Emerging Products

VRF Market Characterization for ADR Program Readiness

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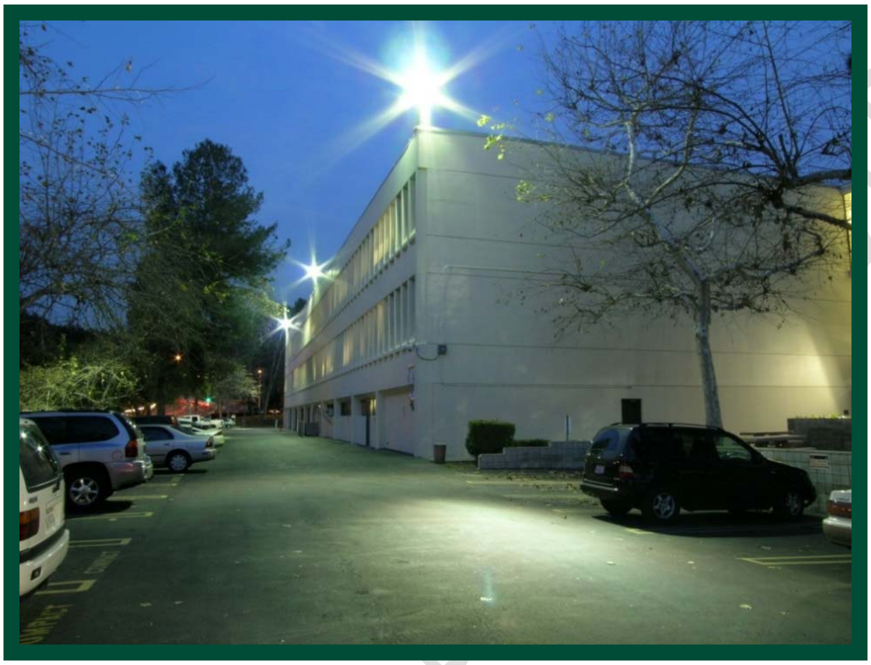

Prepared by:

Emerging Products
Customer Service
Southern California Edison

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Disclaimer

EXECUTIVE SUMMARY

Variable refrigerant flow (VRF) systems are well-suited for automated demand response (ADR) because of their higher efficiency, inherently flexible design, and zone-based controls available from the factory. VRFs are heat pumps that use inverter-controlled, variable speed compressors to modulate capacity to meet varying demand. These modular systems can be scaled from six tons up to hundreds of tons and consist of an outdoor condenser unit connected by refrigerant lines to multiple indoor evaporator units that serve each zone. A subclass of VRFs includes mini-split and multi-split systems ranging from 0.75 to 5 tons, which are used for residential and small commercial applications. This market characterization study focuses on the larger VRF systems only.

In 2016, California sales of commercial VRF systems (with 3-phase condensing units) totaled 3,500 units, with an estimated market value of approximately $210 million, conservatively.[1] VRF sales nationally are expected to grow at 11 percent compound annual growth rate (CAGR) through 2018 (Krawcke, 2015).

PROJECT OBJECTIVES

Although VRF has demonstrated energy efficiency savings, its applicability to ADR is still unclear. The objectives of this study are: to report the status of ADR-capable controls across VRF manufacturers, and to report on VRF controls compliance with the demand response (DR) requirements in both California's existing building energy code (2013 Title 24)[2], and DR guidelines in ASHRAE 189.1-2014.

The Research Team (Team) conducted phone interviews with seven VRF manufacturers and their controls engineers during August and September 2016. Questions pertained to key product features and controls that can be used for demand response participation as well as to the types of DR strategies that can be implemented. The interviews were supplemented by a review of manufacturer websites, product literature, and relevant conference presentations. The interview responses and information were compared with the demand response and zone thermostat requirements in Title 24. This report documents the research Team's findings and includes recommendations for SCE to encourage the further development of ADR-capable controls in VRF equipment.

TECHNOLOGY DESCRIPTION

VRFs are integrated solutions with microprocessor controls that are networked together using proprietary digital communication protocols to coordinate their operations. The controls are distributed in the system, such that programmable functionality can exist at both the zonal and central controller level. The controllers

[1] Equipment only, and does not include labor costs. Assumes average installation includes one outdoor 3-phase condensing unit, indoor air units, central controller and thermostats. Additional sales of single-phase VRF systems apply to residential installations and are not included in this estimate of total market value in California.

[2] The 2016 Title 24 Code comes into effect on July 1, 2017. It is expected that the DR requirements will be clarified but not change in level of stringency.

communicate over a proprietary local network that connects them to the indoor and outdoor units.

The simplest configuration consists of zone level controllers that individually control the indoor units via separately programmed, multi-day schedules. A larger system may include a central controller that coordinates the operations of multiple outdoor condenser units and multiple indoor units in all the zones.

The most complex configurations include VRF central controllers coordinating with a building energy management control system (EMCS) that is directing an entire building's lighting, heating, ventilation, and air conditioning (HVAC), and other systems. Some VRF manufacturers offer an integrated EMCS that can communicate directly to the VRF central controller. Those manufacturers that do not offer their own EMCS can connect to a third-party system using an optional interface for a standard building network protocol such as BACnet® or LonWorks™.

READINESS SUMMARY AND OUTLOOK

At this time, VRF systems can manually carry out demand reduction strategies. However, the functions are not sufficiently integrated to perform ADR. To provide ADR functionality, there is a need to add Virtual End Node (VEN) hardware, custom programming, and/or input/output wiring, in addition to the standard VRF communications network. While ADR can be achieved on a custom or demonstration basis, to make ADR attractive to customers on a commercial scale, the VRF manufacturers will need to address these issues, offer DR-specific controls functions, and offer VEN communications solutions as standard features.

More than half of the manufacturers do not currently offer DR-related commands in their central controller, and all manufacturers currently lack the ability to recognize an OpenADR 2.0 communication signal from SCE with their central controller. None of the VRF manufacturers fully comply with Title 24 requirements for DR and zonal thermostats. Two manufacturers can meet all the Title 24 requirements except for automated demand shed control. Less than half can meet all the requirements for zonal thermostats.

VRF manufacturers had a wait-and-see attitude on making their VRF solutions fully ADR-capable for SCE program participation. Many wanted to first see clear market signals such as ADR features requested by their customers and utilities. Manufacturers communicated that adding these capabilities may take a year or more. They would need to justify the cost of development with confidence in increased sales. VRF manufacturers agreed on prioritizing compliance with state code requirements. However, the interviews indicated a lack of familiarity with the specific requirements, particularly related to DR. Manufacturers are generally interested in utility incentive programs to reduce purchase costs for customers.

Several VRF manufacturers have inquired about California's ADR program requirements and incentives. One manufacturer learned about SCE's 2014-2016 Upstream HVAC with ADR incentives through their distributor, who was enrolled in the pilot. At the time of this writing, the companies did not express plans to add OpenADR communications to their VRF equipment, at least not until they felt the market demand or program need for such features.

RECOMMENDATIONS AND CONCLUSION

Given the wait-and-see attitude, manufacturers did not offer a roadmap to developing ADR capability for VRFs. Therefore, the research team recommends that SCE continue engaging the market. SCE can encourage the development of ADR capabilities and communicate the market demand through both education and incentives. Engagement efforts need to be regular, consistent, and sustained and can begin with education on the DR requirements in the Title 24 building code. Compliance with the building code will move the market towards the inclusion of a standard set of built-in DR commands in VRF equipment.

Beyond code compliance, one of the strongest and clearest signals that SCE can provide is to offer incentive programs for DR-capable VRF equipment. SCE should continue ADR Program incentives as well as pilots that encourage further development of more DR-friendly VRF systems.

Additionally, SCE can help manufacturers by providing technical support. OpenADR certification does not guarantee smooth integration with a utility's DR automation server, since the interpretation of the OpenADR standard can often vary between utilities. Technical support during product testing, pre- and post-installation project commissioning will be valuable to the manufacturers.

Lastly, this study reports on the available DR functionalities described by the VRF manufacturers. A recommended next step is to validate the manufacturer claims on the operation of these features for a select group of manufacturers. The controls capabilities and execution sequences can be demonstrated first in a laboratory setting, which offers the freedom of repetition in a controlled environment with no disruption to actual building occupants.

ABBREVIATIONS AND ACRONYMS

ADR	Automated Demand Response
ADSC	Automated Demand Shed Control
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
DDC	Direct Digital Control
DR	Demand Response
DRAS	Demand Response Automation Server
EMCS	Energy Management Control System
EPRI	Electric Power Research Institute
HVAC	Heating, Ventilation and Air Conditioning
IOU	Investor-Owned Utility
I/O	Input/Output
kW	Kilowatt
kWh	Kilowatt-hour
MWh	Megawatt hour
OCST	Occupant Controlled Smart Thermostats
PG&E	Pacific Gas & Electric
SCE	Southern California Edison
SDG&E	San Diego Gas & Electric
VEN	Virtual End Node
VRF	Variable Refrigerant Flow
VTN	Virtual Top Node

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INTRODUCTION

Demand response in California continues to be viewed as an essential resource for meeting the state's renewable and clean energy goals. Demand response remains second in the energy resource loading order after energy efficiency (State of California, 2008). Furthermore, demand response is evolving from traditional reliability services to increasingly diverse system-level roles, such as wholesale market integration, time differentiated retail tariffs, and targeted geographic dispatch based on relative locational value. In their recently published demand response potential study, Lawrence Berkeley National Laboratory scientists stated that "DR-enabled variable frequency drives (VFDs) in commercial HVAC are an extremely responsive technology that…should be piloted to test performance and scalability for transmission and distribution services." Furthermore,

> "Aggregation of commercial HVAC units with VFD, coupled with "plug-and-play" access to markets, could provide Shed, Shape, and Shimmy services to the grid. The functionality of the VFDs allows for full automation technology to maintain customer comfort levels, limit disruption to operations, and provide fast response DR service to the grid." (Alstone et al., 2016, p. 7-5).

Some heating, ventilation, and air conditioning (HVAC) controls manufacturers are developing automated demand response (ADR)-capable controls. VRF manufacturers, on the other hand, already sell equipment with integrated controls capable of reducing demand. However, the status of the ADR functionality of the VRFs currently available on the market is still emerging. SCE needs to clarify the capabilities and validate performance of ADR-capable VRF controls before supporting them in scaled adoption programs to drive demand. This report is a market characterization study of VRF controls among VRF manufacturers. It builds on the existing research demonstration performed by SCE in 2013-2014. This effort also incorporates lessons learned from the 2014-2016 SCE pilot incenting HVAC distributors and manufacturers to stock and upsell high efficiency, ADR-capable equipment including VRFs.

ASSESSMENT OBJECTIVES

This project will enable SCE program staff to make informed decisions about the ADR capabilities of VRF control systems and determine which are ready for accelerated commercialization in SCE incentive programs. Specific objectives include:

- Research the status of ADR-capable VRF controls among different VRF manufacturers.
- Review whether or not VRF controls meet demand response requirements in 2013 Title 24 energy code.
- Report on available plans by VRF manufacturers to offer ADR-capable controls.

The Research Team (Team) examines the features and capabilities that are already available, or may be available following further development, for ADR. The Team proposes a set of features that might be desirable for determining eligibility of VRF equipment in a future ADR technology incentive program. The features comprise both code mandated requirements and subjective recommendations to maximize the program benefits of the unique characteristics of the VRF technology.

TECHNICAL APPROACH/METHODOLOGY

The Team conducted a technology and market assessment characterizing the available DR strategies and ADR capabilities of VRFs. During the assessment, the Team conducted phone interviews with seven VRF manufacturers. Interviews focused on the key product features and HVAC controls parameters that can be used for demand response participation and on what types of DR strategies can be implemented by the VRF controls. The interviews were supplemented by a web-based research of manufacturer websites, product literature, and relevant conference presentations.

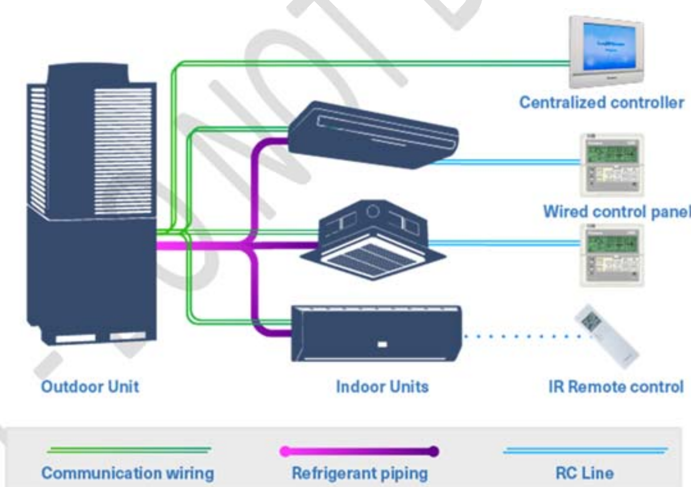
The interviews with VRF manufacturers also included questions relating to the 2013 Title 24 code. The Team examined whether VRFs are required to meet the Automated Demand Shed Control (ADSC) measure or the Occupant Controlled Smart Thermostat (OCST) measure within Title 24. The Team also compared VRF capabilities against zone thermostat requirements in Title 24. Finally, the Team reviewed language in the ASHRAE 189.1-2014 code for high-performance buildings, discussing implications for VRF compliance. This report provides findings on: the market status of VRF controls capabilities; the extent to which these capabilities can be successfully employed for demand response; an assessment of what additional development efforts are needed, if any, to comply with Title 24 and allow VRFs to participate more easily in SCE's ADR Program; a high-level analysis of development costs; and recommendations for SCE and the market to encourage the development of the recommended features in the report. The report also reviews key lessons learned from SCE's 2013-2014 site demonstration as well as the 2014-2016 SCE pilot for HVAC distributors and contractors to promote ADR-capable HVAC equipment.

BACKGROUND

VRF systems are well-suited for ADR because of their high efficiency, inherently flexible design, and more sophisticated controls available from the factory relative to traditional air conditioners. This section describes VRF equipment and architecture, as well as the standard operation and controls capabilities that point to their demand response potential. Furthermore, this section also covers VRF efficiency performance, followed by a discussion of the current market for VRF systems.

SYSTEM TYPES

Variable Refrigerant Flow (VRF) systems are a multi-zonal heat pump technology that provide an efficient alternative to conventional unitary air conditioners and variable air volume (VAV) systems. Developed in Japan in the 1980s, VRF system architecture is comprised of an outdoor condensing unit connected to multiple evaporator fan coil units that are located inside the individual conditioned zones. The outdoor unit contains the compressor, condenser, propeller fan(s), circuit board, and a heat exchanger coil. The indoor unit consists of a heat exchange coil, expansion valve, air filters, and fan. Air-source VRFs have an exterior condensing (heat rejection) unit while water-source VRF systems reject heat via a water loop in the building connected to a cooling tower and possibly a boiler. Most manufacturers offer both air-source and water-source VRF systems. The example shown in below displays the components of a typical VRF system.



Source: CoolAir Australia

FIGURE 1. TYPICAL VRF SYSTEM STRUCTURE

Subclasses of VRFs include mini-splits and multi-splits. A mini-split consists of a single outdoor unit with a single indoor unit. A multi-split includes a single condensing outdoor unit connected to multiple indoor evaporators. VRF systems have much larger capacity and are more complex versions of mini-splits and multi-splits. VRFs can have many evaporators of differing capacities and configurations, and some systems simultaneously heat and cool different zones within a building. While ductless mini- and multi-split systems range from 0.75 tons up to 5 tons, VRF systems can range in size from 6 tons to hundreds of tons. This market characterization study focuses specifically on VRF systems and does not address mini- and multi-splits.

SYSTEM OPERATION

Unlike conventional systems that transport heat by forcing air through ducts or by circulating chilled or hot water through pipes, VRF systems use a network of refrigerant piping installed throughout the building. Using inverter-controlled compressors, VRF systems can vary the amount of refrigerant to the indoor units, hence the name “variable refrigerant flow.” As occupancy, exposure, and time of day change the heating and cooling loads on the indoor units, the connected VRF (outdoor) condensing units can modulate capacity to match the actual demand, allowing the system to ramp down when unneeded, significantly reducing energy use. Current VRF equipment has part-load Integrated Energy Efficiency Ratio (IEER) ratings as high as 30 or more.[3] By comparison, the IEER ratings of package rooftop HVAC units greater than 6 tons range from 10.1 to 23.0, according to the Air Conditioning, Heating and Refrigeration Institute (AHRI) directory.

Each zone in a VRF system can have its own setpoint temperature. VRF systems with the heat recovery option can operate in both heating and cooling modes simultaneously by removing heat from zones that are calling for cooling and moving the heat to other zones that are calling for heating. This capability contributes to the high efficiency of VRF systems.

Control over the compressor speed enables many VRF systems to be able to temporarily place a limit on compressor power as a technique to reduce electric demand. This compressor throttling, along with selective zone shutdown, further allows VRFs to operate extremely efficiently. These capabilities are also very suitable for demand response participation.

CONTROL ARCHITECTURE

The control architecture for VRF is sophisticated. All components in the system are tied together using a local area communications network that is proprietary to each manufacturer. Operational data, commands, fault status, and diagnostics are typically shared over this network.

The simplest configuration may consist of zone-level controllers that can be individually programmed with a multi-day schedule (see Table 1). A larger system with multiple outdoor units may include a central controller that coordinates the operations of all the zones. Lastly, the most complex applications may have VRF central controllers coordinating with an EMCS that is directing an entire building’s lighting, HVAC, and other systems.

[3] IEER replaced the Integrated Part-Load Value (IPLV) after January 1, 2010 as the rating for direct exchange 3-phase ($\geq$ 5.4 tons) packaged equipment and VRFs. IEER is a measure of the part-load performance of the unit. It is calculated using a standard test procedure developed by AHRI. For VRFs, the IEER test procedure is based on AHRI Standard 1230-2010. It is calculated by taking the EER of the unit at 25%, 50%, 75%, and 100% net capacity and specified ambient conditions. The Energy Efficiency Ratio (EER) is expressed as the ratio of the total Cooling Capacity in Btu/h to the power input values in watts [W] at any given set of rating conditions expressed in Btu/W·h.

Small equipment that are single-phase (< 5.4 tons) use the Seasonal Energy Efficiency Ratio (SEER), which is the total heat removed from the conditioned space during the annual cooling season, expressed in Btus, divided by the total electrical energy consumed by the air conditioner or heat pump during the same season, expressed in watt-hours (Btu/wh).

TABLE 1. DISTRIBUTED LEVELS OF CONTROL IN A VRF SYSTEM

CONTROLLER	COMPONENT CONTROLLED	EXAMPLE APPLICATION
Zonal	single indoor unit	small business
Central	multiple indoor units and/or outdoor units	medium business, each floor of a large building
EMCS	multiple central controllers	whole building* or campus

*May include lighting and other system controls in addition to VRF system

VRFs are integrated solutions and the manufacturers provide proprietary zonal and central controllers for their systems. The controllers communicate over a proprietary network that links the controllers to the indoor and outdoor units. Some manufacturers may also offer an integrated EMCS that will communicate directly to the VRF central controller over a proprietary protocol. Those manufacturers that do not offer their own EMCS can connect to a third-party EMCS using an optional interface for a standard building network protocol such as BACnet® or LonWorks™.

OVERVIEW OF VRF MARKET IN THE UNITED STATES

In the U.S., VRFs were introduced into the market in the early 2000s. Early adoption was slow and concentrated in specialty retrofit applications where the equipment was considered a "problem solver." This included buildings where it was not economical to install ducting for forced air systems due to space restrictions. Currently, the VRF market share is estimated to be approximately five percent of total annual HVAC sales, with much of the growth occurring in the last five to ten years. Utility incentive programs, manufacturer and distributor investments in training centers, and increased installer and designer experience with these systems all contribute to the greater awareness and implementation of VRFs.

VRF systems are best suited for multi-zonal applications, especially when there is large diversity in the loads. Typical applications include:

- Commercial offices (owner occupied and individual tenants including core and shell projects),
- Educational facilities (primary and secondary schools, universities),
- Healthcare facilities and clinics (not hospitals),
- Assisted living and nursing homes,
- Multi-family residential buildings,
- Retail buildings,
- Lodging such as hotels, motels, and associated conference and banquet halls,
- Restaurants, and
- Churches and community facilities.

STATUS OF VRF ADOPTION IN CALIFORNIA

In 2016, sales of commercial VRF systems totaled approximately 3,500 units. This represented a 60 percent increase compared to 2015 (Confidential, 2017). Assuming an average unit size of 10 tons, costing approximately $60,000, the estimated market value of commercial VRFs in California is approximately $210 million, conservatively.[4] Both SCE and Pacific Gas and Electric (PG&E) offer prescriptive incentives for VRF equipment. Since 2010, VRF equipment applications submitted statewide under IOU incentive programs totaled approximately 1,000 installations.

[4]Equipment only, and does not include labor costs. Assumes average installation includes one outdoor 3-phase condensing unit, indoor air units, central controller and thermostats. Additional sales of single-phase VRF systems apply to residential installations and are not included in this estimate of total market value in California.

TECHNOLOGY/PRODUCT EVALUATION

LOAD SHED STRATEGIES

Manufacturers offered several control functions that can be used as load shed strategies for demand response in SCE programs. They were developed for a variety of reasons other than demand response, such as noise control or operation in multi-tenant facilities. With limited exceptions, these functions are offered at an extra cost as options above the base control functions. To use the existing available functions described in this section for demand response, manufacturers require additional custom programming to the central controller or Energy Management Control System (EMCS).

Furthermore, in terms of the specific control command and mode of communication (e.g., binary via dry contact, software digital communication, communication from outdoor unit, communication from central controller), the implementation of these functions varies from manufacturer to manufacturer. Table 2 summarizes the existing control functions of VRF systems studied that are suitable as load shed strategies for DR. The paragraphs following describe the specific control functions in more detail.

TABLE 2. NUMBER OF MANUFACTURERS WITH EXISTING VRF CONTROL FUNCTIONS APPLICABLE TO DEMAND RESPONSE

	AVAILABLE AS OPTION	AVAILABLE AS OPTION WITH CUSTOM PROGRAMMING OR WIRING	AVAILABLE	UNKNOWN OR N/A
Remote Setpoint Control		1	2	4
Automated Setpoint Setback		6		1
Turn off Units in Rotation		3		4
Compressor Demand Limit		4		
Other Demand Limit	2	1		
Zone Differentiation		5		2
Power Meter Reading	2	1		4
Snapback Control		1	3	3

SETPOINT SETBACK CONTROL

Virtually all manufacturers offer some form of setpoint control. However, this feature varies in relative sophistication and in how the command is communicated to the zone controllers. VRF manufacturers do not consider thermostat setpoint reset to be the optimal control strategy for efficiency or demand response, since the kW impact is indirect.

TABLE 3. EXISTING SETPOINT CONTROL CAPABILITIES OF VRF SYSTEMS STUDIED

	Controller Level			Control Method			
	Central Controller	Zone Controller	Own EMCS	Built-In Program	Custom Program	Contact Closure	Manual
Number of Manufacturers	2	3	1	1	1	3	1

Two manufacturers reported having the capability to remotely change setpoints via their central controller. The first manufacturer has the built-in capability to set upper and lower temperature limits in the central controller that the zone controllers cannot exceed. The second manufacturer can set back setpoints at the zone controllers remotely from the central controller using switch closure inputs normally connected to occupancy sensors. This option requires individual input/output (I/O) wiring to each zone controller in addition to the standard control wiring.

Three other manufacturers rely on zone controllers to change temperature setpoints. These models can be adjusted for demand response either manually or automatically if individually wired to receive a control signal via dry contact closure. One manufacturer can also wire the controllers to adjust fan speed of the indoor unit.

The sixth manufacturer can set back or adjust zone temperatures remotely when connected with their own EMCS. Additional custom programming is required to specify the temperature setpoint adjustment. Without connecting to their EMCS, the zone controllers are manually adjusted locally.

One manufacturer reported the ability to adjust the temperature setpoint of its fan coil units. However, this function requires further clarification and the Team was not able to reach the manufacturer for further comment.

TURN OFF UNITS IN ROTATION

This is a strategy whereby individual indoor units or groups of indoor units can be completely turned off for a set period of time while other indoor units are left operating. For example, the indoor unit in a building lobby can be turned off while other zones remain operating, and then the lobby can be turned back on while the conference rooms are turned off, and so on.

Three manufacturers reported the ability to shut off units in rotation. One manufacturer accomplishes this via custom programming of their EMCS product. For the second manufacturer, the indoor unit shutoff rotation is an energy saving option available with existing VRFs via the central controller. The indoor units can be grouped or selected for shutoff or operation at certain times and days, based on an annual schedule. Additional on/off functionality can be provided by connecting with other sensor switches (e.g., temperature, CO_2 or occupancy sensors). A third manufacturer can shut off outdoor units in rotation via one of three programmable inputs at each outdoor unit.

DEMAND LIMITING

Variable speed compressors are a key feature of VRFs, which allows most manufacturers to offer a direct demand limiting function. Table 4 summarizes the existing demand limiting capabilities of VRF systems studied.

TABLE 4. EXISTING DEMAND LIMITING CAPABILITIES OF VRF SYSTEMS STUDIED

	CONTROLLER LEVEL			CONTROL METHOD			
	Central Controller	Own EMCS	Other/Un-Known	Built-In Program	Contact Closure	Manual	Other/Un-Known
Number of Manufacturers	2	1	4	2	3	1	1

Two manufacturers can limit the outdoor unit compressor power via the central controller. The first manufacturer uses an optional power meter connection to monitor the total power consumption of the unit while the central controller changes the indoor unit temperature setpoints, forces the indoor unit off, or takes other measures to the meet the unit's target demand limit while maintaining comfort. The second manufacturer has a peak control function that is available through one of their central controller products. The function caps the compressor power at a specific percentage of the maximum load. The controller can command both the cap and the percent reduction amount to the outdoor units. The system will automatically distribute the available capacity to the indoor units calling for cooling.

Three other manufacturers implement demand limiting via control directly at the outdoor unit. The first manufacturer has a built-in compressor demand limiting feature with programmable inputs at the outdoor unit. Each input can be manually programmed locally to take various actions, for example: stop only outdoor units, stop both indoor and outdoor units, stop the outdoor unit but keep the indoor units running at low fan speeds, or set the compressor current limit to a percent of full capacity. The second manufacturer limits electric current on the condenser manually via a button on the outdoor unit. The current limiting function is primarily used for noise reduction. The third manufacturer sells an optional circuit board which enables capacity limiting of the outdoor unit, also for sound attenuation in noise-sensitive areas. The capacity limiting function can be externally triggered using contact closures for three steps including full capacity.

The last manufacturer can limit demand through a contact closure at the outdoor unit. They can also set custom demand limiting preferences to any level via custom programming of their EMCS product.

ZONE DIFFERENTIATION

Inherently zone-based systems, all VRF manufacturers have manual zone-differentiated operation. However, two manufacturers are able to issue zone-differentiated commands remotely via the central controller, which is a key capability for ADR (see Table 5). The first manufacturer can group indoor units for rotation and set a different demand limit for each group or zone. The central controller of the second manufacturer can group indoor units together but requires additional custom programming to achieve the desired temperature setback for each zone. Each zone controller will need individual I/O wiring to connect them to the central controller.

The number of addressable zones depends on the controller and may consist of 16 to 128 indoor units.

TABLE 5. SUMMARY OF ZONE DIFFERENTIATION CAPABILITIES OF VRFS STUDIED

	Controller Level			Control Method			
	Central Controller	Zone Controller	Own EMCS	Built-In Program	Custom Program	Contact Closure	Manual
Number of Manufacturers	2	2	3	0	5	1	N/A

Three other manufacturers can program a different command for different zones when the system is connected to their own EMCS. The first manufacturer can control individual zone temperature setbacks. The EMCS can combine zones into groups and assign different levels of priority for setback or other commands, which is useful for demand response. The second manufacturer can also custom program groups of indoor units to designate priority of response by zone when connected to their own EMCS. Facility personnel can also opt out individual zones from participation, which is also useful for demand response. The third manufacturer can differentiate control preferences by zone using their own EMCS, if each indoor unit is also wired individually.

Two manufacturers can differentiate comfort preferences by zone through individual wiring of the zone controller. The first manufacturer's VRF product will differentiate temperatures by zone if the local controllers were grouped and wired to each zone. The second manufacturer can group different fan coil units, in which each group is given a different temperature setpoint response.

SNAP BACK CONTROL

Snapback control is an important function for demand response, particularly for HVAC systems. When cooling or heating service is reduced during a demand response event, the indoor space will warm up or cool down, respectively. When the event concludes, HVAC systems move to the pre-event setpoint aggressively. If not managed, this sudden power draw or "snapback" can create a new demand peak. Controlling compressors and fan operation in a coordinated manner after a demand response event can help buildings avoid setting a new peak demand.

Four manufacturers reported that they have functions related to snapback control, while other manufacturers did not confirm if they offer this functionality. They reported that their inverter-controlled compressors can have a soft ramp up which will reduce "snapback" after a demand response event. Inherent in the controls are "snapback" limiting functions to prevent the system from drawing full power immediately after a setpoint change. This feature is understood to be a gradual ramp up in load when setback commands are released. However, it is currently unknown if the ramp up period is of sufficient duration to prevent the 15-minute average kW reading from causing excessive demand charges following a DR event.

READING POWER FROM METER

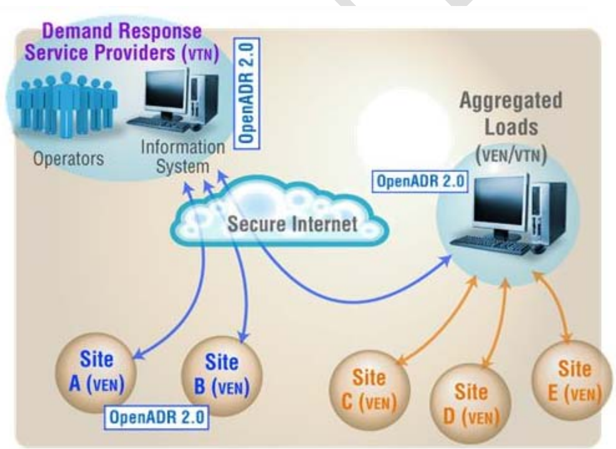
The ability to read the instantaneous power from a building meter is a useful function for demand response. This will allow feedback to the VRF system to adjust controls as needed to meet a desired load reduction target. Three manufacturers offer optional software products for their VRF controllers to receive power readings.

EVENT SIGNALING

In manual DR, customers are notified of an impending or ongoing DR event via phone call, email, or text. In ADR, the utility server initiates a DR event notification, which is retrieved by a gateway device at the customer site. It is important to note that that the communication signal between the utility server and the customer gateway is simply an announcement of a pending or active DR event. It is not a command to turn off equipment at customer sites. This section discusses the signal pathway and protocol used for ADR-enabled equipment in SCE's ADR program, and describes how VRF equipment might also receive the event signal.

OPENADR SIGNALING OF DR EVENTS IN CALIFORNIA UTILITY PROGRAMS

Figure 2 shows a schematic of the typical ADR communications pathway. The normal structure involves a "virtual top node" (VTN) which is a central computer server or other device that sends ADR information to local devices called "virtual end nodes" (VENs) at the customer site. Information is sent via a standardized communications protocol called OpenADR. In California, the utility's VTN is also referred to as the Demand Response Automation Server (DRAS). The DRAS manages DR event scheduling, notification, and tracking. A VEN is typically a "client" and is any device that can accept the OpenADR signal from the VTN. Examples of VENs include a building EMCS, connected thermostats, and dedicated gateway devices. In California, to be eligible for utility technology incentives via the ADR Program, both VTNs and VENs must be certified by the OpenADR Alliance and must operate using the OpenADR 2.0 framework.



Source: OpenADR Alliance

FIGURE 2. OPENADR COMMUNICATIONS SCHEMATIC

VENs communicate with the DRAS by "polling" the server through outgoing network ports. Each VEN is programmed to contact the DRAS (or VTN) on a regular basis. In the interest of cyber-security (as the VENs are generally located within a facility's Internet "firewall"), no incoming communications are allowed for the VEN. Once the VTN has identified the VEN, the VEN is then able to retrieve ADR information from the VTN (assuming that there is information waiting to be transferred). If there is no information to be transferred, the communication link is ended, and the VEN waits to poll the VTN at the next time interval (which is usually one minute).

Once a VEN has acquired a positive ADR signal from the VTN, and depending upon the sophistication of the implementation, the VEN may communicate DR event to a separate control system – in this case, possibly the VRF central controller. For cyber-security, at a minimum, a contact closure or another signal can be triggered to indicate the presence of the DR event. In this case, no information is transferred between the VEN and the control system. More complex implementations can allow for software communication between the VEN and the control system. Customers have full control over how the building energy systems respond to the request to shed load for the DR event. The only stipulation is that equipment is pre-programmed to auto-execute load shed strategies upon receipt of the ADR event signal.

OPENADR COMMUNICATIONS FOR VRF SYSTEMS

Currently, there is no standard integrated VEN solution among VRF manufacturers. Manufacturers feel that market demand for these solutions has not yet reached an economically actionable level. Ideally, VRF central controllers will be capable of receiving DR event notifications directly, via OpenADR communication. However, this option is not commercially available. Interviews with manufacturers indicated that some form of external input to VRF controls will be required. This input will be provided either by a building EMCS or custom integration of a standalone VEN, if there is no EMCS system at a facility.

OPTIONS FOR ADR EXECUTION

The proprietary communications network between the distributed control components is both a strength and a limitation for this technology. Built-in commands allow for very sophisticated coordination over this network. Because of their focus on comfort and energy efficiency, the VRF system is optimized for system energy performance. VRF manufacturers have not focused their development on event-driven ADR, and commands for these features are not always available.

In Japan, where VRF manufacturers are predominantly based and systems widely installed, utilities may negotiate demand caps with their customers. The customer agrees to limit their facility peak demand to a maximum MW value. Exceeding that limit will incur penalties such as a rate increase for the following year. Thus, VRF equipment from Japan will typically have hardware settings to limit compressor load. Even though the capability exists in the equipment, the controllers are not necessarily able to execute them seamlessly nor automatically.

For example, VRF local zone controllers may be able to perform a temperature setback of their cooling or heating setpoint. But for some manufacturers, these adjustments were intended to be controlled by occupancy sensors and are triggered by a contact closure on the zonal controller. In these systems, the VRF central controller may not be able to command a zonal setback over the system network. Given these current limitations, VRF systems require different strategies to potentially implement ADR. Some possible approaches are described below.

IMPLEMENTING ADR USING AN INTEGRATED CENTRAL CONTROLLER AND VEN

Figure 3 shows a schematic of an ADR solution using a central controller. This is the preferred solution of SCE. The central controller has a built-in OpenADR-certified VEN. It can receive ADR signals from SCE's DRAS and remotely execute a variety of demand reduction strategies for DR. ADR strategies are executed within the system network.

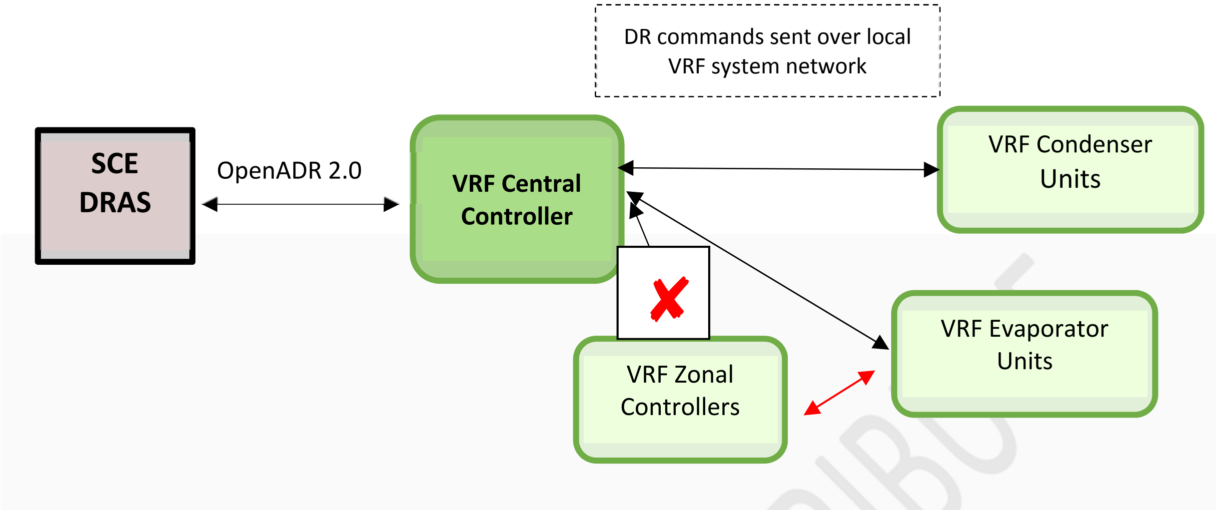


FIGURE 3. ADR IMPLEMENTATION USING AN INTEGRATED CENTRAL CONTROLLER

IMPLEMENTING ADR IN CONJUNCTION WITH A SEPARATE VEN

If the VRF controller is not capable of receiving an OpenADR notification, a separate OpenADR certified VEN must be employed. The DR event status can be communicated from the VEN to the VRF controller through a standard building automation protocol, such as BACnet or LonWorks, or in the simplest case, via a contact closure to a dedicated input on the VRF controller. Figure 4 shows an example schematic of this implementation.

Once the event signal is received, how the DR strategies are implemented will depend on the available DR commands and features offered by the specific VRF manufacturer. If commands to execute a DR-type function exist in the VRF central controller, the control logic that is triggered by the event signal can execute these DR strategies over the standard VRF system network. In the case that DR actions can only be triggered by a contact closure, each individual zone component, and possibly the outdoor units, must be wired via a digital I/O interface to the VRF central controller, or possibly the VEN.

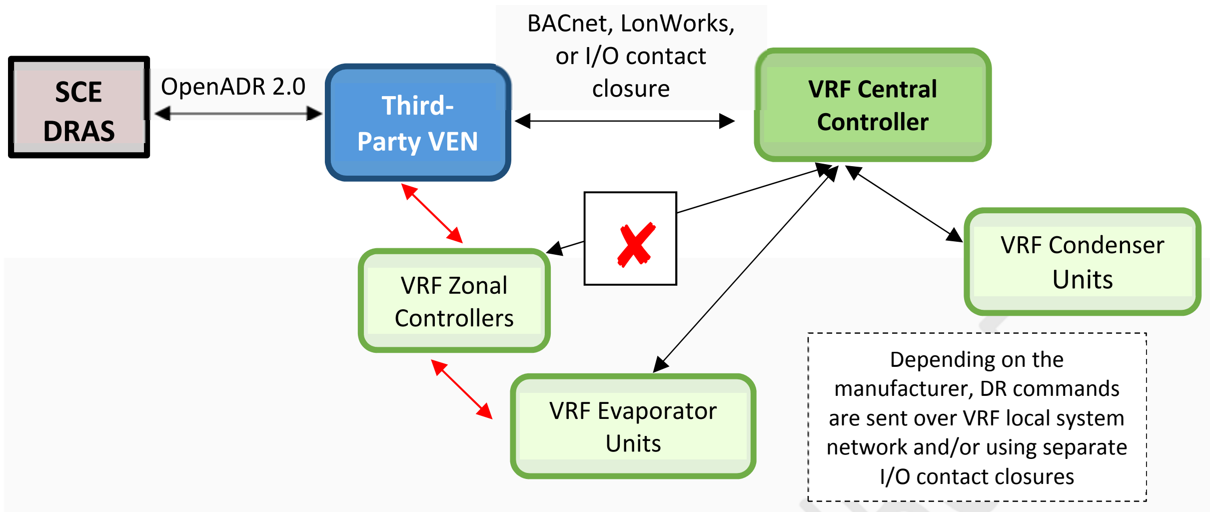


FIGURE 4. ADR IMPLEMENTATION USING THIRD-PARTY VEN

IMPLEMENTING ADR IN CONJUNCTION WITH A BUILDING EMCS

When a VRF system is connected to a building EMCS, the DR control logic can reside in either the VRF controller or in the EMCS. If the EMCS is supplied by the VRF manufacturer, it typically will be able to connect and communicate over the VRF system network, allowing it to potentially command the DR functions directly. Figure 5 shows a schematic of this implementation.

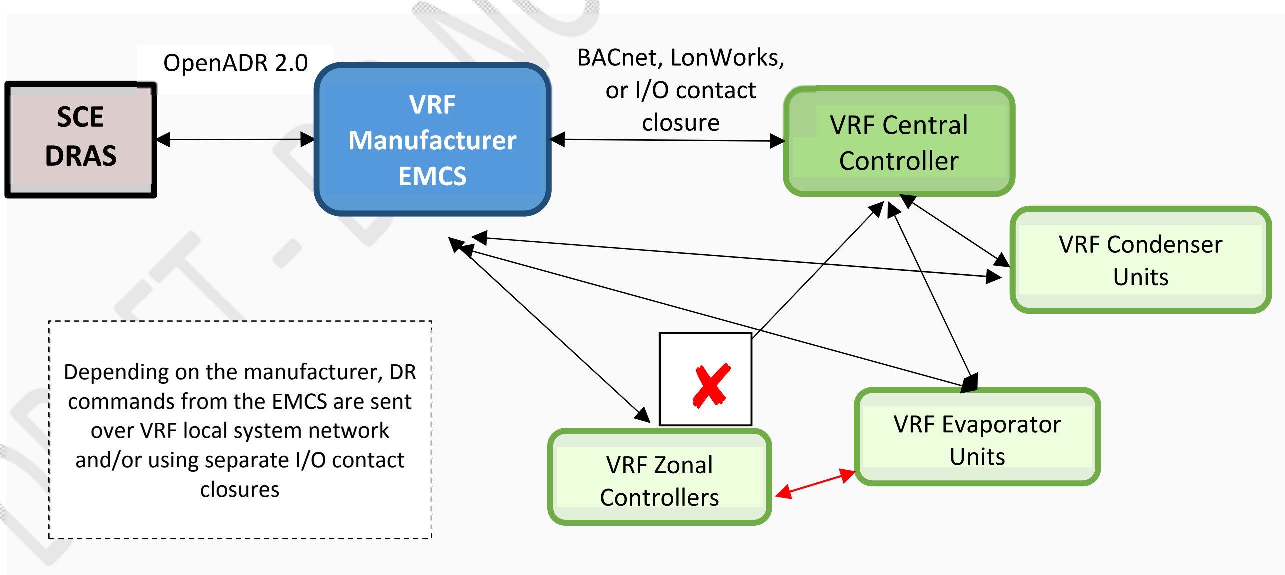


FIGURE 5. ADR IMPLEMENTATION USING VRF MANUFACTURER EMCS

If a VRF system is installed in a facility that uses a building EMCS from a different manufacturer, the implementation is similar to a connection with a VEN. The VRF central controller may be able to receive the notification using BACnet/LonWorks or a dedicated input, but the DR control logic will likely be programmed into the VRF controller and implemented through a combination of built-in commands and wired contact closures at the local VRF components. Figure 6 shows a schematic of this implementation.

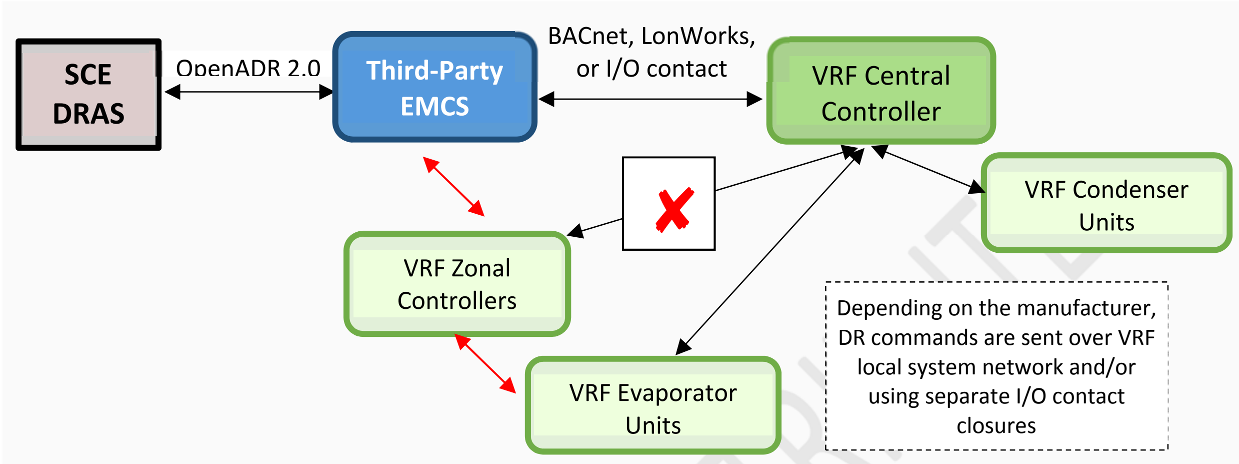


FIGURE 6. ADR IMPLEMENTATION USING THIRD-PARTY EMCS

DISPLAYS AND REPORTING FOR DR OF VRF CONTROLS

VRF manufacturers offer a dizzying variety of controls interfaces to satisfy the diverse needs and desires of their customers. However, none of the available products yet include displays and reports specific to demand response. The diverse options take into account the cost sensitivities of the user and range from the basic, no-frills thermostat all the way up to a multi-building EMCS with 3-D graphical displays of the HVAC system in each floor of each building. Additional details on VRF displays and reporting capabilities are provided in Appendix A: VRF Displays and Reporting Capabilities.

DATA SECURITY

The strongest defense against intentional sabotage of automated digital control systems by unauthorized agents is to be isolated from the Internet. The vast majority of VRF systems are still controlled through the local area network only. Each VRF manufacturer has their own proprietary communication protocols for sending and receiving controls commands to and from central and local system controllers either via wired or wireless signals. Remote monitoring and control through the Internet is available as an option by four manufacturers, while the remaining three manufacturers studied do not offer web-based controls. A few manufacturers allow for restricted access to the local controllers. These features include setpoint lockout, password-required access, and multiple account types with differentiated levels of access.

In cases where the optional web-enabled controls are used, facilities must employ best practices available for ensuring security. In these cases, the responsibility falls to the information technology (IT) management team at the facility to develop and enforce Internet security policies. Where VRFs are multi-zoned systems installed in medium to large facilities, IT expertise is available to implement Internet security. Methods of protecting data and network from sabotage include data encryption, firewalls, passwords and/or other means of authentication, restriction and verification of access to equipment controls.

DATA SECURITY MEASURES FOR OPENADR

OpenADR communicates through the Internet. The OpenADR Alliance instituted additional security requirements with the release of the OpenADR 2.0B protocol. The security requirements were developed in partnership with National Institute of Standards and Technology (NIST) and are based on NIST guidelines for computer security. OpenADR Alliance requirements include unique digital certificates on both the client and server side. This is referred to as *dual-side* authentication, where both the VEN and VTN need to recognize each other as an authentic source. Communication between the VTN and one or more VENs is authenticated via "handshake" or confirmation between trusted roots. In comparison, in a username and password authentication, the VEN always recognizes the VTN as authenticated, but the VTN doesn't authenticate the VEN unless it recognizes its username and password. Thus, dual-side authentication is more secure, particularly when the VEN needs to push information from the facility to a remote VTN via the Internet.[5]

Both the OpenADR server (VTN) and the OpenADR client (VEN) manufacturers need to purchase valid OpenADR-specific certificates to authenticate communication links. Digital certificates are issued by an independent certificate authority, Kyrio. The use of a third-party issuing authority allows the certificates to be tracked so that if the system is compromised the source of the compromise can be traced.

Additional precautions can be taken to isolate the building energy control system from the VEN by using a dedicated DSL connection separate from the building network to connect the VEN. Furthermore, the VEN can be programmed just to close a dry contact (without exchanging any software communication with the system) when an OpenADR event notification is received. The building EMCS interprets the closing of the dry contact to mean that a demand response event is starting and initiates the pre-programmed demand response actions via the local area network.

[5] This dual-side security feature is currently not fully utilized, as VENs in California's ADR Programs are currently not required to push any information to SCE.

ASSESSMENT OF VRF TECHNOLOGIES AND ENERGY CODE COMPLIANCE

This section introduces the demand response requirements in California's Title 24 Building Energy Code and in ASHRAE 189.1-2014, which contains voluntary design guidelines for green buildings. The Team compared the controls capabilities reported by VRF manufacturers during the interviews to the building code requirements for demand response. Title 24 DR requirements do not explicitly mention VRFs. The DR definitions were reviewed to analyze whether and how VRFs are subject to the DR requirements in the code. Additional analysis and discussion with respect to compliance with zone thermostat requirements in Title 24 are also provided in this section.

TITLE 24, PART 6 REQUIREMENTS FOR DEMAND RESPONSE

The current 2013 Title 24, Part 6 Building Energy Code for the State of California has DR requirements for lighting, large display signs, and HVAC equipment.[6] For HVAC equipment, the code describes DR requirements for two types of measures. First, DR-capable controls are required for HVAC systems in nonresidential buildings with direct digital control (DDC)[7] down to the zone level. This is applicable mostly to buildings with centralized Energy Management Control Systems, also referred to as EMCS. DR requirements for these systems fall under the Automated Demand Shed Control (ADSC) measure. HVAC systems exempted from ADSC measure requirements are subject to the Occupant Controlled Smart Thermostats (OCST) measure requirements.

DEMAND RESPONSE DEFINITIONS

The definitions related to DR were expanded and clarified in the 2013 Title 24 cycle. The Team believes that over time, these updates reflect a perceived evolution of the concept of DR, and they reduce ambiguity and possible misinterpretation of the code.

TABLE 6. 2013 TITLE 24 DEFINITIONS RELATED TO DEMAND RESPONSE

	DEFINITION
Demand Response	Short-term changes in electricity usage by end-use customers, from their normal consumption patterns. Demand response may be in response to: a) changes in the price of electricity; or b) participation in programs or services designed to modify electricity use in response to wholesale market prices, or when system reliability is jeopardized.
Demand Response Period	A period of time during which electricity loads are modified in response to a demand response signal.

[6] The 2016 Title 24 Code will be effective July 1, 2017. It is expected that the DR requirements will be clarified but not change in level of stringency.

[7] Direct digital control systems consist of networked microprocessor-based controllers connected to analog and digital devices, which sense information and control components of a building's energy-using equipment.

Demand Response Signal	A signal sent by the local utility, Independent System Operator (ISO), or designated curtailment service provider or aggregator to a customer, indicating a price or a request to modify electricity consumption for a limited time period.
Demand Responsive Control	A kind of control that is capable of receiving and automatically responding to a demand response signal.
Direct Digital Control (DDC)	A type of control where controlled and monitored analog or binary data, such as temperature and contact closures, are converted to digital format for manipulation and calculations by a digital computer or microprocessor, then converted back to analog or binary form to control mechanical devices.
Energy Management Control System (EMCS)	A computerized control system designed to regulate the energy consumption of a building by controlling the operation of energy consuming systems, such as the heating, ventilation and air conditioning (HVAC), lighting, and water heating systems, and is capable of monitoring environmental and system loads, and adjusting HVAC operations in order to optimize energy usage and respond to demand response signals.

OCST Measure Requirements

The OCST measure (110.2c and Appendix JA5) requires that new construction of nonresidential buildings with unitary, single-zone air conditioners (AC) or heat pumps (HP), or furnace fans be equipped with OCSTs. The specifications for this measure are detailed in Title 24's Appendix JA5. Title 24 requires OCSTs to have the ability to receive a DR event signal and the ability to adjust temperatures by +/- 4°F. OCSTs must also have override, reset, and programmable modes for setpoints, with capability for specific responses to price and DR periods. Additionally, the display interface must indicate connection status, DR period/price event progress, current temperature reading, and current setpoint. As mentioned in the introduction to this section, the OCST measure is a mandatory measure for the nonresidential sector and applicable to buildings exempted from the ADSC measure.

In this report, VRFs are characterized as multi-zone HVAC systems with DDC to the zone level. The components that comprise the VRF system – indoor units, outdoor units, zone controllers, and central controllers - are individually intelligent with microprocessor controls that are networked together using proprietary digital communication protocols to coordinate their operations or be commanded from the central controller. For some of the smaller VRF installations, a central controller may not be required. (Because VRFs are inherently multi-zone systems, the Team concluded that the Title 24 OCST requirements for single zone HVAC do not apply to VRFs.)

ADSC Measure Requirements

The VRF system control characteristics reviewed match the description of ADSC measures in Table 7. (The Team therefore concludes that VRFs are required to comply with the ADSC measure of the Title 24 code.) The ADSC measure requires that nonresidential, new construction facilities with DDC to the zone level can control temperature setpoints from a centralized contact or software point within an EMCS. Additionally, the EMCS must be capable of automatically responding to a demand response or price event signal (see Appendix C: Code Requirements for Automatic HVAC Demand Shed Controls for code language).

The basic DR strategy outlined in the code is to be capable of resetting temperature setpoints in non-critical zones by +/- 4°F or more during a demand response event. Critical zones include any zone that serves a process where the reset of the zone temperature setpoint during a demand shed event might disrupt the process. This includes, but is not limited to data centers, telecommunications, laboratories and private branch exchange rooms. It should be noted that the definition of critical zone is loose and can be interpreted differently. For example, a retail owner can assert that all zones where customers are present are “critical” and thus exempt from the code.

The EMCS must also be capable of providing an adjustable rate of change for temperature setup and reset, a disabled mode, manual control, and automated shed control (global control from a single point) functions. These functions are defined as follows:

- **Disabled:** Disabled by authorized facility operators;
- **Manual control:** Manual control by authorized facility operators to allow adjustment of heating and cooling setpoints globally from a single point in the EMCS; and
- **Automatic demand shed control:** Upon receipt of a demand response signal, the space-conditioning systems shall conduct a centralized demand shed, for non-critical zones during the demand response period.

Minimal acceptance testing is specified by the code. Simple activation of the centralized demand shed control and verification of a 4°F minimum change in setpoint during and after control shed engagement is required. This measure does not mandate participation in a DR program or the need to respond to price signals; it exclusively specifies the system’s capability to respond to a demand response or price event signal. The measure also does not specify how the signal is received or how the signal is processed by the EMCS.

TABLE 7. ADSC MEASURE REQUIREMENTS SUMMARY

	2013 TITLE 24 REQUIREMENTS
Scope	Applicable to buildings with direct digital control to zone level (90% of nonresidential new construction)
	Requires capability, does not mandate participation
Description	Capable of remotely controlling temperature setpoints via centralized contact or software point within an EMCS
	Change setpoint +/- 4°F in non-critical zones;[1] reset setpoints
	EMCS needs to provide an adjustable rate of change for temperature setup/reset

	Include Disabled mode, Manual Control, and ADR Control (globally from a single point) functions
Triggers	All new construction projects in California must conform to these requirements
	Alterations:[2] all altered equipment must comply with code
	Additions:[3] requirements are applicable to new systems, however pre-existing systems that are part of an expansion are exempted
	Relocations:[4] does not need to comply with code when existing equipment is moved within a building
Acceptance Testing	Does not require testing of receipt of/response to a DR signal
	Only specifies verification of global demand shed activation, change in setpoint of non-critical spaces, return to setpoint in non-critical spaces, maintenance of setpoints in critical spaces
Exemptions	Systems serving loads that must have constant temperatures (e.g., hospital patient rooms, museums, certain manufacturer facilities)

[1] Non-critical zones are those that do not serve a process where the reset of the zone temperature setpoint during a demand shed event might disrupt the process, including but not limited to data centers, telecom, laboratories, and private bank exchange rooms.
[2] Alterations include any change to a building's water-heating system, space-conditioning system, lighting system, or envelope that is not an addition.
[3] Additions include newly installed space-conditioning systems or water-heating systems. If the additions are provided by expanding an existing system, the existing system does not need to comply.
[4] Relocations include moving existing equipment within the same building or to a new building.

This measure is largely applicable to new construction in the nonresidential space. A survey from a 2006 Title 24 Codes and Standards Enhancement (CASE) Report on the DDC to zone measure indicated that roughly 90 percent to 95 percent of the new construction market utilizes systems with DDC to the zone level. Within the retrofit market, this measure is applicable to new additions or alterations where the existing HVAC equipment is modified or replaced. Relocation of existing equipment within the building does not need to comply. Exemptions include buildings or spaces that require constant temperature control to prevent degradation of materials or to protect the safety of the environment, such as hospital patient rooms, some manufacturing processes locations, and some museums.

REQUIREMENTS FOR ZONAL THERMOSTATS

For zonal thermostats used with EMCS in nonresidential buildings, section 120.2b of Title 24 requires that thermostats controlling comfort cooling must be capable of being set either locally or remotely to up 85°F or higher. Thermostats controlling comfort heating must be capable of being set either locally or remotely down to 55°F or lower. Furthermore, unless the HVAC system requires a manual changeover from heating to cooling modes, the thermostat must provide a temperature deadband of at least 5°F between the cooling and heating setpoints.

ASHRAE REQUIREMENTS FOR DEMAND RESPONSE

Demand response language from ASHRAE was first introduced in 2014 with Standard 189.1-2014. ASHRAE 189.1-2014 is intended for buildings that wish to go beyond ASHRAE Standard 90.1, which provides minimum requirements for the energy-efficient design of new and renovated or retrofitted buildings. ASHRAE 189.1-2014 provides design guidelines for high-performance green buildings, except low-rise residential buildings.

The complete requirements for demand response are included in section 7.4.5.1 of ASHRAE 189.1-2014 as follows:

> "*7.4.5.1 Peak Load Reduction. Building projects shall contain automatic systems, such as demand limiting or load shifting, that are capable of reducing electric peak demand of the building by not less than 10% of the projected peak demand. Standby power generation shall not be used to achieve the reduction in peak demand.*
>
> > *Exception: Building projects complying with the Alternate Renewables Approach in Section 7.4.1.1.2 and containing automatic systems, such as demand limiting or load shifting, that are capable of reducing electric peak demand by not less than 5% of the projected peak demand."*

Thus, the requirements in ASHRAE 189.1-2014 are much less specific than those in Title 24. It does not specify DR strategies such as temperature reset or lighting dimming. However, it requires that facilities have automated controls that can be programmed with a variety of strategies to reduce facility demand by at least 10 percent relative to projected peak demand. It also acknowledges that facilities with onsite renewables have reduced load shed potential, and thus requires a 5 percent reduction using automated systems for demand response for these facilities.

The language does not clarify whether reducing the building peak demand refers to its annual peak or the peak demand on a demand response event day triggered by the utility. However, the term "projected peak demand" implies building a counterfactual baseline against which the actual load reduction will be evaluated. This contrasts with the annual or monthly peak demand of a building that will be read directly from a meter. Therefore, it is assumed that the 10 and 5 percent reduction requirements refer to demand response event day performance.

ENERGY CODE COMPLIANCE DISCUSSION

Table 8 summarizes available controls options of major VRF systems compared to code requirements for demand response and zone thermostats.

ASHRAE 189.1 COMPLIANCE

With respect to ASHRAE 189.1-2014 compliance in section 7.4.5.1, VRF controls can only influence the HVAC energy use of a facility. To the extent that cooling and heating make up more than 10 percent of a building's peak demand, it may be possible to comply with the requirements in section 7.4.5.1. Otherwise, VRF systems can contribute to the overall 10 percent demand response goal of a building. Section 7.4.5.1 presumes that one or more strategies are employed between one or more energy consuming systems in a building to achieve the minimum demand reduction. Five percent is typically the minimum amount of demand responsive reduction that can be confirmed using whole building meter data. Below 5 percent, it is difficult to distinguish between the intentional reduction resulting from demand response actions versus natural operational variations among all energy consuming equipment in a building.

Title 24 Compliance

The remaining discussion in this section focuses on Title 24 requirements. We consider first the DR requirements of Title 24, then the zonal thermostat requirements.

Automated Demand Shed Control

In , ADSC refers to the capability to a) receive a demand response signal from “either a centralized contact or software point within an EMCS” and b) remotely reset the operating cooling temperature setpoints by 4°F or more in all non-critical zones. (See ADSC Measure Requirements.) Where manufacturers do not have ADSC capability, the manual disable function required by Title 24 does not apply. The Team considered two parts of ADSC.

For the first part of the ADSC requirement, the Team asked whether the VRF systems of each manufacturer have the capability to receive a demand response signal, either from a centralized contact or software point within an EMCS. Only one manufacturer has a commercially available ADSC solution that uses a software VEN added to their own EMCS. The Team is aware of only one pilot installation of this solution. Given the very limited application, the Team gave a score of “(Yes)” for this solution in Table 8. The remaining manufacturers do not have commercially available VEN solutions for their VRF systems available.

For the second part of the ADSC requirement, the Team asked which VRF systems have the capability to remotely reset temperature setpoints, differentiated by zone, from the central controller. Two manufacturers reported that they had this capability built-in. The rest stated that the zone thermostats needed to be individually wired or have additional I/O hardware interfaces to be able to receive differentiated setback commands. Whether the central controllers can control the temperatures by zone after the additional wiring and programming is completed is unclear. For these systems, connecting them to a building EMCS will not overcome the issue. As noted in the Communications section, the level of VRF control available to an EMCS is somewhat limited and more complex operations must be handled by the VRF system’s internal controls.

Table 8. Number of VRF Manufacturers Meeting Title 24 DR and Zonal Thermostat Requirements

Title 24 Demand Response Requirements

Manual disable (opt out of DR)		1	6	
Automated Demand Shed Control (ADSC)		1	6	
Remote temperature reset by 4 °F in non-critical zones	3		3	1

Remotely revert to original thermostat setting	3		3	1
Adjustable rate of temperature change	2		4	1
Manual global temperature adjustment	5		1	1
TITLE 24 ZONAL THERMOSTAT REQUIREMENTS				
Manually adjust zone heating temperature < 55°F	3		3	1
Manually adjust zone cooling temperature > 85°F	6			1
5°F deadband between cooling and heating setpoints	3	4		
4 or more programs within 24-hour period	7			
ASHRAE 189.1 REQUIREMENTS				
Reduce building peak by 10 percent or more	VRF demand reduction affects HVAC end use only. Load shed strategies will contribute to total reduction of building's peak demand.			

ADDITIONAL REQUIREMENTS FOR ZONAL THERMOSTATS

In reviewing the zone thermostat requirements in Title 24, the systems marked as "(Yes)" in parentheses for the 5°F deadband requirement in Table 8 indicates those VRF systems that do not offer the capability but meet the intent of Title 24. The goal of the minimum 5°F deadband requirement for zonal thermostats is to save energy by avoiding simultaneous heating and cooling within one zone. When temperatures are inside the deadband, the code requires that units are either shut off or reduced to a minimum. This language was written for traditional, single-speed, unitary rooftop and ducted air systems that only turn on or off to provide cooling or heating. For those VRF manufacturers that do not provide 5°F deadband capabilities in their thermostats, their variable speed compressors allow for reducing operation to a minimum. VRFs are designed to run efficiently at a low power using variable speed drives within the deadband, rather than frequent on and off cycling that shortens equipment life. In standard air conditioning equipment, space temperatures may drift until the setpoint is reached and the compressor kicks on at full power to bring the zone temperatures back into the deadband. Based on this reasoning, the Team asserts that all VRF manufacturers meet the deadband requirement in Title 24.

For zonal thermostat requirements only, three manufacturers currently meet all of the requirements. Three other manufacturers meet four out of five zonal thermostat requirements, and one manufacturer did not reply to confirm if they meet all the requirements.

In summary, no VRF manufacturer currently meets all the ADSC and zonal thermostat requirements of Title 24. Discussions with VRF manufacturers indicated relative unfamiliarity with the specifics of both Title 24 and ASHRAE 189.1 requirements related to DR. However, all manufacturers expressed interest in developing the technology to meet all the requirements. Three manufacturers inquired about participating in the 2019 Title 24 code development process.

DISCUSSION: OVERALL MARKET CHARACTERIZATION

In reviewing the current market offerings for VRF ADR implementation, it is also important to compare these features to the potential requirements of current and future DR programs. These program requirements should be based on the expected needs for load shed and should also consider any DR advantages offered by the VRF technology. By performing this “gap analysis” between what is desired by the programs and what is offered by the market, it is possible to make to an assessment of program readiness or the level of effort needed to bring the market to program readiness.

The following sections outline the recommended requirements for equipment eligibility to participate in ADR and then examine the readiness of the market to provide these features. Final requirements for ADR are not defined, but the list provides an indication of features considered desirable for participating equipment.

OPENADR 2.0 CERTIFICATION STATUS

OpenADR 2.0 is the current protocol used by California IOUs including SCE to signal DR events. Ability to receive an OpenADR 2.0 signal is the main requirement for automated participation in a DR event. There are three options for VRF equipment to comply with this requirement.

- **Option 1:** Central controller with an internal VEN
- **Option 2:** Connecting the VRF central controller to a third-party VEN
- **Option 3:** Connecting the VRF central controller to own or third-party EMCS

Options 2 and 3 will likely require an additional BACnet/LonWorks interface for communication between the VEN/EMCS and the VRF central controller. (See Event Signaling section.) The BACnet/LonWorks command set used by these systems should include those needed to signal an event and execute DR strategies like those listed below.

MARKET STATUS

At the time of this report, none of the VRF manufacturers had a central controller with an internal VEN capable of communicating via the OpenADR protocol. In order to receive an ADR event notification, all manufacturers will need to implement option 2 or 3.

All manufacturers can use a third-party VEN outfitted with a standard building automation network protocol such as BACnet or LonWorks (option 2), but additional development labor will be needed to create a working solution. All VRF manufacturers offer optional interfaces for BACnet and LonWorks which will enable the central controller to communicate and receive a DR event trigger from the VEN.

The central controller will also need to command the DR load shed strategies to the VRF indoor and outdoor units. This requirement is discussed in a later section.

One manufacturer can use their own EMCS to communicate using the OpenADR protocol, but they have not yet certified their solution with the OpenADR Alliance. Two other manufacturers have their own EMCS but do not yet have integrated OpenADR capability. These latter EMCS may program DR commands to their respective VRF systems, but they still require a third-party VEN to receive the ADR event signals.

BUILT-IN DR COMMANDS AND INTEGRATION INTO VRF SYSTEM NETWORK

The VRF central controller should have built-in commands for the proposed DR strategies to allow the customer/installer to easily program a sequence of actions in response to an ADR event signal. The minimum command set should include both the code mandated DR actions as well as those recommended in this section. Furthermore, these commands should be executable through the standard VRF system network that ties all the VRF hardware together. For the broadest applicability, the DR functions should not be programmed and executed in an EMCS and communicated over a third-party communication network such as BACnet or LonWorks. Nor should these commands be triggered via external contact closures that require additional wiring and I/O interface hardware in excess of the VRF system's standard network.

MARKET STATUS

The tables below show each manufacturer's readiness to provide built-in commands and communications for these DR functions, from the central controller:

TABLE 9.

	BUILT-IN COMMAND	OVER SYSTEM NETWORK	CENTRAL CONTROLLER ADJUSTMENT
Number of VRF Manufacturers	4	4	The central controller can command the setting and resetting of at least 4°F of setback for both cooling and heating setpoints at individual zones:
Number of VRF Manufacturers	2	3 (WITH CUSTOM PROGRAMMING)	The central controller can adjust the rate of change for both cooling and heating setpoints at individual zones
Number of VRF Manufacturers	N/A	1 (WITH CUSTOM PROGRAMMING)	DR event actions can be overridden through the central controller by authorized facility operators
Number of VRF Manufacturers	1	3 (WITH CUSTOM PROGRAMMING)	The central controller can command different levels of compressor limits (demand cap) at the outdoor unit
Number of VRF Manufacturers	1	4 (WITH CUSTOM PROGRAMMING)	The central controller can group zones by priority and provide tiered responses based on shed requirements

MANUFACTURER OUTLOOK ON ADR

Despite having DR-related control functions and an interest in supporting ADR, most VRF manufacturers had a wait-and-see attitude on making their VRF solutions fully ADR-capable. Some thought that because VRFs were more efficient, the benefits of DR will be diminished for customers. Many felt that they needed to see clear market signals from their customers and/or the IOUs requesting ADR features in order to add functions beyond those required by code. Adding these capabilities can take a year or more and the manufacturers will need to justify the cost of development with confidence in market sales.

One manufacturer reported that their main goal is to provide value for their customers. They are interested in how SCE incentives can improve the financial case for VRF sales and want to comply with state code requirements. Two other manufacturers indicated support for more residential applications of ADR and low-cost solutions for small and medium customers. One manufacturer felt that industrial customers are more likely to participate in DR, commenting that industrial customers are more technically savvy and attuned to the costs of energy. Commercial customers, in their view, have less technical acumen and the building owner may not be paying the utility bill so there is less incentive to track energy and demand charges. The remaining companies did not express any current plans to add OpenADR connectivity directly into their VRF equipment, at least not until they felt stronger market demand or program need for such features.

EXISTING VRF ADR INSTALLATIONS OR OTHER DR EXPERIENCE

There are very few VRF ADR installations in California, and none were reported in the rest of the country. Two VRF systems with ADR were tested in California; one at an office building in Mission Viejo and another at a graduate housing complex in UCLA. The Mission Viejo installation was part of a demonstration sponsored by SCE and EPRI in 2014. The UCLA study was detailed in a report prepared for the California Energy Commission (Prabhu, Trinkande, Sheik, and Gadh, 2015). The VEN developed for the study was custom-built by the researchers. The VEN used BACnet to command the different DR actions including:

- reducing the compressor speed,
- turning zones on/off in sequence,
- turning off zones selectively, and
- sequential startup of outdoor units to reduce power spikes after a DR event.

The system implemented these tests successfully in response to simulated DR events, however the campus network did not allow the researchers to measure the actual curtailment.

While VRFs are eligible for SCE, PG&E, and SDG&E's ADR incentive programs, there have been no projects installed to date. SCE's 2014-2016 SCE Upstream HVAC with ADR Pilot also offered incentives for VRF installations and increased the awareness of OpenADR requirements among HVAC manufacturers and distributors. Nevertheless, no VRF projects were completed before the pilot ended.

OVERALL READINESS SUMMARY

At this time, VRF systems are capable of participating in ADR programs. However, the solutions are not integrated and may require extra VEN hardware, custom programming, and/or I/O wiring in addition to the standard VRF communications network. To make ADR participation attractive to VRF customers, VRF manufacturers will need to address these issues.

No VRF manufacturer currently meets all the zonal thermostat and DR requirements of Title 24. Two manufacturers can meet all the Title 24 requirements except for ADSC. For zonal thermostat requirements, less than half or manufacturers meet all the requirements. There are just two pilot installations in California.

More than half of the manufacturers do not offer DR-specific commands in their central controller. These commands include zonal grouping and prioritization, zone temperature adjustment, capacity caps to limit demand, and others. The first two commands, zonal grouping and zone temperature adjustment from a central contact point or EMCS, are mandated by California's Title 24 building code. Manufacturers can add these commands via custom programming, but it is an expensive option especially for small and medium customers. Providing built-in DR commands will eliminate the need for specialized programmers and allow these features to be set up by VRF system installers.

About half of the VRF manufacturers allow potential DR commands to be triggered over their standard VRF communications network. The remaining systems enable and disable a DR response such as temperature setback or compressor limiting via a contact closure at the periphery device (e.g., local controller or the outdoor unit). These require customers to install additional digital I/O interfaces and wire individual contacts to the local controllers or outdoor units at extra cost.

TABLE 10. SUMMARY OF ADR-READINESS, NUMBER OF MANUFACTURERS

	VIA CENTRAL CONTROLLER	WITH OWN EMCS	CUSTOM VIA CONTACT CLOSURE	MANUAL ONLY
Receive OpenADR 2.0 Signals	n/a	1	n/a	n/a
Set and Reset Zone Temperature	2	1	3	1
Adjust Rate of Temperature Change by Zone	2	n/a	n/a	n/a
Demand Limit	3	n/a	3	1
Group Zones	2	3	1	n/a
Built-in DR Commands	0	0	0	0
Allow DR Commands Over System Network	3	n/a	n/a	n/a

All manufacturers currently lack the ability to recognize OpenADR communications sent from a utility's DRAS. One manufacturer has an EMCS that can be custom-configured to recognize OpenADR signals, but this is an expensive option for virtually all but the largest customers. All other manufacturers need to use a third-party VEN to receive OpenADR signals. There will also be costs to enable communications between the VEN and the VRF central controller, and between the VRF central controller and a building EMCS, plus custom programming by the manufacturer to set up DR implementation strategies.

CONCLUSIONS

DR remains a key energy resource in California's portfolio, second in the loading order after energy efficiency. Its importance in the next decade will continue to grow in light of accelerating renewable energy adoption. Electricity produced by millions of solar photovoltaics (PVs) throughout California is already depressing the net load by several thousand megawatts during the midday hours from 10 a.m. to 4 p.m., year-round. DR is a carbon-free, low-cost alternative to gas-fired plants to mitigate the steep ramp up in system demand as solar PV generation declines in the late afternoon to early evening hours.

At first glance, VRFs appear to be ideal solutions for ADR participation. Beyond traditional temperature setback strategies, VRF systems lend themselves to zone grouping, as well as the potential ability to differentiate DR strategies between critical and non-critical zones. As such, VRFs are an eligible measure in SCE's existing ADR Program, although no VRF project applications have been submitted to date. VRFs also have the potential to support SCE's key guiding principles for DR by increasing available DR that can be integrated into CAISO market. Furthermore, their inverter-driven compressors are equivalent to the commercial VFDs identified by LBNL as a cost-competitive DR technology for HVAC (Alstone et al., 2016, p. 7-5)[8]. The zone-based grouping and inverter-driven compressors allow for a great degree of demand flexibility and customization that helps improve the customer experience overall in DR events.

However, VRF technology remains an untapped potential for ADR at this time. Despite having sophisticated controls and a built-in communications network between system components, the current ability of VRF systems to implement ADR is incomplete. Nearly all manufacturers offer compressor demand limiting functionality and zonal temperature setback features, but (with limited exceptions) these functions often reside in the zonal controller or the outdoor condenser unit, and generally cannot be executed via commands from the VRF central controller. Furthermore, no manufacturer can currently receive OpenADR communications at the central controller without being relayed through a third-party VEN, or in some cases, the manufacturer's own EMCS product. If a customer wanted to participate in DR events, the VRF system will need to be custom-modified with additional programming required. This adds complexity and additional cost to implementing a DR solution.

Nevertheless, the VRF manufacturers interviewed for this study were aware of demand response and acknowledge the opportunity for flexible demand management solutions on the electricity grid. To motivate VRF manufacturers, a clear market demand for ADR in VRF must be shown. SCE can help accelerate this process through increased market engagement and programs. Targeted efforts to educate the VRF manufacturers about the Title 24 code requirements for DR will cover the basic functions that need to be built into systems. Beyond code, SCE can further educate VRF manufacturers about requirements for existing California ADR programs, explain DR event participation, clarify technical specifications for DRAS integration, and support OpenADR testing. VRF-specific incentives will also signal the market of interest that will encourage the development of additional capabilities for shedding load, which will make the best use of VRF technology.

[8] In their recently published DR potential study, LBNL identified that commercial HVAC equipment with VFDs can cost competitively provide significant DR services at approximately 3,643 to 3,749 MWh-yr ("Shift") plus 10 to 12 MW-yr of load following and regulation grid services ("Shimmy").

RECOMMENDATIONS

The recommendations in this section are intended to help SCE with the following:

- Identify VRF manufacturers on the market with products that are capable of shedding load for DR,
- confirm readiness of VRF systems for implementing automated response in California DR programs, and
- identify additional features or control capabilities needed to allow VRFs to implement ADR for DR programs in California.

The Team reviewed seven VRF manufacturers and their available controls solutions. The recommendations are highlighted below and discussed in more detail in the sections that follow:

- Confirm readiness of VRF systems for implementing automated response by verifying VRF manufacturer claims of current DR/ADR capabilities in a lab setting.
- Encourage manufacturers to develop and commercialize ADR-capable controls through the following:
  - Utility engagement and outreach to the manufacturers
  - Education on Title 24 code, which requires minimum built-in control functions to perform ADR
  - Utility technical support for ADR implementation
- Signal market demand for ADR-capable VRFs through the following:
  - Offer manufacturer incentives for built-in default DR strategies in VRF controls
  - Offer incentives for distributors to stock and sell ADR-capable VRF systems
  - Offer higher incentives for advanced HVAC controls in existing California ADR Programs

CONFIRM ADR-READINESS: VERIFY DR/ADR FEATURES IN LAB SETTING

This study documented manufacturer descriptions of VRF controls functions that can be used for demand response implementation. As a next step, the potential ADR capabilities for VRF manufacturers can be validated. The Team recommends verifying control operations as laboratory demonstrations. This entails observing the operation of VRF controls in executing pre-programmed demand reduction sequences and documenting their actual sequence of operations. The Team also recommends conducting end-to-end signal testing on the VRF systems using OpenADR 2.0 communications protocol. The advantages of lab observations are greater environmental control and no disruption for building occupants.

ENCOURAGE MANUFACTURERS: UTILITY ENGAGEMENT AND OUTREACH

Given the wait-and-see attitude of manufacturers, SCE can send stronger and clearer signals to encourage the market. VRF manufacturers stated that if they can see that there is market demand, manufacturers will make it a higher priority to develop ADR-capable controls. Several of the VRF manufacturers are new to the U.S. market. They might prefer to focus on selling their initial products to establish a foothold before developing new capabilities. On the other hand, these new manufacturers may be willing to invest in R&D to test a variety of offerings to gain market share. The more established manufacturers are also open to expanding their product offerings and market share.

SCE staff can engage with VRF manufacturers more frequently and more regularly. One option is scheduled calls at planned intervals, for example every 6 months, to each manufacturer. Especially for those manufacturers new to the U.S. market, additional education is needed on the minimum code requirements. Additional education is needed on the requirements for voluntary DR programs and ADR participation, including OpenADR certification and the SCE DRAS configuration. Even for established manufacturers, the interviews revealed there were many questions relating to existing code requirements, DR Programs and ADR incentives eligibility.

ENCOURAGE MANUFACTURERS: INFORM VRF MANUFACTURERS ON TITLE 24 CODE AND MINIMUM DR REQUIREMENTS

Conversations with the VRF manufacturers indicated a lack of familiarity with the relevant sections in Title 24, though all were open to learning more. A first step in this area will be to help VRF manufacturers comply with the DR requirements in Title 24 building energy code. This can help promote the development of a standard set of built-in DR capabilities from the factory, to enable customers with VRF systems to execute ADR more easily.

As part of SCE outreach to the VRF manufacturers, the Team recommends targeted education campaigns about the relevant aspects of Title 24. Information on the DR requirements in the code should be provided, particularly for the ADSC measure applicable to VRFs. It should also include a discussion about the zonal thermostat requirements and event-based setpoints for DR participation versus schedule-based setpoints for everyday operation.

Once VRF manufacturers meet the Title 24 requirements for DR and zonal thermostats, customers will have access to a standard set of control functions built in from the factory. However, like computers that ship with energy saving functions, user preferences for screen saver and sleep modes need to be set up after purchase. SCE can support efforts to ensure that the available DR capabilities are enabled upon installation onsite, such as through its existing ADR Program.

ENCOURAGE MANUFACTURERS: TECHNICAL SUPPORT FOR ADR IMPLEMENTATION

Once a manufacturer's VEN is OpenADR certified, it should connect to the utility DRAS. In practice, issues can arise in the field during commissioning. OpenADR is a relatively new standard that continues to mature. There is enough flexibility in the standard around areas such as VEN registration or resource targeting that utilities will interpret pieces of the standard slightly differently, and manufacturers may need to configure their VENs to fully integrate with a specific utility's DRAS. Thus, technical support is valuable for manufacturers to clarify SCE technical specifications for DRAS integration and to troubleshoot integration issues during pre-installation and post-installation testing.

SIGNAL MARKET DEMAND: MANUFACTURER INCENTIVES TO DEVELOP ADR-CAPABLE CONTROLS

Beyond code compliance, SCE can incent VRF manufacturers to enhance and further integrate existing control capabilities to be more DR-friendly. These existing capabilities include: demand limiting, cycling or rotating indoor units, improved displays, and reporting of DR events.

One of the strongest and clearest signals that SCE can provide is to offer manufacturers incentives to build demand reduction commands into their systems. A well-known example of this is the super-efficient refrigerator program in the 1990s, also known as SERP or the golden carrot program. It was a collaborative of West Coast utilities including SCE and PG&E, along with the U.S. EPA and the Natural Resources Defense Council that created a competitive bid solicitation for refrigerator manufacturers. It effectively guaranteed increased market share for the winner who designed a super high-efficiency refrigerator, since utilities promised to promote the winner's product in their efficiency programs (Eckert, 1995). The winning plan also had to show that the company could manufacturer the product, distribute it, and track its sales (Consortium for Energy Efficiency, 2015). When 24 additional utilities joined the collaboration, the potential market represented was even more enticing for manufacturers. While Whirlpool won the first contest in 1993, other manufacturers quickly followed with a high-efficiency product to compete in the market. Starting in 1994 manufacturers stated the intention to incorporate some of the efficiency features proposed in the contest as standard features for all models (Feist et al., 1994). It was the first successful market transformation case-study.

While the super-efficient refrigerator golden carrot program was a multi-year, multi-million-dollar effort, it is possible for more modest efforts to influence the market in substantive ways. SCE can encourage voluntary enhancement of these existing DR capabilities by offering manufacturers incentives that promote product innovation around ADR-capable controls. The scale of effort needed can be smaller than a golden carrot program that seeks only to accelerate commercialization of solutions under development. SCE can incent manufacturers to embed or build in ADR-capable controls from the factory. When DR-capable controls are integrated with the equipment from a single manufacturer, it is more likely to operate more reliably and seamlessly than retrofit add-on controls from different manufacturers. Customers can benefit from participating in DR more conveniently.

SIGNAL MARKET DEMAND: DISTRIBUTOR INCENTIVES TO STOCK AND SELL ADR-CAPABLE VRFS

Distributor incentives benefit VRF manufacturers by making equipment more affordable for a larger population of customers. Distributors of VRF equipment were motivated by incentives in SCE's Upstream HVAC with ADR pilot, which accepted applications from 2015 to 2016. The pilot paid distributors $2,000 per project for VRF installations that incorporated ADR-capable solutions, plus a $2,000 per project bonus when the customer enrolled in an eligible DR program. The Team recommends that SCE consider offering the Upstream with ADR pilot again. Since the initial pilot design and infrastructure are already in place, the cost to continue implementation is modest. The lessons learned can be applied while they are still fresh and while distributor interest remains high.

SIGNAL MARKET DEMAND: CUSTOMER ADR PROGRAM INCENTIVES TO INSTALL VRFS AND ENROLL IN A DR PROGRAM

SCE realizes the benefits of DR only when customers participate in DR programs and shed load when requested during events. A main challenge of distributor incentive programs is the reduced interaction between the utility staff and customers. This interaction helps customers enroll in utility DR programs. Distributors have direct relationships with nationally-based or regional customers, but the majority of distributor relationships are with contractors. VRFs are an exception in that manufacturers often interact with customers directly in commissioning VRF systems.

Customer-focused incentive programs, on the other hand, do allow SCE to interact directly with customers to motivate DR program enrollment and active participation in DR events. Similarly, the Team can work with SCE program managers and account representatives to raise awareness about demand response to customers and to educate customers about the benefits of ADR participation.

The current ADR programs at SCE, PG&E, and SDG&E allow eligible customers to install VRF projects, but to date there are almost no VRF projects in these programs. The standard one-time ADR incentive is currently $200 per kW of load reduction with no VRF projects paid in the program. In 2014-2016, when PG&E's ADR program offered incentives of $350 per kW for advanced HVAC technologies, VRF manufacturers reached out to the PG&E ADR Program Team on how to apply. Notably, the advanced HVAC technology incentives were not limited to VRFs. The incentives supported ADR functions for other HVAC technologies, such as add-on retrofit controls for rooftop units, advanced energy management control systems, and connected thermostats.

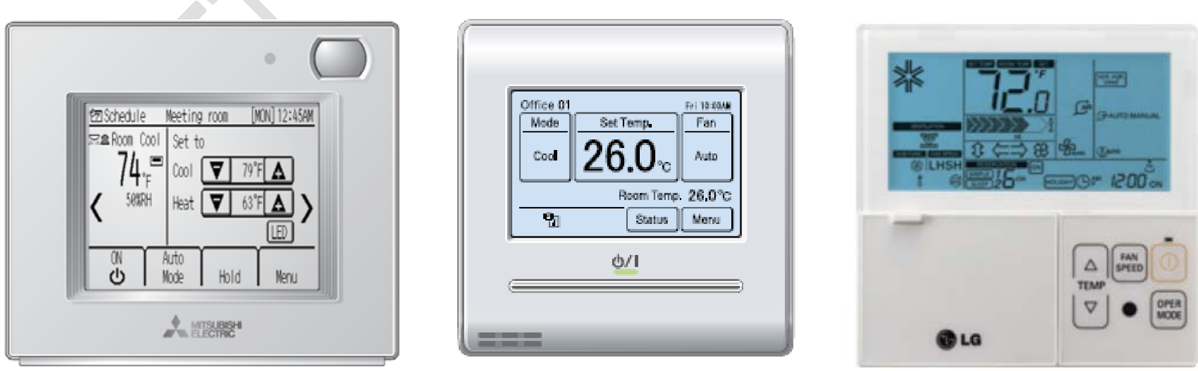
Additionally, SCE has a deemed ADR offering for small and medium facilities up to 499 kW. Upon installation, the incentive of $300 per kW is paid in full upfront. Approximately 80 percent of VRF installations are in facilities below 499 kW. Currently, deemed load shed calculations are available for the retail and office sectors for unitary AC equipment. It is recommended that the SCE ADR Program Team explore the option of including VRFs as part of its deemed offerings.

APPENDIX A: VRF DISPLAYS AND REPORTING CAPABILITIES

This section describes typical display and reporting functions for local zone controllers, central controllers, and system controllers or building EMCS. At the zone level, users affect their desired indoor comfort conditions by modifying set-point temperature, operation mode (on/off), state (cool/heat/fan/dry/auto), and fan speed (high/medium/low/auto) parameters. These commands are carried out locally via the zone controller, which uses a combination of buttons and screen display. The most basic zone controllers consist of push-buttons with a simple black-and-white LCD screen, which may include a back-lit feature for viewing in dim settings. More sophisticated VRF zone controllers replace buttons with a touch screen and color LCD display, alarms or other interactive messages, and include scheduling programs such as time of day, weekday/weekend, and/or vacation/holidays. While basic zone controllers are manual and wired, more sophisticated controllers may be wireless or come with a remote controller.

Source: VRF product catalogs

FIGURE 7. DISPLAY STYLES OF BASIC ZONE CONTROLLERS



Source: VRF product catalogs

FIGURE 8. MORE ADVANCED ZONE CONTROLLER DISPLAYS USING TOUCH SCREENS

Source: VRF product catalogs

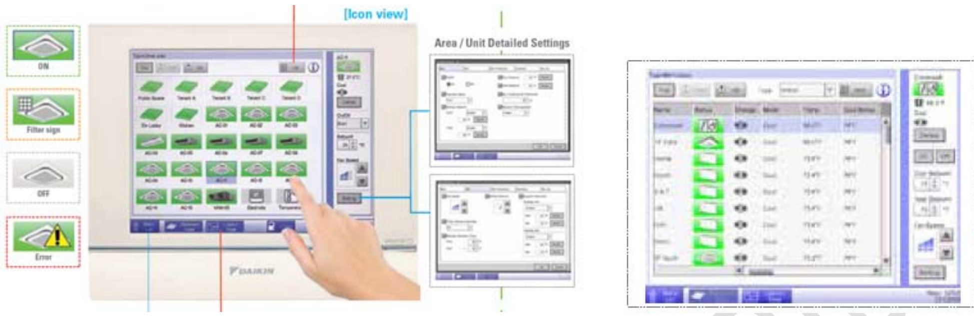
FIGURE 9. REMOTE ZONE CONTROLLERS

Central controllers control multiple zone controllers from a central location. Central controller commands and programs supersede local zone controller commands. Manufacturers offer central controllers for 16, 64, 128, 160, 400 or 512 zone devices. Groups of devices can be created for central control such as: lobby, kitchen, conference, or banquet hall. Manufacturers offer capabilities for 2, 16, 32, or 64 groups. A few manufacturers offer PC-based displays, and most central controllers are color touch screens. Typical displays consist of icons to represent each zone, and the operating mode, setpoint temperature, state, fan speed, and schedules of each zone controller. Typical central displays are shown in through below.

Source: VRF product catalogs

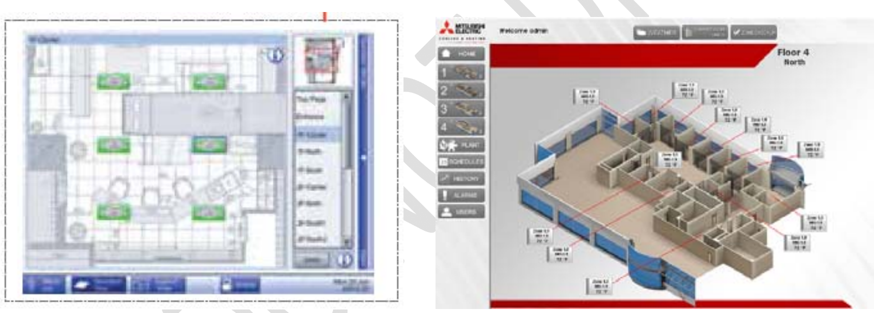
FIGURE 10. CENTRAL CONTROLLER TOUCH PANEL DISPLAYS

System controllers are PC-based and aggregate multiple central controllers across multiple floors of a building. More sophisticated system controllers are essentially energy management control systems, with monitoring and capabilities for zone comfort (heat/cool settings), equipment operation and maintenance status, and equipment component status (compressors, fans, pumps) across multiple building systems (VRF, unit ac, and chiller). Several manufacturers have the additional capability to control lighting systems with their system controllers. Associated display and capabilities are thus relatively powerful and wide ranging as well. Multiple display options are available, starting with standard icon and list views. With the increased quantity of zones under control, spatial visualization becomes valuable for users to track the location and status of hundreds of local devices. System controllers offer 2-D plan layouts of multiple rooms and floor space, while more sophisticated controllers offer 3-D graphical displays.



Source: VRF product brochure

FIGURE 11. EXAMPLE OF SYSTEM CONTROLLER DISPLAYS



Source: VRF product brochures

FIGURE 12. GRAPHICAL DISPLAYS: 2-D PLAN VIEW AND 3-D VISUALIZATION

System controller reporting capabilities are available, although energy-specific monitoring and reporting are limited. No DR displays or reporting capabilities are present in any of the current VRF system controls. Several VRF manufacturers offer kWh indicator functions when combined with power metering options. One manufacturer offers a direct energy management software option that indicates accumulated power consumption and current power demand, when connected with an AC-watt hour transducer or pulse meter. Another manufacturer offers power modules that display and record current and previous day power, with data storage of two days. One manufacturer displays instantaneous kW, 24-hour trends for energy consumption, and onsite generation such as solar.

Moving beyond sophisticated system controllers, several manufacturers offer advanced energy management intelligence and data analytics via cloud-based services. These services were developed independently from VRF systems and marketed to large buildings or portfolios of buildings with tradition rooftop units, chillers, and building energy management control systems. For buildings with VRF systems, they will likely need to interface with a building energy management control system to access the intelligent cloud services. The features and functions of cloud-based services have an energy management focus, such as consumption trends, maintenance tracking, benchmarking and retro-commissioning.

APPENDIX B: VRF SYSTEM COMMUNICATIONS

Communication protocols of VRF units are not published or publicly disclosed by the manufacturers. The Team presumes that each manufacturer maintains its own unique communication protocol within their VRF product's internal control space. Broadly, the physical level of VRF communication as implemented by the various manufacturers consists of a 2-wire cable normally daisy-chained (meaning that the communications cable goes from one unit to the next, and then finally to the last one in the line) from the outdoor unit to the indoor units, creating an internal closed-loop network that is an essential part of a VRF installation. Each indoor unit can be controlled by its own wired control panel, although there are provisions made for the use of wireless (IR) remotes. Centralized controllers can also be used, enabling control of many indoor units from one location.

In general, once a user turns one of the indoors units on (either by its local wired or wireless remote or a central controller), the outdoor unit is initialized and begins compressor operation. The outdoor unit will generally evaluate the outdoor temperature, the indoor unit's operating parameters (mode, temperature setpoint), and will tune the compressor's output to provide the exact volume and pressure required to comply with the indoor requirements.

If a second indoor unit then begins operation, the outdoor unit will notice and recalculate the refrigerant volume necessary to serve all the operating indoor units, increasing the compressor's output to match the level of demand now required as there are two indoor units now operating.

This process is continual, and the outdoor unit matches supply with demand whenever any change in status is noted in the VRF system. As described, the VRF system is fully automatic, and regulates its power consumption based on the demand presented by the indoor units and outdoor air temperature.

APPENDIX C: CODE REQUIREMENTS FOR AUTOMATIC HVAC DEMAND SHED CONTROLS

The following functions are mandated by the 2013 Title 24 Building Energy Efficiency Standards for Residential and Nonresidential Buildings.

DEMAND SHED IN NON-CRITICAL ZONES

Per section 120.2 (h), HVAC systems with DDC to the Zone level shall be programmed to allow centralized demand shed for non-critical zones as follows:

- The controls shall have a capability to remotely setup the operating cooling temperature set points by 4 degrees or more in all non-critical zones on signal from a centralized contact or software point within an Energy Management Control System (EMCS).
- The controls shall have a capability to remotely setdown the operating heating temperature set points by 4 degrees or more in all non-critical zones on signal from a centralized contact or software point within an EMCS.
- The controls shall have capabilities to remotely reset the temperatures in all non-critical zones to original operating levels on signal from a centralized contact or software point within an EMCS.
- The controls shall be programmed to provide an adjustable rate of change for the temperature setup and reset.
- The controls shall have the following features:
  - **Disabled:** Disabled by authorized facility operators; and
  - **Manual control:** Manual control by authorized facility operators to allow adjustment of heating and cooling set points globally from a single point in the EMCS; and
  - **Automatic Demand Shed Control:** Upon receipt of a DR signal, the space-conditioning systems shall conduct a centralized demand shed, as specified in Sections 120.2(h)1 and 120.2(h)2, for non-critical zones during the demand response period.

CRITERIA FOR ZONAL THERMOSTATIC CONTROLS

Per section 120.2 (b), the individual thermostatic controls required by Section 120.2(a) shall meet the following requirements as applicable:

- Where used to control comfort heating, the thermostatic controls shall be capable of being set, locally or remotely, down to 55 °F or lower.
- Where used to control comfort cooling, the thermostatic controls shall be capable of being set, locally or remotely, up to 85°F or higher.
- Where used to control both comfort heating and comfort cooling, the thermostatic controls shall meet Items 1 and 2 and shall be capable of providing a temperature range or deadband of at least 5°F within which the supply of heating and cooling energy to the zone is shut off or reduced to a minimum.

EXCEPTION to Section 120.2(b)3: Systems with thermostats that require manual changeover between heating and cooling modes.

Thermostatic controls for all single zone air conditioners and heat pumps, shall comply with the requirements of Section 110.2(c) and Reference Joint Appendix JA5 or, if equipped with DDC to the Zone level, with the Automatic Demand Shed Controls of Section 120.2(h).

EXCEPTION 1 to Section 120.2(b)4: Systems serving exempt process loads that must have constant temperatures to prevent degradation of materials, a process, plants or animals.

EXCEPTION 2 to Section 120.2(b)4:, Package terminal air conditioners, package terminal heat pumps, room air conditioners, and room air-conditioner heat pumps.

Thermostat Setback

Per section 110.2 (c), All unitary heating or cooling systems not controlled by a central energy management control system (EMCS) shall have a setback thermostat.

Setback Capabilities: All thermostats shall have a clock mechanism that allows the building occupant to Program the temperature setpoints for at least four periods within 24 hours. Thermostats for heat pumps shall meet the requirements of Section 110.2(b).

Combined Peak Load Reduction

Per ASHRAE 189.1-2014 section 7.4.5.1, building projects shall contain automatic systems, such as demand limiting or load shifting, that are capable of reducing electric peak demand of the building by not less than 10 percent of the projected peak demand. (Exception for facilities with onsite renewables, where automated control strategies shall be able to reduce peak demand by not less than 5 percent of projected peak demand)

Requirements for Occupant Controlled Smart Thermostats

Appendix JA5 contains demand response requirements for occupant controlled smart thermostats (OCSTs). Appendix JA1 Glossary and JA5.5 Terminology are listed below:

- CURRENT SETPOINT: The setpoint that existed just prior to the price event or Demand Response Period.
- DEMAND RESPONSE: Short-term changes in electricity usage by end-use customers from their normal consumption patterns. Demand response may be in response to:
    - Change in the price of electricity; or
    - Participation in programs or services designed to modify electricity use:
        - In response to wholesale market prices; or
        - System reliability being jeopardized.
- DEMAND RESPONSE PERIOD: A period of time during which electricity loads are modified in response to a DR signal.

- DEMAND RESPONSE SIGNAL: A signal sent by the local utility, Independent System Operator (ISO), or designated curtailment service provider or aggregator, to a customer, indicating a price or a request to modify electricity consumption, for a limited time period.
- DEMAND RESPONSIVE CONTROL: A kind of control that is capable of receiving and automatically responding to a demand response signal.
- ENERGY MANAGEMENT CONTROL SYSTEM: A computerized control system designed to regulate the energy consumption of a building by controlling the operation of energy consuming systems, such as the heating, ventilation and air conditioning (HVAC), lighting, and water heating systems, and is capable of monitoring environmental and system loads, and adjusting HVAC operations in order to optimize energy usage and respond to demand response signals.
- OVERRIDE: An occupant adjusting thermostat settings to either not respond to a Demand Response Signal or adjusting the setpoint compared to the OCST's programmed response to a price signal or Demand Response Signal.
- PRICE EVENT: A change in pricing sent to the OCST from the utility or the occupant's selected demand response provider.

Per JA5.2.3, OCST communications capabilities shall enable Demand Responsive Control through receipt of Demand Response Signals or price signals. After OCST communication is enabled and the occupant has enrolled in a DR program or subscribed to receive DR or pricing related messages or information updates, the OCST shall be capable of both receiving and responding to Demand Response Signals. The OCST with communications enabled recognizes two basic system event modes: price response and Demand Response Periods. Both basic system event modes can be overridden by the occupant.

Per JA5.2.4, OCSTs shall be capable of receiving and automatically responding to the Demand Response Signals as follows:

- A Demand Response Signal shall trigger the OCST to adjust the thermostat setpoint by either the default number of degrees or the number of degrees established by the occupant.
- When a price signal indicates a price in excess of a price threshold established by the occupant, the OCST shall adjust the thermostat setpoint by either the default number of degrees or the number of degrees established by the occupant.
- In response to price signals or DR signals, the OCST shall default to an event response that initiates setpoint offsets of +4°F for cooling and -4°F for heating relative to the current setpoint.
- The OCST shall have the capability to allow occupants or their representative to modify the default event response with occupant defined event responses for cooling and heating relative to the current setpoint in response to price signals or Demand Response Signals.
- Override Function: Occupants shall be able to change the event responses and thermostat settings or setpoints at any time, including during price events or Demand Response Periods.
- The Demand Response Signal shall start the Demand Response Period either immediately or at a specific start time as specified in the event signal and continue for the Demand Response Period specified in the Demand Response Signal or until the occupant overrides the event setpoint.

- The thermostat's price response shall start either immediately or at a specific start time as specified in the pricing signal and continue for the duration specified in the pricing signal or until the occupant overrides the event setpoint.
- The OCST shall have the capability to allow occupants to define setpoints for cooling and heating in response to price signals or Demand Response signals as an alternative to the default event response.
- At the end of a price event or Demand Response Period, the thermostat setpoint shall be set to the setpoint that is programmed for the point in time that the event ends or to the manually established setpoint that existed just prior to the Demand Response Period.

For more details about the OCST requirements in Appendix JA5, readers can access the full appendix here: http://www.energy.ca.gov/2015publications/CEC-400-2015-038/CEC-400-2015-038-CMF.pdf

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