humidity	Dwyer RHT-R016 RH	±2% @ 10-90%

For transferring the data back to EPRI server, communications products from Obvius (Obvius Holdings, LLC) were used.

- AcquiSuite – data acquisition server
- FlexIO – universal input / output module
- ModHopper – wireless Modbus transceiver
- Cell Modem – Airlink 3G

Miscellaneous hardware includes NEMA 4X boxes, power supplies, fuses and power strips. A schematic of data acquisition setup is shown in Figure 3-5. The AcquiSuite is the main on-site data acquisition server and the entire site has only one AcquiSuite. The AcquiSuite collects data from all the sensors (one minute resolution) and stores it on its onboard memory. Data from the AcquiSuite memory is uploaded to EPRI server every eight hours using a 3G cell connection. Numerous fail safe software procedures are programmed into the AcquiSuite to avoid any data loss.

The ModHopper is a wireless transceiver that can communicate with the AcquiSuite and with other ModHoppers. The data is gathered from all the sensors attached to a FlexIO and handed over to the ModHopper to transmit data wirelessly to the AcquiSuite. Numerous ModHoppers, FlexIO's and sensors can be connected to the system. For sake of simplicity only one such ModHopper is shown. The site has five ModHoppers (one for each floor and one at the outdoor unit) that will talk to the AcquiSuite and amongst each other to transmit the data.

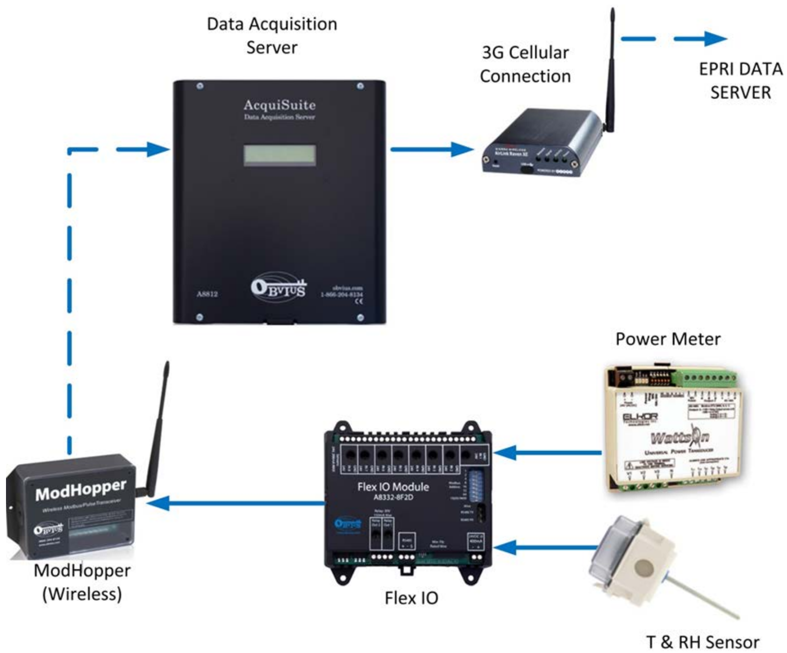

Figure 3-5
Schematic of Data Acquisition

4

DATA ANALYSIS

The baseline and treatment systems were monitored for a period of one full year, from April 2014 to March 2015. Data analysis for this period is presented in this section. Charts show data from January to December for ease of reading and must be noted that data from April through December is from 2014 and January through March is from 2015.

Weather

The site selected is California CZ 10 which is has four reference cities – Redlands, El Cajon, Riverside and San Bernardino according to Pacific Energy Center's Guide to 'California Climate Zones and Bioclimatic Design' [6]. Of the four cities, El Cajon is the closest city to the selected site and is used as a reference. El Cajon, per the design guide is expected to have 1560 HDD (heating degree days) and 1371 CDD (cooling degree days).

Figure 4-1 shows the HDD's and CDD's calculated based on the monitored outdoor temperature at the site. The numbers based on actual site measurement show HDD's to be 1783 and CDD's to be 2190. Figure 4-2 shows the average, minimum and maximum outdoor temperature for each month and also highlights the comfort zone between 68°F and 80°F. Figure 4-3 shows the average outdoor relative humidity measured at 4 am and 4pm for each month.

Figure 4-1, Figure 4-2, and Figure 4-3 are included to compare the monitored data with trends from the design guide. The monitored data shows variation from the data presented in the guide. The variations can be attributed to the limited data set that is available for site - single point measurement made only for one year. The design guide data is compiled based on significantly large data set and is representative for the entire area than just one point measurement made at the site.

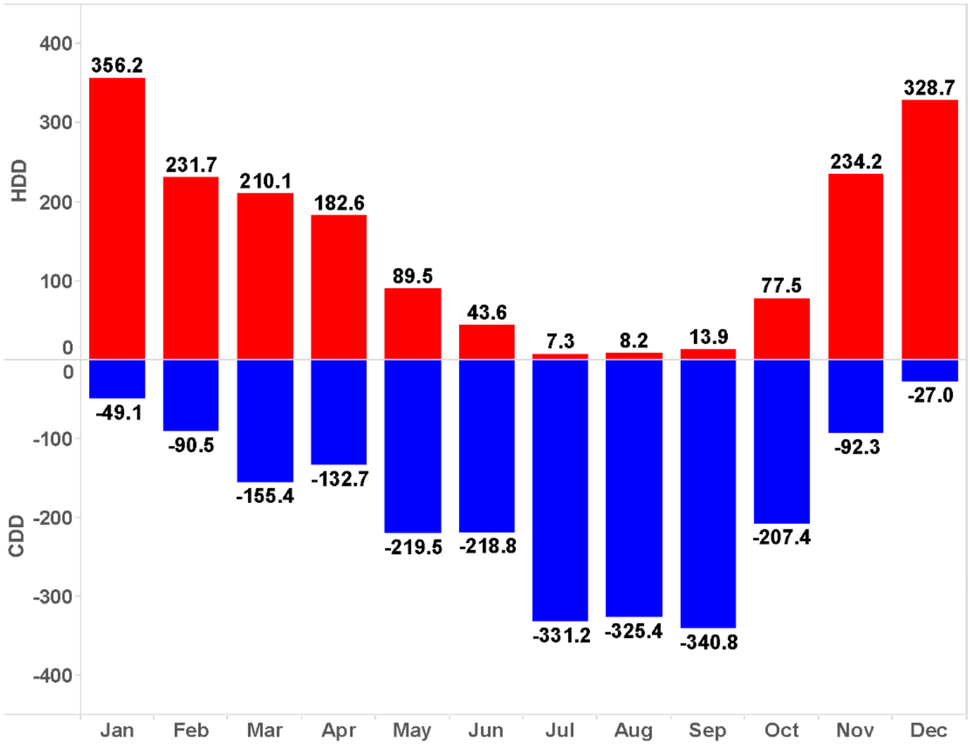

Figure 4-1
Heating and Cooling Degree Days (65°F base)

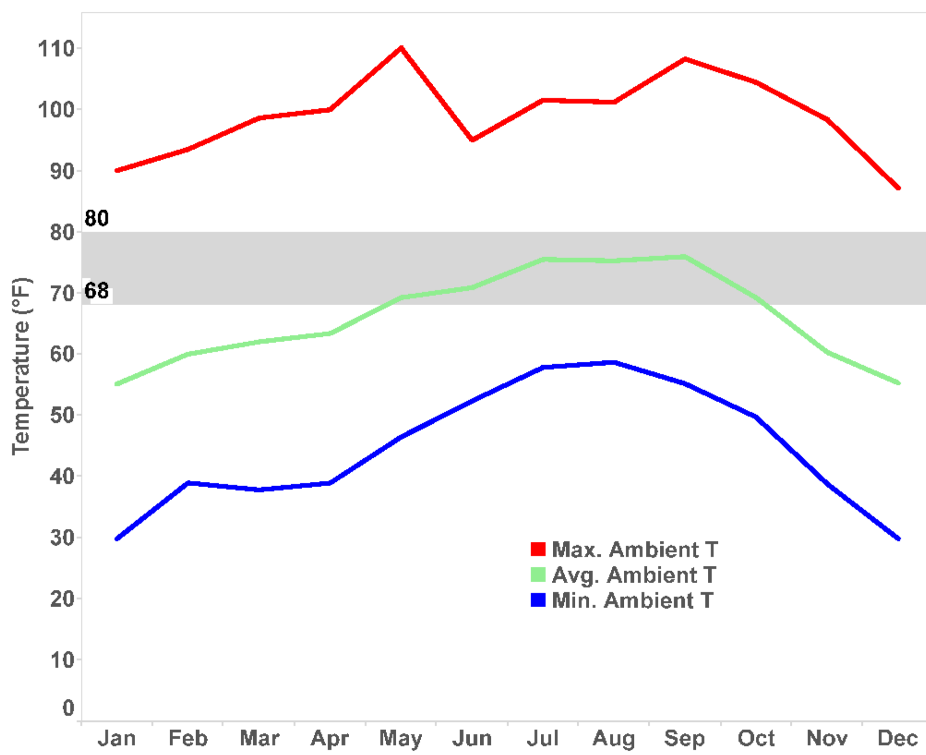

Figure 4-2
Measured Temperature (68-80°F Comfort Zone)

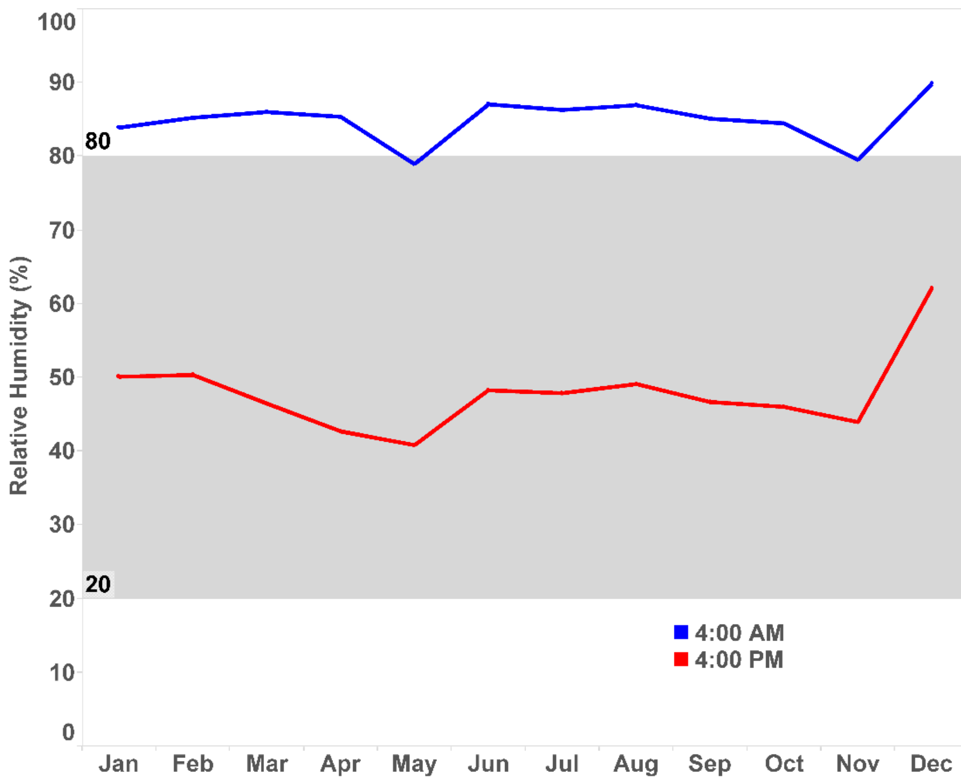

Figure 4-3
Measured Relative Humidity (20-80% Comfort Zone)

Outdoor T (°F)

RH (%)	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110
5									0	1	0	1	4	11	9	4	1	0
10								0	1	1	2	9	10	19	15	6	1	
15							0	0	1	3	17	28	37	34	16	3		
20							0	1	4	8	23	36	44	25	9	1		
25						0	1	6	8	17	34	44	28	19	10	0	1	
30						1	2	7	13	26	41	40	35	27	17	7	2	
35				0	0	2	5	10	24	34	46	50	46	39	24	5	0	
40				0	2	4	11	23	35	40	57	62	73	51	16	0		
45				3	2	7	23	32	40	55	78	97	92	46	4			
50				7	5	18	31	36	64	85	90	126	83	14	0			
55				9	12	27	37	50	72	97	103	109	37	1				
60			1	18	30	38	56	74	102	105	104	45	5					
65			4	31	35	46	62	99	109	98	69	15	1					
70			7	31	43	61	105	140	130	96	29	6	0					
75		3	7	29	59	82	149	207	162	103	17	3						
80	0	18	13	46	68	108	227	303	288	75	10	1						
85	0	16	31	103	122	230	349	379	295	40	2							
90		7	26	113	236	282	259	133	54	15	0							
95				1	6	15	5	10	1									

Figure 4-4
Temperature and Relative Humidity

Figure 4-4 shows the binned outdoor temperature and relative humidity data for the year under consideration. The numbers in the squares indicate the number of hours for that particular outdoor condition. The chart gives a graphical representation of the outdoor conditions at this particular site. For example, the outdoor conditions were in the temperature range of 57.5°F and 62.5°F and relative humidity range of 82.5% and 87.5% for 379 hours for the entire year. The total number of hours in comfort zone highlighted in the figure were 2088. It must be noted that the indoor conditions might be different than the outdoor conditions and air conditioning might be needed even when outdoor conditions are in comfort zone.

Comparison between Baseline Unit and Treatment

The VCHP is compared to a baseline unit based on the size of the condos that they were installed on. Condo number 352 and 357 are outside units (which have more exterior walls) whereas condo number 358 and 359 are interior units. As such condo 352 and 357 are compared to each other and 358 and 359 are compared to each other.

352 Versus 357 (Outside Condos)

Figure 4-5 shows the average power draw from the baseline unit and the VCHP unit. The data is presented in temperature bins. The data shows significant demand reduction by using a VCHP unit. The data is filtered such that the comparison is made only when the outdoor units are operating in the same ambient condition i.e. at 95°F the data is taken when both the baseline and treatment unit are operating. If one of the unit or both units are not operating, the data is not included for this graph. On average the demand reduction is 1.2 kW which can be a significant reduction when aggregated over a large population of systems.

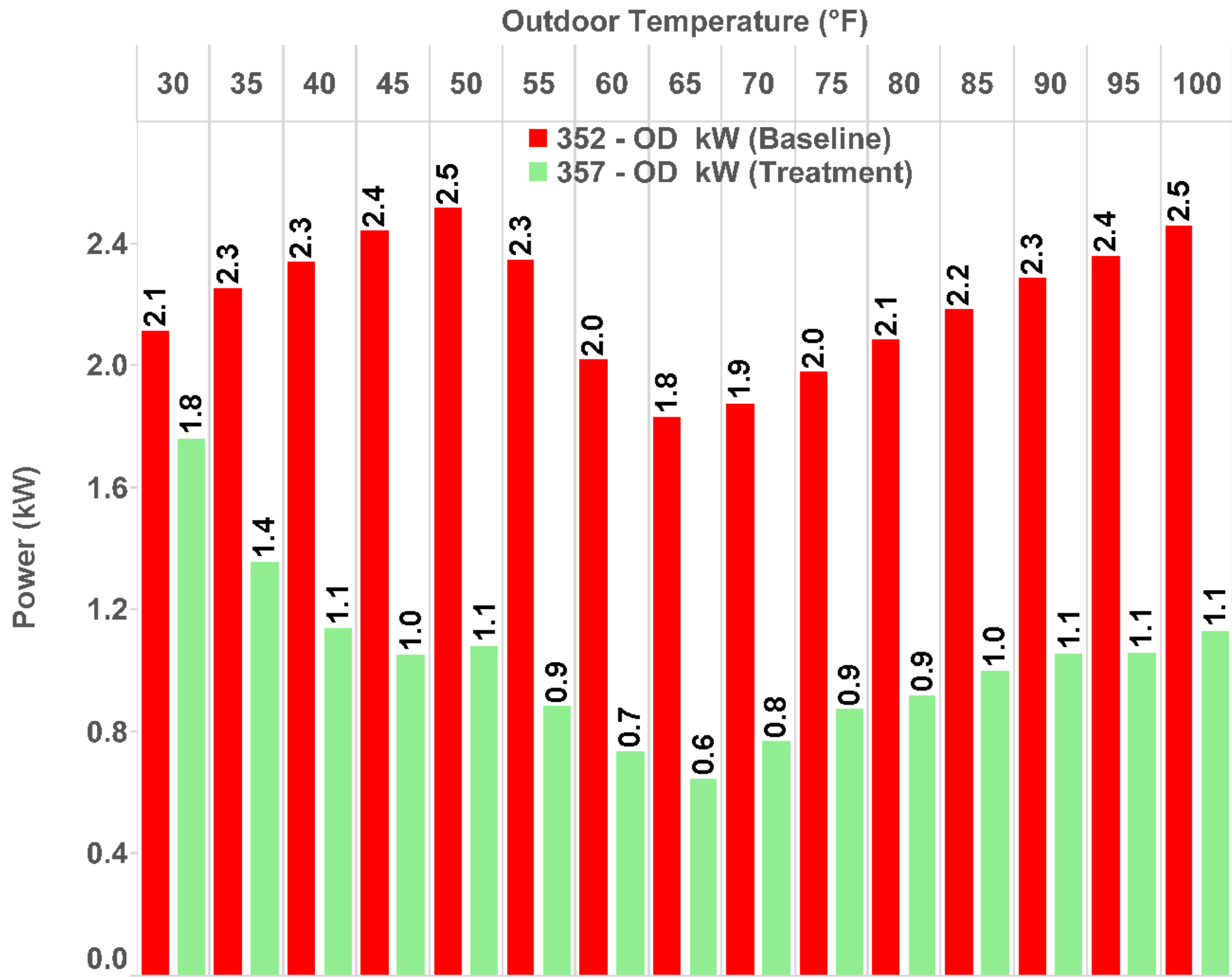

Figure 4-5
Outdoor power comparison for outside Condos 352 and 357

Figure 4-6 shows the average indoor unit power draw for the same two condos. As expected, average power draw from indoor unit 352 is 270 W which is constant since it is a fixed speed unit. The power draw from indoor unit 357 varies throughout the range since it's a variable speed indoor unit and offers the ability to change fan speed. The fan speed can be automatic or user controlled. In this case it is assumed the fan was set at Auto on the thermostat and no user control was used.

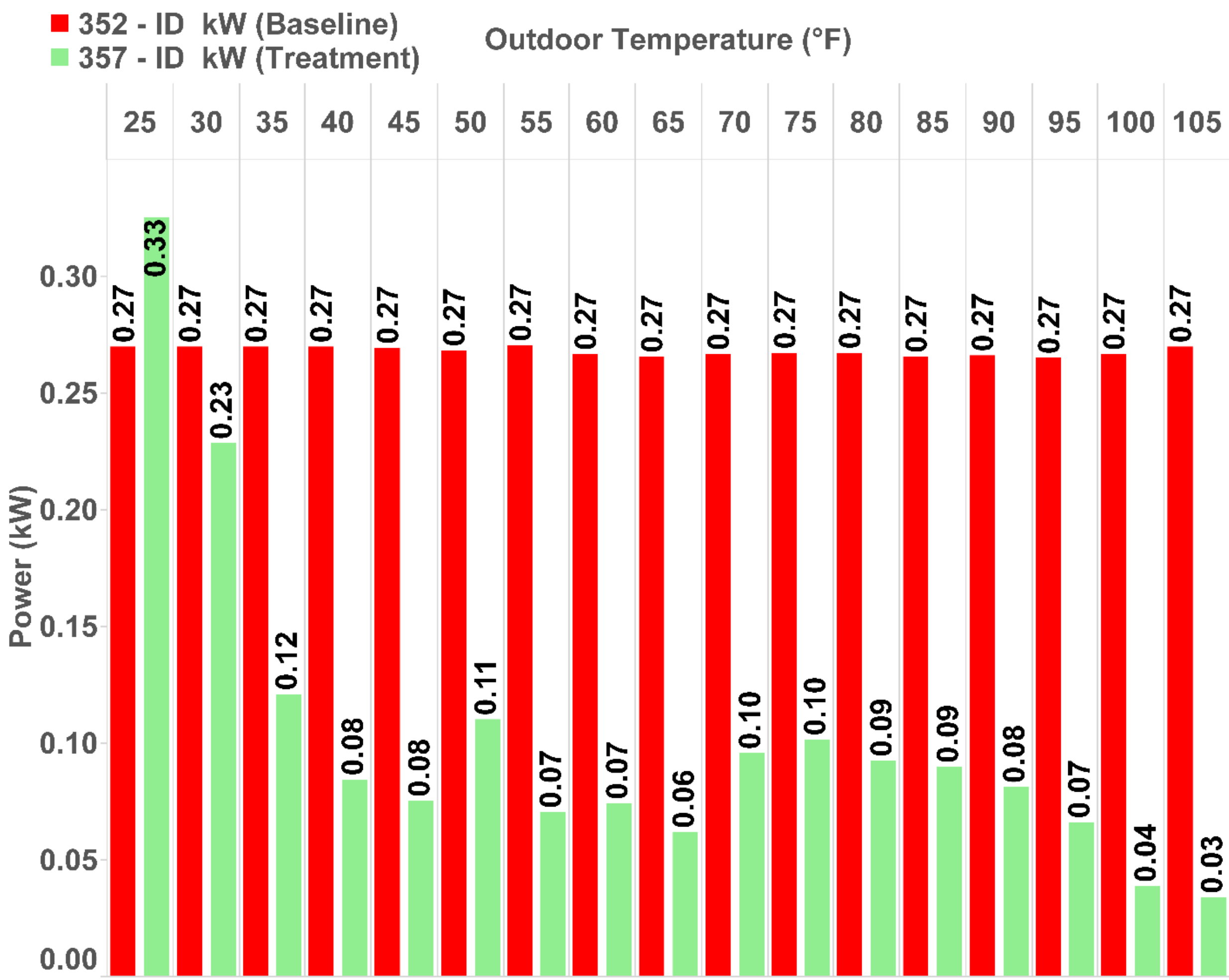

Figure 4-6
Indoor power comparison for outside Condos 352 and 357

VCHP are advertised as systems able to maintain high occupant comfort and steady space temperatures without hunting around the set point. Both the condos where instrumented with supply and return air temperature and relative humidity sensors. The return air temperature is a good proxy for the ambient temperature in the zone because usually the return air is very well mixed before it is drawn back into the indoor unit (for well-designed installations).

Figure 4-7 shows the supply air, return air and the ambient temperatures for one day (September 8th). The blue line shows the supply air temperature whereas the red line shows the return air temperature. Due to measurement scheme, sensor location and air column stratification it must be noted that the sudden drop in return air temperature or sudden increase in supply air temperature is not a function of the VCHP actively managing the temperature but a result of fan being turned ON or OFF. When the fan turns OFF, the cold air in the indoor unit sinks to the bottom and as such the return air temperature sensor senses that cold temperature. Same thing happens on the supply air side as the supply air temperature no longer senses the cold air coming from the indoor unit but the warm air that stagnates at the top of the indoor unit.

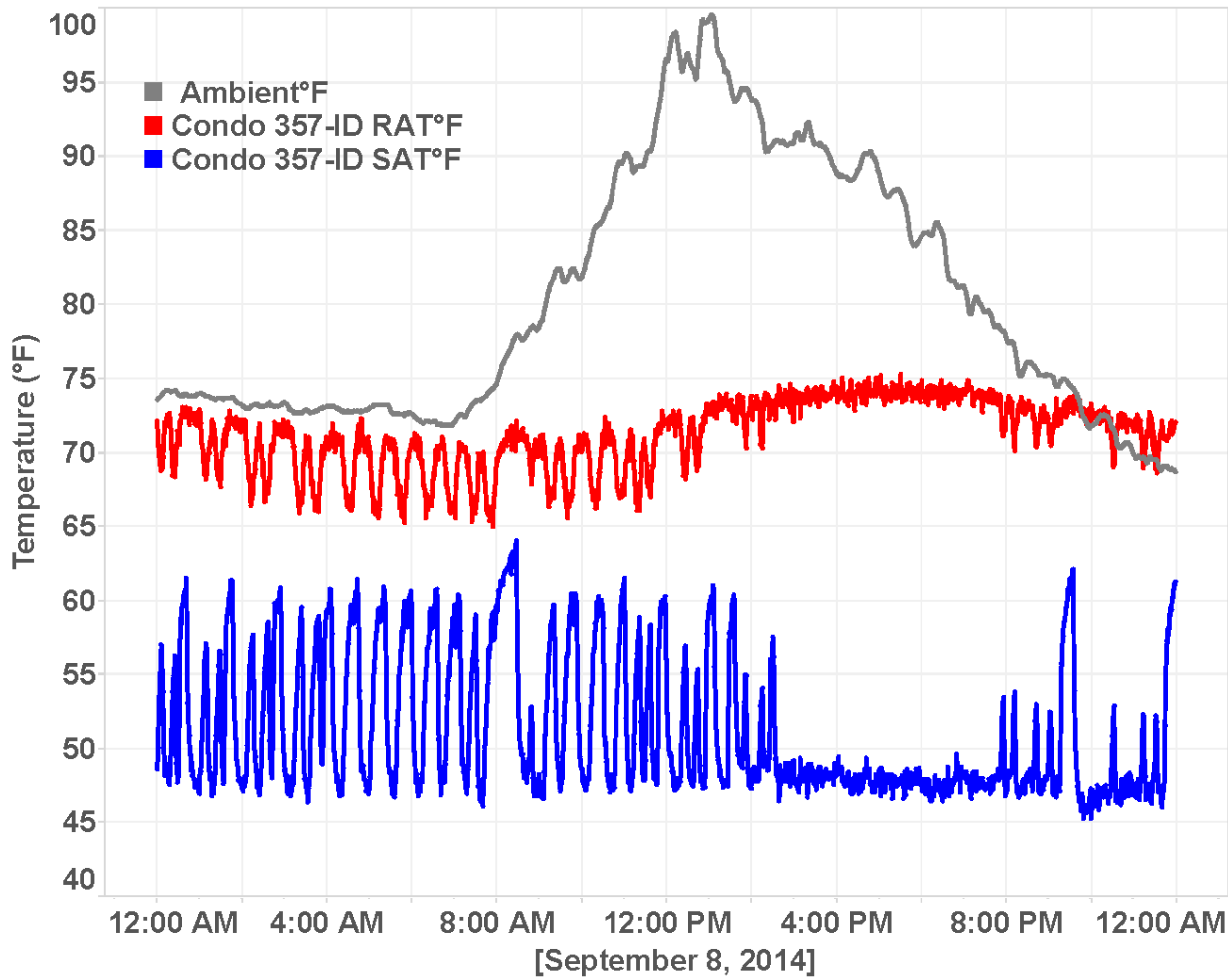

Figure 4-7
Supply Air Temperature and Return Air Temperature for Condo 357 (treatment)

The figure shows that the VCHP provides colder air for long durations (2pm to 9 pm) and does not turn OFF. Figure 4-8 shows same parameters for the fixed speed unit from condo 352. The fixed speed unit shows significant cycling as compared to VCHP. The VCHP manages run time as well as supply temperature because of the ability to vary air flow rate.

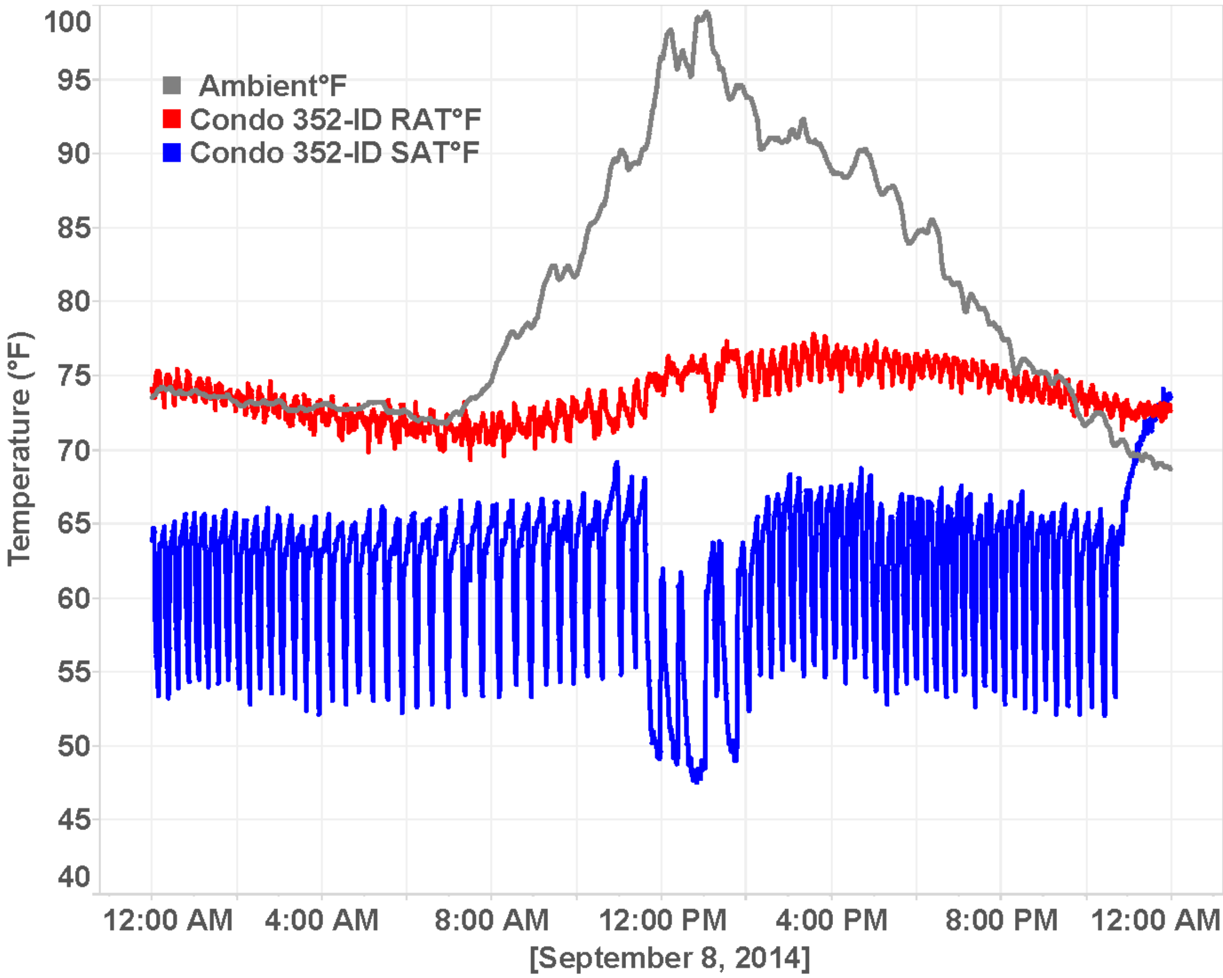

Figure 4-8
Supply Air Temperature and Return Air Temperature for Condo 352 (baseline)

The energy use for the day under consideration was 11.12 kWh for the VCHP and 16.98 kWh for the fixed speed unit. For fairly similar conditions, the energy savings for the outdoor unit on this particular day are 34.5%.

For the entire Summer 2014 (March 1st, 2014 to October 31st, 2014) the total energy use for the VCHP outdoor unit was 1284 kWh and for the fixed speed unit was 1424 kWh. It must be noted that the comparison between the units on the basis on total energy used is slightly misleading since the data on occupancy of these units (since these are time share condos) is not available. Furthermore behavioral aspects of occupants are also overlooked which can have significant impact on energy usage.

Figure 4-9 shows the load shape for condo 352 and condo 357 for summer months. The average demand for the treatment unit is lower during the peak summer hours.

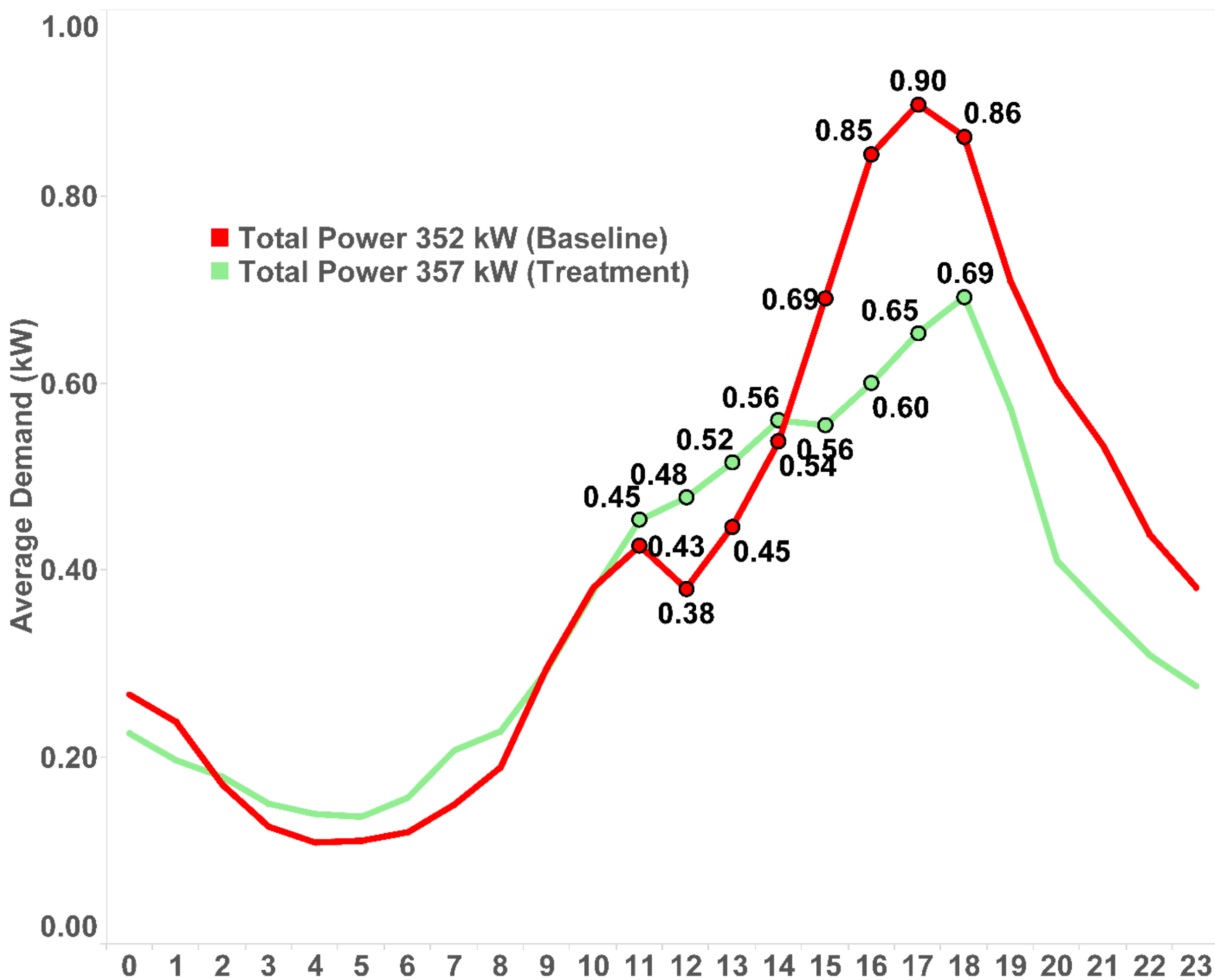

Figure 4-9
Average demand – single speed versus variable capacity unit (Summer only)

358 Versus 359 (Inside Condos)

Similar analysis is performed for data acquired from condos 358 and 359. The Condo 358 is treatment condo and 359 is the baseline unit. Figure 4-10 shows the average power draw from the baseline unit and the VCHP unit. Similar to Figure 4-5, Figure 4-10 shows a reduced kW (average 1.1 kW reduction) draw when compared to similar outdoor conditions in which both units are running.

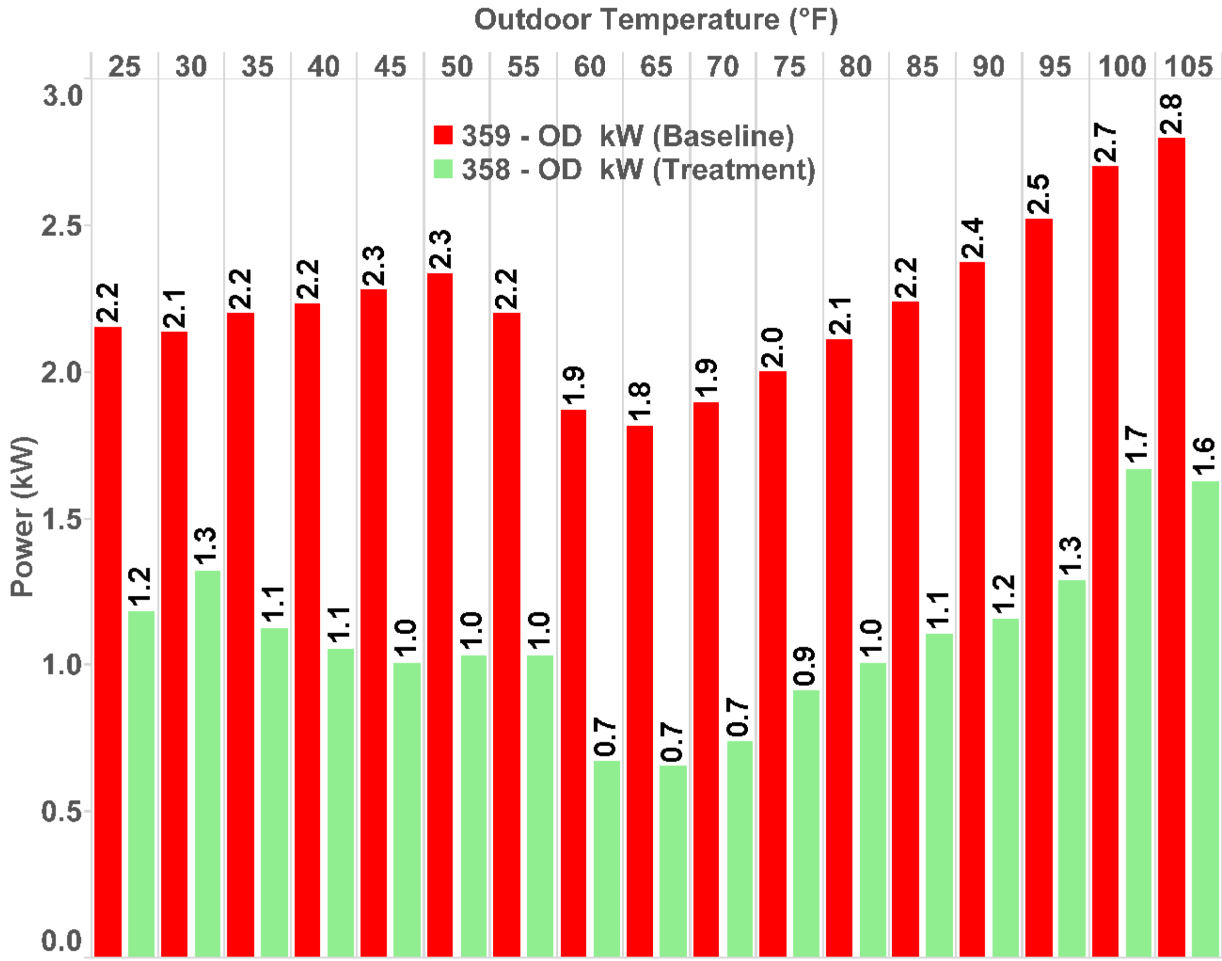

Figure 4-10
Outdoor power comparison for inside Condos 358 and 359

Figure 4-11 shows the average indoor unit power draw for condo 258 and 350. Similar to the trends seen between condo 352 and condo 357, the power draw for the VCHP indoor units fluctuates indicating active control over air flow rate whereas the unit with fixed speed unit (condo 359) does not change power draw.

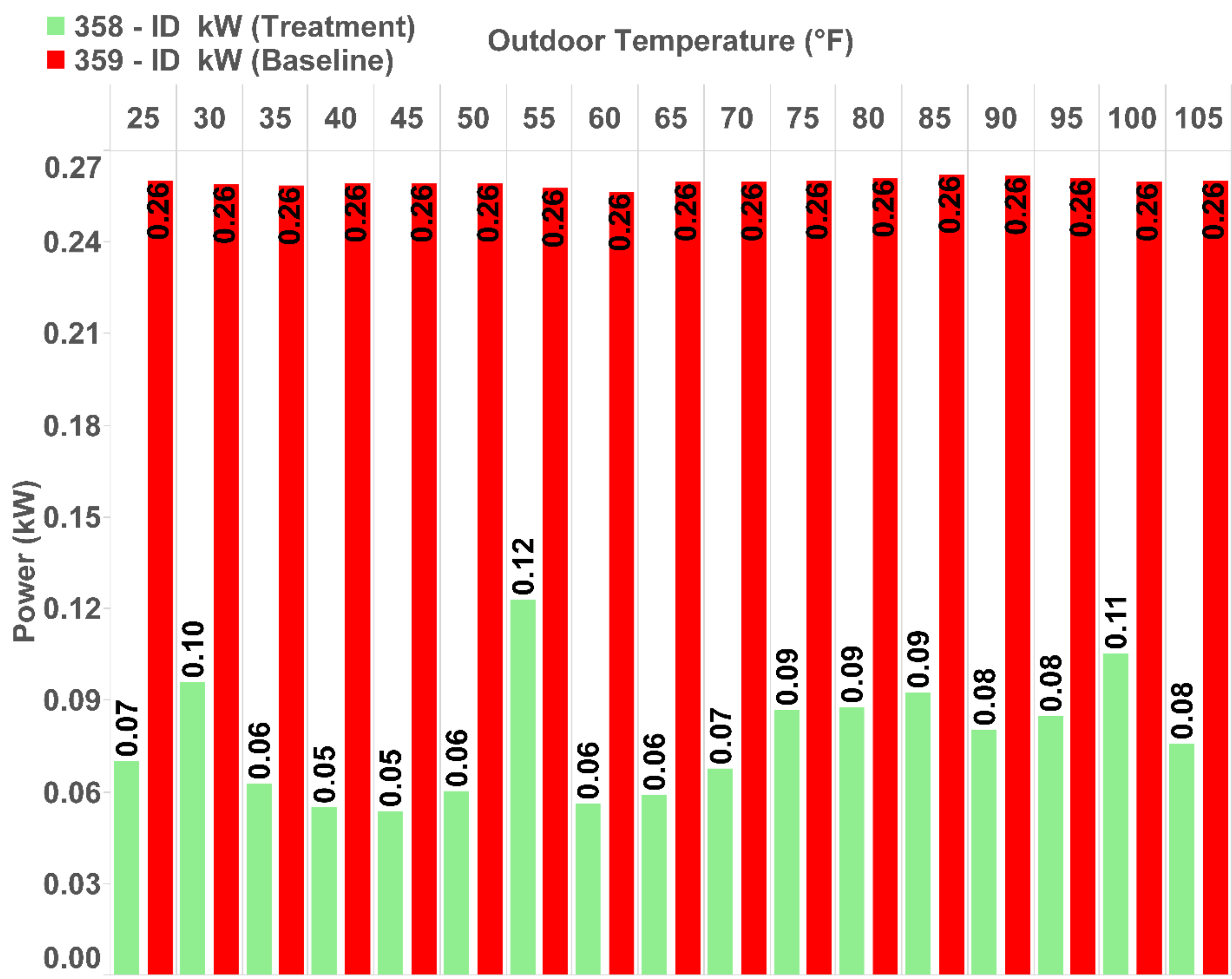

Figure 4-11
Indoor power comparison for inside Condos 358 and 359

Figure 4-12 and Figure 4-13 show ambient temperature, return air temperature and supply air temperature for condo number 358 and 359 respectively for one day (September 13, 2014). The trends are similar to what was seen in Figure 4-7 and Figure 4-8. The fixed speed unit cycles quite often than the VCHP. The energy use for condo 358 is 17.94 kWh and for condo 359 is 20 kWh for the day under consideration which is a 10.3% reduction in energy use.

For the entire Summer 2014 (March 1st, 2014 to October 31st, 2014) the total energy use for the VCHP outdoor unit was 1484 kWh and for the fixed speed unit was 2080 kWh. It must be noted that the occupancy, temperature set points etc. are not available for this study.

Figure 4-14 shows the load shape for condo 359 and condo 358 for summer months. On an average the treatment unit shows a demand reduction of 0.3 kW during the peak summer hours.

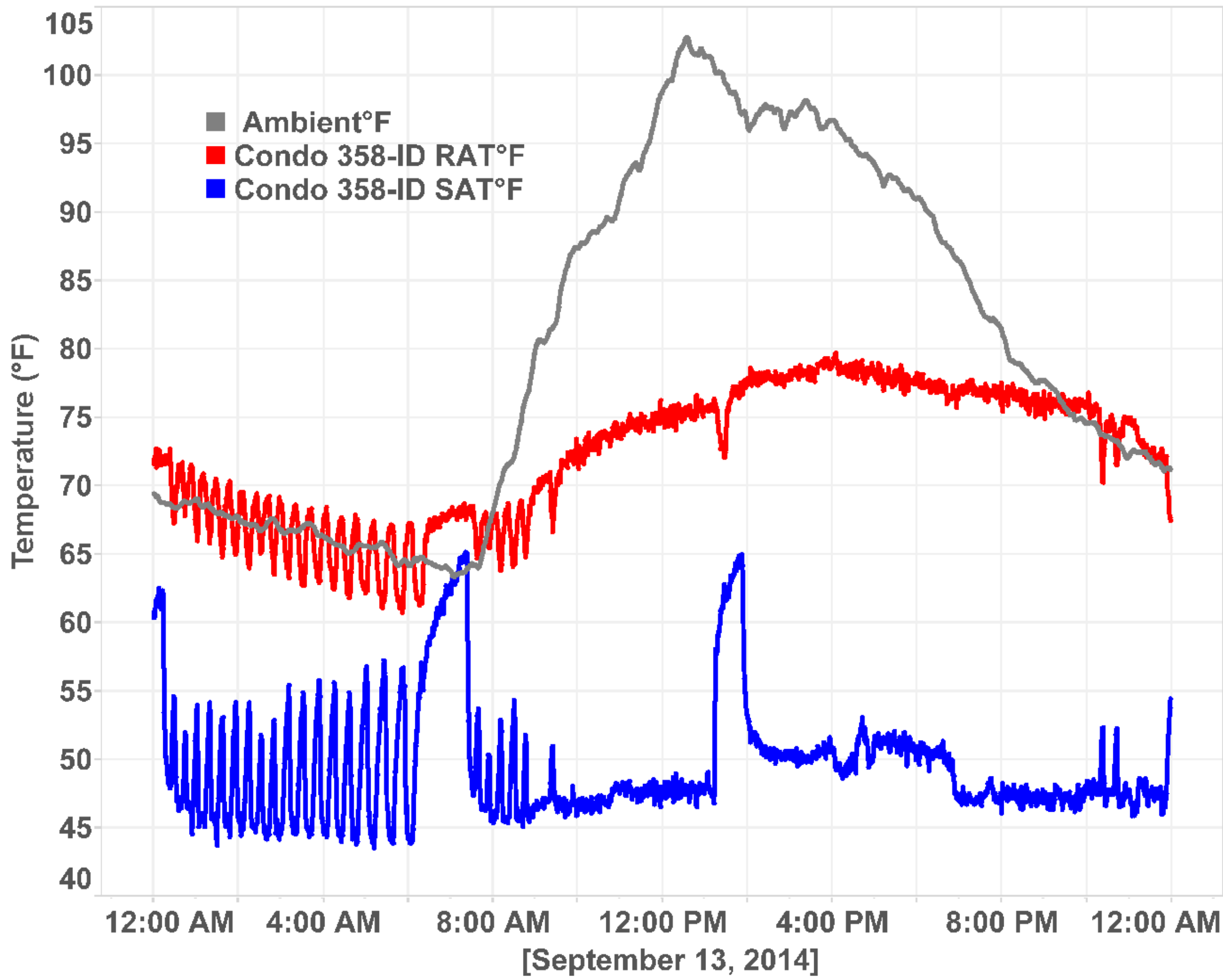

Figure 4-12
Supply Air Temperature and Return Air Temperature for Condo 358 (treatment)

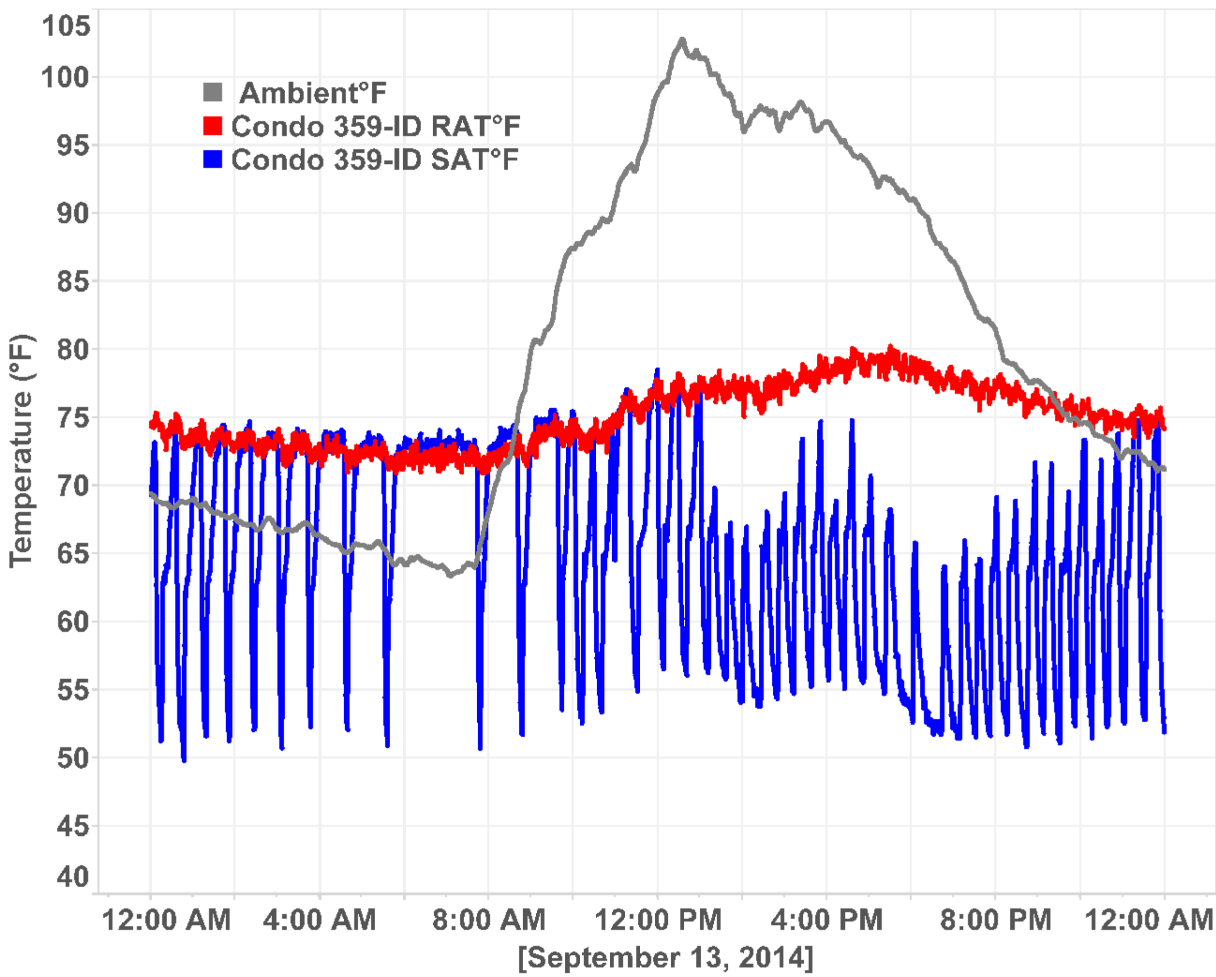

Figure 4-13
Supply Air Temperature and Return Air Temperature for Condo 359 (baseline)

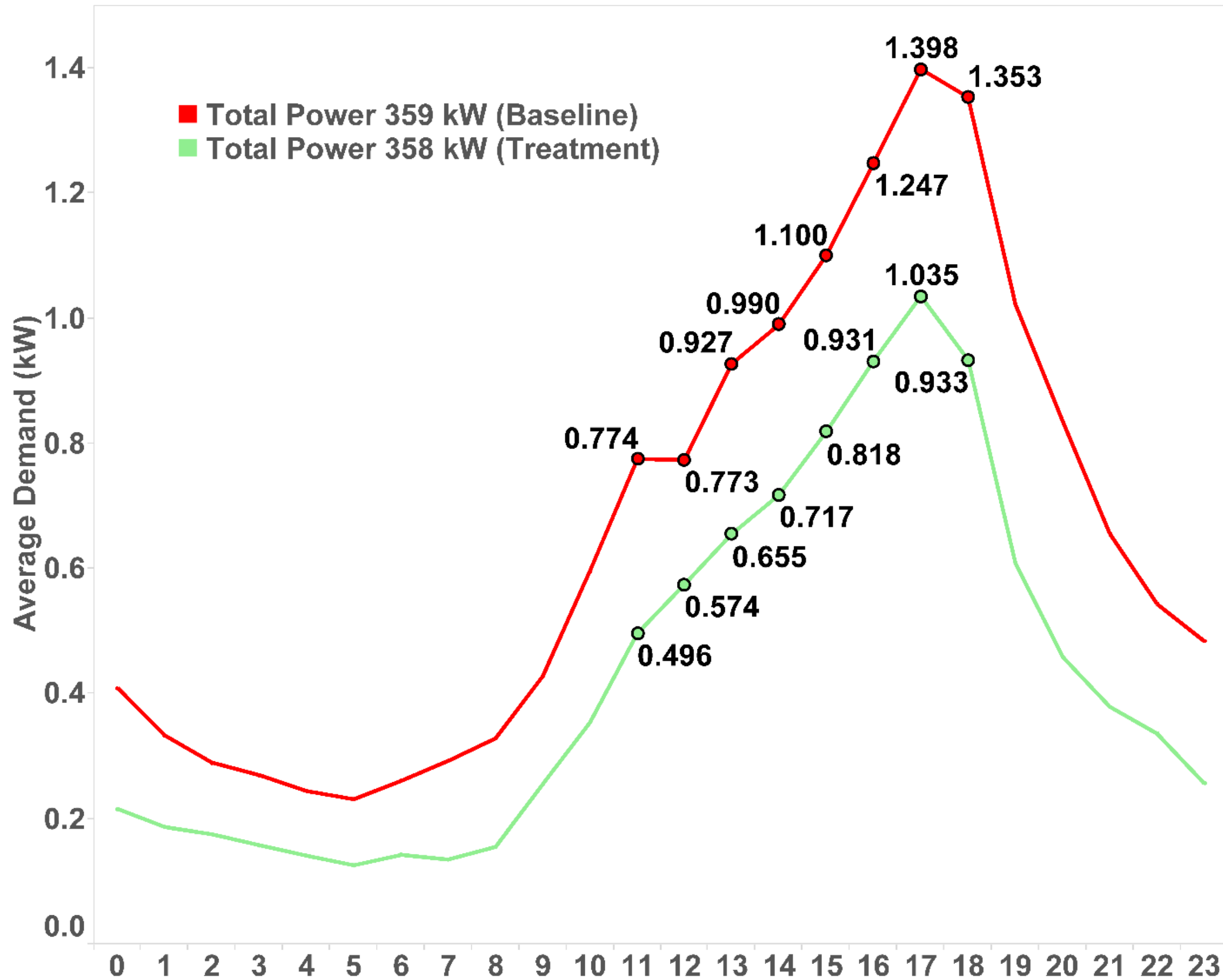

Figure 4-14
Average demand – single speed versus variable capacity unit (Summer only)

Energy Efficiency Estimate

Estimating energy savings is dificult with the given data set since the occpancy data nor the set points on thermostats were available. To estimate occupancy an averaging methodolody was used to determine heat pump operating hours and thus concluding whether the condos were occupied or not. For condo numbers 358 and 359 month of July showed high correlation for average indoor temperatures and unit run times in hours. This indicated that the units were occupied and the HVAC system was running to keep the space conditioned. The VCHP outdoor unit consumed 304 kWh for conditioning the space whereas the fixed speed outdoor unit consumed 450 kWh for the same month. The average indoor temperature during this same time was 74.52°F for VCHP condo and 74.98°F for the fixed speed unit. Based on same indoor and outdoor temperatures and assuming similar loads the energy efficiency improvement is 32%.

In between condo 352 and 357, condo number 352 had very low occupancy based on the hours of operation. A conservative estimate of 30% energy savings over a code minimum system is predicted based on data from condo number 358 and 359.

5
UTILITY IMPLICATIONS

Cost Considerations

The total cost of removing two previously installed systems and installing two new variable capacity heat pumps for this project was $18,300. The cost included the following key items along with many standard install line items –

- All new electrical (low voltage and electrical whip connector)
- Condenser pad, vibration isolation pads
- Meet all code requirements and work in conformance with city codes
- Infinity controls for thermostats
- New condensate drain hookups
- All monitoring equipment install

Based on the wholesale cost information for the variable capacity system and a federal minimum system, the variable capacity system cost is presented as a multiplier to the cost of the federal minimum equipment. In this case the cost multiplier is 2.66 for the variable capacity system. This cost does not consider the actual retail cost for a consumer or any installation costs which vary regionally.

A single speed federal minimum, 3 ton split system will cost about $2,000 at wholesale. Using the 2.66 as a multiplier the variable capacity system evaluated in this study will cost in the range of $5,320 i.e. a premium of $3,320.

Each condo at the site is on a small commercial 'A' rate which is a flat seasonal rate. Assuming average cost of electricity for the customer to be $0.245/ kWh the cost savings for using this high SEER unit are only $146 for summer months (based on 596 kWh savings for summer months in between condo 358 and 359). These savings can swing significantly based on:

- Variability in occupant behavior (temperature set points, windows and balcony doors open, shutting down or using set back during unoccupied hours)
- Rates – the site currently is on a rate that's not time of use which can change the savings significantly

The payback period when compared to a baseline system (federal minimum SEER rating) is greater than 20 years. For a customer the following non-energy benefits can be significant when deciding between a baseline system and a higher SEER system:

- Higher occupant comfort, separate control over temperature and humidity
- Most of the higher SEER systems offer some sort of connectivity through a web app or a mobile device app which have become 'must have' features in HVAC systems.

Variable Capacity Heat Pump Potential in California

The U.S Energy Information Administration's (EIA) Residential Energy Consumption Survey (RECS) was queried to determine the number of residences in the state of California that have air conditioners or heat pump installed. Table 5-1shows a condensed version of the 'Table HC7.11 Air Conditioning in Homes in West Region, Divisions, and States, 2009'.

Table 5-1
California Residences using Air Conditioning Equipment (2009)

Air Conditioning	Total U.S. (Millions)	CA Census Division (Millions)
Total Homes	113.6	12.2
Use Air Conditioning Equipment	94.0	6.9
Type of Air Conditioning Equipment*		
Central Air Conditioning	69.7	5.0
Window / Wall Air Conditioning	25.9	2.0

*Some residences may have both, a central air conditioning system and window air conditioners

Assuming a conservative estimate of only one central air conditioner per residence, the total market size for the variable capacity heat pump is approximately 5 million units. This number includes only primary occupied housing units and does not include second homes, vacant housing units etc. For the purpose of predicting energy savings and demand reduction potential, the estimate of 5 million units is used.

Table 5-2
Household energy usage

Total Housing Units (millions)		12.2
Total Site Energy Consumption (quadrillion BTU)	Total	0.751
	Space Heating	0.199
	Water Heating	0.190
	Air Conditioning	0.030
	Refrigerators	0.044
	Other	0.288
Average Site Consumption (million BTU per household)	Total	61.5
	Space Heating	19.1
	Water Heating	15.7
	Air Conditioning	4.4
	Refrigerators	3.6
	Other	23.6

EIA’s household energy data indicates that California households use 0.751 quadrillion BTU of energy (site energy - electric, gas and other sources combined). 0.287 Quad BTU of the total site energy consumption is Electricity (Table CE2.5). Of the total electric consumption (site energy) 0.030 Quad BTU (8792.5 MWh) is for air-conditioning (cooling and dehumidification).

Based on an estimate of average 30% savings will result in energy savings of 2637.75 MWh.

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