2023 TECHNICAL UPDATE

Demand Response Control on Integrated Space Conditioning System

Field Test Results of Integrated Variable Refrigerant Flow and Indirect Evaporative Cooling System

DR18SDGE0002 Report

Demand Response Control on Integrated Space Conditioning System

Field Test Results of Integrated Variable Refrigerant Flow and Indirect Evaporative Cooling System

3002028309

EPRI
3420 Hillview Avenue, Palo Alto, California 94304-1338 USA
800.313.3774 ▪ 650.855.2121 ▪ askepri@epri.com ▪ www.epri.com

DISCLAIMER OF WARRANTIES AND LIMITATION OF LIABILITIES

This is an EPRI Technical Update report. A Technical Update report is intended as an informal report of continuing research, a meeting, or a topical study. It is not a final EPRI technical report.

NOTE

For further information about EPRI, call the EPRI Customer Assistance Center at 800.313.3774 or e-mail askepri@epri.com.

Together…Shaping the Future of Energy®

ACKNOWLEDGMENTS

This report was prepared by EPRI.

Principal Investigator
O. Siddiqui

This report describes research conducted by EPRI. EPRI would like to acknowledge the support of San Diego Gas & Electric (SDG&E) and the California Energy Commission (CEC) for sponsoring this work.

This publication is a corporate document that should be cited in the literature in the following manner: *Demand Response Control on Integrated Space Conditioning System: Field Test Results of Integrated Variable Refrigerant Flow and Indirect Evaporative Cooling System.* EPRI, Palo Alto, CA: 2023. 3002028309.

ABSTRACT

As an activity adjunct to the California Energy Commission (CEC) project "Climate Appropriate Innovations for Variable Refrigerant Flow Systems: Integrated Indirect Evaporative Cooling Adaptive Controls and Advanced Refrigerants" (CEC-500-2021-028), EPRI tested the demand response capability of a customized controller regulating a hybrid space conditioning system comprising a variable refrigerant flow (VRF) unit and indirect evaporative cooling (IEC) units. With sponsorship from San Diego Gas & Electric (SDG&E), the tests were conducted May 4-8, 2020, at SDG&E's Energy Innovation Center (EIC), one of three demonstration sites for the CEC project.

The controller, specified by EPRI and developed by Melrok, was used to schedule the test mode, adjust thermostat set points and collect power and environment data from the system and site. The Melrok controller had supervisory control over the VRF system and IEC units, overriding each product's individual remote controls to set on/off, cool/vent mode, and fan speed.

During this cooling season, the hybrid system was configured to operate under a default "IEC priority mode", meaning that the IEC units (Coolerado Model H80) first operate to meet the indoor temperature set point. The Melrok controller (designed and configured specifically to support this hybrid system) activated the VRF unit (LG Electronics) when the IEC units did not provide sufficient cooling to sustain the temperature set point, triggered by a combination of high ambient temperature and high occupancy.

On the baseline days, the cooling control setpoint was set at 70°F for the period of 11:00 am to 4:00 pm before being deactivated. On the treatment days, the cooling control setpoint was set at 70°F at 11:00 am, then 73°F at noon, then back to 70°F at 3:00 pm, and finally deactivated at 4:00 pm. The performance hypothesis was for significant demand reduction of the VRF outdoor unit between noon and 3:00 pm triggered by setback of cooling control setpoint, with a slight increase in demand between 3:00 – 4:00 pm as the VRF system adjusts load to achieve the default setpoint temperature. Furthermore, the expectation was for minimal impact on the IEC units, since they operate as the primary baseline cooling systems and chiefly during ventilation mode at low fan speed during most hours of operation.

The results of the experiment showed the following range of demand reductions for the VRF outdoor units:

- first hour of active control (11:00 am – noon): 44-50%
- second hour of active control (noon – 1 :00 pm): 18-24%
- third hour of active control (1:00 – 2:00 pm): 23-31%

- fourth hour of active control (2:00 - 3:00 pm): (5-27)% increase in demand to adjust indoor temperature back to original setpoint (rebound effect)

Overall, the testing validated the proof-of-concept that a standalone controller can provide supervisory control of an integrated VRF + IEC space conditioning system to effect demand response actuated by a change in the control setpoint temperature.

Keywords

Demand response

Variable refrigerant flow

Indirect evaporative cooling

HVAC controls

Hybrid HVAC system

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 BACKGROUND

As an activity adjunct to the California Energy Commission (CEC) project “Climate Appropriate Innovations for Variable Refrigerant Flow Systems: Integrated Indirect Evaporative Cooling Adaptive Controls and Advanced Refrigerants” (CEC-500-2021-028)[1], EPRI tested the demand response capability of a customized controller regulating a hybrid space conditioning system comprising a variable refrigerant flow (VRF) unit and indirect evaporative cooling (IEC) units. With sponsorship from San Diego Gas & Electric (SDG&E), the tests were conducted May 4-8, 2020, at SDG&E’s Energy Innovation Center (EIC), one of three demonstration sites for the CEC project.

This underlying CEC project demonstrated the application of a hybrid space conditioning system that integrates VRF with IEC as a more energy-efficient alternative to rooftop units (RTUs) prevalent in small- to medium- commercial buildings throughout California. While VRF has been demonstrated as an energy-efficient space conditioning technology, one of its inherent challenges is limited ventilation capacity. This hybrid configuration utilizes IEC as a dedicated outside air system (DOAS) to satisfy ventilation requirements, eliminate outside air loads during cooling, and reduce heating loads as an air-air heat exchanger.

Field demonstrations at three sites – a multi-purpose office building in Northern California (PG&E territory), a quick-serve restaurant in Southern California (SCE territory), and a multi-purpose office building in San Diego (SDG&E territory) – sought to validate energy savings relative to modeled baseline performance, as well as peak load reduction, demand responsiveness, and occupant comfort.

A key advancement of this project was the development of an integrated system controller that optimizes operation of the combined ‘VRF + IEC’ configuration through zonal occupancy sensing and learned building behavior. Control sequence algorithms were based on governing logic informed by adaptive capabilities and response to inputs such as ambient weather conditions, humidity control, occupancy, and occupant comfort preferences.

Supplemental funding by SDG&E supported testing of the demand response functionality of the integrated system controller at the SDG&E Energy Innovation Center (EIC) in San Diego. That is the subject of this report.

[1] “Climate Appropriate Innovations for Variable Refrigerant Flow Systems: Integrated Indirect Evaporative Cooling Adaptive Controls and Advanced Refrigerants”. California Energy Commission. 2021. https://www.energy.ca.gov/sites/default/files/2021-05/CEC-500-2021-028.pdf

2 SITE DESCRIPTION

The San Diego Gas & Electric (SDG&E) Energy Innovation Center (EIC) is a multi-purpose education, training, and meeting facility that showcases innovative energy efficiency technologies and green building practices to the public. As a double LEED® platinum facility, the EIC serves as a living laboratory that provides visitors with hands-on interactions with emerging energy-efficient technologies, building materials, and design practices. The EIC features versatile classrooms and meeting rooms that can be partitioned in a variety of ways to host groups throughout the year. One of the distinguishing features of the EIC is its Commercial Demonstration Kitchen, which provides the food service industry with a hands-on opportunity to test innovative energy-efficient commercial cooking equipment.

Figure 1. SDG&E Energy Innovation Center – Street Facing View

Six conditioning zones along one side of the building, as shown in the bird's eye view of Figure 2, had been served by three incumbent IEC units. SDG&E and EIC staff had indicated that the IEC units were unable to provide sufficient cooling during peak loading periods (i.e., during the summer months), particularly to sustain comfort levels for high occupancy. As a result, the project team deemed this an appropriate opportunity to retrofit a VRF to provide cooling for peak demand and high occupancy periods.

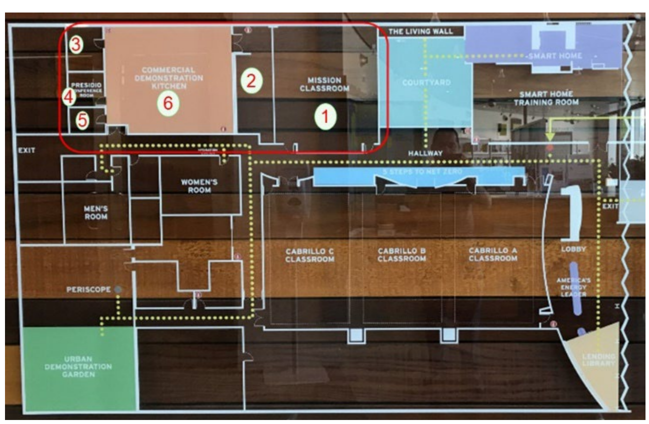

Figure 2. EIC Conditioned Zones for VRF Retrofit

These six zones, collectively an area of 5,000 square feet, were served by three IEC units as shown in Table 1 and in Figure 3:

Table 1. Mapping of IEC Units to Conditioning Zones

Zone	IEC Unit
1) Mission Classroom	#1 ("AC-10")
2) Kitchen staging area	#2 ("AC-11")
3) Storage room	#3 ("AC-9")
4) Conference room	#3 ("AC-9")
5) Conference room	#3 ("AC-9")
6) Commercial Demonstration Kitchen	#3 ("AC-9")

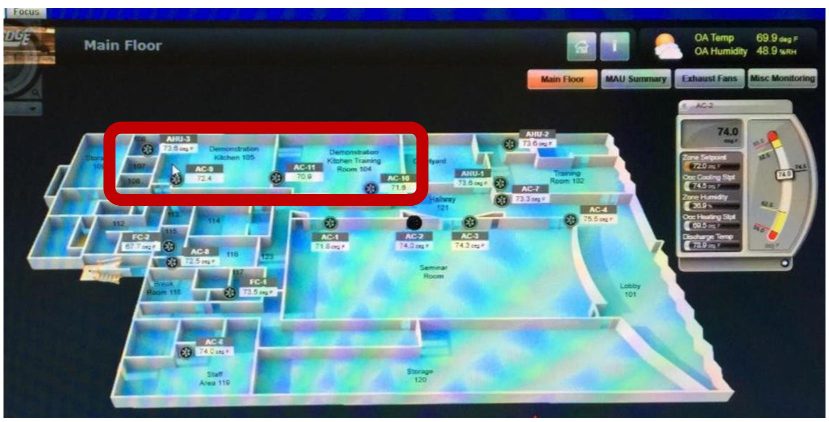

Figure 3. Incumbent HVAC Equipment at EIC, Building Automation View

For this site the operative goal was not energy savings but rather increased comfort and utilization of space through as energy-efficient a method as possible. Although the existing building automation system had baseline data on the energy consumption of these IEC units, which could be compared to the post-retrofit VRF + IEC system, the operative metrics were qualitative, based on feedback from the EIC staff on the performance of the hybrid system and tangible impacts on occupant comfort and increased utilization of space to host events during hot days and with higher occupancies.

The pre-existing IEC units that had been serving the targeted zones within the EIC building had each been previously instrumented with power meters, with the results being logged into the building automation system – Johnson Controls Metasys. However, retrieving this data proved to be problematic. For one, the Metasys data dashboard for the building did not include information on the power consumption of these IEC units. Secondly, during the course of this project the EIC changed its building control system provider, which required transfer of historical energy consumption data for those IEC units. For a significant period of time this baseline data was not available or otherwise accessible to the project team. The data that was eventually obtained was incomplete.

As a result of the problems with obtaining baseline data a more qualitative approach was taken at the EIC site. The premise of investigation was that the existing IEC units were not adequately cooling its zones during periods of high ambient temperatures and/or high occupancy. It was explained to the project team that, for example, events planned for the Mission Classroom in the past would sometimes have to be moved or rescheduled due to uncomfortable conditions, particularly during the summer and to support higher occupancies. The solution, therefore, was to install a VRF system to augment the cooling load for these peak periods while allowing the existing IECs to continue operation during most periods of the year, as regulated by the newly developed master controller.

It was understood that VRF solution was not intended in this case to provide energy savings, since the IEC units themselves are highly energy efficient, but rather to enhance utilization of the designated spaces and increase occupant comfort. Therefore, the metrics of a successful installation were qualitative measures of improved comfort and usability of the spaces during times of peak cooling loads and high occupancy, as determined by EIC facility staff.

VRF Installation

The project team specified and sized a 10-ton VRF system capable of providing sufficient cooling for the six conditioned zones without the operation of the pre-existing IEC units. To provide vendor diversity in VRF units across the three demonstration sites, the VRF model selected for the EIC site was the LG ARUM121DTE5, a 10-ton unit (cooling) outdoor unit. Six ceiling cassettes were also installed as indoor units for the conditioned zones. The retrofit also required the installation of 305 feet of piping along with thermostats for each zone. A diagram of the VRF installation is shown in Figure 4.

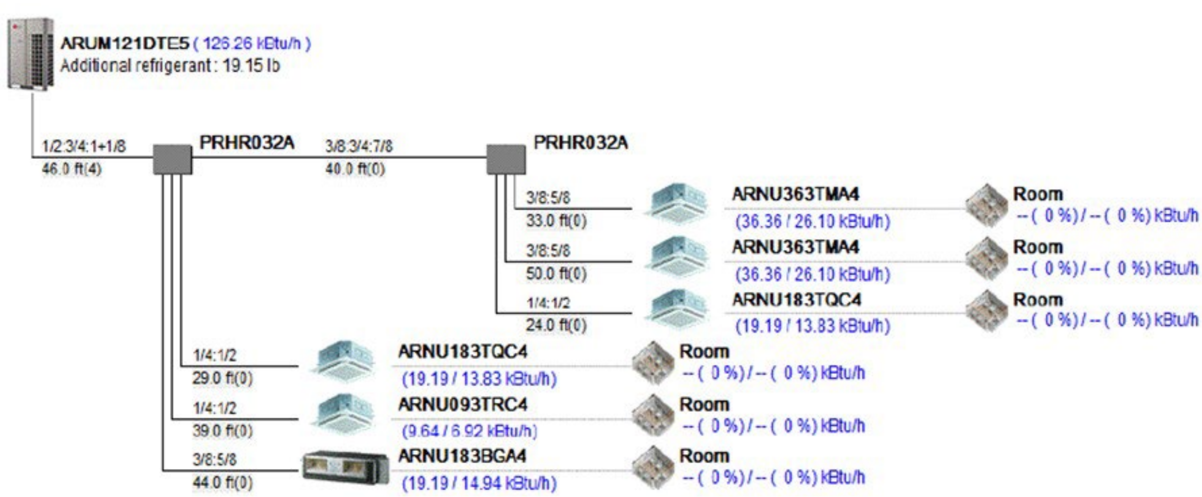

Figure 4. EIC VRF Installation Diagram

The major activities of the installation process undertaken by the HVAC contractor were:

1. Develop drawings for city permit approvals
2. Provide and install one new LG 10-ton VRF condensing unit
3. Set new condensing unit on lay down polymer roof pad
4. Provide hoisting and rigging to set new condenser on roof
5. Core holes through roof to allow for new refrigerant lines
6. Provide roofer to patch cores and seal tight
7. Provide unistrut and hangers to mount fan coils
8. Install soft copper refrigerant lines to connect cassettes to condensing unit
9. Install hard copper and fittings to connect condensing unit to branch
10. Install pipe hangers to properly support new piping
11. Insulate new copper refrigerant piping
12. Install pipes and fittings to drain condensate from all fan coils
13. Tie condensate drain into nearest acceptable receptacle
14. Install new thermostats for fan coil units
15. Run new thermostat wire from fan coils to new thermostats
16. Run new thermostat wire from fan coils to condensing unit
17. Provide electrician to run new power to ceiling cassettes and condensing unit
18. Provide startup technician to start and test and commission new units for proper operation

Energy Monitoring Field Results

After the VRF retrofit plans were finalized, but prior to VRF installation, the EIC staff and IEC vendor (Seeley) determined that the insufficient cooling from the incumbent Coolerado IEC units was due to a sensor malfunction. Those sensors were recalibrated by Seeley and as a result the cooling capacity improved noticeably to the point that it was deemed sufficient for most occupancy conditions. Nevertheless, with the installation plans in place, the VRF installation commenced.

The VRF unit was commissioned and deemed to work satisfactorily, providing sufficient cooling for all of the zones during the test periods. EIC staff indicated that the blast of cool air from the VRF indoor cassettes was a big difference from what the Coolerado IEC units had been able to previously provide. The controller was also installed and tested for control of the VRF and pre-existing Coolerado IEC units. For a brief period of time the hybrid VRF + IEC system operated between alternating modes of exclusive IEC operation and exclusive VRF operation.

However, during a round of LEED re-certification testing the EIC staff determined that the operation of the VRF system would invalidate the building's distinguished LEED Double Platinum status – a recognition shared by fewer than two dozen facilities around the world – based on not meeting a minimum ASHRAE fresh air ventilation standard for each zone. To retain its LEED Double Platinum status, the EIC facilities staff decided to limit the annual operating hours of the VRF unit. As a result, during the summer season of 2019 there was insufficient data of operation beyond attestation of the EIC staff that the VRF unit worked well. During the winter heating season, the VRF was available as a secondary backup heating source but was rarely deployed in this capacity.

3 CONTROLLER DEVELOPMENT

One of the most technically challenging elements, and key advancements, of the project was developing an integrated controller to regulate and optimize the operation of the VRF + IEC hybrid system. The primary function of the controller was to regulate the operation of the VRF + IEC system to optimize energy savings while maintaining occupant comfort requirements. The secondary function was to manage the operation of the VRF + IEC system during simulated demand response (DR) events.

Developing the controller involved the following steps:

1. Develop governing logic for system operation
2. Source a solutions provider to implement the controller
3. Convert governing logic into control sequence algorithms
4. Design control architecture, combining site hardware with cloud computing
5. Establish data input and output requirements
6. Install and commission controller
7. Integrate controller with data monitoring devices
8. Test performance on-site

Traditionally, VRF and IEC systems operate as stand-alone systems, with an optional additional interface that connects them to building management system using standards such as BACnet, Modbus or other proprietary communication protocols. Melrok was commissioned through the CEC study to develop a standalone controller programmed to supersede the native controllers of both the LG VRF unit and IEC units with integrated supervisory control.

The integrated control schema developed for the VRF + IEC hybrid system was based on governing logic informed by adaptive capabilities (learned building behaviors) and response to monitored inputs such as ambient temperature, indoor temperature set points, humidity control, occupancy sensing, and occupant comfort preferences. These inputs serve as triggers for the controller to shift the integrated system between the following four modes of operation:

- Economizer-only mode
- IEC-only mode
- VRF-only mode (partial or full loading)
- Simultaneous IED and VRF mode

1. Economizer-only mode to provide “free-cooling”

When outside air dry-bulb temperature (OAT DB) is lower than supply air dry-bulb temperature (SAT DB) the optimal operational mode is economizer-only.

OAT DB < SAT DB = Economizer mode

SAT DB is typically set at the building balance point temperature when neither heating nor cooling is needed, typically at 65 °F. In this mode, either the outside air damper or a variable speed fan regulates the amount of air intake and reaches 100% of damper position, or fan speed, when OAT DB is equal to 65 °F.

2. **Indirect evaporative cooling (IEC) mode**

When OAT DB is higher than the building balance point temperature (65 °F) but less than the outside air web-bulb temperature (OAT WB), the optimal operational mode is IEC mode only.

Building balance point (65 °F) < OAT DB < OAT WB = IEC mode

The rationale for this control logic is illustrated in the IEC schematic diagram of Figure 5. Return air passes from the conditioned space over a wetted medium to remove sensible heat, and the outside air enters and is indirectly cooled evaporatively before being delivered to the space.

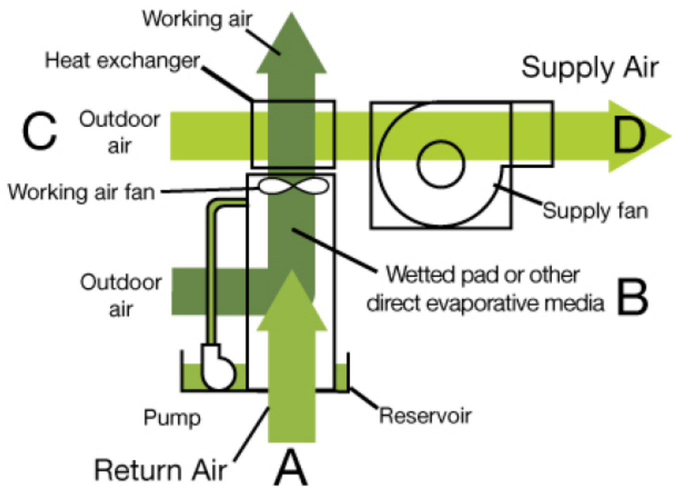

Figure 5. Indirect Evaporative Cooler Schematic Diagram

Source: E Source

3. **VRF only mode**

This mode can be an option to toggle the control mode from operation of IEC to the VRF only mode.

When OAT DB > 65 °F and OAT WB > 58 °F, the operational mode can be the following two conditions: VRF only or VRF + IEC.

4. **VRF + IEC mode**

In this mode, the IEC ramps up as the first stage and then activates the VRF system as a second stage of cooling to meet any individual zone's cooling loads.

Return air passes from the conditioned space over a wetted medium in the IEC system to remove sensible heat, and the outside air enters and is redirected to second stage cooling for the VRF system.

The next step was converting governing logic into corresponding control sequence algorithms and developing a cloud-based architecture and communications platform to provide overlaying controls for both a VRF and IEC system. We addressed this challenge by identifying and securing a controls vendor, Melrok, with the requisite expertise to build a controller using generic hardware and applying BACnet to extract data and send control signals to the VRF system. This challenge was compounded by the fact that all commercial VRF systems employ proprietary control systems. The control system architecture is illustrated in Figure 6.

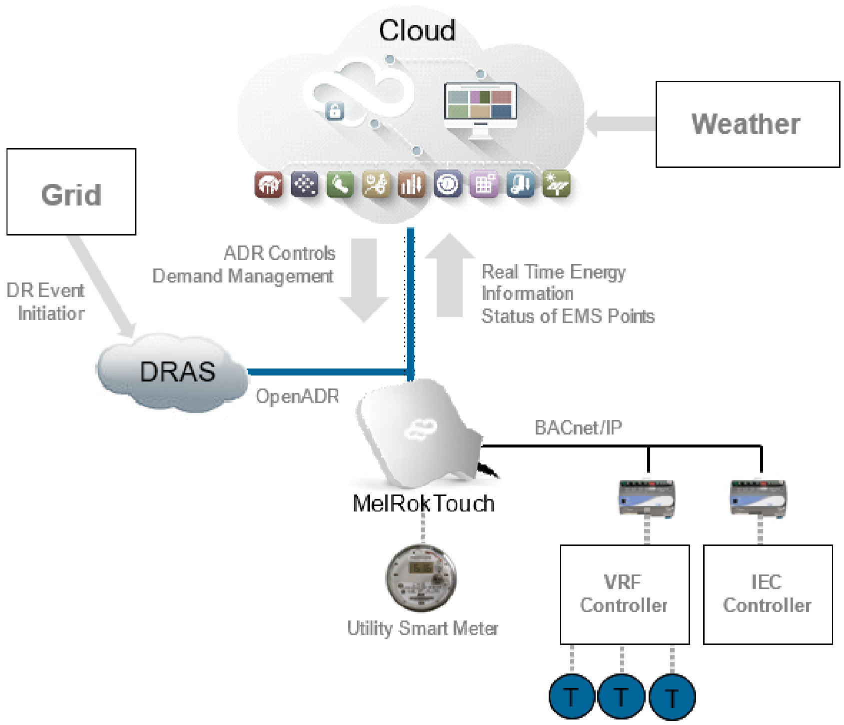

Figure 6. Control System Architecture

Source: Melrok and EPRI

While the controller's primary objective was to optimize for energy savings a secondary objective was to enable demand response (DR). DR signals are initiated by the utility's system operations, requesting load shedding to rebalance energy demand with supply. Referring to the DR control architecture depicted in Figure 7, this signal is processed by the DR automation server (DRAS), which sends the control mode in a discrete signal to the building and also sends a notification in advance of the event. This control mode is typically sent over the internet, typically as an extensible markup language (XML) instruction. Thus, the setup typically requires a Java Application Control Engine (JACE) controller to integrate loads for unified real-time control. Then the control modes are implemented as a set of load control strategies, codified as algorithms, to provide load controls to respond to DR events.

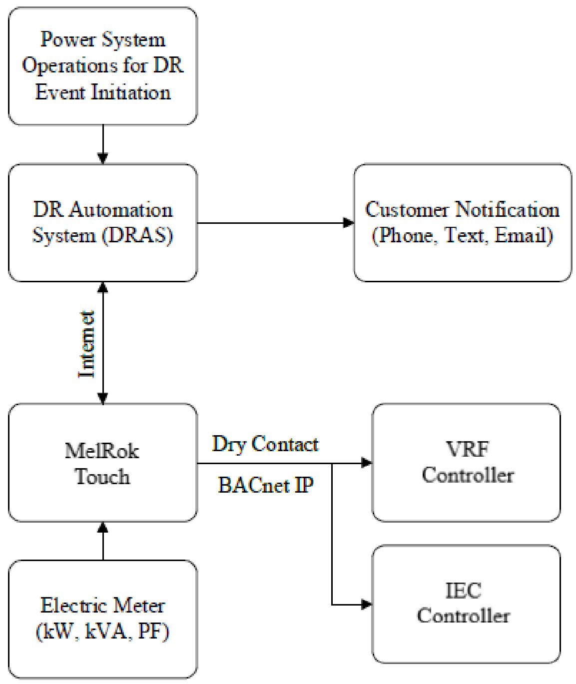

Figure 7. Automatic DR Control Architecture

Source: EPRI

Communication between components is achieved via open standards – OpenADR 2.0b and BACnet. As shown in Figure 8, the MelRok cloud on the upper right sends control commands that determine which of the four operational modes of the VRF + IEC system are actuated, and the sequence of components that are activated for a DR event. The control sequence is sent out via MelRok Touch to the VRF units. The controlled object of the IEC will be the fan speed, and the controlled object of the VRF will be the thermostat setpoint. During a DR event, the virtual top node (VTN) – the system operations, sends the signal to the MelRok Touch as the virtual end node (VEN) via OpenADR 2.0b, and acknowledges the VTN – DR Automation Server, upon receiving the signal. Then, the MelRok Touch translates the DR event information (e.g., critical peak pricing info, kW reduction requirement, etc.) into signals that interoperate with the components for end-use controls.

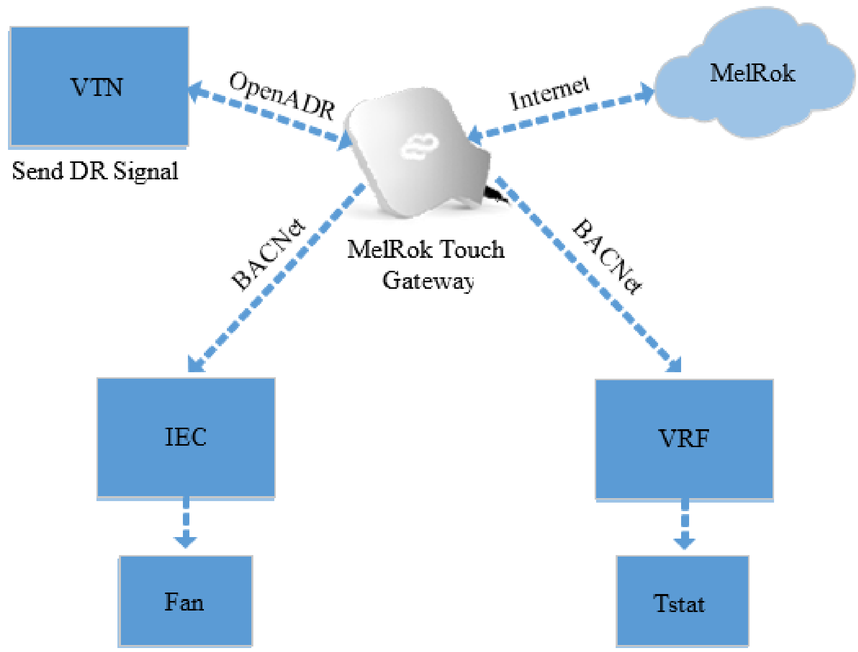

Figure 8. Open Standards Communications for Control of Components

Source: EPRI

4 DEMAND RESPONSE TESTING

The experimental design for the demand response testing involved three baseline days and two treatment days from the week of May 4th, 2020:

Table 2. Baseline and Treatment Days for Demand Response Testing

Baseline Days	Treatment Days
May 4, 2020 (Monday)	May 5, 2020 (Tuesday)
May 6, 2020 (Wednesday)	May 7, 2020 (Thursday)
May 8, 2020 (Friday)	

The selected days were all weekdays in the same week to normalize for nearly identical weather and occupancy conditions.

On the baseline days, the cooling control setpoint was set at 70°F for the period of 11:00 am to 4:00 pm before being deactivated. On the treatment days, the cooling control setpoint was set at 70°F at 11:00 am, then 73°F at noon, then back to 70°F at 3:00 pm, and finally deactivated at 4:00 pm.

Table 3. Test Methodology, Temperature Control Setpoints

Baseline Days	Treatment Days
• 11:00 am, cooling control setpoint @ 70°F • 4:00 pm, deactivate remote control	• 11:00 am, cooling control setpoint @ 70°F • noon, cooling control setpoint @ 73°F • 3:00 pm, cooling control setpoint back @ 70°F • 4:00 pm, deactivate remote control

The performance hypothesis was for significant demand reduction of the VRF unit between noon and 3:00 pm triggered by the setback of cooling control setpoint, with a slight increase in demand between 3:00 – 4:00 pm as the VRF system adjusts load to re-achieve the control setpoint temperature of 70°F. Furthermore, the expectation was for minimal to no impact on the IEC units, since they operate as the primary cooling systems and chiefly during ventilation mode at low fan speed during the hours of operation.

Test Results: VRF Outdoor Unit

The test results for the VRF outdoor unit are measured in terms of the difference in average hourly load between two treatment days and each adjacent baseline day, i.e., the day prior and the day after. Time series data of the VRF outdoor unit with minute-by-minute granularity was aggregated to the hourly level and compared on the respective days. Tables 4 through 7 summarize the results for each set of comparison days for the hours of noon to 4:00 pm.

- Table 4: 5/5/50 Treatment vs. 5/4/20 Baseline
- Table 5: 5/5/50 Treatment vs. 5/6/20 Baseline
- Table 6: 5/7/50 Treatment vs. 5/6/20 Baseline
- Table 7: 5/7/50 Treatment vs. 5/8/20 Baseline

Table 4 shows that the setpoint change at noon actuated a dramatic 43.9% load reduction in the first hour, stabilizing to 18.6% and 23.0% load reductions in the next two hours, before a load rebound of 15.5% in the final hour as the setpoint was adjusted back to the original target.

Table 4. Demand Reduction of VRF Outdoor Unit: 5/5/20 Treatment vs. 5/4/20 Baseline

	Baseline Demand (kW)	Treatment Demand (kW)	Demand Reduction (kW)	Percentage Reduction
Noon – 1 pm	2.24	1.26	0.98	43.9%
1 – 2 pm	2.17	1.76	0.40	18.6%
2 – 3 pm	2.18	1.68	0.50	23.0%
3 – 4 pm	2.21	2.55	-0.34	-15.5%

Table 5 shows that the setpoint change at noon actuated a dramatic 47.3% load reduction in the first hour, stabilizing to 24.0% and 22.7% load reductions in the next two hours, before a load rebound of 6.8% in the final hour as the setpoint was adjusted back to the original target.

Table 5. Demand Reduction of VRF Outdoor Unit: 5/5/20 Treatment vs. 5/6/20 Baseline

	Baseline Demand (kW)	Treatment Demand (kW)	Demand Reduction (kW)	Percentage Reduction
Noon – 1 pm	2.38	1.26	1.13	47.3%
1 – 2 pm	2.32	1.76	0.56	24.0%
2 – 3 pm	2.17	1.68	0.49	22.7%
3 – 4 pm	2.39	2.55	-0.16	-6.8%

Table 6 shows that the setpoint change at noon actuated a dramatic 50.1% load reduction in the first hour, stabilizing to 23.0% and 27.7% load reductions in the next two hours, before a load rebound of 4.7% in the final hour as the setpoint was adjusted back to the original target.

Table 6. Demand Reduction of VRF Outdoor Unit: 5/7/20 Treatment vs. 5/6/20 Baseline

	Baseline Demand (kW)	Treatment Demand (kW)	Demand Reduction (kW)	Percentage Reduction
Noon – 1 pm	2.38	1.19	1.19	50.1%
1 – 2 pm	2.32	1.79	0.53	23.0%
2 – 3 pm	2.17	1.57	0.60	27.7%
3 – 4 pm	2.39	2.50	-0.11	-4.7%

Table 7 shows that the setpoint change at noon actuated a dramatic 44.0% load reduction in the first hour, stabilizing to 18.9% and 30.6% load reductions in the next two hours, before a significant load rebound of 26.9% in the final hour as the setpoint was adjusted back to the original target.

Table 7. Demand Reduction of VRF Outdoor Unit: 5/7/20 Treatment vs. 5/8/20 Baseline

	Baseline Demand (kW)	Treatment Demand (kW)	Demand Reduction (kW)	Percentage Reduction

Noon – 1 pm	2.12	1.19	0.93	44.0%
1 – 2 pm	2.20	1.79	0.42	18.9%
2 – 3 pm	2.26	1.57	0.69	30.6%
3 – 4 pm	1.97	2.50	-0.53	-26.9%

In summary, the results of the experiment showed the following range of demand reductions for the VRF outdoor unit:

- first hour of active control (11:00 am – noon): 44-50%
- second hour of active control (noon – 1 :00 pm): 18-24%
- third hour of active control (1:00 – 2:00 pm): 23-31%
- fourth hour of active control (2:00 - 3:00 pm): (5-27)% increase in demand to adjust indoor temperature back to original setpoint (rebound effect)

The load reductions for the VRF outdoor units during the first three hours of active control, in absolute terms, ranged from 0.4 to 1.2 kW, representing the largest contribution towards overall demand response.

Load reductions for the VRF indoor fan coils across the first three hours of active control ranged from 6 to 15%, equating to only a minimal impact of 0.007 to 0.018 kW. Load impacts for the IEC units, as expected, were negligible. Results for both are provided in the Appendix.

Overall, the testing validated the proof-of-concept that a standalone controller can provide supervisory control of an integrated VRF + IEC space conditioning system to effect demand response actuated by a change in the control setpoint temperature.

A APPENDIX: ADDITIONAL TEST RESULTS

Load reductions for the VRF Indoor Fan Coils and IEC units were low to negligible, respectively, both in relative and absolute terms.

There was a total of six (6) VRF Indoor Fan Coil units serving the conditioned zones of the EIC space. Fan Coils #1 and #2 were on the same dedicated circuit and were therefore measured together. Similarly, Fan Coils #3, #4, and #5 were on the same dedicated circuit and also measured together. However, data for Fan Coils #4 and #6 were omitted because setpoint commands were not received by their respective thermostats.

Test Results: VRF Indoor Fan Coils #1 & #2

Table 8 shows that the setpoint change at noon actuated a 11.2% load reduction in the first hour, stabilizing to 7.2% and 7.5% load reductions in the next two hours, before a load rebound of 0.6% in the final hour as the setpoint was adjusted back to the original target.

Table 8. Demand Reduction of VRF Indoor Fan Coils #1 and #2: 5/5/20 Treatment vs. 5/4/20 Baseline

	Baseline Demand (kW)	Treatment Demand (kW)	Demand Reduction (kW)	Percentage Reduction
Noon – 1 pm	0.037	0.033	0.004	11.2%
1 – 2 pm	0.037	0.034	0.003	7.2%
2 – 3 pm	0.037	0.034	0.003	7.5%
3 – 4 pm	0.037	0.037	0.000	-0.6%

Table 9 shows that the setpoint change at noon actuated a 11.3% load reduction in the first hour, stabilizing to a 7.8% load reduction over the next two hours, before a load equilibrium in the final hour as the setpoint was adjusted back to the original target.

Table 9. Demand Reduction of VRF Indoor Fan Coils #1 and #2: 5/5/20 Treatment vs. 5/6/20 Baseline

	Baseline Demand (kW)	Treatment Demand (kW)	Demand Reduction (kW)	Percentage Reduction
Noon – 1 pm	0.037	0.033	0.004	11.3%
1 – 2 pm	0.037	0.034	0.003	7.8%

2 – 3 pm	0.037	0.034	0.003	7.8%
3 – 4 pm	0.037	0.037	0.000	0.1%

Table 10 shows that the setpoint change at noon actuated a 11.2% load reduction in the first hour, stabilizing to 8.1% and 7.0% load reductions in the next two hours, before a load rebound of 0.4% in the final hour as the setpoint was adjusted back to the original target.

Table 10. Demand Reduction of VRF Indoor Fan Coils #1 and #2: 5/7/20 Treatment vs. 5/6/20 Baseline

	Baseline Demand (kW)	Treatment Demand (kW)	Demand Reduction (kW)	Percentage Reduction
Noon – 1 pm	0.037	0.033	0.004	11.2%
1 – 2 pm	0.037	0.034	0.003	8.1%
2 – 3 pm	0.037	0.034	0.003	7.0%
3 – 4 pm	0.037	0.037	0.000	-0.4%

Table 11 shows that the setpoint change at noon actuated a 10.7% load reduction in the first hour, stabilizing to 7.4% and 6.7% load reductions in the next two hours, before a load rebound of 0.9% in the final hour as the setpoint was adjusted back to the original target.

Table 11. Demand Reduction of VRF Indoor Fan Coils #1 and #2: 5/7/20 Treatment vs. 5/8/20 Baseline

	Baseline Demand (kW)	Treatment Demand (kW)	Demand Reduction (kW)	Percentage Reduction
Noon – 1 pm	0.037	0.033	0.004	10.7%
1 – 2 pm	0.037	0.034	0.003	7.4%
2 – 3 pm	0.037	0.034	0.002	6.7%
3 – 4 pm	0.037	0.037	0.000	-0.9%

In absolute terms, the range of load reductions for the first three hours ranged from 0.002 to 0.004 kW.

Test Results: VRF Indoor Fan Coils #3 & #5

Table 12 shows that the setpoint change at noon actuated a 15.1% load reduction in the first hour, stabilizing to 8.5% and 11.0% load reductions in the next two hours, before a load rebound of 1.6% in the final hour as the setpoint was adjusted back to the original target.

Table 12. Demand Reduction of VRF Indoor Fan Coils #3 and #5: 5/5/20 Treatment vs. 5/4/20 Baseline

	Baseline Demand (kW)	Treatment Demand (kW)	Demand Reduction (kW)	Percentage Reduction
Noon – 1 pm	0.118	0.100	0.018	15.1%
1 – 2 pm	0.115	0.105	0.010	8.5%
2 – 3 pm	0.114	0.102	0.013	11.0%
3 – 4 pm	0.115	0.117	-0.002	-1.6%

Table 13 shows that the setpoint change at noon actuated a 14.5% load reduction in the first hour, stabilizing to 10.3% and 9.0% load reductions in the next two hours, before a load rebound of 2.7% in the final hour as the setpoint was adjusted back to the original target.

Table 13. Demand Reduction of VRF Indoor Fan Coils #3 and #5: 5/5/20 Treatment vs. 5/6/20 Baseline

	Baseline Demand (kW)	Treatment Demand (kW)	Demand Reduction (kW)	Percentage Reduction
Noon – 1 pm	0.117	0.100	0.017	14.5%
1 – 2 pm	0.117	0.105	0.012	10.3%
2 – 3 pm	0.112	0.102	0.010	9.0%
3 – 4 pm	0.114	0.117	-0.003	-2.7%

Table 14 shows that the setpoint change at noon actuated a 14.8% load reduction in the first hour, stabilizing to 9.7% and 8.0% load reductions in the next two hours, before a load rebound of 6.3% in the final hour as the setpoint was adjusted back to the original target.

Table 14. Demand Reduction of VRF Indoor Fan Coils #3 and #5: 5/7/20 Treatment vs. 5/6/20 Baseline

	Baseline Demand (kW)	Treatment Demand (kW)	Demand Reduction (kW)	Percentage Reduction
Noon – 1 pm	0.117	0.100	0.017	14.8%
1 – 2 pm	0.117	0.106	0.011	9.7%
2 – 3 pm	0.112	0.103	0.009	8.0%
3 – 4 pm	0.114	0.121	-0.007	-6.3%

Table 15 shows that the setpoint change at noon actuated a 11.8% load reduction in the first hour, stabilizing to 6.0% and 11.1% load reductions in the next two hours, before a load rebound of 10.1% in the final hour as the setpoint was adjusted back to the original target.

Table 15. Demand Reduction of VRF Indoor Fan Coils #3 and #5: 5/7/20 Treatment vs. 5/8/20 Baseline

	Baseline Demand (kW)	Treatment Demand (kW)	Demand Reduction (kW)	Percentage Reduction
Noon – 1 pm	0.113	0.100	0.013	11.8%
1 – 2 pm	0.113	0.106	0.007	6.0%
2 – 3 pm	0.116	0.103	0.013	11.1%
3 – 4 pm	0.110	0.121	-0.011	-10.1%

In absolute terms, the range of load reductions for the first three hours ranged from 0.007 to 0.018 kW.

Test Results: IEC Units

Tables 16 through 19 show that the setpoint change had virtually no effect on the IEC units. This result is consistent with expectations since the IEC units operated as the baseline cooling source. The demand response signal effected VRF operation at the margin.

Table 16. Demand Reduction of IEC Units: 5/5/20 Treatment vs. 5/4/20 Baseline

	Baseline Demand (kW)	Treatment Demand (kW)	Demand Reduction (kW)	Percentage Reduction
Noon – 1 pm	0.075	0.075	0.000	0.4%
1 – 2 pm	0.075	0.075	0.001	0.7%
2 – 3 pm	0.075	0.076	-0.001	-1.2%
3 – 4 pm	0.075	0.075	0.000	0.5%

Table 17. Demand Reduction of IEC Units: 5/5/20 Treatment vs. 5/6/20 Baseline

	Baseline Demand (kW)	Treatment Demand (kW)	Demand Reduction (kW)	Percentage Reduction
Noon – 1 pm	0.076	0.075	0.001	0.9%
1 – 2 pm	0.074	0.075	0.000	-0.6%
2 – 3 pm	0.075	0.076	0.000	-0.5%
3 – 4 pm	0.075	0.075	0.001	0.7%

Table 18. Demand Reduction of IEC Units: 5/7/20 Treatment vs. 5/6/20 Baseline

	Baseline Demand (kW)	Treatment Demand (kW)	Demand Reduction (kW)	Percentage Reduction
Noon – 1 pm	0.076	0.075	0.000	0.5%
1 – 2 pm	0.074	0.076	-0.001	-1.6%
2 – 3 pm	0.075	0.075	0.000	0.4%
3 – 4 pm	0.075	0.075	0.000	-0.2%

Table 19. Demand Reduction of IEC Units: 5/7/20 Treatment vs. 5/8/20 Baseline

	Baseline Demand (kW)	Treatment Demand (kW)	Demand Reduction (kW)	Percentage Reduction
Noon – 1 pm	0.075	0.075	0.000	-0.1%
1 – 2 pm	0.075	0.076	0.000	-0.5%
2 – 3 pm	0.076	0.075	0.001	1.2%
3 – 4 pm	0.076	0.075	0.001	0.7%

TBD

Export Control Restrictions

Access to and use of this EPRI product is granted with the specific understanding and requirement that responsibility for ensuring full compliance with all applicable U.S. and foreign export laws and regulations is being undertaken by you and your company. This includes an obligation to ensure that any individual receiving access hereunder who is not a U.S. citizen or U.S. permanent resident is permitted access under applicable U.S. and foreign export laws and regulations.

In the event you are uncertain whether you or your company may lawfully obtain access to this EPRI product, you acknowledge that it is your obligation to consult with your company's legal counsel to determine whether this access is lawful. Although EPRI may make available on a case-by-case basis an informal assessment of the applicable U.S. export classification for specific EPRI products, you and your company acknowledge that this assessment is solely for informational purposes and not for reliance purposes.

Your obligations regarding U.S. export control requirements apply during and after you and your company's engagement with EPRI. To be clear, the obligations continue after your retirement or other departure from your company, and include any knowledge retained after gaining access to EPRI products.

You and your company understand and acknowledge your obligations to make a prompt report to EPRI and the appropriate authorities regarding any access to or use of this EPRI product hereunder that may be in violation of applicable U.S. or foreign export laws or regulations.

About EPRI

Founded in 1972, EPRI is the world's preeminent independent, non-profit energy research and development organization, with offices around the world. EPRI's trusted experts collaborate with more than 450 companies in 45 countries, driving innovation to ensure the public has clean, safe, reliable, affordable, and equitable access to electricity across the globe. Together, we are shaping the future of energy.

Program:

Customer Insights

3002028309

EPRI
3420 Hillview Avenue, Palo Alto, California 94304-1338 USA
800.313.3774 ▪ 650.855.2121 ▪ askepri@epri.com ▪ www.epri.com