Testing of Commercial Variable Capacity Heat Pump (VCHP) for Small Commercial Office Buildings

ET12SCE1090 and DR 12.16 Report

Prepared by:

Emerging Products
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The Electric Power Research Institute (EPRI) conducted the technology evaluation. EPRI report '*Field Analysis of Commercial Variable Refrigerant Flow Heat Pumps.* EPRI, Palo Alto, CA: 2014. 3002004364' was used extensively as reference for this study and report. The EPRI report is also published as PG&E's Emerging Technologies Program ET Project Number ET12PGE1381.

Disclaimer

EXECUTIVE SUMMARY

At the heart of the drive toward making buildings highly energy efficient and demand responsive is the need to use the precise amount of energy required to perform certain tasks, and no more. The historical norm, with a source of plentiful and inexpensive energy, was to use energetically competing systems that ultimately balance according to comfort and task execution needs, without serious regard to energy consumption. The new approach is to understand the overall exchange of energy throughout a building, including the exchange with the outside environment and the needs of the interior building functions, and implement systems that provide for these needs.

Space conditioning is one such load where providing precise amount of cooling or heating will result in high efficiency gains compared to legacy systems. Variable Refrigerant Flow (VRF) systems use inverter driven compressors and fans, electronic expansion valves and advanced control strategies to deliver just enough cooling or heating to each zone. The ability to modulate capacity fits very well with the operating characteristics of a Heating, Ventilating, and Air Conditioning (HVAC) system which is part load. The HVAC systems for most of the time are operating in part load conditions where technologies like VRF can provide significant performance advantage by modulating components within the system.

In addition to energy efficiency, demand response is another important aspect of a load that is of interest to the utilities. HVAC systems are coincident load on the electric system i.e. as the ambient temperature increases, HVAC load increases, increasing the overall load on the electric grid. Reduction in demand imposed by HVAC systems during these peak hours will help the electric utilities economically and reliably serve the loads during these hours.

To understand the energy efficiency and demand response capabilities of a VRF system in the field, a 24 ton, 17 zone VRF-HR (heat recovery) system was installed and monitored in Southern California. This report documents the findings from this monitoring exercise for twelve months, from April 2014 to March 2015. The project had the following objectives:

- To collect operational performance data on an installed VRF-HR system
- To collect a data set that is appropriate to provide energy modeling developers with a validation tool
- Provide objective analysis and performance characterization of a field installed VRF-HR system
- Assess the ability of installed system to respond to OpenADR signals as a resource for load management (demand response)

The data set will also be available for any further analysis or validation of new VRF models.

SELECTED SITE AND VRF SYSTEM DETAILS

The selected site for this VRF field monitoring project is an office building in Mission Viejo, California which is in California Climate Zone 8. The building is a 2 floor office building with approximately 5,710 square feet of conditioned space. This building has a front customer lobby area, two small data centers (one on each floor), a conference room on first floor and the remainder of the building space is designated for cubicles, offices, kitchen, storage, and bathrooms.

The VRF system installed at this location is a 24-ton Mitsubishi City Multi 2-pipe VRF system with heat recovery capabilities (simultaneous heating and cooling operation is possible). The system has a total of 17 indoor units connected to it. The VRF system can also be considered as two individual systems of 12 ton each serving the first and second floor. The refrigerant circuits of the first floor and second floor are separate.

DATA ANALYSIS

Data representing thermal and electrical characteristics of the VRF system was collected from the site for a period of 12 months – from April 2014 to March 2015. The electrical characteristics were used to determine the energy used, load profile, and demand imposed by the system on the grid. The total energy usage of the building is 163,094 kWh for the year which equates to 28.6 kWh/sq. foot/year. The total VRF system energy use for entire year is 43,418 kWh which is 7.6 kWh/sq. foot/year.

The average load shape as well as load shape for summer months is presented. In summer months the load shape shows high demand (kW) during peak hours which makes this system a great candidate for demand response. Billing analysis using utility bills is also presented in this study. The average other loads (loads excluding VRF system) were 10,000 kWh/month. The average demand from other loads during peak periods were 21.8 kW.

The operating mode of the indoor units is determined by comparing the return air temperature and the supply air temperature. If the temperature difference between return air and supply air is greater than 5°F, the unit is assumed to be in cooling mode. If the temperature difference is less than -5°F, the unit is assumed to be in heating mode. For the temperatures in between, the unit is considered to be in fan or OFF mode. The outdoor unit is in cooling mode, heating mode or a mixed mode based on the operating modes of the 17 indoor units (Table 3 provides details of indoor units). Determining the operating modes helps understand the overall system operation as well as characteristics of the building. During the milder temperatures between 65°F to 75°F, the fan or OFF mode dominates. The mixed mode operation is evident during the 50°F and 65°F where there might be need for cooling as well as heating. The lower outdoor temperatures were not reached during the monitoring period but would be interesting to see if the existence of data centers will force the system to run in mixed mode because of cooling needs to the data center.

Capacity delivered (cooling or heating) by each indoor unit is estimated using the air enthalpy method. Capacity delivered was high in the months of April and May where the system was not optimized for schedules and other operating parameters. Once the system was setup properly, the capacity delivered to the first floor and the second floor showed correlation with the outdoor temperature. Knowing the estimated capacity delivered and energy consumed, the estimated energy efficiency ratio (EER) of the system can be calculated. The estimated EER value is an important finding of this project since this is a calculation done on a VRF-HR system in the field and includes the building effects (versus against laboratory testing which does not include the building effects). The EER trends are correlated to the ambient conditions with peak efficiencies with second floor show better estimated EER’s than the first floor system.

DEMAND RESPONSE

Demand response capabilities of the VRF system were demonstrated using OpenADR 2.0a messages sent from a Virtual Top Node (VTN) setup at EPRI. An additional controller setup on-site acted as an OpenADR Virtual End Node (VEN) and translated the OpenADR commands to native machine language for the VRF system. The control strategy was to increase the temperature set point by 3°F to reduce HVAC electric demand. The system during a demand response event shed a maximum of 1.7kW of load. The preliminary results are encouraging but the test was mostly for communications verification and was not carried out when the ambient conditions were high, and so the actual load impact was not representative of a summer peak day. Two important take-aways from this DR testing were:

- Communication via the open standards protocol used by SCE to implement DR were successful in this trial.
- Demand reduction was demonstrated by the system responding to a pre-scheduled event, demonstrating a successful "machine to machine" interface.

FUTURE WORK

To further expand on the OpenADR capabilities of the system and to include more testing, the EPRI project team intends to run numerous DR events during the summer season with a focus on a more detailed investigation of DR performance. When those tests are available, they may be incorporated into a future report.

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INTRODUCTION

At the heart of the drive toward making buildings highly energy efficient is the need to use the precise amount of energy required to perform certain tasks, and no more. The historical norm, with a source of plentiful and inexpensive energy, was to use energetically competing systems that ultimately balance according to comfort and task execution needs, without serious regard to energy consumption. The new approach is to understand the overall exchange of energy on a temporal basis throughout a building, including the exchange with the outside environment and the needs of the interior building functions, and implement systems that provide for these needs – space conditioning, lighting, appliances, etc. – treating energy as a valuable and limited resource that should be expended only as necessary.

Technological improvements in the Heating, Ventilation, and Air Conditioning (HVAC) industry focus on matching the energy supplied (e.g., cooling or heating) to the load demanded, and doing so with smooth control and efficient delivery. New technologies like Variable Refrigerant Flow (VRF) which employ inverter driven technology, variable speed drives for motors and compressors, on-board diagnostics and inexpensive controls have made it possible to provide highly efficient and flexible cooling and heating.

In addition to energy efficiency, demand response (DR) for peak load reduction, reducing facility loading, managing renewable integration, and other uses are important to utilities. New technologies for adjustment of power used by air conditioners, water heaters, and appliances are being introduced around the country.

BACKGROUND

Over the course of the last several years, a VRF rating standard was developed and resulted in the ANSI/AHRI Standard 1230: Performance Rating of Variable Refrigerant Flow (VRF) Multi-Split Air-Conditioning and Heat Pump Equipment. This standard identifies the methodology for determining standard cooling, heating, and simultaneous cooling & heating operational efficiency. The intent of the standard was to allow comparison of VRF equipment performance with that of unitary equipment at similar operating conditions.

Many utility programs base incentive amounts and calculated energy savings on the marginal difference between rated efficiencies of particular classes of HVAC equipment, such as packaged rooftop air conditioners & heat pumps. Comparison of VRF to traditional unitary equipment in this similar manner represents a partial change in approach since two different classes of HVAC equipment are being compared. The crafters of the 1230 rating standard attempted to address this by making the testing conditions and methodology as similar to the unitary standards (ANSI/AHRI 210/240 and 340/360) as possible by allowing for VRF systems to be operated at manufacturer-determined fixed operating conditions (compressor, fan speeds, and expansion valve openings). This leaves a rating standard which tests equipment at fixed operation, while the same equipment in the field will vary its operation in accordance with changing load. This creates questions as to the direct applicability of the rating test as an accurate representation of actual field performance relative to other unitary equipment.

Much of the potential energy savings attributed to VRF systems may come from the interaction of the system with the building—such savings would not be captured by a rating test. Examples of this type of savings are: lower convection losses from refrigerant lines compared to ductwork, delivery of conditioned air more directly to the occupied space, rather than to the entire building volume and increased zoning with individual temperature control.

Simple comparison of rating numbers may turn out to be a valid method for comparing VRF to unitary systems, but there are currently sufficient questions that require further understanding. Currently, energy savings derived from VRF use are generally considered difficult to characterize via any deem-able method and are thus typically modeled via EnergyPro, Energy Plus, and related building simulation software packages.

Laboratory testing is used for characterization and verification of equipment performance, but does not address the HVAC system interaction with the building. Field testing will be used to develop energy and power consumption profiles of the integrated building/HVAC (VRF-HR) system. Robust field data can then be used to vet and validate VRF modeling modules, with the aim of producing reliable and repeatable models of energy and power draw characteristics of buildings using VRF systems.

There is a need for detailed measurement of field performance of variable refrigerant flow heat recovery systems (VRF-HR) to both help characterize actual yearly energy savings potential, and to provide quality data for use in energy modeling verification.

ASSESSMENT OBJECTIVES

This project will comprise instrumenting and measuring the in-situ performance of a system VRF-HR system with the following objectives:

- To collect operational performance data on an installed VRF-HR system
- To collect a data set that is appropriate to provide energy modeling developers with a validation tool
- Provide objective analysis and performance characterization of a field installed VRF-HR system
- Assess the ability of installed system as a resource for load management (demand response)

SITE DETAILS

The selected site is a two floor office building located in Mission Viejo, CA 92691. The site is in California Climate Zone 8 (CZ8). The building space is designated for cubicles, offices, conference room, kitchen, storage, bathrooms, and a small data center on each floor. The application is a retrofit application i.e. an existing rooftop unit setup will be demolished and VRF system will be installed in its place. Figure 1 shows the birds eye-view of the building which also shows the existing rooftop units.

FIGURE 1: BIRDS EYE-VIEW OF SELECTED SITE (FROM BING.COM)

HVAC SYSTEM DETAILS

The entire building is split into two air conditioning systems, the first floor and second floor. Both the floors will have a 12 ton Mitsubishi VRF system with heat recovery. The first floor will have a total of 9 indoor units (IDU) connected (IDU 1 thru IDU 9) and the second floor will have 8 indoor units connected (IDU 10 thru IDU 17). The system also includes a ventilation system bringing in fresh air from the outside and feeding on the return air side of one indoor unit on each floor. Table 1, Table 2, and Table 3 show the details of the installed equipment on the building.

TABLE 1: OUTDOOR UNITS

OUTDOOR UNIT (ODU)	MODEL NUMBER	COOLING CAPACITY (BTU/H)	HEATING CAPACITY (BTU/H)	FLOOR SERVED
ODU 1	Mitsubishi PURY-P144TKMU-A	144,000	160,000	1st (IDU 1-9)
ODU 2	Mitsubishi PURY-P144TKMU-A	144,000	160,000	2nd (IDU 10-17)

TABLE 2: BRANCH SELECTOR BOXES

BRANCH SELECTOR BOX	MODEL NUMBER
BC-1A	Mitsubishi CMB-P1010NU-GA
BC-1B	Mitsubishi CMB-P1010NU-GA

TABLE 3: INDOOR UNITS

INDOOR UNIT	MODEL NUMBER	TYPE	COOLING CAP (KBTU/H)	HEATING CAP (KBTU/H)
IDU 1	PEFY-P36NMAU-E2	DUCTED	36	40
IDU 2	PEFY-P24NMAU-E2	DUCTED	24	27
IDU 3	PEFY-P18NMAU-E2	DUCTED	18	20
IDU 4	PLFY-12NCMU-ER4	CEILING	12	13.5
IDU 5	PKFY-P30NKMU-E2	WALL	30	34
IDU 6	PEFY-P15NMAU-E2	DUCTED	15	20
IDU 7	PEFY-P24NMAU-E2	DUCTED	24	30
IDU 8	PEFY-P12NMAU-E2	DUCTED	12	13.5
IDU 9	PEFY-P15NMAU-E2	DUCTED	15	17
IDU 10	PLFY-24NBMU-ER4	CEILING	24	27
IDU 11	PEFY-P36NMAU-E2	DUCTED	36	40
IDU 12	PEFY-P18NMAU-E2	DUCTED	18	20
IDU 13	PEFY-P12NBMU-ER2	DUCTED	12	13.5
IDU 14	PKFY-P18NHMU-E2	WALL	18	20
IDU 15	PEFY-P08NMAU-E2	DUCTED	8	9
IDU 16	PEFY-P36NMAU-E2	DUCTED	36	40
IDU 17	PEFY-P15NMAU-E2	CEILING	15	17

The ratio of total indoor cooling capacity to the outdoor unit cooling capacity is called combination ratio. The combination ratio for first floor is 1.3 and combination ratio for the second floor is 1.16.

INSTRUMENTATION PLAN

The system will be monitored for two characteristics – electrical and thermal. Data from numerous channels monitored will be recorded every minute (1 minute resolution data). The electrical characteristics include power draw (kW), energy consumption (kWh), voltage (V), current (I) and power factor (PF) at the outdoor units and indoor units. The indoor units on each floor of the building are connected to separate breakers grouped in 4 or 5 units on one breaker. The electrical characteristics at this breaker would be monitored (four in all) in order to keep the instrumentation effort within reason.

The thermal characteristics will include temperature (T) and relative humidity (RH) measurements at various points in the building. The T and RH are made at supply air and return air of each of the 18 indoor units. The ambient (outside) T and RH will also be measured close to the outdoor unit with precautions taken to keep the sensor away from the exhaust air stream of the outdoor units. Based on the T and RH measurement and the air flow measurements from the test and balance report (already provided) capacity measurements for each indoor unit will be made. For the non-ducted units, the air flow will be assumed to be the rated air flow from the manufacturer. A detailed monitoring plan for each floor, outdoor unit and associated indoor units is provided at the end of this section.

AIR FLOW MEASUREMENT

Air flow measurement is a critical piece in calculating air side cooling or heating capacity delivered. The capacity is determined by the following formula -

$$Cooling (or\ Heating)\ Capacity\ \left(\frac{Btu}{h}\right) = Air\ Mass\ Flow\ \left(\frac{lbm}{h}\right) x\ (Return\ Air\ Enthaply - Supply\ Air\ Enthalpy)\ (\frac{Btu}{lbm})$$

During normal operation of a VRF system all three parameters – air mass flow, return air enthalpy and supply air enthalpy change resulting in changing capacity. The air enthalpies are measured using Dwyer temperature and relative humidity sensors. Measuring air flow is challenging. For each individual unit installing an air flow device is cost prohibitive. Instead a different approach is used.

The fan speed on the indoor units is set to provide desired cubic feet per minute (cfm) per zone. This speed is set and not allowed to be changed by the occupants of the zone. This guarantees that each zone will receive designed flow of conditioned air as well as additional ventilation air required by code. If the flow rate is modulated by the occupants, the ventilation fan is not able to provide the right amount of outside air to the building. This fact that each indoor unit is held to certain airflow can be used to measure air flow. An air test and balance from a licensed and certified contractor will be carried out and values reported in the report will be used as fixed values for the respective indoor unit. This approach simplifies the air flow measurement problem and also provides design outside air to each zone.

EQUIPMENT USED

a. Power Meter – Shark 100T – Revenue Grade
b. Current Transformers (CT) – CR Magnetics (200:5, and 60:5 amps; used with multiple wire turns to reduce the primary ratio). Four turns around each CT effectively reduces the ratio by four, Thus the 200:5 CT becomes a 50:5, and the 60:5 Ct becomes a 15:5 ratio.
c. Temperature and Relative Humidity - Dwyer (different models, duct, wall, OSA, and wireless wall)
d. Communications – Obvius products
    1. AcquiSuite – data acquisition server (DAQ)
    2. Flex I/O – universal input / output module
    3. ModHopper – wireless Modbus transceiver
e. Cell Modem – Airlink 3G

TABLE 4: ACCURACY OF SENSORS USED

INSTRUMENT	ACCURACY
Dwyer RHP-2D11 RTD Temperature	±0.3°C @ 25°C
Dwyer RHP-2D11/2R11 RH	±2% 10-90% RH @ 25°C
Dwyer RHT-R016 Temperature	±2% @ 10-90%
Dwyer RHT-R016 RH	±2% @ 10-90%
Dwyer WHP-000 Temperature	±0.3°C
Dwyer WHP-000 RH	±2.0% RH
Shark 100T	<0.2% @ 25°C
CT 200A, 60A	±0.3%, ±1.3%, respectively

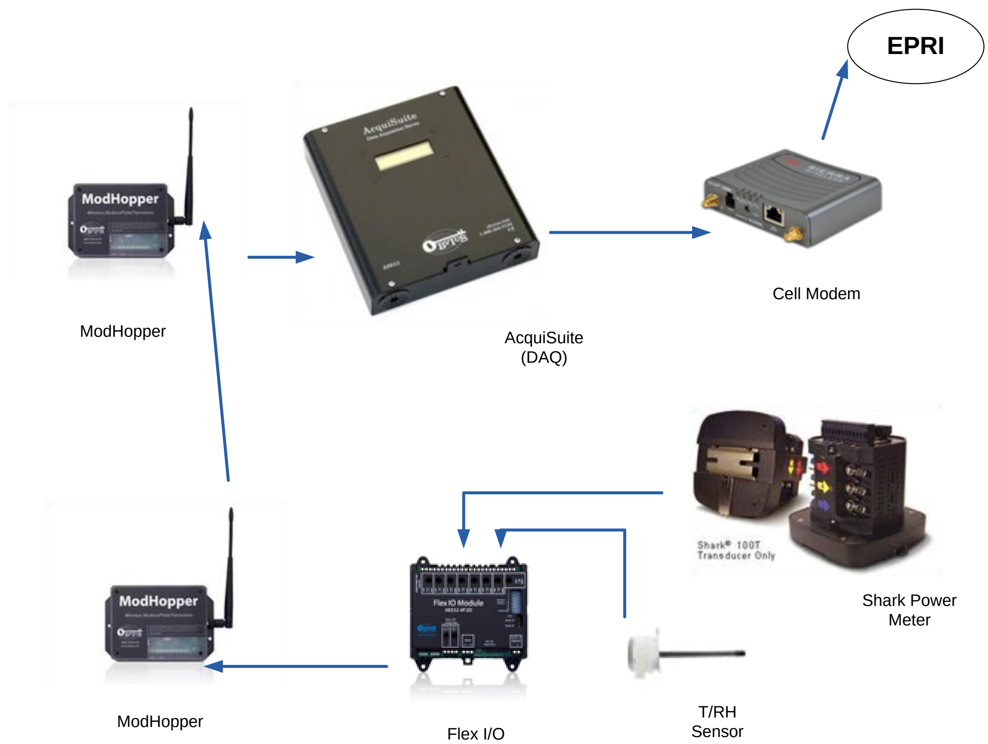


FIGURE 2: SCHEMATIC OF DATA ACQUISITION

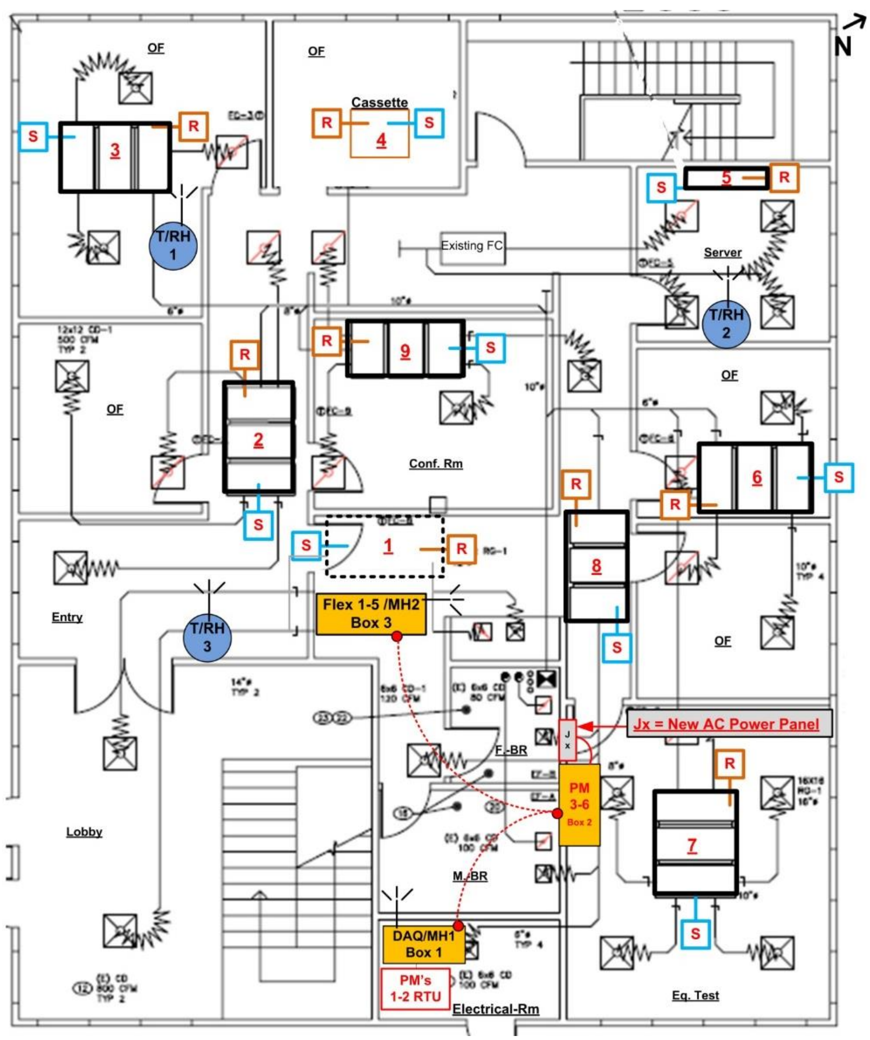


FIGURE 3: FIRST FLOOR DATA ACQUISITION PLAN

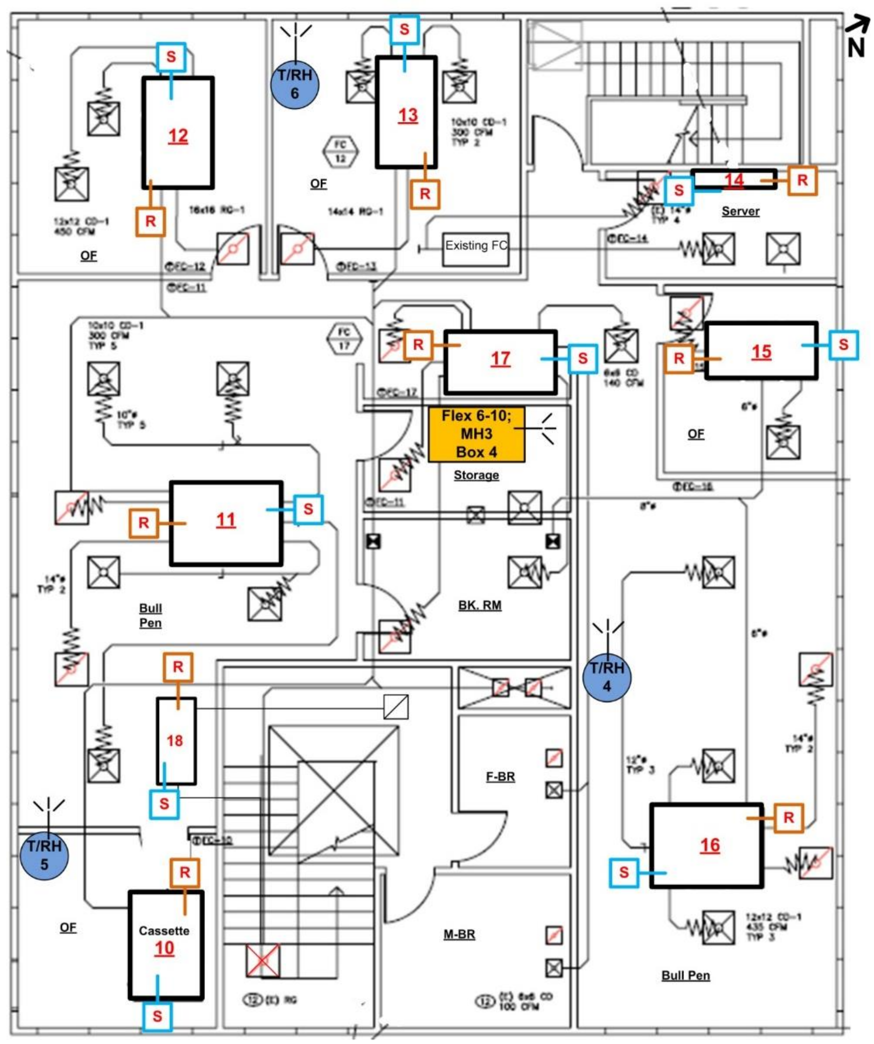


FIGURE 4: SECOND FLOOR INSTRUMENTATION PLAN

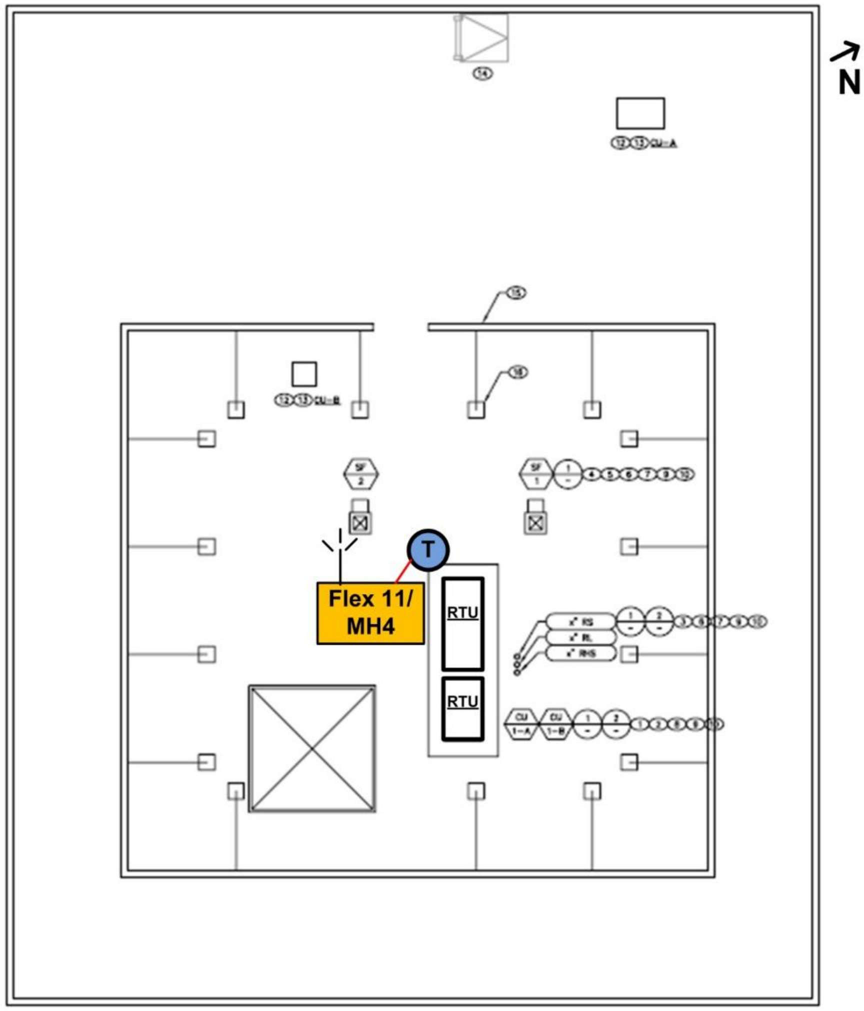


FIGURE 5: ROOFTOP INSTRUMENTATION PLAN

ANALYSIS

The data is collected for 12 months, April 2014 to March 2015 which covers the entire cooling and heating seasons.

WEATHER

The selected site lies in California Climate Zone 8 (CZ 8) which is an inland zone influenced by marine air. The proximity to the ocean keeps the temperatures from being extreme. Both, cooling and heating, are necessary in this CZ to maintain comfortable indoor conditions per the Pacific Energy Center's Guide to 'California Climate Zones and Bioclimatic Design' (http://www.pge.com/includes/docs/pdfs/about/edusafety/training/pec/toolbox/arch/climate/california_climate_zone_08.pdf accessed 12/17/2014)

Per the design guide, Anaheim (which also is in CZ 8) is expected to have 1286 Heating Degree Days (HDD) and 1294 Cooling Degree Days (CDD). The HDD and CDD are determined by summing up the average temperature per day below or above 65°F (base temperature).

Figure 66 shows the HDD and CDD's calculated based on the monitored outdoor temperature at the site. The numbers based on the actual site measurements show that the CDD's were 2235 and HDD's were 1062.

Figure 77 shows the average, minimum and maximum outdoor temperature for each month and also highlights the comfort zone between 68°F and 80°F. Figure 88 shows the average outdoor relative humidity measured at 4 am and 4pm for each month.

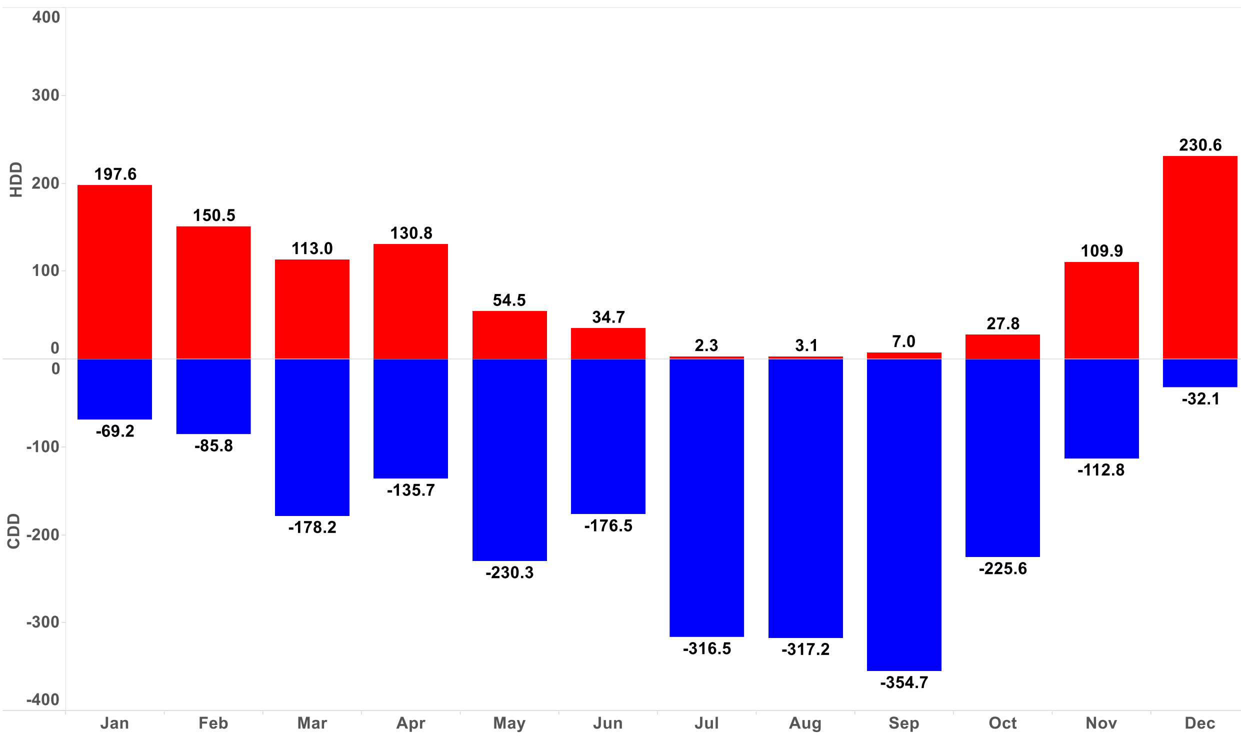


Figure 6: Cooling Degree Days (CDD) and Heating Degree Day (HDD) (Base 65°F)

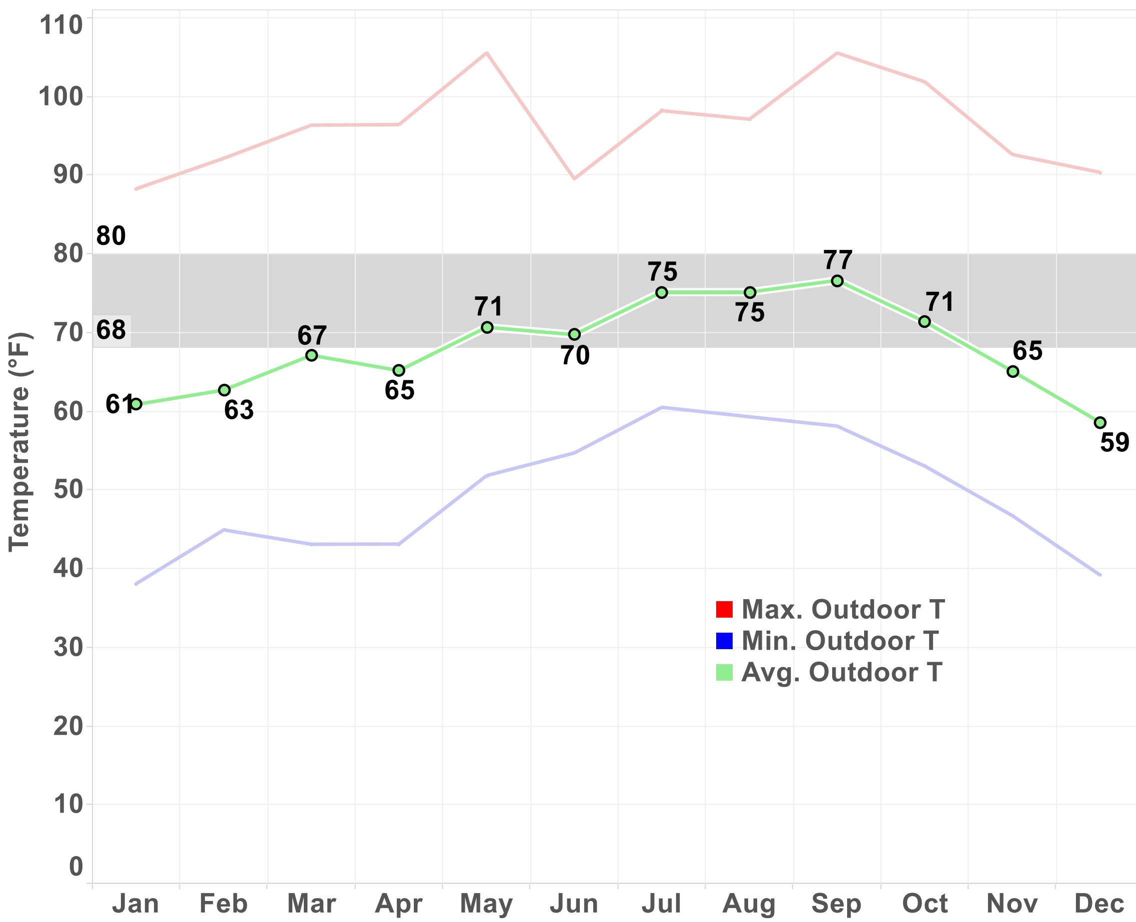


FIGURE 7: MEASURED TEMPERATURE

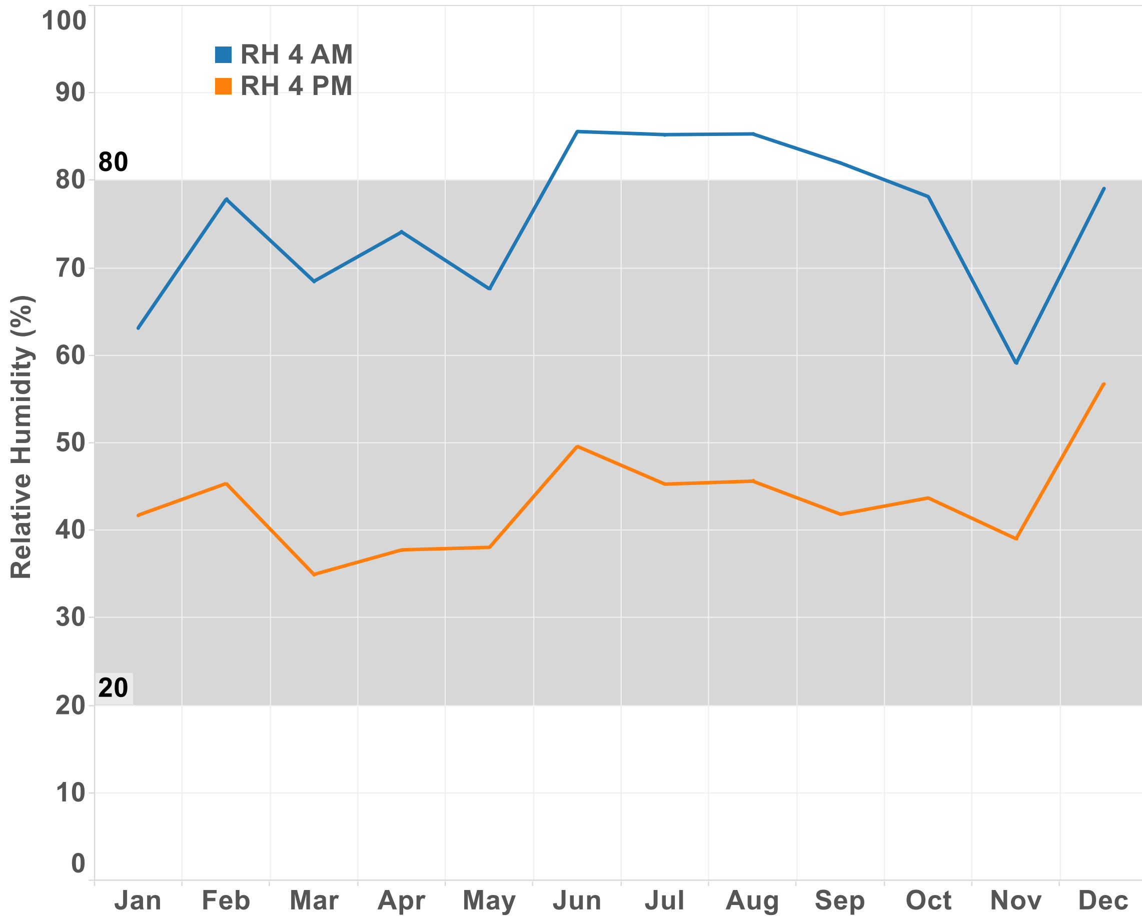


FIGURE 8: MEASURED RELATIVE HUMIDITY (AVERAGE FOR EACH MONTH AT 4 AM AND 4 PM)

Figure 66, Figure 77, and Figure 88 are included to compare the monitored data with trends from the design guide. The monitored data shows slight 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 rather than just one point measurement made at the site.

Figure 99 shows entire outdoor temperature and relative humidity data set split out in temperature and relative humidity bins. The numbers in the square indicate number of hours the outdoor conditions were in a particular bin. For example, the outdoor conditions were in the range of 72.5°F and 77.5°F and relative humidity of 32.5% and 37.5% for 11 hours. This chart is a graphical representation of the outdoor conditions experienced by the VRF system. The comfort zone designated in the design guide is also superimposed on the chart—the total number of hours in the comfort zone is 2,261. Figure 1010 shows the same chart, but the data is filtered for actual office hours (system occupied mode) which are defined as Monday through Friday 7:00am to 7:00pm. The hours in comfort zone are reduced to 1,332.

It must be noted that although these hours are in comfort zone, it does not mean the HVAC system is not operating. There are internal building loads that will necessitate HVAC system operating.

	Outdoor T (°F)													
Outdoor RH %	40	45	50	55	60	65	70	75	80	85	90	95	100	105
0									0	1	1	7	7	0
5						0	1	8	20	16	30	25	5	
10				0	1	2	13	26	35	47	41	17	0	
15			1	9	10	22	36	38	46	50	32	5		
20		0	16	29	20	35	37	45	35	24	16	4	2	0
25	0	3	12	30	46	55	39	42	25	18	29	9	6	0
30	3	6	11	24	46	46	51	27	22	32	35	15	3	
35	4	5	11	25	36	46	22	27	38	46	32	11	0	
40	4	5	11	29	39	34	30	40	64	55	26	1		
45	4	2	18	19	37	46	56	81	103	71	6			
50	3	2	21	32	46	68	99	139	152	51	0			
55	3	3	22	26	48	89	133	155	123	5	0			
60	3	4	27	36	69	106	124	109	22	1				
65	3	7	27	69	102	112	122	60	5	0				
70	8	10	49	106	119	126	121	19	0					
75	9	31	73	142	228	209	89	3	0					
80	10	35	88	202	330	357	45	1						
85	4	23	110	270	340	241	15	0						
90		22	118	187	112	27	3							
95		11	40	33	16	1								

FIGURE 9: OUTDOOR CONDITIONS SPLIT IN TEMPERATURE AND RELATIVE HUMIDITY BINS

	Outdoor T (°F)													
Outdoor RH %	40	45	50	55	60	65	70	75	80	85	90	95	100	105
0										0	1	7	7	0
5								2	6	13	29	23	3	
10						1	6	12	21	40	30	13	0	
15				1	3	6	16	27	30	33	18	2		
20		0	3	5	2	9	20	27	22	17	11	3	0	0
25	0	2	3	3	8	12	19	22	14	15	20	4	4	0
30	2	1	2	1	5	14	24	14	15	24	25	11	2	
35	0	1	1	4	11	17	15	20	26	30	20	8	0	
40			1	4	11	15	20	26	40	39	17	0		
45		0	3	3	17	23	41	53	67	48	3			
50		0	2	6	27	33	72	85	112	37				
55		1	2	8	20	59	85	99	88	3				
60	1	0	4	9	29	69	65	70	11	0				
65	0	2	4	16	47	65	53	30	1					
70	0	2	5	17	50	38	41	9	0					
75	1	2	6	22	49	40	26	1						
80		1	7	29	37	44	7	0						
85		2	8	30	24	20	1							
90		2	12	24	12	4	0							
95		2	11	5	2	1								

FIGURE 10: OUTDOOR CONDITIONS SPLIT IN TEMPERATURE AND RELATIVE HUMIDITY BINS (VRF SYSTEM IN OCCUPIED MODE)

ELECTRICAL CHARACTERISTICS

The electrical characteristics of the VRF system are of great interest due to the energy efficiency benefits that can be realized as well as the demand response potential of the system. This section presents analysis of the monitored data for twelve months and particularly for the summer months.

Load shape of the VRF system is shown in Figure 111. The load shape in this document is defined as the average power draw (kW) during the hour for the entire system. This kW number includes outdoor unit power, power draw from all the indoor units, branch selector boxes and the fresh air fan. By definition, the load shape does not include the maximum demand imposed by the system but just the hourly average. The load shape is further split out in terms of a summer shape and the average 12 months shape. Summer is defined time between as June 1st and October 1st. Summer load shape showed high demand during peak periods for utilities. The overall load shape for the 12 months also shows significant load during 'on-peak' hours defined as hours between noon and 6pm. This high load during on-peak times makes this technology a great candidate for demand response which is discussed later on in a separate section.

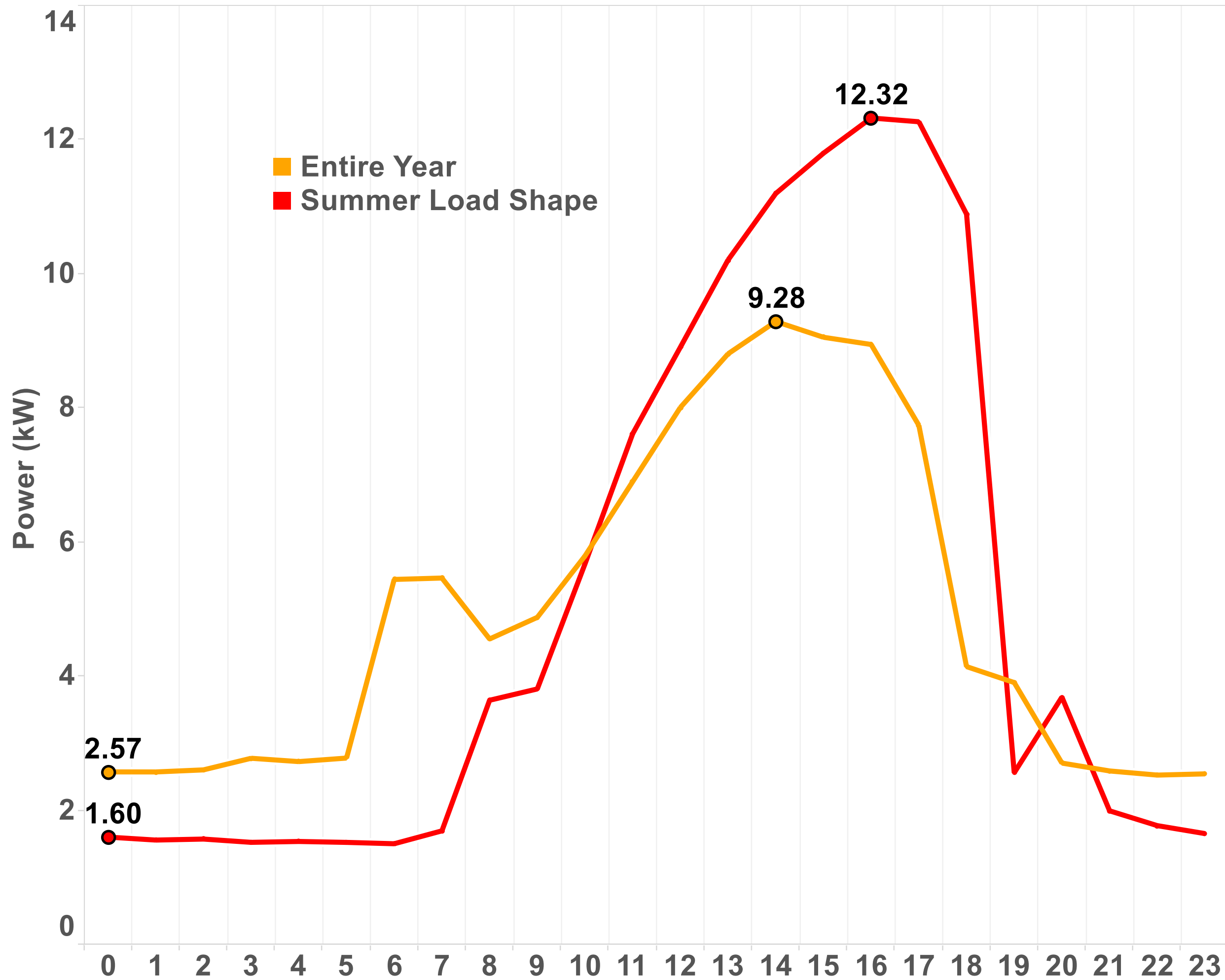


FIGURE 11: LOAD SHAPE OF VRF SYSTEM (AVERAGE FOR ENTIRE YEAR AND SUMMER MONTHS)

Billing data for the building was made available for the purpose of this analysis. The tabulated data is presented in Table 5. The meter reading date does not exactly align with month end dates. For example, when month of June 2014 is considered, the actual readings are from 06/03/2014 to 07/02/2014. The time period between the two dates is considered as month of June since majority of the time is in month of June. The EPRI data is also filtered to make sure the data presented corresponds to billing dates. The billing data provided is for the entire building – it covers more than just the VRF system. It includes lighting loads, two small data centers, computers in the building and other plug loads. The EPRI monitoring data captures all the energy used by the VRF system only. Table 5 shows the total energy consumed by the building and the energy consumed by the VRF equipment. The difference is also presented which gives an idea of the other loads in the building. The other loads seem to be approximately 10,000 kWh every month on average.

TABLE 5: BILLING ANALYSIS (TOTAL ENERGY VERSUS VRF ENERGY CONSUMPTION)

MONTH	BILLING START DATE	BILLING END DATE	TOTAL KWH (SCE METER)	VRF TOTAL KWH (EPRI MONITORING)	OTHER LOADS KWH (SCE−EPRI)
January	1/2/2015	2/2/2015	11,815	2,223	9,592
February	2/2/2015	3/4/2015	12,019	2,464	9,555
March	3/4/2015	4/3/2015	12,104	2,951	9,153
April	4/3/2014	5/2/2014	15,186	5,620	9,566
May	5/2/2014	6/3/2014	16,955	6,637	10,318
June	6/3/2014	7/2/2014	12,807	2,576	10,231
July	7/2/2014	8/1/2014	14,279	3,744	10,535
August	8/1/2014	9/2/2014	15,413	4,062	11,351
September	9/2/2014	10/1/2014	14,883	4,224	10,569
October	10/1/2014	10/31/2014	14,324	3,880	10,444
November	10/31/2014	12/3/2014	11,433	2,441	8,992
December	12/3/2014	1/3/2015	11,878	2,596	9,282

The building monitored recently transitioned to a Time of Use (TOU) rate. The building is classified under the TOU-GS-2-B rate schedule. Figure 122 shows the rates by season and time (from SCE website). For summer season there are three periods: off-peak, mid-peak, and on-peak. In winter the on-peak is done away with and only two periods, off-peak and mid-peak are defined. Table 6 shows the energy usage during the summer months split by the periods that the energy was consumed in. In the peak periods, 35-45% of the energy is used by the VRF equipment.

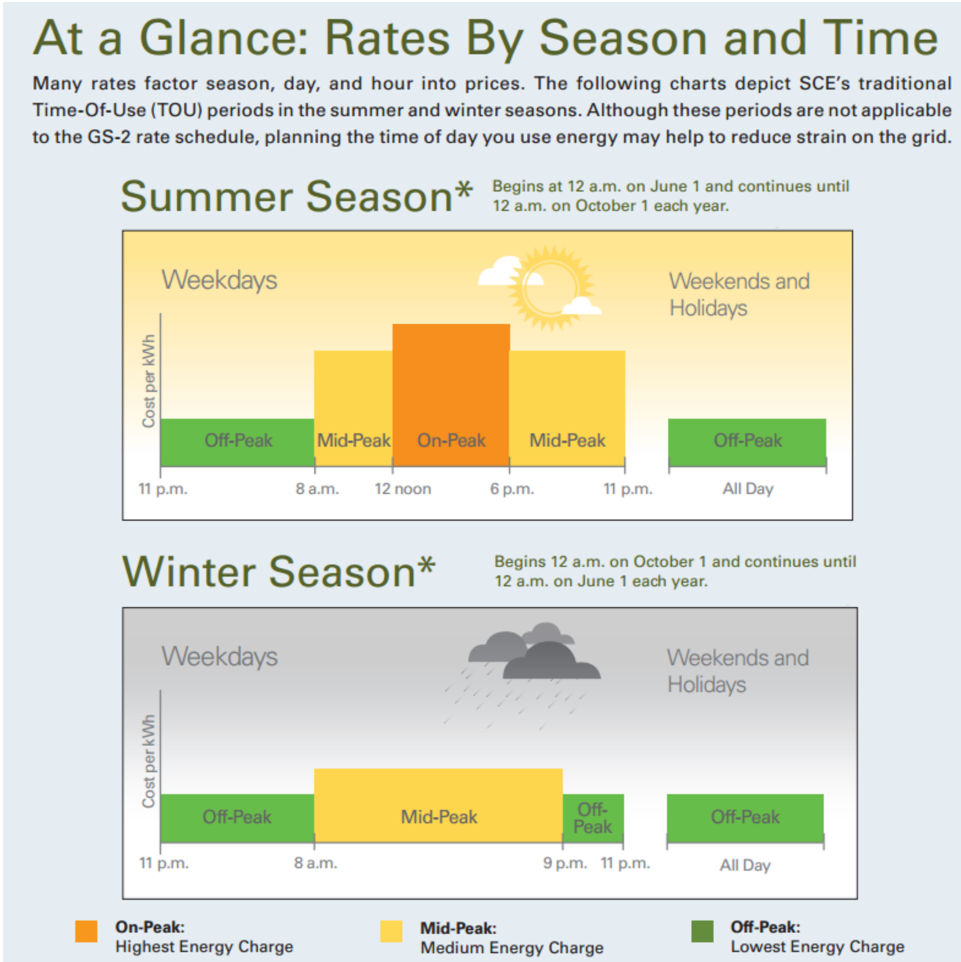


FIGURE 12: EXPLANATION OF TIME OF USE (TOU) RATES FOR THE FIELD SITE (SOURCE SCE WEBSITE)

TABLE 6: ON-PEAK, MID-PEAK, AND OFF-PEAK ENERGY USAGE FOR SUMMER MONTHS

MONTH	ON-PEAK KWH (SCE)	VRF ON-PEAK KWH	MID-PEAK KWH (SCE)	VRF MID-PEAK KWH	OFF-PEAK KWH (SCE)	VRF OFF-PEAK KWH
June	3,449	1,233	3,569	697	5,789	646
July	3,845	1,736	3,820	1,021	6,614	987
August	3,994	1,861	3,843	1,023	7,576	1,178
September	4,270	2,011	4,023	1,092	6,590	1,121

Energy usage is split based on indoor or outdoor unit energy usage. The indoor unit energy includes indoor unit energy use, branch selector and fresh air fan energy usage. Figure 133 and Figure 144 show energy usage split by outdoor unit energy consumption and indoor unit energy usage for the summer months. For months of July, August, and September the energy usage from the indoor fan units is fairly constant but the outdoor energy usage fluctuates with the ambient conditions (as expected).

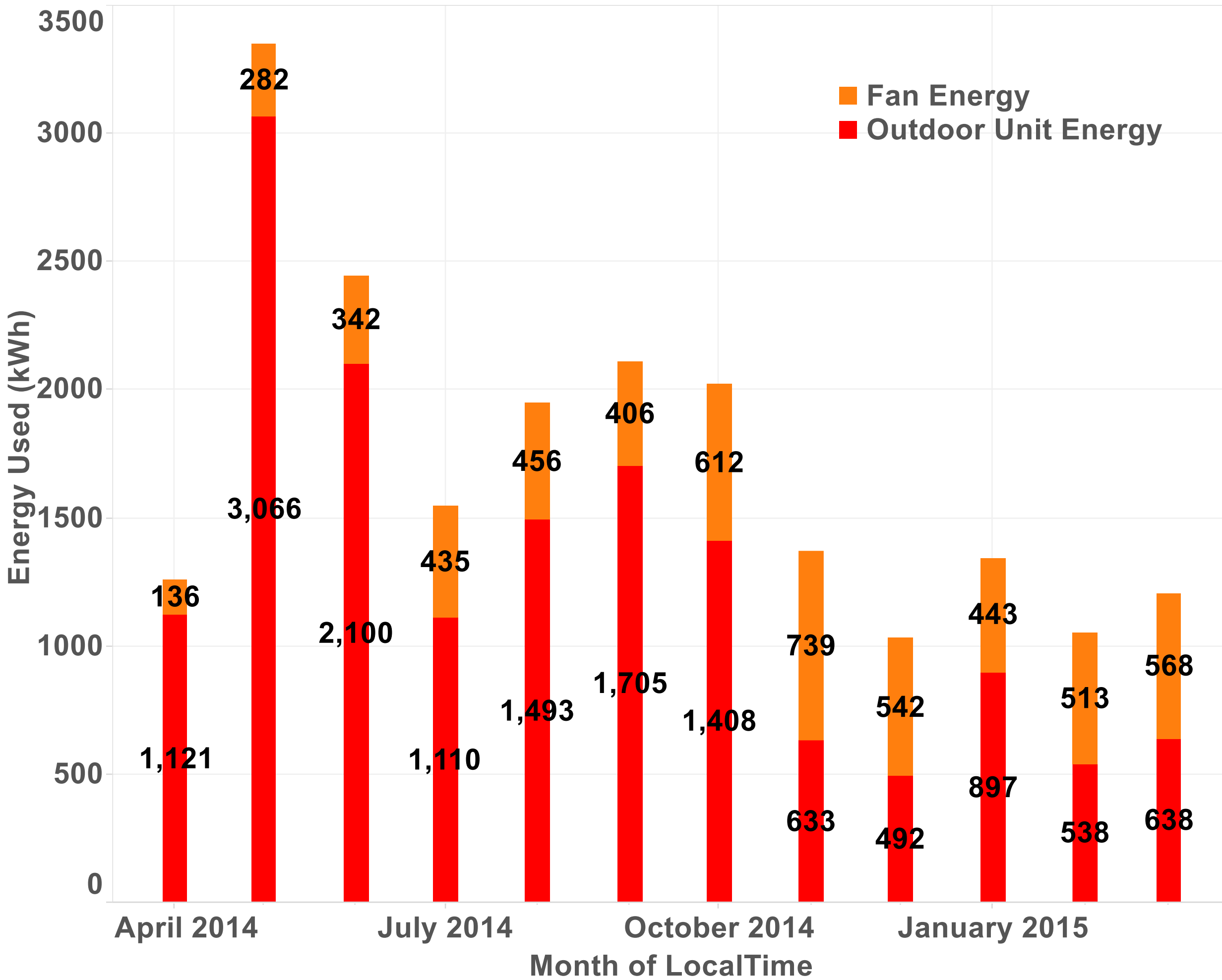


FIGURE 13: FIRST FLOOR ENERGY USAGE

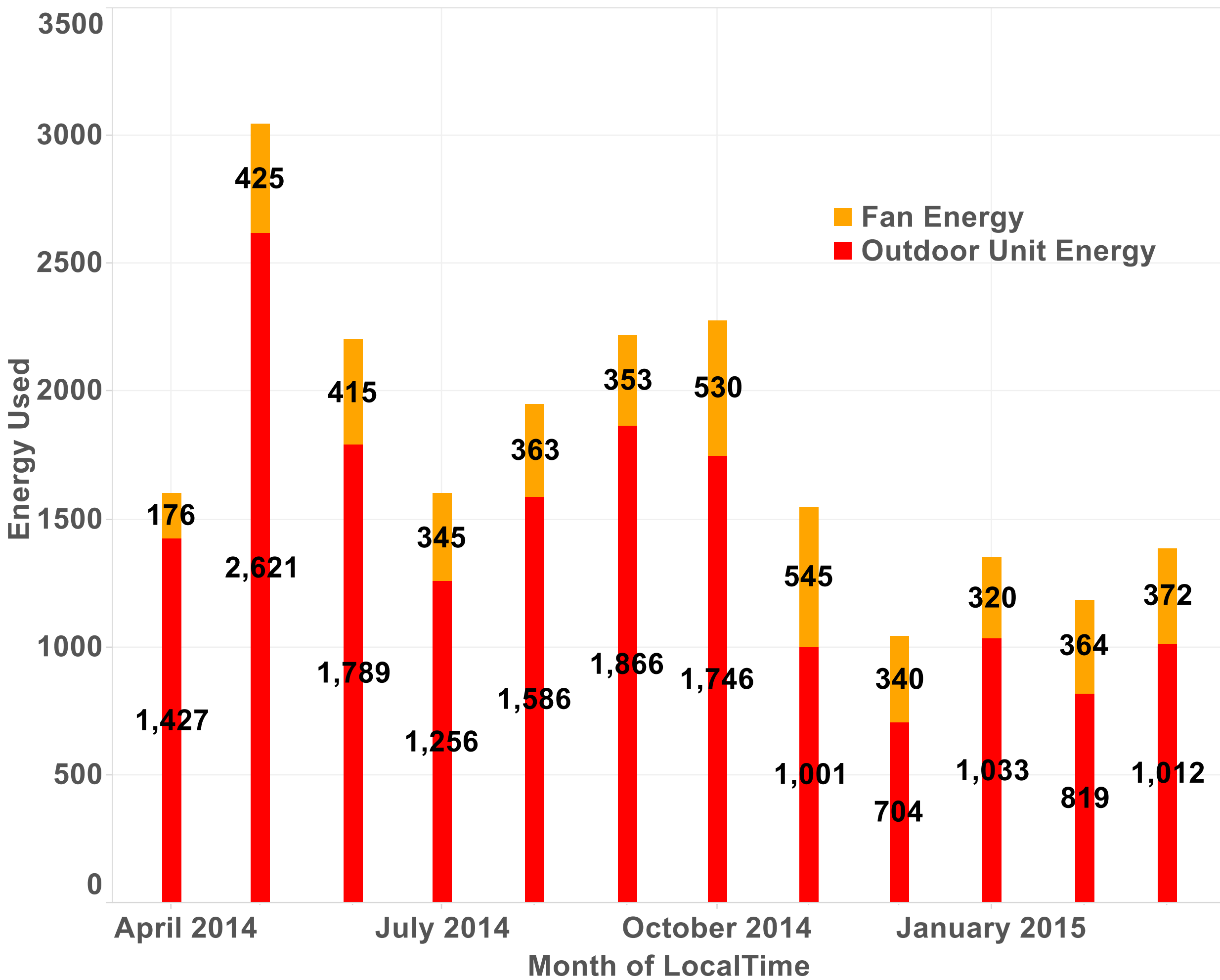


FIGURE 14: SECOND FLOOR ENERGY USAGE

ENERGY USAGE COMPARISON WITH PREVIOUS YEAR

To understand the energy efficiency gains made by replacing the earlier rooftop units, billing data from previous years is compared with billing data for period of this field trial. Since the building did not undergo any other changes in terms of occupancy, loads or energy efficiency measures, savings if any can be attributed to the installation of the VRF system and weather.

The average 'other loads' are assumed to be 9,966 kWh per month based on the data provided in Table 5.

TABLE 7: COMPARING ENERGY USAGE FROM 2013 TO ENERGY USAGE DURING THIS TRIAL

MONTH	SCE KWH YEAR 2013	SCE KWH (APR '14 – MAR '15)	BASELINE SYSTEM KWH (SCE KWH 2013 – 9,966)	VRF TOTAL KWH (EPRI MONITORING)	ENERGY DIFFERENCE (KWH)
January	14,349	11,815	4,383	2,223	2,160
February	15,464	12,019	5,498	2,464	3,034
March	14,014	12,104	4,048	2,951	1,097
April	13,665	15,186	3,699	5,620	-1,921
May	14,714	16,955	4,748	6,637	-1,889
June	15,505	12,807	5,539	2,576	2,963
July	16,926	14,279	6,960	3,744	3,216
August	15,468	15,413	5,502	4,062	1,440
September	17,437	14,883	7,471	4,224	3,247
October	15,571	14,324	5,605	3,880	1,725
November	16,441	11,433	6,475	2,441	4,034
December	11,846	11,878	1,880	2,596	-716

The total HVAC energy usage in 2013 was 61,812 kWh whereas during the period of this monitoring it was 43,418 kWh, a 29.7% reduction. The months of April and May show a negative energy difference which indicates that energy usage was higher than the baseline system. This has been addressed before in the report. The system control was not setup properly initially resulting in higher energy consumption. If the months of April and May are ignored because of the known issue, a 41% energy reduction is achieved by using the VRF system.

Commercial accounts get billed for the demand they create in addition to the energy used. Demand is also measured in the same time buckets as energy is measured – on-peak, mid-peak, and off-peak. Table 88 shows the measure maximum demand by the SCE meter and the corresponding demand imposed by the VRF system. The billing demand is defined as the maximum average kW for 15 minute block during the billing cycle. The blocks are defined as 2:00 to 2:15, 2:15 to 2:30 and so on. The table indicates the time in terms of the starting point of the 15 minutes of which the average is taken i.e. 3:45 pm on 04/30/2014 for the month of April means that the average demand during 3:45 pm and 4:00pm was 40 kW as measured by the SCE meter. The demand data shows that there is an average 20.1 kW other load on the building besides the VRF system during the peak hours.

TABLE 8: COMPARISON OF SCE BILLING DATA AND EPRI MONITORING DATA FOR DEMAND (KW)

MONTH	DATE	TIME	MAX DEMAND (KW) SCE	VRF DEMAND DURING SAME PERIOD (EPRI MONITORING)	OTHER LOADS KW (SCE−EPRI)
January	1/2/2015	6:15am	37	27.6	9.40
February	2/24/2015	6:15am	34	23.1	10.90
March	3/13/2015	1:00pm	34	16.0	18.00
April	4/30/2014	3:45pm	40	19.89	20.11
May	5/15/2014	12:45pm	42	21.83	20.17
June	6/3/2014	3:45pm	35	13.93	21.07
July	7/2/2014	3:00pm	40	16.02	23.98
August	8/4/2014	2:15pm	38	16.81	21.19
September	9/16/2014	1:15pm	46	22.38	23.62
October	10/2/2014	2:00pm	45	21.66	23.34
November	11/6/2014	12:15pm	32	11.11	20.89
December	12/31/2014	6:15am	38	26.94	11.06

THERMAL CHARACTERISTICS

The outdoor conditions in which a VRF system is operating has significant impact on the power draw from the system. The data is filtered to include only weekdays and working hours (7am to 7pm). Figure 155 shows the power draw trend and the amount of time in hours spent in each bin (numbers on top of bars). The trend in power draw with respect to the outdoor temperature is as expected. At the extremes of temperature range, the power draw is higher and in the milder ambient conditions the power draw is lower. The 40°F bin shows lower power draw, but this can be attributed to the limited time that the system spent in that time bucket (<1 hour).

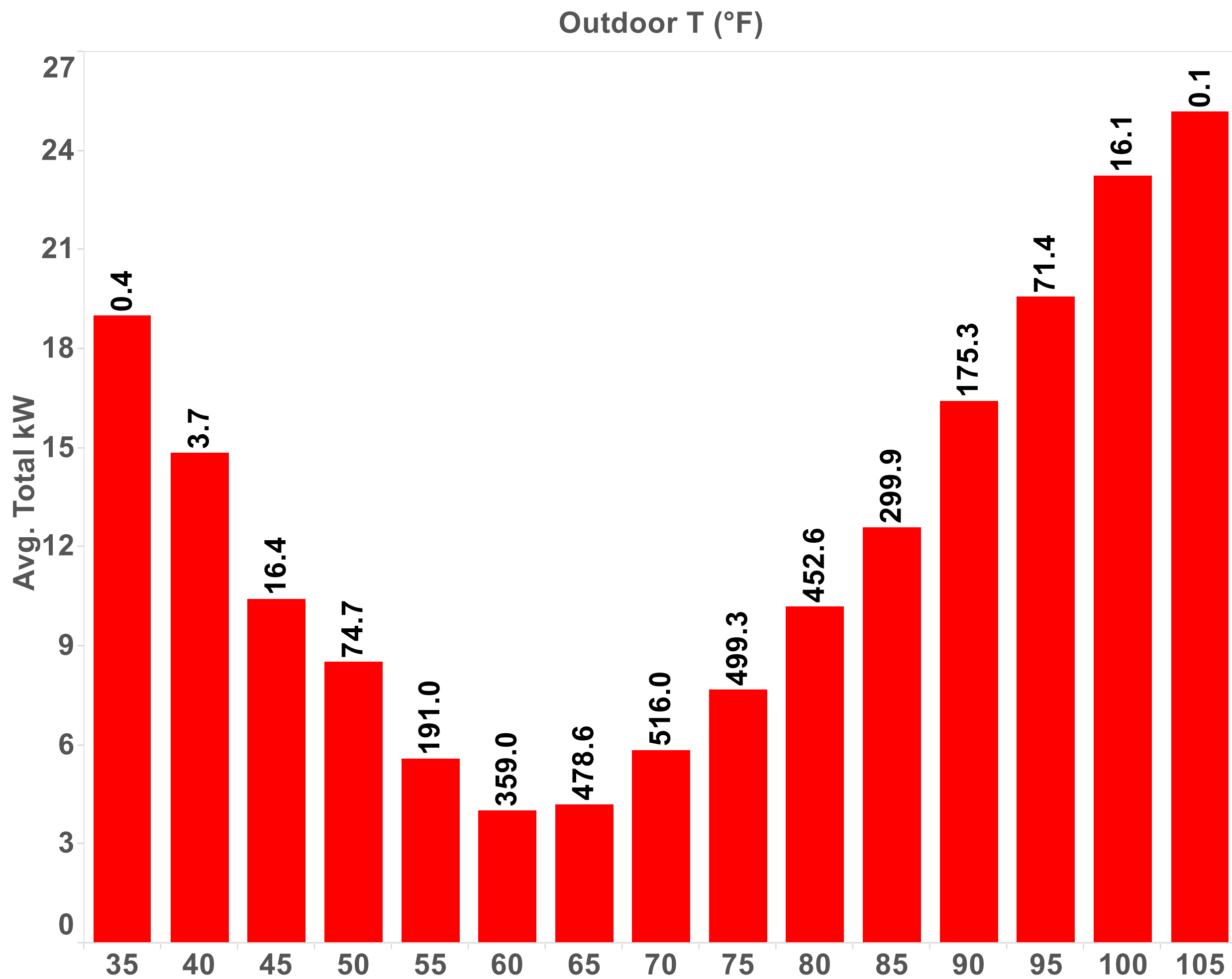


FIGURE 15: AVERAGE POWER DRAW VERSUS TEMPERATURE BINS

DETERMINING MODE OF OPERATION OF INDOOR UNIT

The mode of operation of each individual indoor unit is determined by the difference between the return air temperature and supply air temperature of the same indoor unit. There are three different modes of operation – auto fan, cooling, and heating. The temperature difference for determining the operating mode is set at 5°F. If the temperature difference between return air and supply air is greater than 5°F, then the unit is assumed to be in cooling mode. If the temperature difference is less than -5°F, then the unit is assumed to be in heating mode. For the temperatures in between the unit is in fan mode or OFF. Figure 166 shows the cumulative operating hours of the 17 units in the building. For example, in month of September the total number of hours spent by all units in cooling mode was 3,207 which makes sense due to the hot weather in September seen in Figure 66.

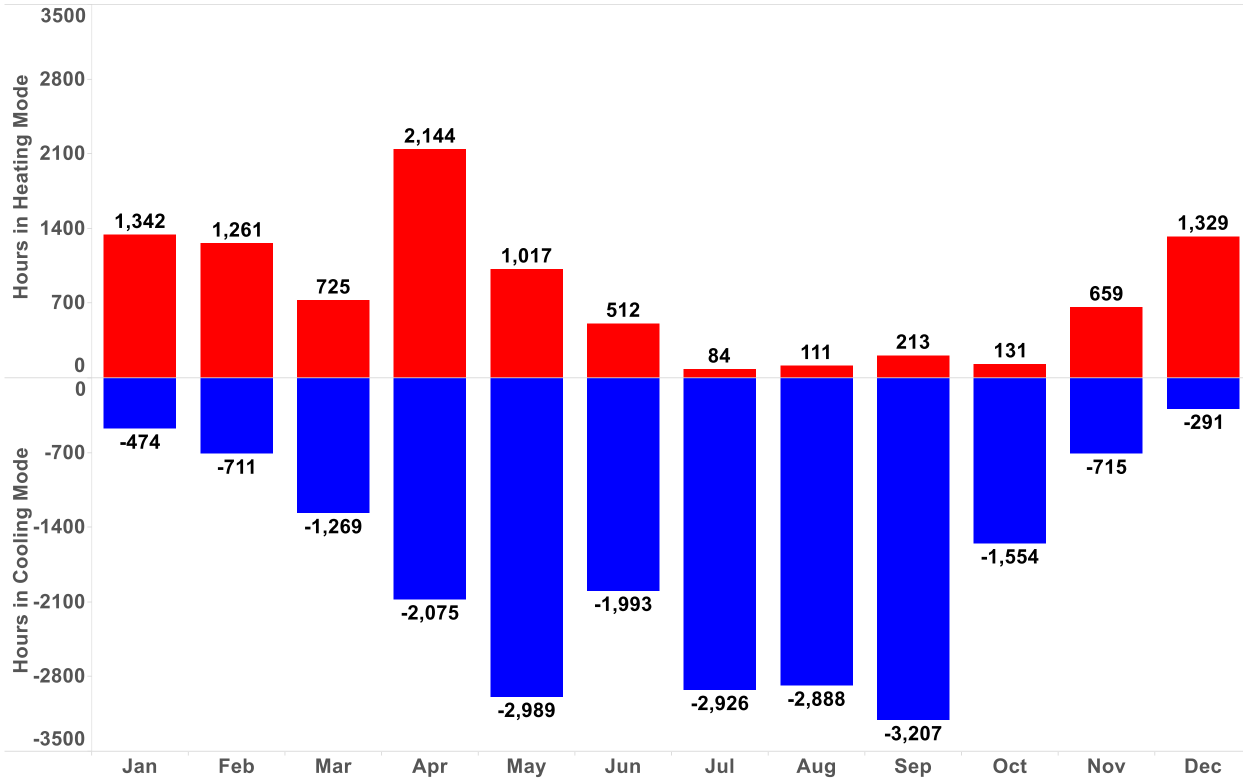


FIGURE 16: INDOOR UNITS OPERATING HOURS IN HEATING OR COOLING MODE (ALL 17 UNITS COMBINED)

OUTDOOR UNIT OPERATING MODE

The outdoor unit can be operating in heating only mode, cooling only mode, or mixed mode depending on the total load on the system. In heating only mode, all the indoor units are operating in either heating mode, or some in heating and some in fan mode. None of the units are in cooling mode. In cooling only operating mode, the indoor units are operating in either cooling mode or some in cooling and some in fan mode. None of the units are in heating mode.

In mixed mode a combination of indoor units operating in heating, cooling, and fan mode is observed. The mixed mode operation is also known as the heat recovery mode where energy from one zone (a warm zone) is transferred to another (a cold zone) whenever possible.

Figure 177 and Figure 188 show the operating hours for the VRF outdoor units for Floor 1 and Floor 2 of the building. Since the two systems are independent based on their refrigeration circuits, the modes of operating for both units are shown separately. As the temperature increases the operating time in cooling mode increases. During the milder temperatures around 65°F, the fan or OFF mode dominates. The mixed mode operation is evident during the 55°F and 65°F where there might be need for cooling as well as heating.

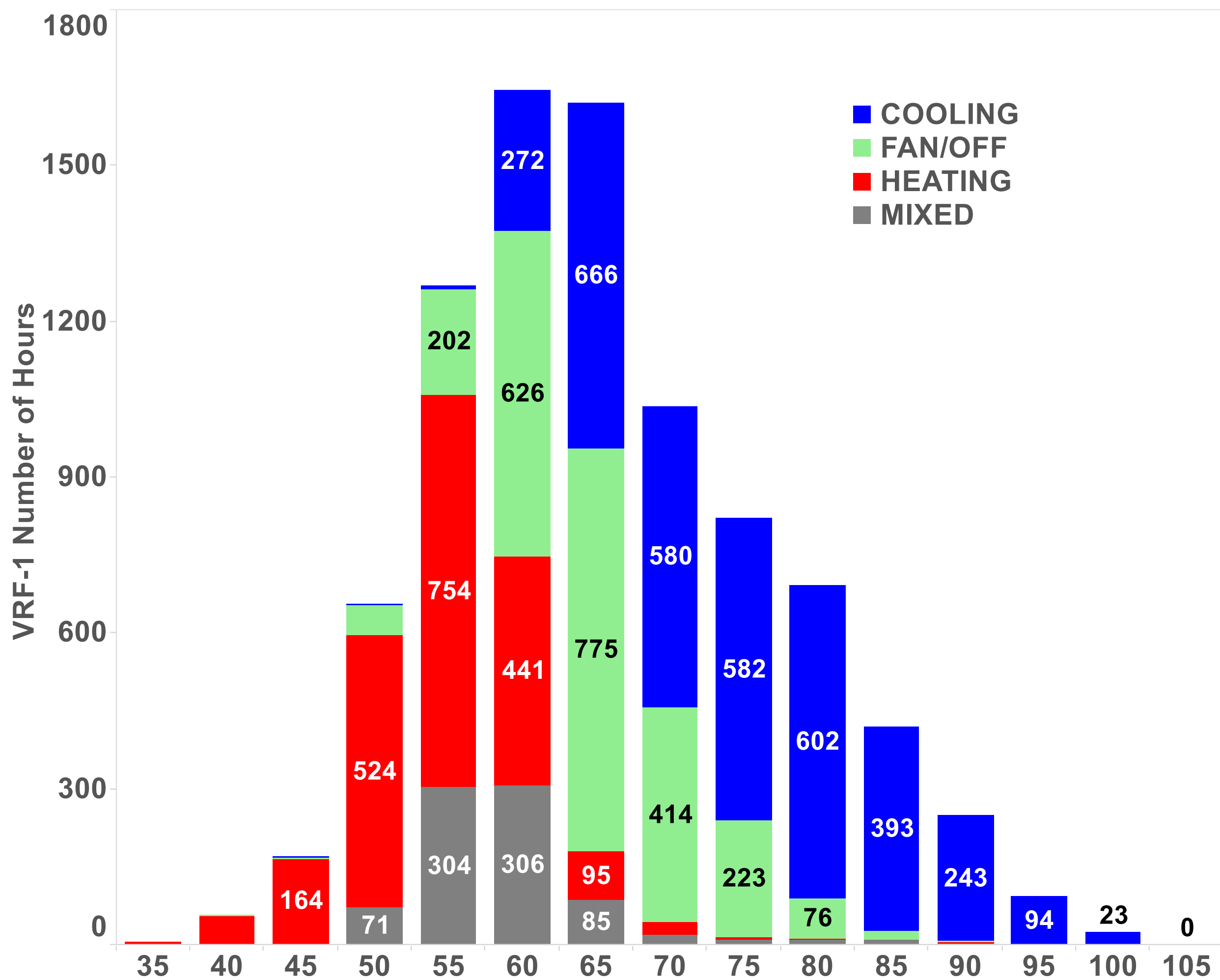


FIGURE 17: OPERATING HOURS FOR VRF UNIT 1 (FLOOR 1)

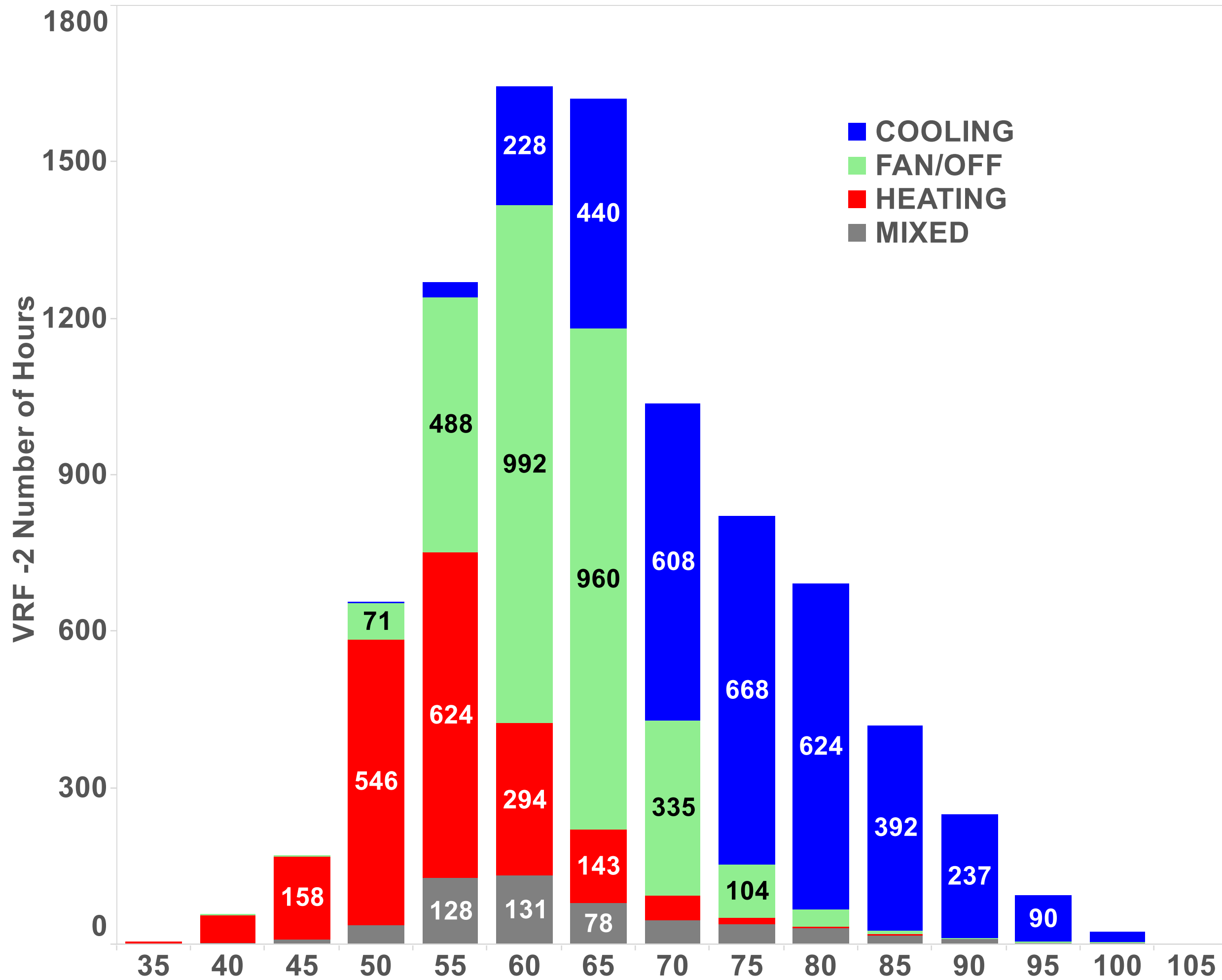


FIGURE 18: OPERATING HOURS FOR VRF UNIT 2 (FLOOR 2)

CAPACITY ESTIMATES

Capacity is estimated for each indoor unit by using the air enthalpy method. The capacity of each indoor unit is the product of mass flow rate of air (lbs/hr) and the change in enthalpy across the indoor unit (BTU/lb).

The airflow rate for each individual indoor is obtained from the test and balance (TAB) report provided by the installing contractor. The TAB report provides airflow rates in CFM for each of the ducted units installed in the building. For ductless units (wall mount or cassette) published airflow from the manufacturer at the high fan speed setting are used. The airflow is measured in CFM (cubic feet per minute) and then converted into mass flow rate of pounds per hour. This mass flow rate is assumed to be constant throughout the data monitoring period.

Enthalpy measurements are derived from the dry bulb temperature and relative humidity (RH) measurement taken at return and supply air of each indoor unit. The enthalpy is calculated based on perfect gas relationships for dry and moist air elaborated in 2009 ASHRAE Handbook – Fundamentals, Chapter 1 Psychrometric.

h= 0.240t + W(1061+0.444t)

h = enthalpy of moist air

t= dry bulb temperature

W=humidity ratio

Humidity ratio is not measured by the installed instrumentation but the relative humidity (RH) is. Saturation pressure over liquid water (p_{ws}) at a given temperature (between 32F and 392F) is given by:

$$\ln p_{ws} = \frac{C_8}{T} + C_9 + C_{10}T + C_{11}T^2 + C_{12}T^3 + C_{13}\ln T$$

Where C8 thru C13 are constants, T is absolute temperature.

C8=-1.044 039 7 E+04

C9=-1.129 465 0 E+01

C10=-2.702 235 5 E-02

C11=1.289 036 0 E-05

C12=-2.478 068 1 E-09

C13=6.545 967 3 E+00

Based on p_{ws}, p_w the partial water vapor pressure of a moist air sample can be calculated:

$$p_w = p_{ws} \times RH$$

Humidity ratio W is calculated by:

$$W = 0.621945 * \frac{p_w}{p - p_w}$$

Where p is atmospheric pressure assumed to be 14.695 psia.

Field capacity measurements are difficult. The calculations made in this report give an estimate of the capacity delivered. For accurate capacity measurement significant additional instrumentation and resources would be required. The assumptions made in capacity measurement are as follows –

- Atmospheric pressure assumed to be 14.695 psia
- Air flow is assumed to be constant and equal to the maximum flow rate of the fan. In actual install, the occupants could change the fan setting to a lower setting. Fan

speed settings (low, medium, or high) could not be confirmed with the available instrumentation. Air flow will also change depending upon the condition of air filter for each indoor unit.

- Temperatures and relative humidity measurements are point measurements and are assumed to be representative for bulk temperature of air.

Figure 19 shows the total capacity (heating and cooling) delivered by the VRF system broken down by each floor for the entire monitoring period.

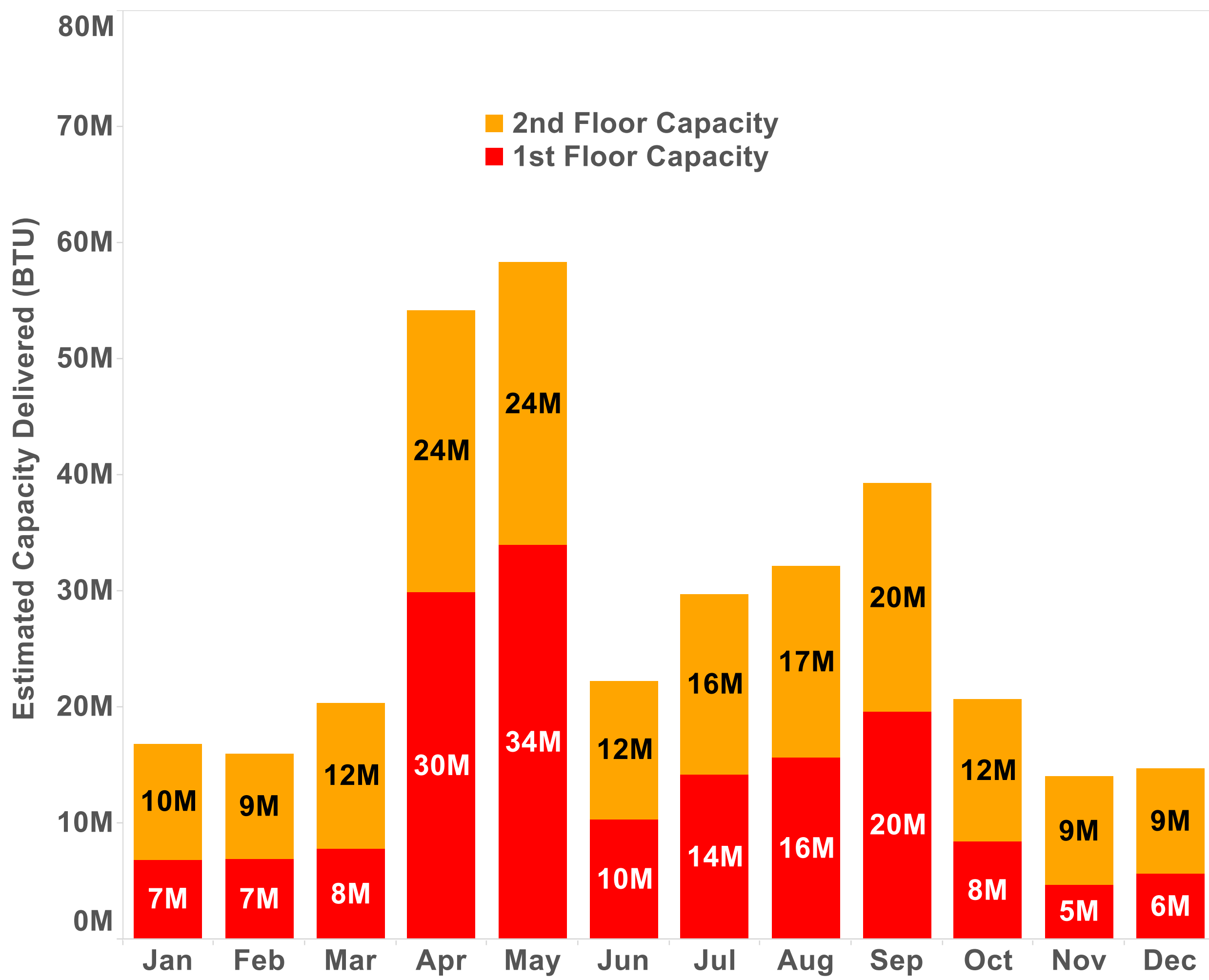


FIGURE 19: ESTIMATED DELIVERED CAPACITY

The months of April and May, the system was not setup for the appropriate setbacks and was without the central controller.

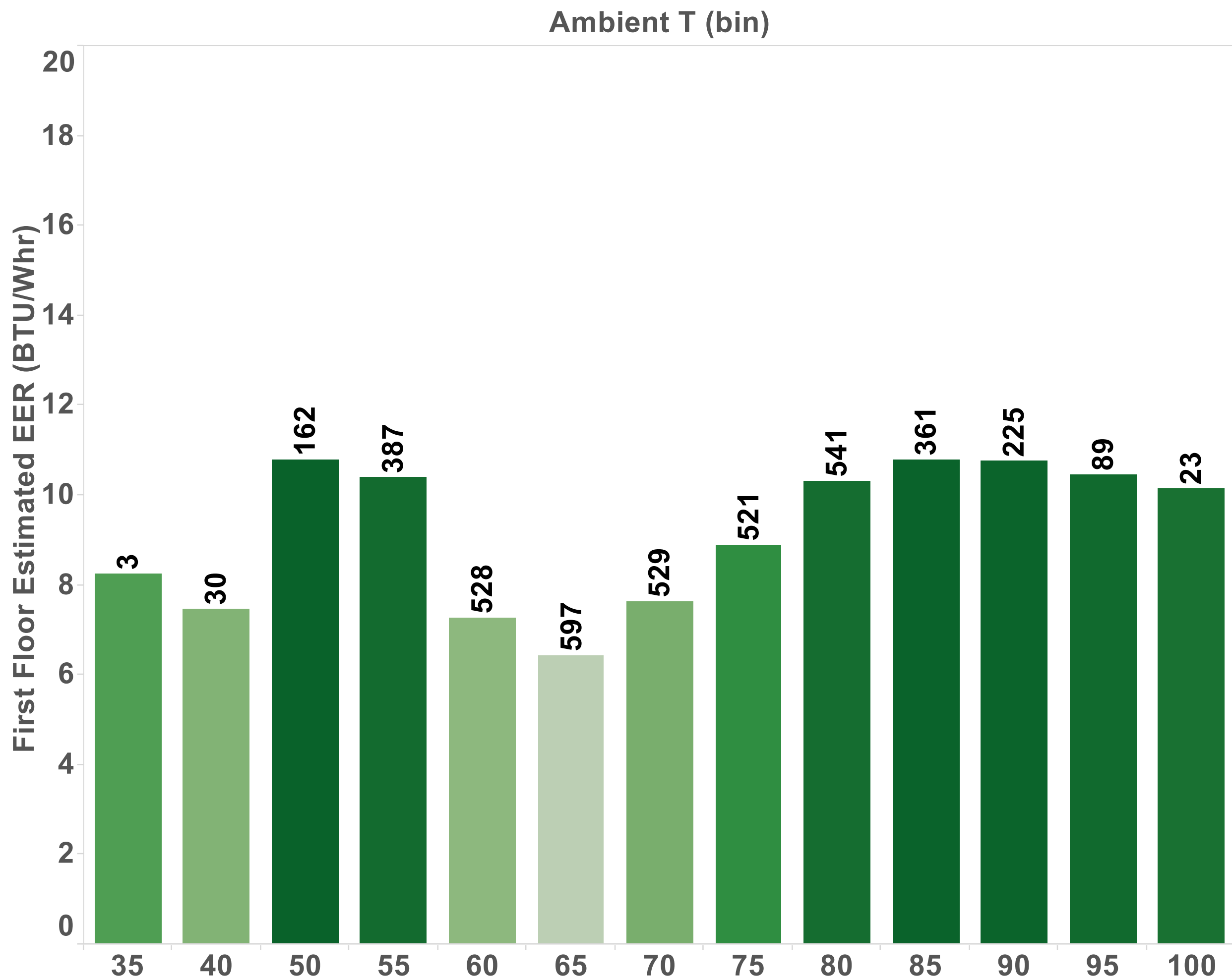


FIGURE 20: FIRST FLOOR ESTIMATED EER FOR SUMMER MONTHS

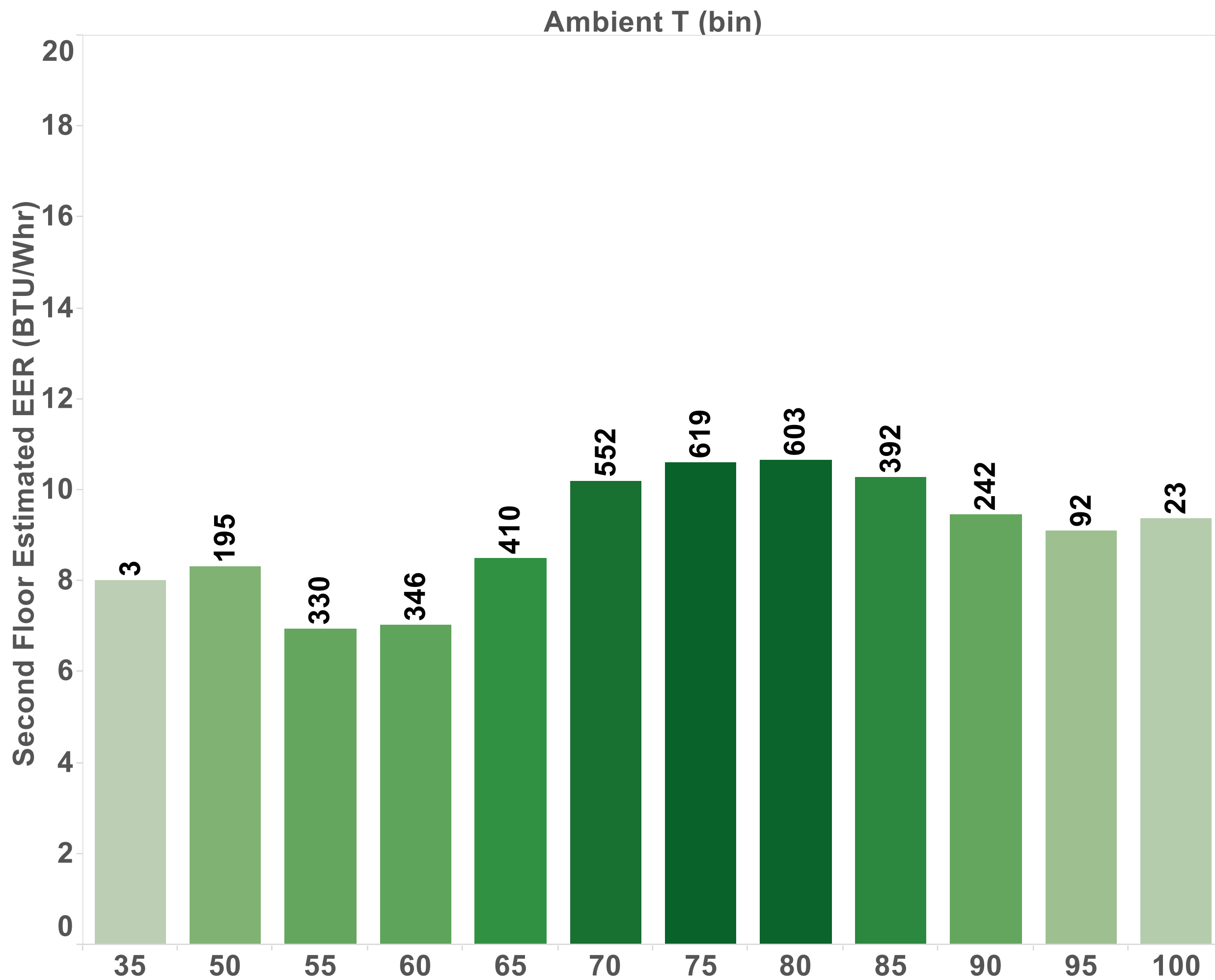


FIGURE 20: SECOND FLOOR ESTIMATED EER FOR SUMMER MONTHS

DEMAND RESPONSE DEMONSTRATION

Demand response (DR) capabilities of VRF equipment are of great research interest to SCE. The summer load shape shown in Figure 111 shows that the VRF equipment load is a coincident load with the utility summer peaks. The demand is very high during peak periods for SCE and any reduction in peak demand will help SCE manage their resources better and in turn provide benefits for customers as well. So, a parallel effort within this project was undertaken to demonstrate demand response capabilities of the installed VRF equipment.

EQUIPMENT INSTALLED

To initiate demand response, the VRF equipment needed to be issued commands (from a remote location). Two challenges are encountered in doing so – communications and protocols.

COMMUNICATION

The VRF equipment has to be able to communicate with an outside entity (a computer server) to receive DR commands. The communication in this trial was implemented by using an off the shelf controller that could interface between the VRF systems controller and the public internet using wired connection. This configuration can be scaled on the hardware side. Some programming was involved on the controller to setup priority zones and other operations constraints. Figure 212 shows the hardware setup to address the communications. The controller on the left is the additional controller was added as part of the DR demonstration. The controller on the right is the existing system controller. The setup is installed in the server room of the second floor. The additional controller is a Mitsubishi Electric DC-600E Diamond Controller which acts as a protocol translator.

FIGURE 21: ADDITIONAL HARDWARE

PROTOCOL

The protocol used in this demonstration is the OpenADR 2.0a messaging system. OpenADR is Open Automated Demand Response information exchange model that allows messages to be passed between utilities, ISO/RTO's, aggregators, and end-use devices. Two important concepts relevant to this demonstration are discussed here –

- Virtual Top Node (VTN) – A VTN is a server that issues commands/signals to the end nodes (devices) that are connected to it in the right format. For this demonstration, a VTN configured by EPRI was used to issue commands to the VRF system.
- Virtual End Node (VEN) – A VEN is the device that receives and responds (as appropriate) to the commands/signals from the VTN. In this demonstration the Mitsubishi DC-600E controller is the VEN.

SCHEDULED DR EVENT

A DR event was scheduled for December 10th 3pm – 4pm PST. The strategy for the DR event was to increase cooling set point by 3°F and reduce the heating set point by 3°F. The date was selected based on readiness from the vendor. Ideally the event should have been scheduled in summer when the AC unit was fully loaded, but the implementation and setup took time which delayed the demonstration. The vendor has agreed to provide support until next summer when further DR demonstrations will be undertaken. In early 2015 the project team at EPRI may undertake further testing to debug any potential issues.

Figure 223 shows the power draw and the ambient temperature before, during, and after the scheduled event.

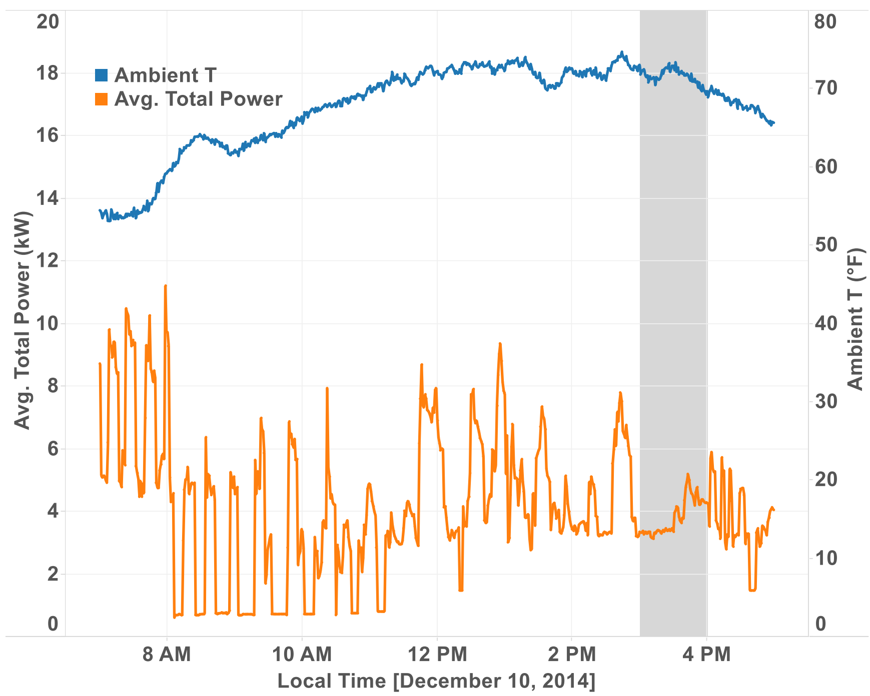


FIGURE 22: POWER DRAW AND AMBIENT CONDITIONS DURING DR EVENT

The average temperature during the event was 71.6°F and the average power draw was 3.82 kW. The temperature was on the milder side with very little heating or cooling demand from the building (and hence the low kW).

From a metering standpoint, the 15 minute average power draw from the VRF system as seen by the SCE meter is shown in Table 99. This is monitoring data from EPRI instrumentation broken down into 15 minute averages. It can be seen that there is an immediate reduction of 1.7 kW at the start of the event which equates to about 35% reduction in demand. This is not a typical response for this type of strategy but gives an idea of how this particular system responded. More testing is required to determine effect of various strategies envisioned.

TABLE 9: DEMAND (VRF ONLY) SEEN BY SCE METER BEFORE, DURING, AND AFTER THE DR EVENT

TIME (FROM)	TIME (TO)	VRF DEMAND (KW)
2:30 pm	2:45 pm	5.4
2:45 pm	3:00 pm	5.0
3:00 pm	3:15 pm	3.3
3:15 pm	3:30 pm	3.4
3:30 pm	3:45 pm	4.1
3:45 pm	4:00 pm	4.4
4:00 pm	4:15 pm	4.5
4:15 pm	4:30 pm	3.7

Figure 234 shows the demand from first floor and second floor during the DR event. The first floor follows the DR signal very well with no demand imposed during the specified time. The second floor on has 1.85kW demand which actually increases during the event at 3:30 pm (half-way into the event). After looking at the data in detail it was found out that one of the indoor units that is installed in an office space turned ON in cooling mode. With the EPRI instrumentation it is not possible to determine whether the occupants changed the setting or if there was another reason for that indoor unit to turn ON. This situation could be resolved with the data logging from the individual indoor unit controllers. The vendor of the control system is working on it to provide us with as much detail as possible in the future trials on this same building.

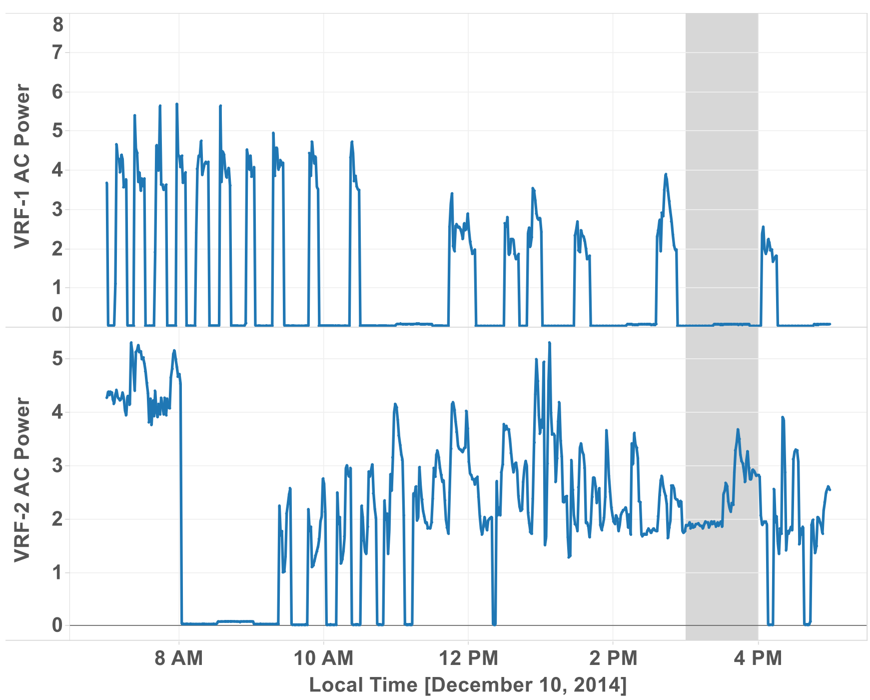


FIGURE 23: DEMAND FROM VRF 1 AND VRF 2 DURING THE DR EVENT

CONCLUSIONS

This report provides analysis of a field installed VRF-HR system in Mission Viejo, CA. The data gathered is grouped into two main types – electrical and thermal. The data set collected can be used for further model validation purposes.

The monitoring and analysis of the VRF-HR system shows that the operating characteristics were in line with the expectations based on understanding of HVAC systems. Summary of the findings and discussion is presented in a numbered list:

1. The monitored ambient conditions show slight variations from the published weather data for Climate Zone 8. The variations can be attributed to the limited data set that is available for this site - single point ambient measurements made only for one year. Besides that, CA CZ8 provides weather data for Long Beach, Anaheim, Tustin, and El Toro with significant difference between the CDD and HDD within the same CZ.
2. Critical detailed measurement of field performance of variable refrigerant flow heat recovery systems (VRF-HR) to help characterize actual yearly energy savings was captured. The goal to provide quality data for use in energy modeling verification was realized. Summer load shape shows high demand during peak periods for utilities (12:00 pm to 6:00 pm). This is typical of commercial HVAC equipment. A winter load shape needs to be developed further, and will available once complete winter data is available.
3. The high demand during summer peak hours makes the VRF installation a potential candidate for the Demand Response program. The VRF system was able to prove that it provided more precise space conditioning than the legacy system which it replaced. The highly efficient VRF was able to reduce the peak demand for the HVAC system and the overall energy consumption through the utilization of inverter driven compressors and fans, electronic expansion valves and advanced controls during the numerous hours of part-load consumption.
4. It was imperative to assess the ability of the VRF equipment to communicate with an outside entity to receive the DR commands. An off-the-shelf controller was used to interface between the VRF systems controller and the public internet using wired connections. An additional controller was required to act as a protocol translator. Some additional programming was necessary. Demand Response communications invoked OpenADR 2.0a protocols sent from a VTN at EPRI and it exchanged information through the required controller setup on-site which acted as an OpenADR Virtual End Node and translated the OpenADR commands to native language for the VRF system.
5. Demand reduction via the OpenADR messaging was demonstrated by the system responding to a pre-scheduled Demand Response event. This verified the ability of the EPRI VTN to communicate with the VRF system. More testing by the EPRI team is expected later in the summer of 2015.

APPENDICES

OBVIUS ACQUISUITE A8810 –DATA ACQUISITION SERVER

Specifications	
Processor	ARM9 embedded CPU
Operating System	Linux 2.6
Memory	32 MB RAM
Flash ROM	16 MB NOR Flash (expandable with USB memory device)
Interval Recording	1 to 60 minutes, user selectable (default 15 minutes)
LEDs	Ethernet, Modbus TX/RX, power, alarm
Console	2 x 16 LCD character, two push buttons
Power	
Power Supply	24VDC, 500mA
	"This unit is to be sourced by a Class 2 power supply with the following output: 24VDC, 500mA min not to exceed 8A
Isolation	RJ45 Ethernet and RS-485 port are isolated to 1500VDC from the main board. (Power and USB non-isolated)
Communication	
Protocols	Modbus/RTU, Modbus/TCP, TCP/IP, PPP, HTTP/HTML, FTP, NTP, XML, SNMP-Trap
LAN	RJ45 10/100 Ethernet, full half duplex, auto polarity
USB	USB expansion port
Inputs	
Serial Port	RS-485 Modbus, supports up to 32 external devices (expandable)
Physical	
Weight	0.42lbs (0.19kg)
Size	4" x 4.25" x 2" (102mm x 108mm x 51mm)
Environment	
North America	-30 to 70C, 95% RH, non-condensing
Codes and Standards	
FCC CFR 47 Part 15, Class A, EN 61000, EN 61326, CE, UL61010 Recognized	

OBVIUS FLEX IO – A8332-8F2D

Specifications	
Processor	ARM7, field upgradable firmware
LEDs	8x input status LEDs (red), 2x Modbus TX/RX (yellow), 1 power/alive status (green)
Memory	Pulse count and runtime values are stored in non-volatile memory
Power	
Power Supply	24VDC, 200mA but not to exceed 8A, Required (not included)
Communication	
Protocols	Modbus/RTU
Inputs	
Voltage Mode	0-10VDC (min/max/average/instantaneous data) Accuracy: +/- 0.25% of full scale at 20C
Current Mode	4/20mA (min/max/average/instantaneous data) Accuracy +/- 0.25% of full scale at 20C
Resistance Mode	100 ohms to 100k (see installation for accuracy specification)
Pulse Mode	• Intended for use with dry contact outputs (consumption/rate/runtime/status) • Standard and KYZ modes for form A and C relay outputs • Input terminals supplies 5V at 5mA sense voltage to detect contact closures • Maximum rate: 10Hz, minimum pulse width 50ms • Adjustable contact closure threshold: 100Ω to 5kΩ, broken wire sense above 10kΩ optional
Serial Port	RS-485 two wire, 19200 or 9600 baud, 8N1
I/O	8 Flex IO inputs with user selectable modes: voltage, current, resistance, pulse and status
Isolation	Pulse outputs and RS-485 port are isolated to 1500VDC; Power input, RS232 and analog/pulse inputs are non-isolated
Outputs	
Relays	2x, dry contact (opto-fet) 30 VDC, 150 mA max
Physical	
Weight	3.7oz (105g)
Size	4.13" x 3.39" x 1.18" (105mm x 86mm x 30mm)
Environment	
North America	-30 to 70C, 0-95% RH, non-condensing
Altitude	2000M max
Pollution	Degree 2
Codes and Standards	
Emissions	FCC CFR 47 Part 15, Class A, EN 61000, EN 61326
Safety	UL61010 Recognized, EN61010
Additional Notes	
NEMA enclosures available upon request.	
For use with any Modbus RTU device / server	
Manufactured in the USA	

c UL us CE

DWYER SERIES RHP – HUMIDITY/TEMPERATURE TRANSMITTER

Series RHP
Humidity/Temperature Transmitter
Passive Temperature Outputs, Sintered Filter Options

CE

Product Specifications

Relative Humidity Range: 0 to 100% RH.

Temperature Range: -40 to 140°F (-40 to 60°C).

Accuracy, RH: Model RHP-2XXX ±2% 10-90% RH @ 25°C; Model RHP-3XXX ±3% 20-80% RH @ 25°C.

Accuracy, Thermistor Temp Sensor: ±0.22°C @ 25°C (±0.4°F @ 77°F).

Accuracy, RTD Temp Sensor: DIN Class B; ±0.3°C @ 0°C (±0.54°F @ 32°F).

Hysteresis: ±1%.

Repeatability: ±0.1% typical.

Temperature Limits: -40 to 140°F (-40 to 60°C).

Storage Temperature: -40 to 176°F (-40 to 80°C).

Compensated Temperature Range: -4 to 140°F (-20 to 60°C).

4-20 mA Loop Powered Models: Power Requirements: 10-35 VDC. Output Signal: 4-20 mA.

0-5/10V Output Models: Power Requirements: 15-35 VDC or 15-29 VAC. Output Signal: 0-10V @ 5 mA max.

Response Time: 15 seconds.

Electrical Connections: removable screw terminal block.

Conduit Connection: Duct Mount: 1/2" NPS; OSA: 1/2" (22.3 mm).

Drift: <1% RH/year.

RH Sensor: Capacitance polymer.

Temperature Sensor: Curves A,B,C; Thermistor; Curves D,E; Platinum RTD DIN 385. **(See R-T Lookup Table)**.

Enclosure: Duct Mount: PBT; OSA: Polycarbonate.

Enclosure Rating: NEMA 4X (IP65) for OSA mount only.

Display: Duct Mount only, Optional 2-line alpha numeric, 8 characters/line.

Display Resolution: RH: 0.1%; 0.1°F (0.1°C).

Weight: Duct Mount: .616 lb (.3 kg) OSA: 1 lb (.45 kg).

Agency Approvals: CE.

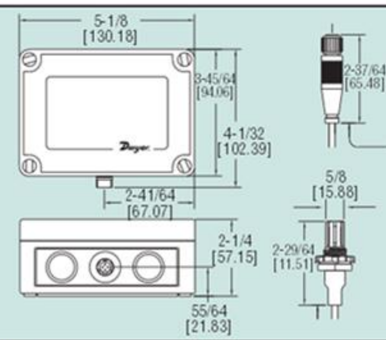
DWYER SERIES RH-R – HUMIDITY/TEMPERATURE TRANSMITTER

Dwyer® Series RH-R

Humidity/Temperature Transmitter

Remote Mount, Field Replaceable Sensor Filter, Up to 16 Cable

CE



The Series RH-R Humidity Transmitter is the ideal transmitter for those applications where space is limited. The compact sensor is protected by a removable filter. It can be mounted up to 16 feet away from the weatherproof base. The Series RH-R is ideal for environmental chambers, rubber bladder burst detection and air handler applications.

Model	Cable Length	Description	Output	Model	Cable Length	Description	Output
RHU-R004	4´	Humidity	Current	**RHU-R104**	4´	Humidity	Voltage
RHU-R008	8´	Humidity	Current	**RHU-R108**	8´	Humidity	Voltage
RHU-R012	12´	Humidity	Current	**RHU-R112**	12´	Humidity	Voltage
RHU-R016	16´	Humidity	Current	**RHU-R116**	16´	Humidity	Voltage
RHT-R004	4´	Humidity/Temperature	Current	**RHT-R104**	4´	Humidity/Temperature	Voltage
RHT-R008	8´	Humidity/Temperature	Current	**RHT-R108**	8´	Humidity/Temperature	Voltage
RHT-R012	12´	Humidity/Temperature	Current	**RHT-R112**	12´	Humidity/Temperature	Voltage
RHT-R016	16´	Humidity/Temperature	Current	**RHT-R116**	16´	Humidity/Temperature	Voltage

SPECIFICATIONS
Service: Dry clean air.
Relative Humidity Range: 0 to 100% RH.
Temperature Range: -40 to 140°F (-40 to 60°C).
Accuracy: ±2% @ 10-90%.
Temperature Limits: -40 to 140°F (-40 to 60°C).
Storage Temperature: -40 to 176°F (-40 to 80°C).
Compensated Temperature Range: -4 to 140°F (-20 to 60°C).
Power Requirements: 10 to 35 VDC.
Output Signal: 4 to 20 mA loop powered or 0 to 10 VDC.
Response Time: Less than 15 seconds.
Electrical Connections: Terminal block.
Conduit Connection: 1/2˝ NPT.
Process Connection: 1/2 NPSM.
Drift: Less than 1%/year.
RH Sensor: Capacitance polymer
Cable Length: Up to 16 ft.
Housing Material: Polycarbonate, aluminum enclosure.
Enclosure Rating: NEMA 4X (IP66).
Agency Approvals: CE.

ACCU-CT – SPLIT-CORE CURRENT TRANSFORMER

ACCU-CT®

SPLIT-CORE CURRENT TRANSFORMER

Revenue-Grade Accuracy, Unprecedented Linearity

Patent pending

0.75 Inch Window, 5 to 250 Amps

The Accu-CT revenue-grade, split-core current transformer offers outstanding accuracy and one-handed operation.

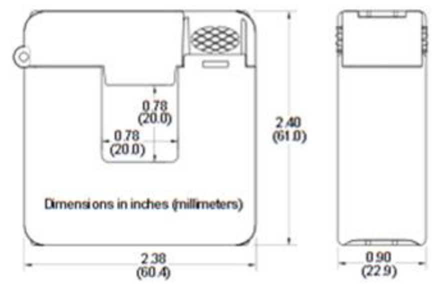
- **Exceptionally low phase angle error:** essential for accurate power and energy measurements
- **IEEE/ANSI C57.13 and IEC 60044-1** accuracy over full temperature range and down to 1% of rated current
- **Glove-friendly** operation with one hand.

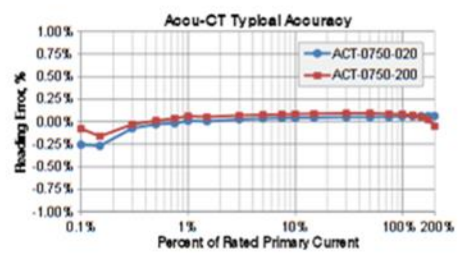
Specifications

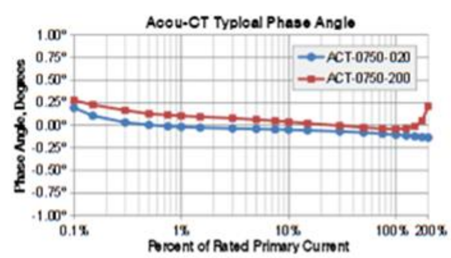
- **Accuracy:** ±0.75% from 1% to 120% of rated primary current (±0.5% with Option C0.6)
- **Phase angle:** ±0.5 degrees (30 minutes) from 1% to 120% of rated current (With Option 0.6: ±0.25 degrees from 1% to 120%, ±0.50 degrees below 0°C from 1% to 10% of rated current)
- **Accuracy standards:** IEEE C57.13 class 1.2 and IEC 60044-1 class 1.0 (Opt C0.6: class 0.6 and class 0.5S, respectively)
- **Primary rating:** 5 to 250 Amps, 600 Vac, 60 Hz nominal
- **Output:** 333.33 mVac or 1.00 Vac (with Option 1V) at rated current
- **Operating temperature:** -30°C to 55°C
- **Safe:** integral burden resistor, no shorting block needed, unless otherwise noted
- **Standard lead length:** 8 ft (2.4 m), 18 AWG
- **UL recognized**, CE mark, RoHS
- **Assembled in USA:** qualified under Buy American provision in ARRA of 2009

Models	Amps	MSRP
ACT-0750-005	5	$43.50
ACT-0750-020	20	$43.50
ACT-0750-050	50	$43.50
ACT-0750-100	100	$43.50
ACT-0750-200	200	$43.50
ACT-0750-250	250	$43.50

- **Non-stock:** 15, 30, 70, and 150 amp
- **Option C0.6:** meets IEEE/ANSI C57.13 class 0.6 accuracy and IEC 60044-1 class 0.5 and 0.5 S accuracy – $57
- **Option 1V:** 1.00 Vac full-scale output
- **Option 50Hz:** calibrate for 50 Hz operation







- Graphs show typical performance at 23°C, 60 Hz
- Graph shows a positive phase angle when the output leads the primary current.

ACT-1.23.13: Specifications are subject to change

ELKOR WATTSON

ELKOR

WATTSON®

SPECIFICATIONS:

INPUTS

Voltage	600 V or 600/347 V 480 V or 480/277 V 208 V or 208/120 V Single Phase, Split Phase, Three Phase 50 or 60 Hz
Current	• 333mV or 1000mV full scale output CTs. • Elkor "Safe" mA output solid/split core CTs. • 5A from standard CTs.

DEVICE SPECIFICATIONS

Power Supply	15-24VAC or 20-30VDC, 100mA max.
Accuracy	Better than 0.2% of reading (at 25°C, pf>=0.5) for most parameters.
Environment	Protected Installation; -40 to +60°C, 10 to 90% RH non-condensing
Isolation	All line inputs are isolated from the outputs Hi-Pot testing: 2500VAC for one minute
Enclosure	3.7" x 3.8" x 1.7" (94mm x 97 mm x 43 mm) W x L x H (note: height does not include DIN base).
Weight	mA/mV : 150g (5.5 oz) 5A : 200g (7 oz)
Safety	UL Recognized (Canada and US)

OUTPUTS

Wh/Qh	Solid state relay (24V, 150mA MAX), change of 100ms pulse on every pre-defined Wh value Qh output may be configured to represent direction of real power via Modbus.
Analog Outputs (optional)	Qh output may be substituted for two 0-10V analog outputs. Output parameters and span, and full scale may be field adjusted using Modbus communications.
RS-485	Modbus RTU; up to 64 units may be connected to one 'chain'.

MEASURED PARAMETERS (available via Modbus)

Voltage [V] (A, B, C, Avg, AB, AC, BC, Avg)
Current [A] (A, B, C, Avg)
Active Power [W] (A, B, C, Total) – Bi-directional
Apparent Power [VA] (A, B, C, Total)
Reactive Power [VAR] (A, B, C, Total) — Bi-directional
Power Factor (A, B, C, System) — Bi-directional
Frequency [Hz]
Import/Export Energy [Wh] (A, B, C, Total)
Inductive/Capacitive Energy [VARh] (A, B, C, Total)
Apparent Energy [VAh] (A, B, C, Total)
Total Demand Power [W]

All parameters are available in integer and floating point format.