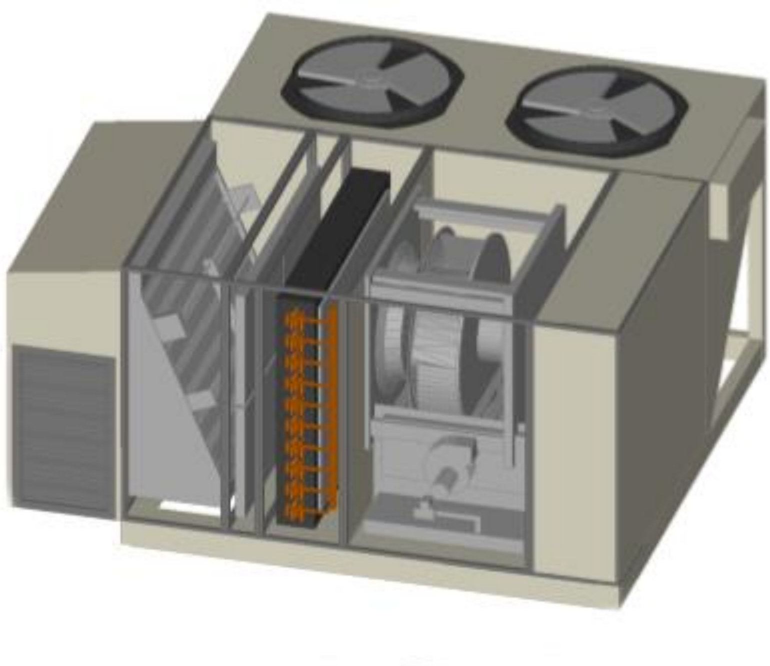
Emerging Products

Field Testing of Climate Appropriate Air Conditioning Systems

ET12SCE1091/DR12.17.00 Report



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EXECUTIVE SUMMARY

In commercial buildings, a heating, ventilating, and air-conditioning (HVAC) system conditions (heats or cools) the building space and provides fresh outdoor air (ventilation) to the building occupants. HVAC equipment in the building can be a primary contributor to overall energy consumption and peak power demand during both summer and winter periods. In recent years, manufacturers have begun to develop commercial HVAC systems with higher energy efficiency and greater flexibility, using variable load capacity technology. The Variable Capacity – Rooftop Unit (VC-RTU) is one of the most advanced vapor compression rooftop air conditioners currently available.

This report examines variable capacity technology as applied within unitary packaged rooftop air-conditioning units, an HVAC configuration commonly used in commercial buildings in the United States. The purpose of this study is to provide a resource for evaluating and potentially implementing a program for variable capacity rooftop units to promote energy efficiency, peak electrical load reduction, and/or increased flexibility (such as for demand response) in commercial space conditioning equipment.

This study provides new information to the growing body of documented performance for VC-RTU equipment. By mapping efficiency, capacity, power draw, and air flow rates, in every operating mode, and across a range of climate conditions, this study paints a clear picture of the VC-RTU's characteristic performance capabilities. The study also presents an application specific assessment of performance for the installation observed to better understand the system's advantages in a particular application that posed a number of unique challenges.

An objective of this project was to document practical challenges associated with installation and operation of this new type of system. With seven distinct modes of operation and a number of variable speed components the VC-RTU is significantly more complex than a conventional rooftop unit. Engineers, contractors, and end users are not familiar with the capabilities and setup requirements for these systems. The lessons learned through this study broaden our understanding of the technology, and should support the evolution of design guidelines, industry standards, and technology function.

Additionally, this project evaluates and demonstrates new potential for otherwise unrealized demand response capability from new-to-market variable capacity commercial HVAC systems in Southern California. Southern California Edison (SCE) and their customers will benefit from this effort by unlocking a new resource for both utility based demand response and customer directed demand management.

The results of this study demonstrate VC-RTU systems achieve superior high energy efficacy at full and part-load conditions. Observations support a 30% reduction in energy usage at peak load. Given additional capabilities to respond to a demand response (DR) signal while optimizing its performance, overall average savings for energy efficiency may be enhanced with the DR functionality, providing a good fit for an integrated EE/DR offering in the future.

The research team recommends the VC-RTU unit as an effective replacement to increase the performance of existing RTUs in both energy efficiency and demand response. The performance increase was most pronounced at hotter outdoor air temperatures, which demonstrates significant peak energy savings potential. The project demonstrates the VC-RTU achieves better efficiency than a compliant RTU across the full range of operating

conditions. Part load efficiency is improved most, and efficiency at peak operating conditions is improved modestly achieving approximately 19% reduction in kW/ton. The technological opportunity presented by this type of advanced rooftop air conditioner will become features made common for future HVAC equipment, but recognize that in the interim there is a significant need for market familiarization and for EE/DR programs to introduce the broader market application for these solutions.

ABBREVIATIONS AND ACRONYMS

ASHRAE	American Society of Heating, Refrigeration and Air-Conditioning
BEM	Building Energy Modeling
BES	Building Energy Simulation
BTU	British Thermal Unit
Btu/Wh	British Thermal Unit per Watt-Hour
CBECC	California Building Energy Code Compliance
CEC	California Energy Commission
CO2	Carbon Dioxide
DHW	Domestic Hot Water
DR	Demand Response
EUI	Energy Use Intensity
EEM	Energy Efficiency Measure
ETM	Emerging Technologies Program
HDD	Heating Degree Day
HVAC	Heating, Ventilating, and Air Conditioning
kBTU	Thousand British Thermal Units
kWh	Kilowatt Hours
LED	Light Emitting Diode
LPD	Lighting Power Density

PPM	Parts Per Million
PV	Photovoltaics
SEER	Seasonal Energy Efficiency Ratio
SCE	Southern California Edison
T-24	California Energy Commission Title 24

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INTRODUCTION

In commercial buildings, a heating, ventilating, and air-conditioning (HVAC) system conditions (heats or cools) the building space and provides fresh outdoor air (ventilation) to the building occupants. HVAC equipment in the building can be a primary contributor to overall energy consumption and peak power demand during both summer and winter periods. In recent years, manufacturers have begun to develop commercial HVAC systems with higher energy efficiency and greater flexibility, using variable load capacity technology. The Variable Capacity – Rooftop Unit (VC-RTU) is one of the most advanced vapor compression rooftop air conditioners currently available.

This report examines variable capacity technology as applied within unitary packaged rooftop air-conditioning units, an HVAC configuration commonly used in commercial buildings in the United States. The purpose of this study is to provide a resource for evaluating and potentially implementing a program for variable capacity rooftop units to promote energy efficiency, peak electrical load reduction, and/or increased flexibility (such as for demand response) in commercial space conditioning equipment.

This report examines variable capacity technology as applied within packaged rooftop units, an HVAC configuration commonly used in commercial buildings in the United States. The purpose of this report is to:

- Provide a resource for evaluating and potentially implementing a program for variable capacity rooftop units to promote energy efficiency
- Verify the potential of variable load capacity technology for peak electrical load reduction
- Verify the potential of variable load capacity technology for increased flexibility (such as for demand response) in commercial space conditioning equipment.

There are a variety of strategies to improve the efficiency of rooftop air conditioners. This study evaluates the observed performance for a VC-RTU designed to meet US DOE EERE’s “High Performance Rooftop Unit” specification (DOE 2014). In addition to several specific functional capabilities, the specification requires cooling performance with a minimum Integrated Energy Efficiency Ratio (IEER) of 18.

As part of the strategic effort to reduce greenhouse gas emissions and to support advancement of zero net energy buildings, California envisions a major shift toward electrification.

BACKGROUND

EMERGING TECHNOLOGY/PRODUCT

PACKAGED ROOFTOP UNITS

According to the U.S. Energy Information Administration (EIA), unitary packaged rooftop units (RTUs) serve over 50% of the U.S. commercial floor space [3]. Office space, retail, medical, and food service are common uses of buildings which implement RTUs as their primary source of space conditioning. The term "rooftop unit" describes the typical location of an RTU, which is typically on top of a curb installed to the roof of commercial building. RTUs can be located on the ground level, but in general for commercial buildings, these units are located on the roof. RTUs typically supply conditioned air from their rooftop location down to the occupied space through ductwork. Figure 1 displays the typical appearance of a RTU.

FIGURE 1 COMMON PACKAGED ROOFTOP UNIT

Multiple configurations of RTUs are available in the HVAC market, but the most common form is an air-source, packaged configuration. "Air-source" refers to air being the medium through which energy is transferred for the direct expansion system. "Packaged" refers to a system which contains all system components (compressor, fan, blower, etc.) within a single structure or casing. The use of "RTU" within this report refers to a direct expansion system in an air-source, packaged configuration.

RTUs come in the configuration of heat pumps and "Gas Packs". These systems offer heat pumps with hybrid heat (gas, electric, or hot water) options. This VC-RTU has the configuration of a variable speed heat pump utilizing variable speed ECM motors on the fans and variable speed inverter scroll compressors. For air conditioning only RTUs, typically a gas furnace or electric resistance elements will be contained within the housing "package" of the RTU to serve as the heating source for the space. For heat pump RTUs, a gas furnace or electric resistance heat section serves as a backup to the heat pump system.

In general, RTUs are used to both heat and cool the occupied space as well as provide some outdoor air to the occupants of the space. Figure 2 illustrates the general airflow layout of a RTU, associated ductwork, and the airflow through the system. Fresh outdoor air and return air from the space are mixed together and conditioned before being supplied back to the occupied space. Further details on the configurations and performance specifications [Table 10] of the selected packaged rooftop units referenced in this report and typically found in commercial buildings throughout the U.S. can be found in Technology/Product Evaluation section.

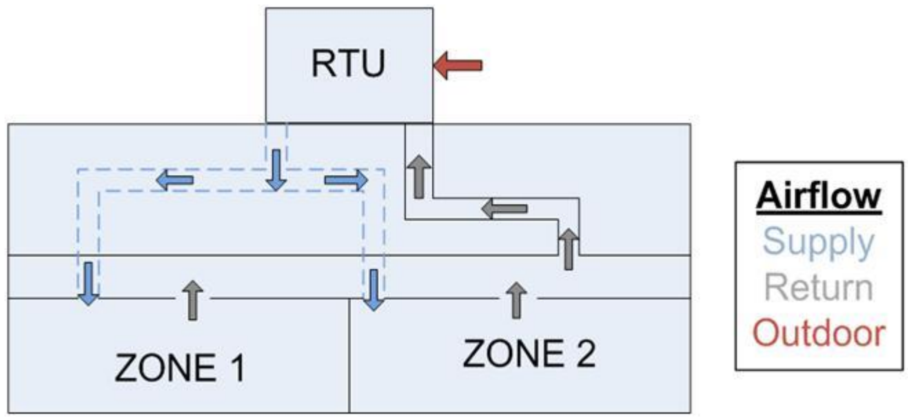

FIGURE 2 AIRFLOW OF A TYPICAL ROOFTOP UNIT

Variable capacity commercial HVAC systems are primarily associated with energy efficiency (EE) and superior customer comfort. Variable Refrigerant Flow (VRF) systems as well as roof top units (RTU) include variable speed compressors, electronic expansion valves and a multitude of refrigerant management features to match output of the HVAC system to the building heating and cooling loads.

One key element in all these advancements is the application of sophisticated control systems to VC-RTU's. These systems apply extensive instrumentation and processing power that acts as its own energy management system. With extensive on-board measurement and processing power, the control system always seeks to operate in an optimized fashion providing superior comfort with maximum efficiency. Over the last five years Southern California Edison (SCE) has gained significant knowledge and understanding of these VC-RTU control systems through laboratory and field testing in Southern California. Efficiency gains between 20% and 40% were observed during these tests with VRF systems as compared to baseline (code minimum requirement) systems.

Overall performance of a new technology can vary by location and application, and can be impacted by the quality of installation and ongoing service. As a result, industry standard ratings and manufacturer specifications do not provide enough information to convince customers and efficiency practitioners about the economic value of a new technological solution.

EFFICIENCY METRICS FOR COMMERCIAL SPACE CONDITIONING EQUIPMENT

The HVAC community quantifies efficiency in commercial space conditioning systems through several metrics for heating and cooling operation. The efficiency metrics used to rate a commercial HVAC system depend upon the nominal size (capacity) of the equipment.

For commercial systems less than a nominal size of 65,000 Btu/h, the Seasonal Energy Efficiency Ratio (SEER) and the Heating Seasonal Performance Factor (HSPF) are the metrics used to govern system efficiency as published in Federal and State requirements or industry standards. SEER and HSPF are seasonal performance indicators (or meant to represent the efficiency over a heating or cooling season), values are determined based on the rating and testing procedures defined in ANSI/AHRI Standard 210/240. Further details on the use and applicability of SEER and Standard 210/240 can be found in *SEER Investigation for Residential and Small Commercial Split Air-Source Heat Pumps* [5].

For commercial HVAC equipment with nominal capacity larger than 65,000 Btu/h, the metrics used to govern efficiency are the Energy Efficiency Ratio (EER), the Integrated Energy Efficiency Ratio (IEER), and the Coefficient of Performance (COP). These efficiency metrics are determined through the rating and testing procedures outlined in ANSI/AHRI Standard 340/360 [6]. EER and COP are single point efficiency metrics determined under specific cooling and heating tests, respectively. IEER is a multiple test point cooling (only) efficiency metric, which is found by weighting several single point tests under a specific structure. A summary of the efficiency metrics used for differing commercial equipment size and operation are illustrated in Table 1 .

TABLE 1 TYPICAL EFFICIENCY METRICS USED FOR COMMERCIAL SPACE CONDITIONING EQUIPMENT STANDARDS

Nominal Capacity	Governing Cooling Efficiency Metrics	Governing Heating Efficiency Metrics	Rating Procedures
<65,000 Btu/h	SEER (Seasonal)	HSPF (Seasonal)	ANSI/AHRI Standard 210/240- [6]
>65,000 Btu/h	EER (Single Point) IEER (Multiple Point)	COP (Single Point)	ANSI/AHRI Standard 340/360 7]

The single point efficiency metrics, namely the EER and COP, are determined under specific indoor and outdoor conditions. The conditions at which EER and COP are determined are shown in Table 2. These metrics represent the actual efficiency of a HVAC system at those specific testing conditions with the system under 100% nominal capacity output. The efficiency value of EER or COP is determined by the following: the amount of cooling or heating output provided divided by the power consumption of the system. EER is calculated in units of Btu/Wh, while COP is determined in units of Btu*h/Btu*h or W/W.

TABLE 2 CONDITIONS FOR SINGLE POINT EFFICIENCY METRICS [8]

Efficiency Metric	Indoor Temperature	Outdoor Temperature	Nominal Capacity Setting

EER	80°F dry bulb 67°F wet bulb	95°F dry bulb	100%
COP	70°F dry bulb	47°F dry bulb 43°F wet bulb	

The multi-point efficiency metric for larger commercial equipment, namely the IEER, is determined based on four test points and a weighting system. The four test points correspond to system operation at 25%, 50%, 75%, and 100% capacity output or the assumed building load. IEER is determined based on the following equation [9]:

$$IEER = (0.02 * A) + (0.617 * B) + (0.238 * C) + (0.125 * D)$$

Where: A = EER at 100% capacity and standard EER conditions
B = EER at 75% capacity and reduced outdoor temperature
C = EER at 50% capacity and reduced outdoor temperature
D = EER at 25% capacity and reduced outdoor temperature

The indoor and outdoor conditions used to determine the 25%, 50%, and 75% portion of IEER are shown in Table 3. The indoor testing conditions remain constant across all test cases. The testing outdoor temperature is a function of the system's capacity output at a specific test.

TABLE 3 INDOOR AND OUTDOOR CONDITIONS FOR DETERMINING IEER [6]

Conditions	Temperature (°F)
Indoor Temperature	80 dry bulb 67 wet bulb
Outdoor Temperature (OAT) for Air Cooled System	For % Capacity > 44.4% OAT = 0.54 * % Capacity + 41
	For % Capacity ≤ 44.4% OAT = 65

For variable capacity systems (which can control capacity output), a unit under IEER testing is controlled to 25, 50, 75, and 100 percent nominal capacity under the corresponding indoor and outdoor conditions. At each test point, the efficiency of the system is determined, and then each efficiency value is weighted into the overall IEER calculation. For variable capacity systems, the four test points and weighting structure are shown in Table 4. The weighting structure associated with each capacity output used to determine IEER is identical for all system types.

TABLE 4 TEST POINTS USED IN DETERMINING IEER FOR VARIABLE CAPACITY RTUS [6]

Capacity Setting	Indoor Temperature	Outdoor Temperature (°F)	Weight in IEER Calculation (%)
25%	80°F dry bulb 67°F wet bulb	65	12.5
50%		68	23.8
75%		81.5	61.7
100%		95	2.0

Notice the weighting of IEER for the various capacity levels in Table 4. 98% of the IEER calculation is based on the test cases at partial capacity output (less than 100% capacity). IEER is representative of the partial capacity performance of a given variable capacity RTU. As shown in Table 2, EER would indicate the performance of a given variable capacity RTU at full capacity (100% capacity). IEER and EER are meant to serve as comparison in efficiency for similar system types. The IEER and EER of one variable capacity RTU can be compared to the IEER and EER of another variable capacity RTU for a general comparison of part load and full load efficiency. The fundamental approach and determination of IEER differs greatly from SEER. SEER and IEER cannot be directly used to compare the efficiency of two similar system types.

ANSI/AHRI Standard 340/360 [6] provides further specifications for determining IEER for various types of unitary air-conditioners and heat pumps. The specific testing methodology will differ slightly depending on the capacity staging (whether variable, multi-speed, single speed, etc.) and airflow staging capabilities of the tested system, but the general four test point structure and weighting system described previously applies to the IEER for all system types. For further clarification, an example IEER calculation of a 10-ton, variable capacity RTU is provided in Table 5.

TABLE 5 EXAMPLE IEER CALCULATION FOR A NOMINAL 10 TON VARIABLE CAPACITY RTU [7]

Test Case	RTU Capacity Output (Btu/h)	RTU Efficiency (Btu/Wh)
25% Capacity	28,682	7.39
50% Capacity	57,365	10.35
75% Capacity	86,047	11.13
100% Capacity	114,730	10.92

$$IEER = (0.02*10.92) + (0.617*11.13) + (0.238*10.35) + (0.125*7.39) = 10.48$$

COMMERCIAL BUILDING STANDARDS

Industry standards directly impact the efficiency and performance of the HVAC systems in commercial buildings across the U.S. Two standards with significant impact on a building's operational efficiency are ASHRAE (American Society of Heating, Refrigeration, and Air-Conditioning Engineers) 90.1, *Energy Standard for Buildings except Low-Rise Residential Buildings* [8], and ASHRAE 62.1, *Ventilation for Acceptable Indoor Air Quality* [10]. The importance of these standards regarding the performance and efficiency of packaged rooftop units is discussed in the following sections.

ASHRAE 90.1

The purpose of ASHRAE Standard 90.1 is to provide "minimum efficiency requirements for the design, construction, and a plan for operation and maintenance" of new buildings and systems [8]. ASHRAE Standard 90.1 consists of minimum efficiency requirements for building envelope, HVAC equipment, water heating system, lighting, and other equipment used in commercial buildings. Most states in the U.S. have adopted a state energy code which corresponds to the specific set of requirements within a given year of ASHRAE Standard 90.1 or a corresponding International Energy Conservation Code (IECC).

The IECC is a set of residential and commercial building codes which can be implemented by state legislators, and the commercial portion of the IECC has adopted the requirements set forth within ASHRAE Standard 90.1. ASHRAE Standard 90.1 is updated approximately every 3 years with appropriate corrections or additions. For example, Table 6 shows the minimum efficiency requirements for air-source packaged air-conditioning equipment in ASHRAE Standard 90.1-2004, 2007, and 2010. Notice in Table 6 that the efficiency requirements were elevated for each revision for the years shown.

The current energy code for a given state may be under the requirements for any year of ASHRAE Standard 90.1. To determine which year of ASHRAE Standard 90.1 that a State Energy Code has adopted or the progression of adoptions over the years, consult the Building Energy Codes Program of the Department of Energy [9]. Even though a State may be under a specific building code, Federal requirements should be considered as well. For instance, the Federal requirement on efficiency in packaged RTUs may be higher than the efficiency stated in ASHRAE 90.1 or building code for a particular State. However, awareness of the more stringent (Local, State, or Federal) requirement will dictate the minimum efficiencies for the respective equipment.

TABLE 6 ASHRAE 90.1 EFFICIENCY STANDARDS FOR AIR-SOURCE PACKAGED AIR CONDITIONING EQUIPMENT [8]

		ASHRAE 90.1 Year		
Cooling Capacity	**Heating Type**	**2004**	**2007**	**2010**
<65,000 Btu/h	All	9.7 SEER (before 2006) 12 SEER (after 2006)	9.7 SEER (before 2006) 13 SEER (after 2006)	13 SEER
65,000 Btu/h and <135,000 Btu/h	Electric Resistance (or none)	10.3 EER	10.3 EER (before 2010) 11.2 EER (after 2010)	11.2 EER 11.4 IEER
	All Other Types of Heating	10.1 EER	10.1 EER (before 2010) 11.0 EER (after 2010)	11.0 EER 11.2 IEER
135,000 Btu/h and <240,000 Btu/h	Electric Resistance (or none)	9.7 EER	9.7 EER (before 2010) 11.0 EER (after 2010)	11.0 EER 11.2 IEER
	All Other Types of Heating	9.5 EER	9.5 EER (before 2010) 10.8 EER (after 2010)	10.8 EER 11.0 IEER

A notable change within the ASHRAE 90.1 – 2010 was the requirement that systems above a nominal capacity of 110,000 Btu/h must utilize a two-speed or variable speed supply fan. Supply fans can consume a significant portion (~30%) of the energy within a rooftop unit. Requiring that systems utilize two-speed or variable speed supply fans allows the system to operate at reduced power consumption under part-load conditions.

ASHRAE 62.1

The purpose of ASHRAE Standard 62.1 is "to specify the minimum ventilation rates and other measures intended to provide indoor air quality that is acceptable to human occupants and that minimizes adverse health effects" [10]. ASHRAE Standard 62.1 applies to commercial buildings and multi-family dwellings larger than three stories. Similar to ASHRAE Standard 90.1, the minimum fresh outdoor air ventilation requirements set forth in Standard 62.1 are adopted by state building codes and are updated periodically. ASHRAE Standard 62.1 provides ventilation requirements for a variety of building types, and the requirements are provided as a function of occupancy and building area. For example, Table 7 provides the required fresh air ventilation rates for a sample of selected buildings according to ASHRAE 62.1 – 2010 [9].

TABLE 7 SAMPLE OF OUTDOOR AIR RATES WITHIN ASHRAE 62.1 – 2010 [10]

Occupancy Category		People Outdoor Air Rate (cfm/person)	Area Outdoor Air Rate (cfm/ft^2)
Educational Facilities	Daycare (through age 4)	10	0.18
	Classrooms (ages 5 - 8)	10	0.12
	Lecture Classroom	7.5	0.06
Food Service	Restaurant Dining Room	7.5	0.18
	Kitchen	7.5	0.12
Office Buildings	Breakrooms	5	0.12
	Office Space	5	0.06
	Reception Areas	5	0.06
Public Assembly Spaces	Auditorium Seating Area	5	0.06
	Libraries	5	0.12
	Museums/galleries	7.5	0.06

As previously discussed, outdoor air is commonly brought into commercial buildings by a packaged rooftop unit. The efficiency and performance of a given air conditioner will vary as a function of outdoor/return air. In the extreme temperatures of summer or winter, the portion of outdoor air mixed into the return air may have an impact on the performance of the HVAC system. Higher concentrations of outdoor air within an outdoor/return air mixture will have more impact on the efficiency of the system.

When packaged RTUs are used to both condition a space and provide ventilation, typically the outdoor air is a smaller percentage of the return air mixture. As an example, for a typical RTU, return air may consist of 25% outdoor air and 75% indoor air. When packaged RTUs are used to supply a commercial building with 100% outdoor air, they are referred to as a Dedicated Outdoor Air System (DOAS).

FEDERAL MINIMUM EFFICIENCY

The federal government has set forth federal minimum efficiency requirements on commercial HVAC systems manufactured and sold within the U.S. Table 8 provides the federal minimum efficiency requirements for packaged air-source RTUs in cooling operation, and Table 9 lists the federal minimum efficiency requirements for packaged air-source heat pumps in heating operation. Listed for each category is the year in which that requirement came into effect. Note that the current federal minimum efficiency requirements activated in 2010 and listed Table 8 are similar to the minimum efficiency requirements set forth in ASHRAE Standard 90.1-2010 shown in Table 6.

TABLE 8 FEDERAL MINIMUM COOLING EFFICIENCY VALUES FOR AIR-SOURCE PACKAGED RTUS [11]

Equipment Type	Cooling Capacity	Sub-Category	Heating Type	Efficiency Level	Compliance Date
Small Commercial Packaged Equipment	<65,000 Btu/h	AC	All	14 SEER	1/01/2015
		HP	All	14 SEER	1/01/2015
Small Commercial Packaged Equipment	>65,000 Btu/h and <135,000 Btu/h	AC	Electric Resistance (or none)	11.2 EER	1/1/2010
			All Other Types of Heating	11.0 EER	1/1/2010
		HP	Electric Resistance (or none)	11.0 EER	1/1/2010
			All Other Types of Heating	10.8 EER	1/1/2010
Large Commercial Packaged Equipment	>135,000 Btu/h and <240,000 Btu/h	AC	Electric Resistance (or none)	11.0 EER	1/1/2010
			All Other Types of Heating	10.8 EER	1/1/2010
		HP	Electric Resistance (or none)	10.6 EER	1/1/2010
			All Other Types of Heating	10.4 EER	1/1/2010
Very Large Commercial Packaged Equipment	>240,000 Btu/h and <760,000 Btu/h	AC	Electric Resistance (or none)	10.0 EER	1/1/2010
			All Other Types of Heating	9.8 EER	1/1/2010
		HP	Electric Resistance (or none)	9.5 EER	1/1/2010
			All Other Types of Heating	9.3 EER	1/1/2010

TABLE 9 FEDERAL MINIMUM HEATING EFFICIENCY VALUES FOR AIR-SOURCE PACKAGED HEAT PUMPS [11]

Equipment Type	Cooling Capacity	Efficiency Level	Compliance Date
Small Commercial Packaged Air-Conditioning and Heating Equipment	<65,000 Btu/h	8.2 HSPF	1/1/2015
Small Commercial Packaged Air-Conditioning and Heating Equipment	>65,000 Btu/h and <135,000 Btu/h	3.3 COP	1/1/2010
Large Commercial Packaged Air-Conditioning and Heating Equipment	>135,000 Btu/h and <240,000 Btu/h	3.2 COP	1/1/2010
Very Large Commercial Packaged Air-Conditioning and Heating Equipment	>240,000 Btu/h and <760,000 Btu/h	3.2 COP	1/1/2010

RTU EFFICIENCY ADD-ONS

Within packaged RTUs, manufacturers have developed several other features which could improve overall system efficiency but are not accounted for in the typical EER, IEER, or COP calculation for commercial air-source equipment. The standard efficiency metrics account for system efficiency based on the compressor, fan, and blower operation and overall system design. The add-on components discussed within this section include enthalpy wheels, add-on evaporative pre-cooling, and modulating hot gas reheat.

ENERGY RECOVERY – ENTHALPY WHEEL

The concept of energy recovery refers to the transfer of energy (both heat and moisture) from a wasted or unused airstream to supply or used airstream. The principle of energy recovery has been implemented in many different configurations, system types, and applications to improve overall HVAC system efficiency. In commercial buildings which require outdoor air ventilation, energy recovery in the form of an enthalpy wheel can be used with a RTU to improve overall system efficiency.

An enthalpy wheel is a device which transfers both heat and moisture between a fresh outdoor airstream and an exhaust airstream. The device consists of a physical wheel designed to transfer both heat and moisture which rotates between the two airstreams. Outdoor fresh air must be delivered into commercial buildings based on local codes, usually in accordance with ASHRAE Standard 62.1.and ASHRAE 90.1-2016. In HVAC systems as, outdoor air is ventilated indoors, typically a similar quantity of indoor air is sent outdoors (exhaust air) in order to maintain pressure inside the building. In many buildings, exhaust air is simply sent into the atmosphere and the energy within the exhaust air is unused. With enthalpy wheels the exhaust air energy is used to pre-condition the outdoor air, before the outdoor air is mixed with return air and conditioned by the RTU. Refer to Figure 2 for an illustration of the typical path of outdoor, return, and supply air in an RTU configuration.

During the extreme ambient temperatures in summer and winter, outdoor air within the return/outdoor air mix can create an increased load on the RTU. Consider the examples of an enthalpy wheel operating during extreme temperatures in Figure 3 and Figure 5. Data for these two examples is taken from the designed performance of an available enthalpy wheel. In Figure 3, the ambient outdoor conditions are 95°F and 99 grains of moisture per pound of dry air. Due to the energy exchanged with the exhaust air stream through the enthalpy wheel, the fresh outdoor air is instead 83°F and 80 grains of moisture per pound of dry air when air is sent into the return/outdoor air mix.

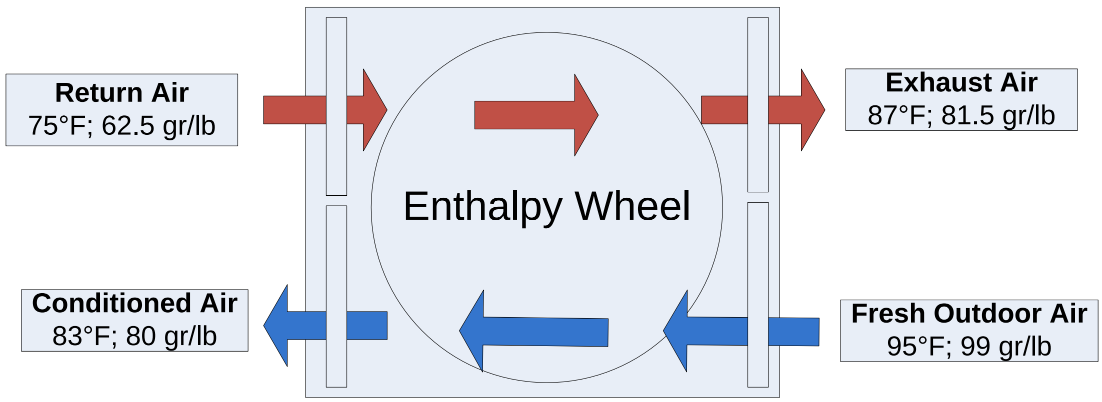

FIGURE 3 EXAMPLE OF ENTHALPY WHEEL OPERATION DURING COOLING SEASON

The features of a sensible cooling process:

- dry bulb temperature decreases
- relative humidity increases
- enthalpy decreases (there is a decrease in the energy level and with the loss of energy, condensation occurs)
- wet bulb temperature decreases
- specific volume decreases
- humidity ratio, vapor pressure and dew point remain constant

The sample psychrometric chart below shows the process line (solid blue) when using enthalpy recovery. As one can see, the cooling load saved is a direct result of the difference in the two enthalpies.

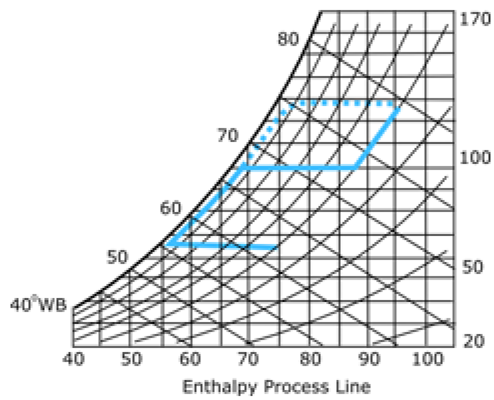

FIGURE 4 SAMPLE PSYCHROMETRIC CHART – COOLING LOAD SAVED

Also, consider Figure 5 which provides an example of enthalpy wheel operation during low outdoor ambient conditions. In the figure, the fresh outdoor air is heated from 10°F to 50°F due to the heat exchanged with the exhaust airstream through the enthalpy wheel. The added efficiency and cost effectiveness of an enthalpy wheel is dependent on the quantity of ventilated outdoor air and the climate in the territory of interest. An enthalpy wheel will be more effective for larger percentages of outdoor air in the return/outdoor air mixture and in climates with more extreme temperatures.

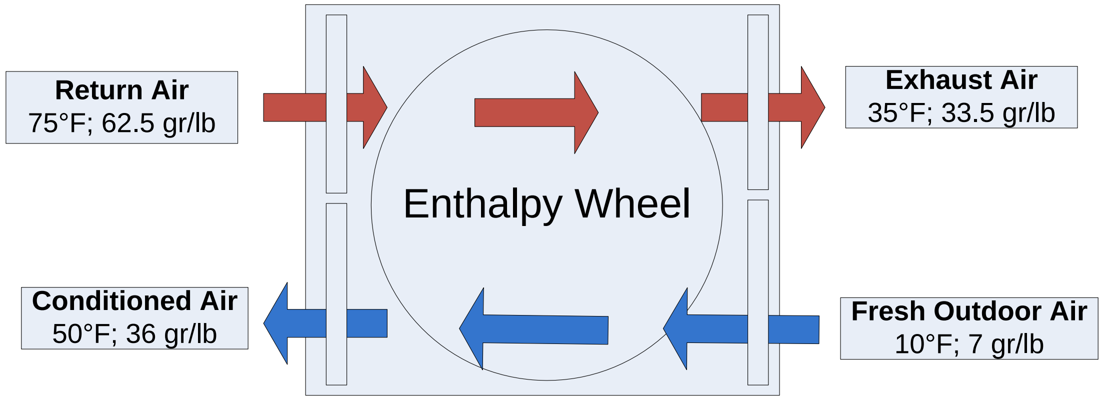

FIGURE 5 EXAMPLE OF ENTHALPY WHEEL OPERATION DURING HEATING SEASON

ADD-ON EVAPORATIVE PRE-COOLING

Evaporative cooling is another concept frequently used within HVAC systems to promote higher overall efficiency. “Evaporative cooling” occurs when water is exposed to hot and dry air to form cooler and more humid air. Fundamentally, energy within the warm air is used to evaporate water, and therefore the loss of energy in the warm air is associated with a reduction in dry bulb temperature and an increase in moisture content.

Efficiency of a direct expansion, packaged rooftop unit is inversely proportional to the dry bulb temperature entering the condenser. As dry bulb temperature entering the condenser of a RTU decreases, the efficiency of the RTU increases. Frequently, evaporative pre-cooling devices are designed to lower the ambient temperature of air sent into the condenser coil in RTUs.

For example, consider the evaporative pre-cooling illustration shown in Figure 6, where the outdoor air is 95°F. The evaporative pre-cooling device lowers the air entering the condenser of the RTU to 85°F, which would increase the efficiency of the RTU. Evaporative pre-cooling strategies are most effective in when there is an appreciable difference between outdoor dry-bulb and wet-bulb temperatures, as occurs frequently in hot-dry climates or during peak temperature hours in humid climates.

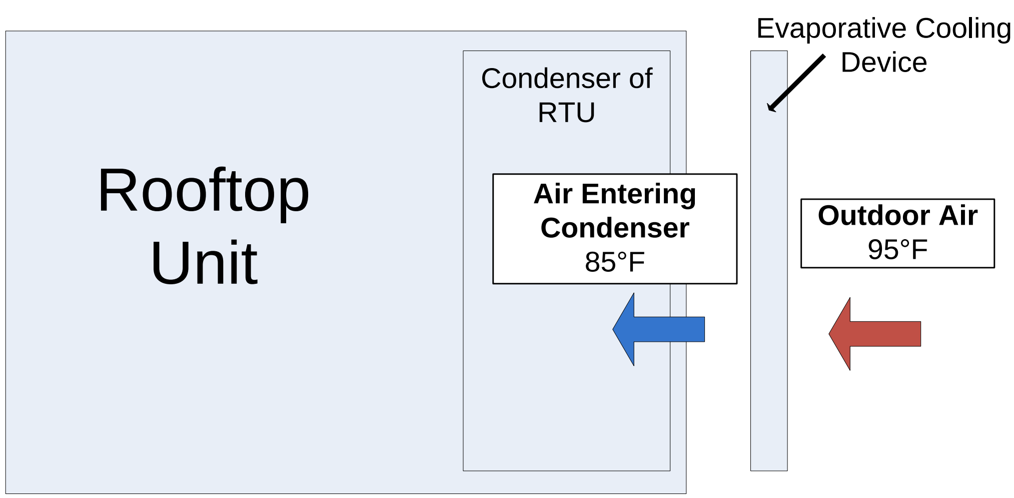

FIGURE 6 EXAMPLE OF EVAPORATIVE PRE-COOLING IN RTUS

MODULATING HOT GAS REHEAT

Packaged rooftop units can be implemented within an HVAC system to accomplish different objectives. A RTU may be designed to satisfy sensible cooling loads, latent cooling loads, outdoor air ventilation, or some combination of the three. In certain situations, a RTU may be designed to provide increased latent cooling or dehumidification through a “reheat” strategy. Reheating is performed as follows: cold air after the evaporator coil is re-heated to a more neutral dry bulb temperature before being supplied into the occupied space.

For example, consider Figure 7, a RTU may condition air to 55°F dry bulb and 57 grains/lb. off the evaporator coil, and then reheat the air to 70°F dry bulb before supplying the air into the space. A RTU operating in a reheat configuration may supply little sensible cooling to the space, but a system in reheat will provide a large amount of dehumidification. Reheat can be accomplished through multiple means including electric resistance, natural gas coil, or a refrigerant coil.

When a refrigerant coil is used for reheating, hot refrigerant gas from the outlet of the compressor is directed into two separate coils: the reheat coil and the condenser coil. Systems which can vary the amount of hot gas to each coil and therefore control the dry bulb supply temperature can be referred to as using modulating hot gas reheat.

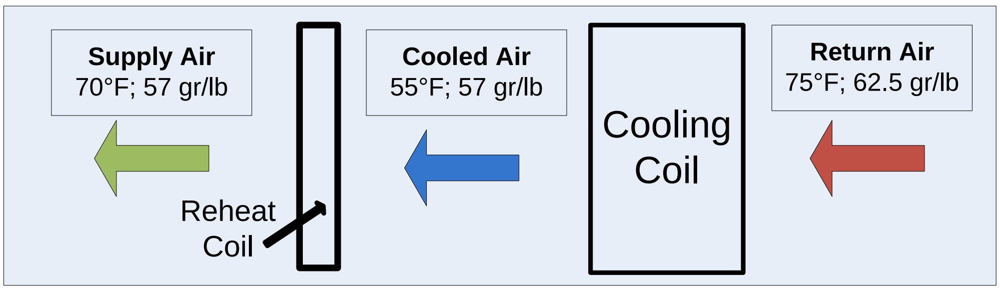

FIGURE 7 EXAMPLE OF MODULATING HOT GAS REHEAT IN RTUS

ADVANCED ECONOMIZER CONTROLS

VC-RTU allows for integrated economizer operation, which allows for compressor operation at the same time as economizer cooling. This is an important feature for all the periods when outside air is cooler than room air, but when the full supply airflow at that temperature is not adequate to maintain room set point. This unit allows for differential enthalpy economizer control which makes an economizer changeover decision by comparing temperature and humidity for the return air and outside air.

DEMAND RESPONSIVE CONTROLS

This VC-RTU was installed with an optional component that allows the utility provider to control the system at various pre-programmed levels, to remotely manage the unit's demand on the power grid during peak periods. The gateways and sensors monitor and tune all aspects of performance (compressors, supply fans, outdoor air fans, etc.). The installed component provides equipment analytics, including real-time HVAC unit performance, remote diagnostics, monitoring and control, advanced energy management, and third-party content integration services. The controller unit can respond to an automated utility signal to enable logic to respond to insufficient electrical capacity. The system can equip VC-RTUs with the capability to participate in a DR scenario by aggregating an end customer's VC-RTUs with the ability to pre-cool a building in advance of the peak power event, then throttling back the HVACs, shedding electrical load.

ASSESSMENT OBJECTIVES

Overall performance of a new technology can vary by location and application, and can be impacted by the quality of installation and ongoing service. As a result, industry standard ratings and manufacturer specifications do not provide enough information to convince customers and efficiency practitioners about the value of a new solution. This study provides new information to the growing body of documented performance for the VC-RTU and other variable speed rooftop units.

By mapping efficiency, capacity, power draw, and air flow rates, in every operating mode and across a range of climate conditions, this study paints a clear picture of the VC-RTU's characteristic performance capabilities. The study also presents an application specific assessment of performance for the installation observed to better understand the system's advantages in an application that posed many unique challenges.

The objective of this project was to document practical challenges associated with installation and operation of this new type of system. With seven distinct modes of operation and many variable speed components the VC-RTU is significantly more complex than a conventional rooftop unit. Engineers, contractors, and end users are not familiar with the capabilities and setup requirements for these systems. The lessons learned through this study broaden our understanding of the technology, and support the evolution of design guidelines, industry standards, and technology function. These lessons will also allow the VC-RTU systems to be properly installed to attain full capability for energy efficiency and effectiveness.

TECHNOLOGY/PRODUCT EVALUATION

VARIABLE CAPACITY TECHNOLOGY

Traditional, single speed RTU space conditioning equipment operates in one of two states: either on or off through cycling. When single speed equipment is operating, it provides 100% heating or cooling output at a fixed efficiency based on the ambient conditions. "Single speed" RTU equipment operates with a single speed compressor, blower, and fan with relatively simple thermostatic controls. "Multi-speed" or "multi-stage" refers to an HVAC system which can output multiple, finite levels of heating or cooling (e.g. 33, 66, and 100% output). Multi-speed operation is achieved with multi-speed compressors and fans operating separately or integrated together to match instantaneous thermal load conditions. A multi-speed system is typically more efficient than a comparable constant or single-speed system, because the multi-speed unit can operate at a reduced load capacity output and power consumption when the conditioned space is at other than full-load conditions.

In cooling operation, variable capacity VC-RTU equipment can adjust system components to accommodate either the sensible or latent cooling loads. In part load operation, variable speed equipment can operate at a reduced capacity and consume less energy while matching the loads of the space.

In humid climates, dehumidification is essential to occupant comfort, and achieving proper dehumidification can result in high energy usage. Both overcooling a supply air and then reheating the air entering the space are approaches used to achieve proper dehumidification which consume high amounts of energy. A variable capacity VC-RTU system modulates system components to achieve a desired latent capacity without consuming extra energy.

In heating operation, some variable capacity VC-RTU systems can provide higher heating capacities at lower outdoor temperatures than similarly sized fixed speed systems by "over-speeding" the compressor of the system. The ability to provide higher heating capacities reduces a systems dependence on backup heat. Reducing the use of electric backup heat can result in high energy savings and potentially peak demand reduction. At part load conditions, variable speed VC-RTU equipment can operate at reduced compressor speeds and higher efficiencies than fixed speed systems in heating operation.

Variable capacity technology has been implemented into several forms of air-source space conditioning equipment in both residential and commercial applications. On the residential side, variable capacity is available in air-source ducted split, ductless split, and small packaged configurations.

On the commercial side for direct expansion unitary equipment, variable capacity has been implemented into RTU's and variable refrigerant flow (VRF) systems. Figure 1-3 shows two variable capacity RTUs available in the market. Within this report, the term "variable capacity" will refer to systems which can modulate cooling or heating output at infinite levels of operation within the rated equipment capacity.

FIGURE 8 VARIABLE CAPACITY ROOFTOP UNITS

TECHNICAL APPROACH/TEST METHODOLOGY

FIELD TESTING METHODS

Minimum capacity available from the manufacturer at the time of the study was a 4-ton system. The rooftop unit prior to installing the VC-RTU was a 2.5-ton unit which was not monitored prior to its decommissioning. The performance specifications of the installed unit are as follows:

TABLE 10 INSTALLED UNIT PERFORMANCE SPECIFICATIONS

Model	Small Cabinet 004
Gross cooling capacity (tons)	4
Nominal airflow (cfm)	1500
EER	12.4
IEER	17.0
High temperature capacity @ 47°F (MBh)	43
COP @ 47°F	8.9
Low temperature capacity @ 17°F (MBh)	24
COP @ 17°F	N/A

MONITORING PLAN

Three performance parameters of the VC-RTU unit that were monitored and recorded are:

- Electrical; Power draw (kW), Energy consumption (kWh), Voltage (V), Current (A) and Power Factor (PF)
- Thermal; Temperature (T) and relative humidity (RH) measurement in the class room, as well as
- Air flow: Supply air return air of the system (CFM)

Data from numerous channels monitored will be recorded every minute (1-minute resolution data). The electrical characteristics will be monitored at the disconnect located on the roof using revenue grade Power meter and current transformers as indicated in the Monitoring Equipment Used section.

. Each T/RH sensor will be wired to Flex I/O's in enclosures as noted in the Monitoring Plan Drawings attached. The ambient (outside) T and RH will also be measured close to the unit with precautions taken to keep the sensor away from the exhaust air stream of the unit. Each of the wired T/RH sensors are 4-20ma loops. EPRI will be providing the cable (Cat5) to connect the T/RH sensors back to the Flex I/O's which power and receive data from the sensors.

Air Flow of the supply air duct and the fresh air inlet to the system will be monitored. The air flow system, from Air Monitor Corporation will be an airflow measuring station (Fan Evaluator) in the duct with a corresponding low range differential pressure and flow transmitter (Veltron DPT 2500) to output the air flow rate to be computed into cfm. The Air Flow System is factory calibrated and will have a NIST certificate.

Miscellaneous hardware includes: NEMA 4X enclosures, power supplies, and fuses. The AcquiSuite is the main on-site data acquisition server (DAQ). The AcquiSuite collects data from all the sensors (minute resolution) and stores it on its onboard memory. The data is gathered by direct connection from all the sensors to the Flex I/O's and handed over to the AcquiSuite via a Modbus 2 wire data connection. Data from the AcquiSuite memory is uploaded to an EPRI server every eight hours using a 3G cell modem connection. Numerous fail-safe software procedures are programmed into the AcquiSuite to avoid any data loss.

MONITORING EQUIPMENT USED

1. Power meter – Elkor, WattsOn-1100 – Revenue Grade
2. Current Transformers (CT) – Continental Controls, "ACT-075-030" (30Amp)
3. Temperature and Relative Humidity - Dwyer (different models, duct, & OSA)
4. Air Flow Monitoring System:
5. Two Veltron DPT 2500 Differential Flow Transmitters
6. Two Airflow Measuring Station FAN-Evaluators, (Supply Duct and Fresh Air Inlet Duct)
7. Communications – Telecommunications Wireless Hotspot
8. AcquiSuite – data acquisition server (DAQ)
9. Flex I/O – universal input / output module
10. Cell Modem – Airlink 3G Verizon

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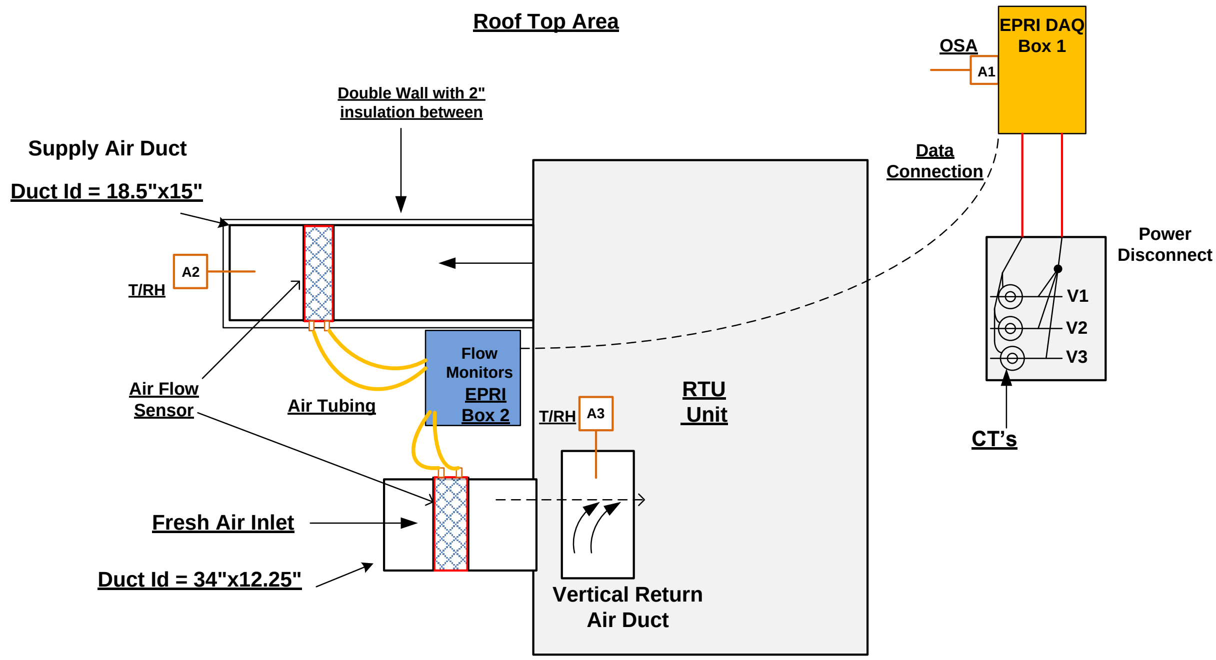

FIGURE 9 MONITORING PLAN – LINE DIAGRAM

RESULTS

DATA ANALYSIS

MONITORING PERIOD

The VC-RTU system was installed and commissioned during August and September 2014. Additional adjustments to the controller (thermostat) were made past the commissioning date (by the occupants as thermostat was not locked). The monitored data for year 2015 is used in this analysis and data from 2014 is not analyzed as data was skewed with the commissioning process.

RESULTS AND DISCUSSION

Figure 10 shows the outdoor temperature and relative humidity data over a period of one year – January 2015 through December 2015; a total of 8760 hours. The numbers in the squares indicate the number of hours for a given outdoor condition. The chart gives a graphical representation of the outdoor conditions at this site. For example, the outdoor conditions were in the temperature range of 45°F and 55°F and relative humidity (RH) range of 75% and 80% for 610 hours for this period.

Outdoor Air Temperature (°F)

Outdoor RH (%)	20	30	40	50	60	70	80	90	100	110
0				2	12	29	61	40	3	1
10			9	32	218	168	174	100	24	2
20			25	83	192	164	139	103	56	
30			30	117	162	167	193	170	11	
40		1	41	147	205	317	422	90		
50		3	42	143	293	367	197	1		
60	0	16	82	229	416	280	29			
70	1	20	138	403	519	159	1			
80	1	47	211	610	548	83				
90		4	53	120	79	5				

FIGURE 10 BINNED TEMPERATURE AND RELATIVE HUMIDITY DATA FOR VC-RTU

Figure 11 shows the cooling degree days (CDD) and monthly energy consumption by the VC-RTU. The CDD's are determined by summing up the average temperature per day above 65°F (base temperature). The trend between CDD's and energy consumption is as expected. It must be noted that although there are CDD's during the colder months, it doesn't essentially equate to compressor run time. A careful investigation of the data revealed that **the system never entered heating mode**. This was confirmed by analyzing supply air temperatures from the system.

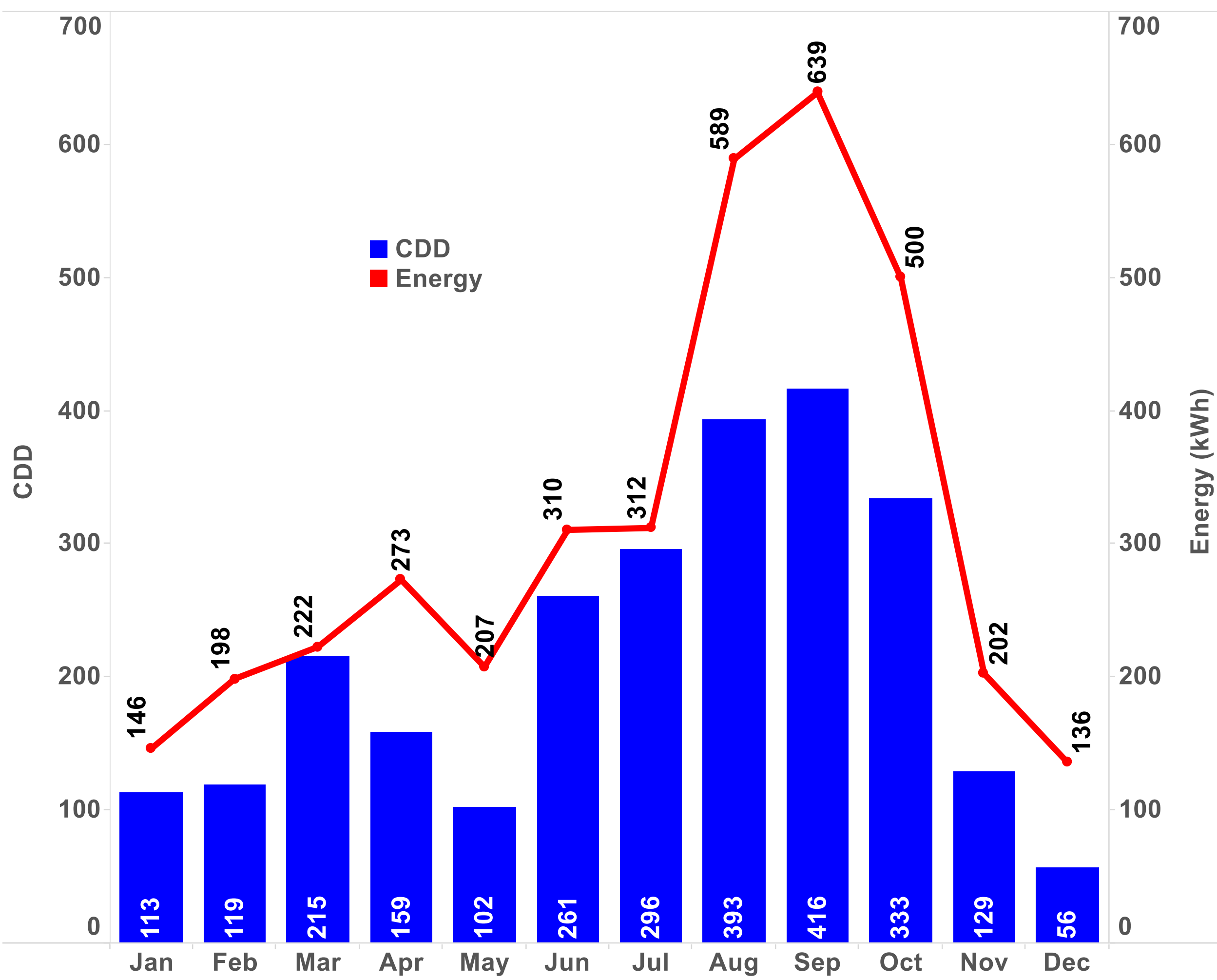

FIGURE 11 CDD'S AND ENERGY CONSUMPTION FOR THE VC-RTU

Figure 13 shows various peak electrical load shapes for the VC-RTU unit. The load shape can be used to determine the operating schedule of the unit if any additional information on the thermostat set points are not available. Detailed analysis of load shape based on variable like season, weekday or weekend was done to estimate the operating schedule for the unit. Figure 12 shows higher peak loads during the summer months which is expected from this application.

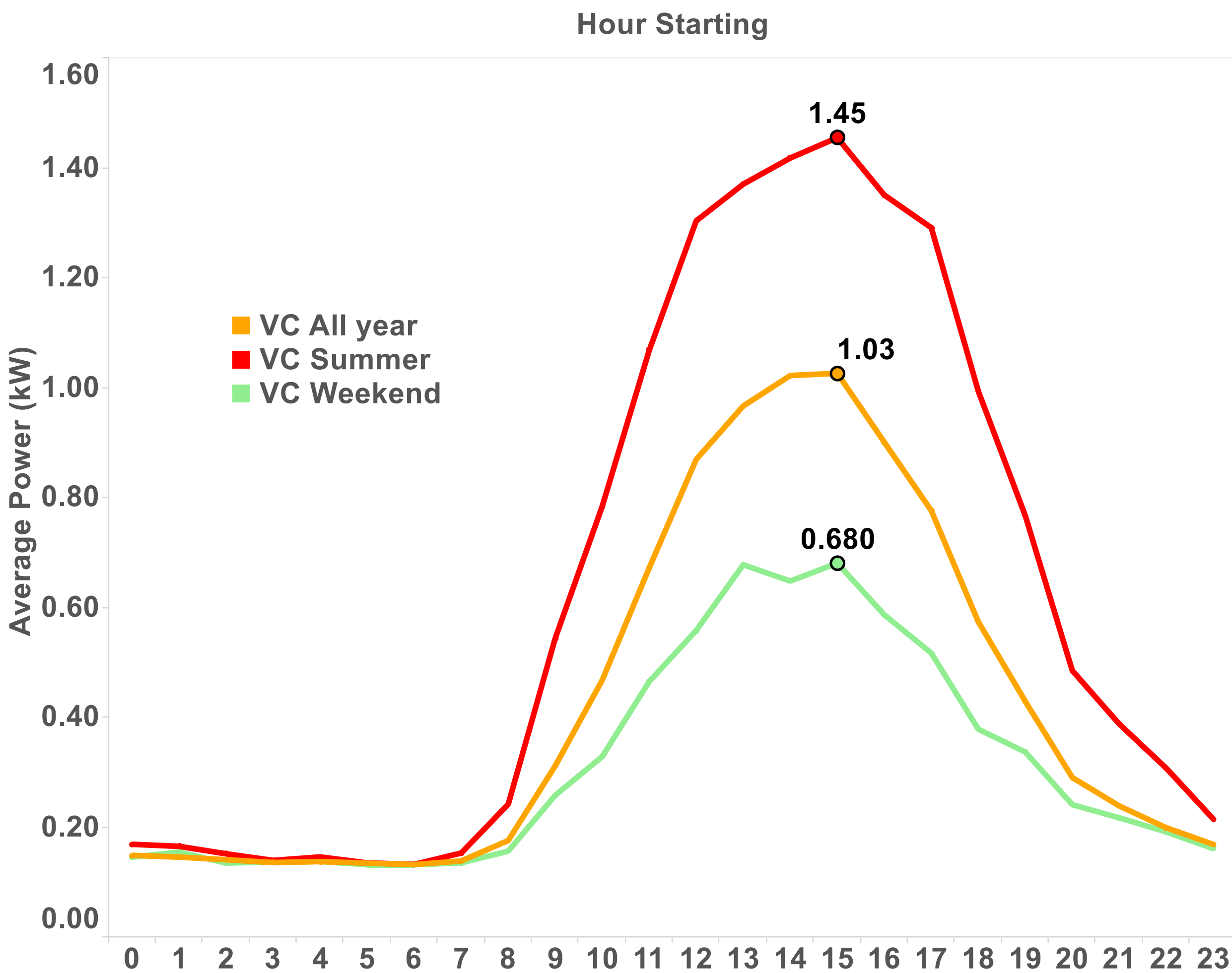

FIGURE 12 LOAD SHAPES FOR VC-RTU

Based on the load shape it can be deduced that the system was set in occupied mode in between 8am and 6pm. The lower average power draw in between 6pm and 8am indicate that the fan was running all the time which provides an opportunity to save energy.

Figure 13 shows the average return air temperature and supply air temperature (vertical scaled) when the VC-RTU is operating during the outdoor ambient temperature (horizontal scale). The average return air temperature is good proxy for indoor air temperature in the zone and the supply air temperature in conjunction with fan speed can be used to verify the variable speed operation of the supply air fan.

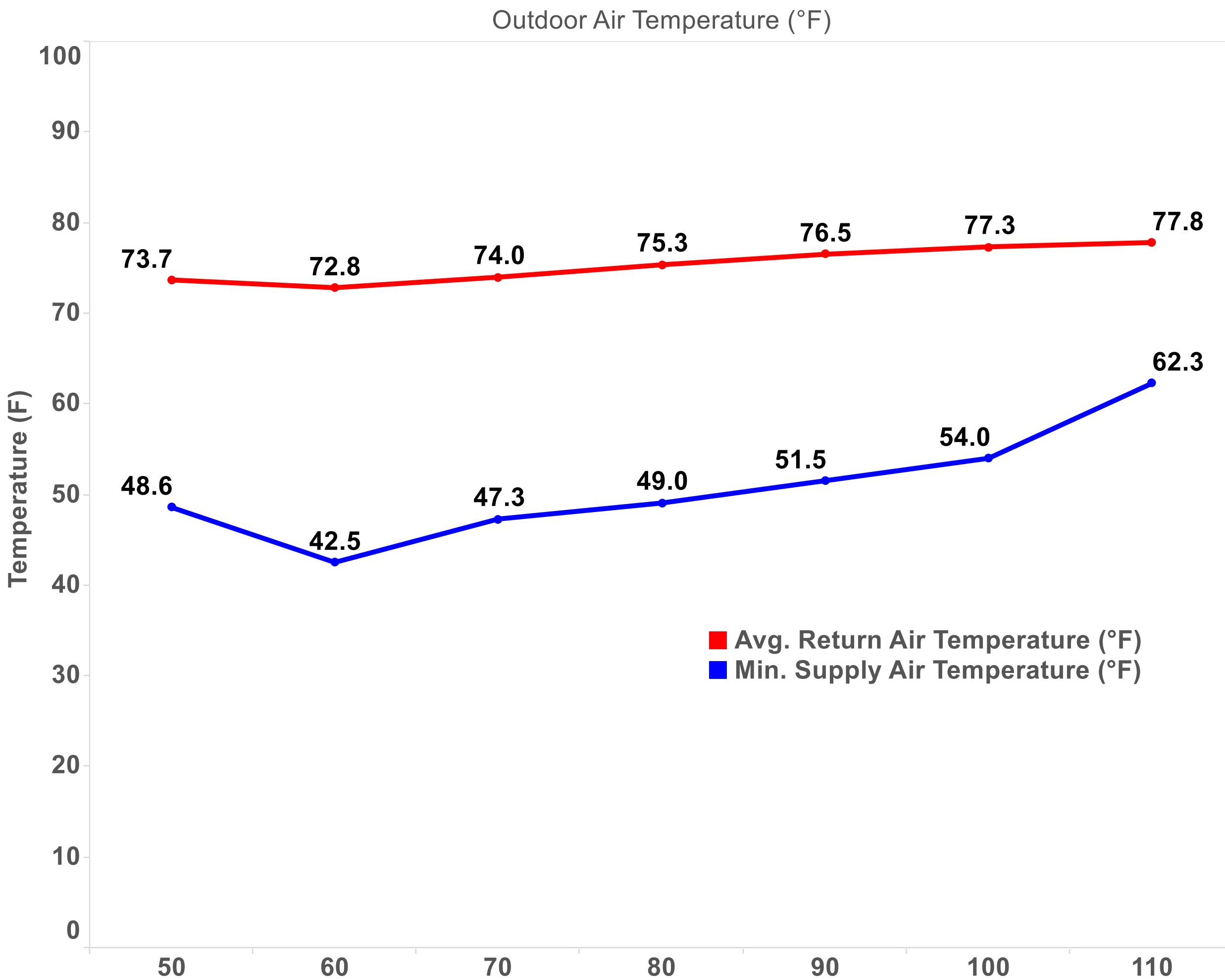

FIGURE 13 AVERAGE RETURN AIR TEMPERATURE AND MINIMUM SUPPLY AIR TEMPERATURE FOR VC-RTU

Figure 14 shows the average supply air volume in cubic feet per minute sorted in outdoor air temperature bins.

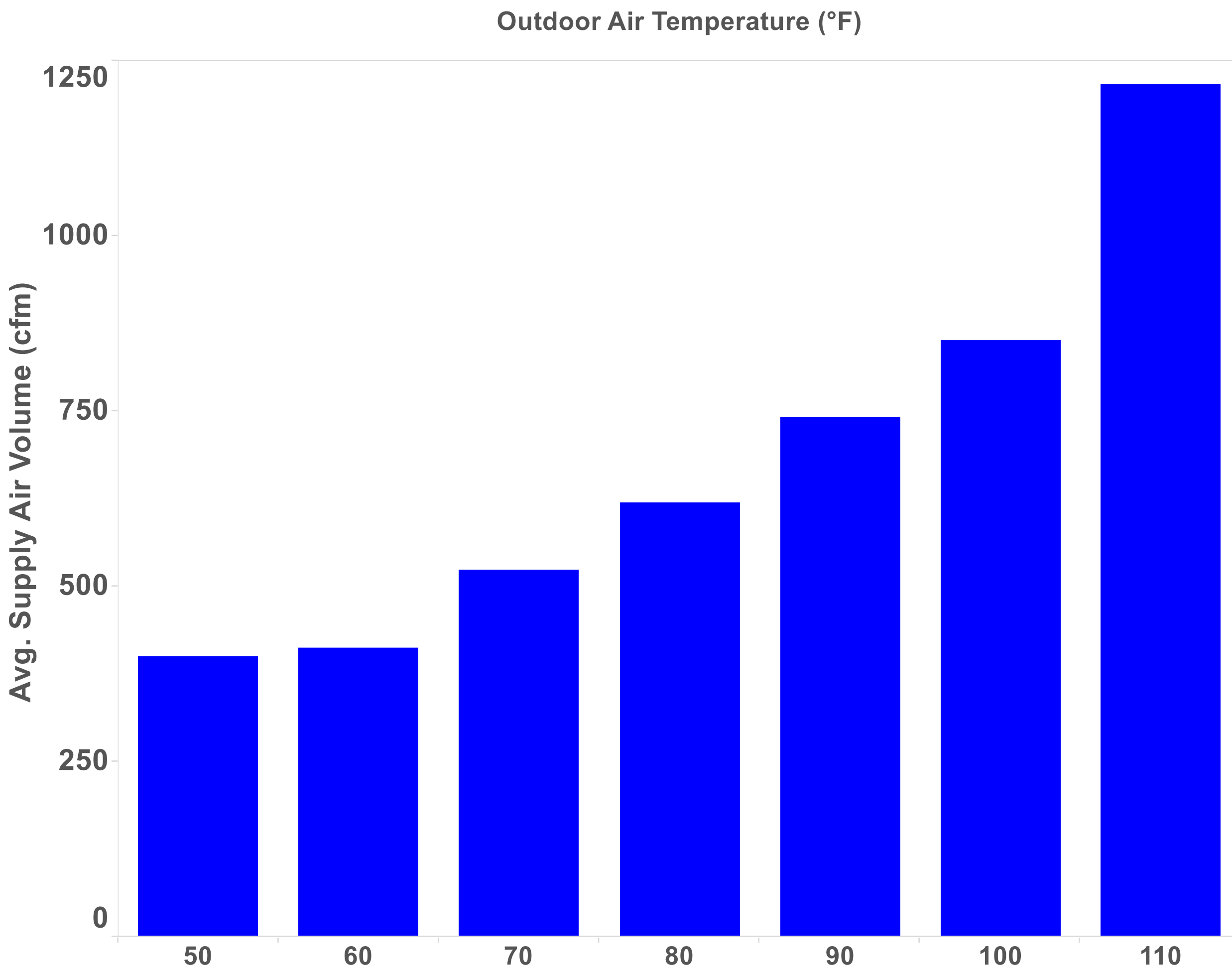

FIGURE 14 AVERAGE SUPPLY AIR VOLUME FROM VC-RTU

The air flow clearly shows increasing fan speeds as the ambient temperature goes higher – an indication of modulating fan speed and increased cooling capacity delivered to the space.

Figure 15 shows the average power draw from the VC-RTU.

	Outdoor Air Temperature (°F)									
Outdoor RH (%)	20	30	40	50	60	70	80	90	100	110
0				0.13	0.17	0.46	0.98	1.55	1.27	2.72
10			0.13	0.13	0.14	0.33	0.76	1.30	2.09	2.71
20			0.13	0.13	0.14	0.33	0.74	1.62	2.09	
30			0.13	0.13	0.17	0.41	1.05	1.68	2.25	
40		0.13	0.13	0.13	0.17	0.52	1.06	1.67		
50		0.13	0.13	0.13	0.21	0.50	1.13	2.20		
60	0.13	0.13	0.13	0.13	0.18	0.47	1.24			
70	0.13	0.13	0.13	0.13	0.15	0.45	1.36			
80	0.12	0.12	0.13	0.13	0.15	0.35				
90		0.13	0.13	0.13	0.14	0.44				

FIGURE 15 AVERAGE POWER DRAW (KW) FROM THE VC-RTU

The findings are to be expected for this type of a unit – as the ambient temperature increases the power draw from the unit increases. For the lower ambient temperature conditions, the average power draw is constant because of the fan only operation at these temperatures. In the lowest ambient temperatures bins, the operating hours are very small (confirmed from Figure 10).

DATA FROM BASELINE UNIT

Data available from a parallel study conducted by SCE is analyzed in this section. A code minimum 4-ton fixed speed (FS) RTU () was installed and monitored for another classroom in the same building and having the same orientation. The monitoring package was a separate package, but the duration of the monitoring period was the same.

Figure 16 shows the outdoor temperature and relative humidity data for a period of one year – January 2015 to December 2015 similar to Figure 10 but measured by a different sensor installed closer to the fixed speed (FS) unit. The sensor locations are slightly different even though they are on the same roof-top. Shading on the sensor can affect the temperature readings.

Outdoor Air Temperature (°F)

Outdoor RH (%)	20	30	40	50	60	70	80	90	100	110
0				2	18	45	72	33	3	3
10			11	72	272	196	189	92	50	1
20			33	102	198	177	150	220	51	
30			29	146	188	220	376	191	1	
40		2	49	157	263	365	265	11		
50		8	67	187	352	269	49			
60	1	26	110	315	449	162	2			
70	1	30	174	560	516	73				
80		34	187	402	361	29				
90		1	30	79	29	0				

FIGURE 16 BINNED TEMPERATURE AND RELATIVE HUMIDITY DATA FOR FS-RTU

With two different sensors at different locations there is a slight difference in measured values, but the overall trend is similar in both Figure 16 and Figure 10.

Figure 17 shows the cooling degree days (CDD) and monthly energy consumption by the FS-RTU. The CDD's are determined by summing up the average temperature per day above 65°F (base temperature) like Figure 11.

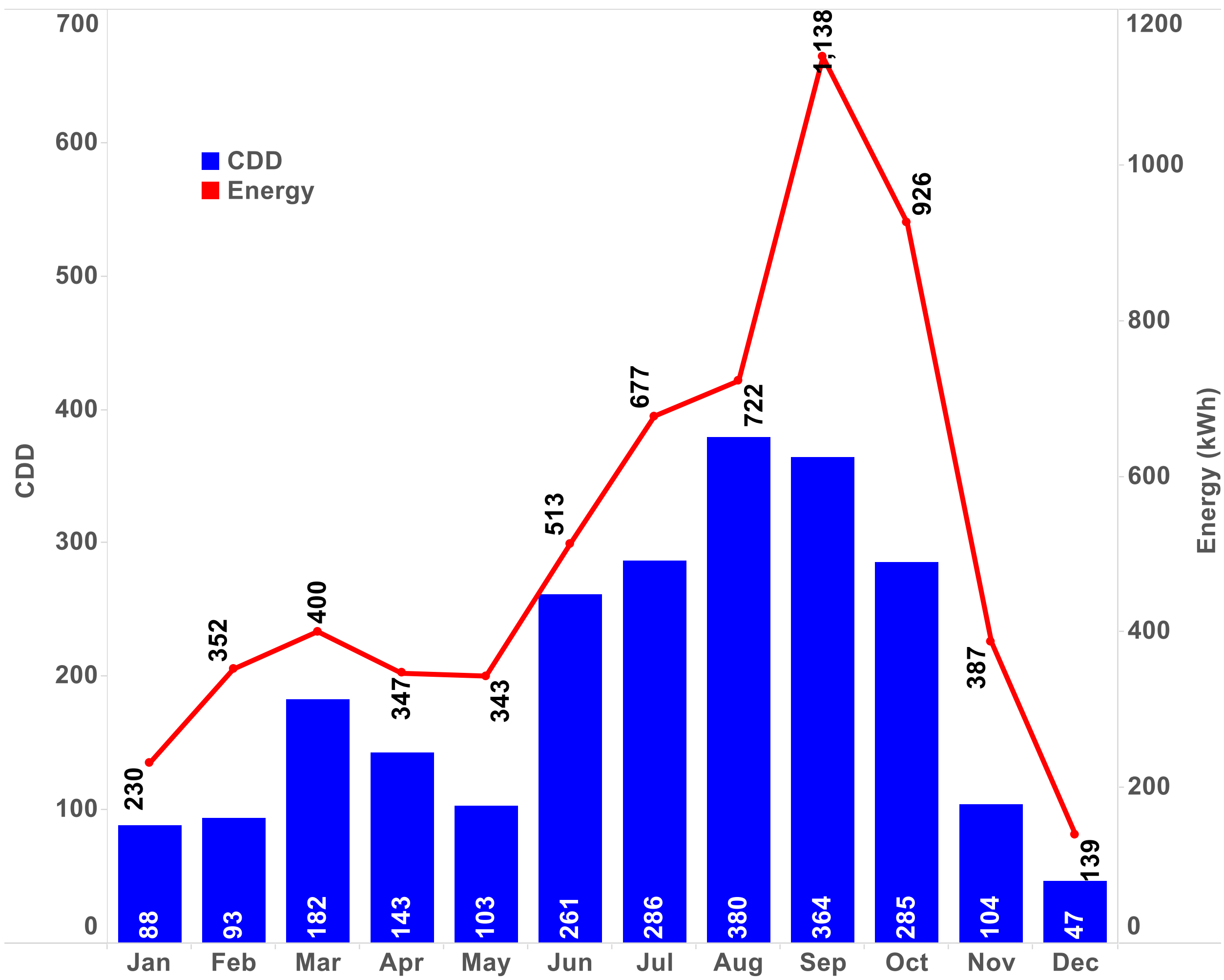

FIGURE 17 CDD'S AND ENERGY CONSUMPTION FOR THE FS-RTU

The CDD's are close between both the units with maximum difference being in January (22%). The summer months (June thru September) are of interest and except for September (12.5%) all other summer months are within 4% of each other (VC CDD's and FS CDD's). For summer of 2015, the VC unit used 1,850 kWh whereas the FS unit used 3,050 kWh. To normalize for size a kWh/ton of installed capacity is used. The VC-RTU energy consumption was 616.7 kWh/ton whereas the FS-RTU used 762.5 kWh/ton for the entire year. Therefore, the VC-RTU appears to provide an energy savings of approximately 19.1%.

Figure 18 shows operation of the VC-RTU and FS-RTU for one day (randomly chosen 08/05/15). The operation clearly shows the reduced demand from the VC unit as compared to the FS unit.

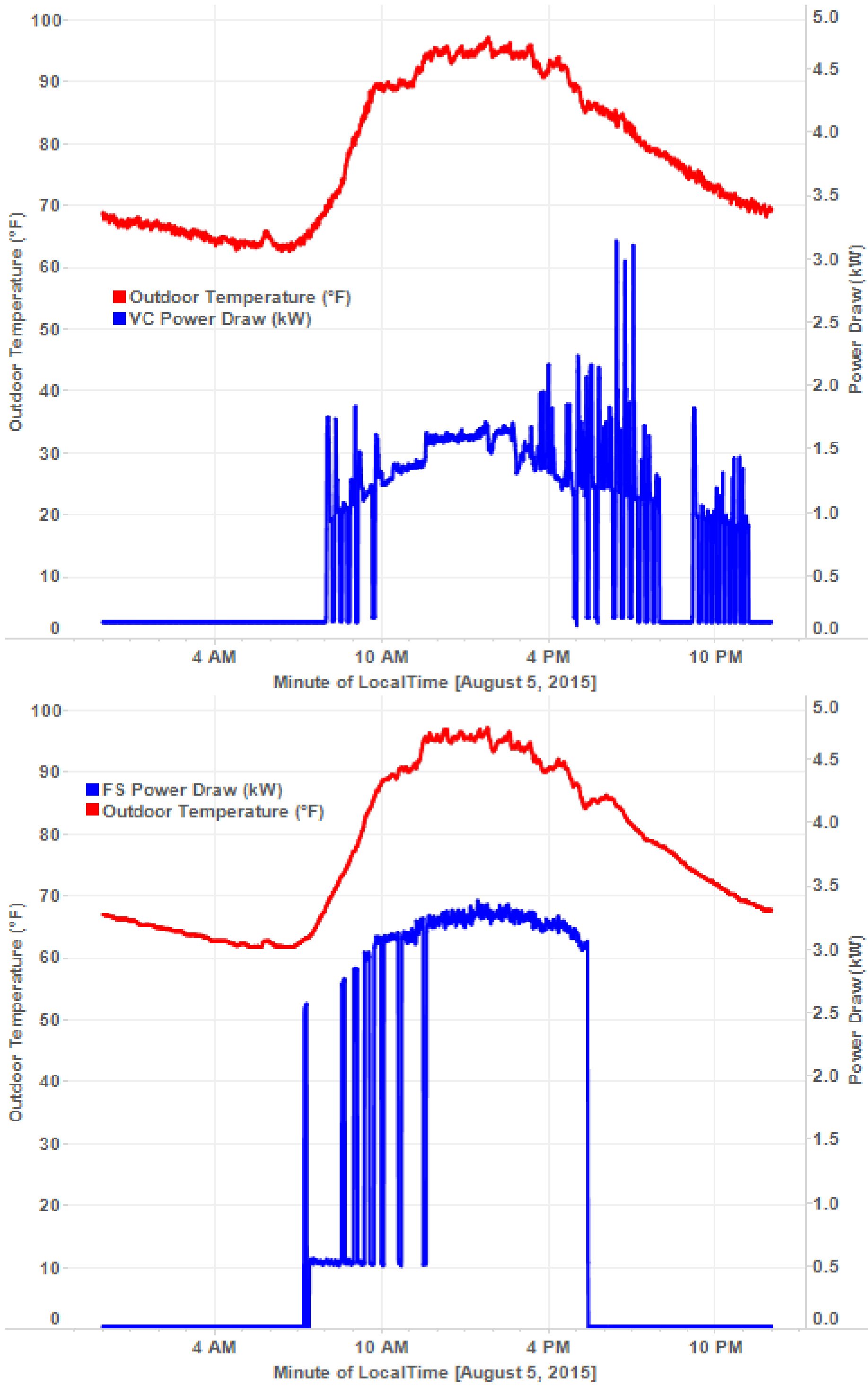

FIGURE 18 POWER DRAW COMPARISON BETWEEN VC-RTU AND FS-RTU FOR SAME DAY (AUGUST 5TH)

The reduction at peak is approximately 30% (0.85 kW/ton to 0.6 kW/ton). This is one of the significant advantages of using VC unit where system components can be modulated to keep demand in check (although modulation is done primarily for efficiency purposes). A check on supply air temperatures during this same period revealed that on average the VC unit provided 5°F colder air than the FS unit (55°F versus 60°F). Air flow measurements for VC unit showed reduced volumetric flow rate which resulted in the colder air and potentially contributed to lower power draw. The compressor speed could also have been modulated but the compressor speed (power) wasn't monitored individually.

Implications for Demand Response (DR): Data seems to suggest that the VC unit is more responsive to load conditions and possibly more adaptable to DR control strategies. Full testing strategies were not conducted at this time, but future program models would inform a recommendation for specific scenarios.

Figure 19 shows the average power draw from the FS-RTU (similar to Figure 15 which shows average power draw for VC-RTU).

	Outdoor Air Temperature (°F)						
Outdoor RH (%)	50	60	70	80	90	100	110
0		1.70	1.66	2.03	2.56	3.32	3.37
10	0.55	0.68	1.24	1.96	2.60	3.33	3.57
20	0.55	0.77	1.24	2.04	2.82	3.41	
30	0.55	0.79	1.32	2.24	2.82	3.32	
40	0.56	0.72	1.42	2.42	3.04		
50	0.58	0.73	1.65	2.58			
60	0.56	0.92	2.00	2.51			
70	0.56	1.13	2.12				
80	0.57	1.41	2.05				
90	0.57	1.42	2.67				

FIGURE 19 AVERAGE POWER DRAW (KW) FROM THE FS-RTU

The findings are to be expected for this type of a unit – as the ambient temperature increases the power draw from the unit increases. For the lower ambient temperature conditions, the average power draw is fairly constant because of the fan only operation at these temperatures.

DISCUSSION

ROOFTOP UNIT'S ENERGY CONSUMPTION

Table 11 lists the number of buildings in the entire US using different types of cooling energy sources (technologies) per the Commercial Buildings Energy Consumption Survey (CBECS 2012) [2]. The packaged air conditioning unit is the appropriate type of technology that the VC-RTU) can potentially replace.

Per CBECS, packaged air conditioning units are defined as a type of heating and/or cooling equipment that is assembled at a factory and installed as a self-contained unit. They are generally mounted on the roof of the building, but also sometimes located on a slab outside the building. Packaged units produce warm or cool air directly and distribute it throughout the building by ducts or a similar distribution system.

Based on the CBECS data there are approximately 1.9 million commercial buildings (37%) that can take advantage of this technology.

TABLE 11 NUMBER OF BUILDINGS (IN THOUSANDS) AND THEIR COOLING ENERGY SOURCES (CBECS 2012) [2]

	All buildings	Buildings with cooling	Electricity	Natural gas	District chilled water
Residential-type central air conditioners	1546	1546	1546		
Heat pumps	692	692	692		
Individual air conditioners	709	709	709	1	2
District chilled water	54	54	13		54
Central chillers	163	163	161	6	1
Packaged air conditioning units	1909	1909	1902	8	7
Swamp coolers	109	109	109		

Table 12 shows the actual square footage conditions using different types of cooling energy sources. Variable capacity rooftop units have the potential to condition 44,890 million square feet (42.7%) of commercial space throughout the US.

TABLE 12 FLOOR SPACE (IN MILLION SQUARE FEET) AND THEIR COOLING ENERGY SOURCE (CBECS 2012

	All buildings	Buildings with cooling	Electricity	Natural gas	District chilled water
Residential-type central air conditioners	14753	14753	14753		
Heat pumps	12538	12538	12538		268
Individual air conditioners	12417	12417	12396	193	636
District chilled water	4608	4608	1586		4608
Central chillers	17048	17048	16745	684	393
Packaged air conditioning units	45112	45112	44890	393	833
Swamp coolers	1918	1918	1918		

The total electricity consumption, and space cooling and ventilation electricity consumption, by commercial buildings is shown in Table 13 .

TABLE 13 TOTAL ELECTRICITY CONSUMPTION AND SPACE COOLING AND VENTILATION ELECTRICITY CONSUMPTION

	Total (trillion Btu)	Cooling + Ventilation (trillion Btu)
Northeast	752	93
New England	172	18
Middle Atlantic	579	75
Midwest	851	121
East North Central	595	82
West North Central	256	39
South	1,809	397
South Atlantic	978	212
East South Central	241	44
West South Central	590	141
West	829	106
Mountain	229	35
Pacific	600	71

West region, Pacific division covers California (along with Alaska, Hawaii, Oregon and Washington) and uses 71 trillion Btu (electricity) in cooling and ventilation. Of that 71 trillion Btu, 30.31 trillion Btu of energy (42.7%) would be used by packaged air conditioning units (from Table 12). A conservative estimate of energy savings of 15% (as compared with 19.1 % found in this study) can potentially save 4.5 trillion Btu of energy per year if the roof top market adopts such variable capacity systems.

TECHNOLOGY CHALLENGES

The contractor responsible for design, installation, and commissioning of the project encountered several challenges with application of the technology. The issues were mostly minor, and can be attributed to the lack of familiarity with the advanced system setup and operation on part of those involved with installation and startup. Some of the issues observed by the research team included:

- The unit was initially setup so that the supply fan would run at full speed during all hours, regardless of cooling load, and whether the space was occupied. Before this issue was resolved, the setup had basically eliminated one of the greatest opportunities for energy savings with advanced rooftop units, and had added a number of unnecessary operation hours.
- The modulating damper was not properly configured, and was setup to remain in a fixed position for all fan speeds. This resulted in excess ventilation at high fan speeds, and inadequate ventilation at lower fan speeds.
- The VC-RTU is delivered with a custom thermostat that controls the system’s unique features in the appropriate way and allows for seven-day scheduling of occupancy and set points. Initially, the contractor did not utilize this thermostat because it used an unfamiliar digital control interface. Instead, a series of timers and override switches were installed to control the unit. Incidentally, this arrangement is not allowed by Title 24 – California’s Building Energy Efficiency Standards require the use of programmable thermostats.
- These issues highlight the fact that many industry practitioners are not familiar with the unique needs for advanced rooftop air conditioners and heat pump systems
- The rooftop unit prior to installing the VC-RTU was a 2.5-ton unit; the minimum capacity for this unit stated at 4 tons, which was installed in its place.

EQUIPMENT COST AND SAVINGS

The complete proposal for removing the baseline system, engineering work (plan check drawings, permits, title 24 calculations, structural review), and installation (equipment, structural, plumbing, roofing) was $58,371 of which $14,787 was equipment cost. One of the major roadblock in this project was screening requirements per City of Simi Valley. By code, new rooftop systems need a screen which added to the cost of the project. Additional $28,601 was required for screening, structural work and roofing work.

The baseline FS-RTU equipment cost was $5,731. From the equipment cost alone, the VC system had a premium of $9,056. The cost premium might be slightly higher if a 4-ton VC cost was included but for purposes of the analysis it is assumed that 3-

ton system costs equal to the 4-ton system. Using the 4-ton system as a common size the savings in energy found in this study is 582 kWh not enough to make a reasonable economic payback period.

CONCLUSIONS

The VC-RTU has a number differentiating features that offer significant energy savings. The most important of these are the variable speed compressor and supply fan, which allow the unit to fluidly match capacity to cooling load. At part speed the VC-RTU can achieve exceptional efficiency – the system averaged around EER SENS = 17.5 for operation below 50% capacity, and reached as high as EER SENS = 40 for some periods.

In January, the unit spent a significant amount of time at part speed. In April and July, part capacity modes accounted for a much smaller number of operating hours, and the unit mostly operated continuously. This study confirms that the VC-RTU can achieve very high efficiency at certain part load conditions and achieves good savings at peak cooling conditions compared to the standard alternative. The measurements recorded in this study indicate that the unit uses 30% less electricity at peak than a minimum standard unit would in the same scenario.

Full speed operation accounted for nearly 50% of all operating hours in April and practically 100% of operating hours in July. As a result, the unit had little opportunity to gain from some of its advanced features. Moreover, since the VC-RTU achieves much higher efficiency at part capacity, a system that is oversized for the application should generally use less energy than a system that is "right sized".

This field installation offered many lessons for future application of advanced rooftop unit technologies. The experience highlights the need for increased education and training for industry practitioners. Initially, there were many problems with the equipment setup that caused the system to use substantially more energy than it should have. None of the problems resulted from technical failure for the unit, but the complexity for setup compared to a conventional rooftop air conditioner was a significant challenge for the installing contractor.

RECOMMENDATIONS

It is recommended that utility programs and standard regulations embrace the technical opportunity presented by this type of advanced rooftop air conditioner. We expect that the strategies introduced by these new products will become mainstay features for future HVAC equipment, but we recognize that in the interim there is a significant need for efforts and programs to introduce the broader market application for these solutions, to provide educational resources and training, and to facilitate successful application of the technology for more commercial buildings.

While these technologies offer the possibility of significant energy savings, it is very important that the industry develop stronger capabilities surrounding the proper application of these opportunities. The research team recommends that any efforts to advance the broader market adoption of these solutions must be accompanied by strong educational components, and should incorporate mechanisms that actively facilitate proper setup and commissioning. Utilities, manufacturers, regulators and industry associations need to work closely together in this regard because the higher degree of complexity with most advanced rooftop unit introduces more opportunity for failures to obtain its potential energy savings and flexible capacity response.

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