Evaluation of the Next Generation Residential Space Conditioning System for California

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ABSTRACT

The 'Next Generation' Residential Space Conditioning System (Next-Gen RSCS) for California (CA) is an integration of multiple advanced HVAC technologies including: variable capacity heat pump compressor, variable speed blower fan, alternative refrigerant (R-32), automated demand response, fault detection and diagnostics, intelligent dual fuel heating (gas/electric), integrated ventilation, and zonal control. Along with the technology evaluation, an assessment was performed on duct losses for single versus multi-zone duct configurations with variable capacity equipment. The experimental results, from 3 leading laboratories, inform the industry on optimizing the system for efficiency, utility integration, and homeowner comfort. Key findings from the laboratory evaluation of the system include:

- Cooling energy savings range between 22-32% for CA compared to a 14 SEER single-speed system as a baseline.
- Capacity to satisfy over 90% of the annual heating load for most of CA without back-up.
- Demand response capability with variable capacity equipment enables utilities to reduce peak demand while reducing customer discomfort.
- Revising ducting standards and more efficient control strategies would improve the integration of heat pumps connected to *attic* ductwork for hot and dry California climates.
- Zonal control, integrated ventilation and intelligent heating with a variable capacity heat pump offer targeted energy savings with system versatility.
- Heating and cooling mode experimental results of variable capacity heat pump with R-32 as a drop-in refrigerant demonstrated comparable or improved performance to R-410A.

The Next-Gen RSC is being field evaluated in 3 homes in the CA IOU service territories (PG&E, SCE, SDG&E). The presentation will include the methodology and status of the field evaluation.

Introduction

Overview

The purpose of the following Electric Program Investment Charge (EPIC) research project, funded by the California Energy Commission (CEC), is to develop, test, and model a prototype Next-Generation Residential Space-Conditioning System that i*ntegrates several advanced technologies and is optimized for the California climate*. Cooling and heating of buildings to achieve comfortable temperature and humidity levels accounts for 48% of the residential energy use in the United States and 31% in California (U.S. EIA 2015). Improving the efficiency of HVAC systems is therefore a primary strategy for reducing the overall energy consumption in California and reducing the greenhouse gasses emitted by the generation of electricity. Many technologies exist that deliver efficiency individually, such as automatic demand- response, variable capacity compressors, use of alternative refrigerants, variable speed fans, and dual fuel technology (intelligent heating). Past research efforts on these technologies for improving residential space-conditioning performance have focused on the incremental improvements of each individual technology rather than the combined performance that make up the entire residential HVAC system (e.g.: the cooling equipment, or the duct system).

The research project evaluated the benefits of integrating such advanced energy-efficient and intelligent technologies into a single optimized residential HVAC system, including both the effects of the conditioning equipment and the ductwork. In addition, the energy efficient technologies currently available are optimized for outdoor conditions that represent a national "average" climate condition that do not address the specific concerns for climate zones that have higher-than-average temperatures and/or low humidity. The only current mandatory test for high temperature is a maximum operating conditions test at 115°F, for which performance information is not published by manufacturers. Accordingly, there is a need for affordable next-generation space-conditioning systems that integrate the individual energy-efficient technologies and components available worldwide or in the R&D phase, to strive for optimal performance in a variety of climates. The net result would be to offer overall decreases in operating cost and increases in efficiency, comfort, and reliability for consumers living in different climates of U.S.

The Next-Gen RSCS evaluated consists of a ducted, split-system, residential-scale variable capacity heat pump with eight efficiency features included: variable capacity compressor, variable speed indoor fan, auto demand response (ADR), alternative refrigerant (R-32 as a drop-in for R-410A), Fault Detection and Diagnostics (FDD), integrated ventilation control (using a heat recovery ventilator), dual fuel or intelligent heating (gas or electric back-up heating), and zonal control (see Figure 1).

Methodology and Scope

The project execution is split into three consecutive phases: Phase 1 and Phase 2 for laboratory evaluation and Phase 3 for field evaluation. Laboratory evaluation was conducted for the Next-Gen RSCS at three independent research facilities: Electric Power Research Institute (EPRI)'s Thermal Testing Laboratory in Knoxville, TN; PG&E's Applied Technology Services in San Ramon, CA; and University of California, Davis' Western Cooling Efficiency Center (WCEC) in Davis, CA. For the laboratory evaluation, each facility tested the same 2-ton system, provided by Daikin/Goodman. The system included off-the-shelf components of current production models of their variable capacity heat pump:

- Outdoor Unit: Daikin Model DZ20VC0241
  - 2-ton rated cooling capacity heat pump with inverter drive compressor
  - R-410A refrigerant
  - Rated SEER 19-21 / HSPF 9.6-10.0
- Furnace: Daikin Model DM97MC0803BN
  - 80,000 Btu/hr modulating burner, ½-hp variable speed blower
  - Rated AFUE 97
- Indoor Coil: Daikin Model CAPF3137B6
- Thermostat: Honeywell ComfortNet CTK04

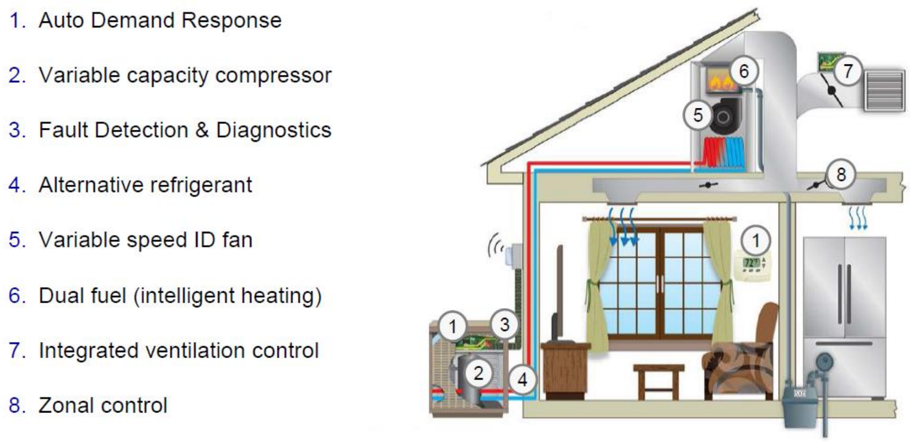

Figure 1: Energy Efficiency Technology Attributes Assessed for the Next-Generation Residential Space Conditioning System

Table 1 illustrates which technology features or attributes were evaluated in each lab, based on the facility's area of focus and expertise.

Table 1: Distribution of Technology Attributes Testing Among 3 Labs for Phase 1 and Phase 2

Phase	Technology	EPRI	PG&E	WCEC
1	Variable-Capacity Compressor	✓	✓	✓
1	Variable-Speed Blower	✓	✓	✓
1	Integrated Ventilation	✓		
1	Demand Response	✓	✓	
1	Dual Fuel (intelligent heating)		✓	
1	Duct-loss assessment for single-zone			✓
2	Alternative Refrigerants	✓	✓	
2	Fault Detection & Diagnostics		✓	
2	Zonal Control	✓		
2	Duct-loss assessment for multi-zone			✓

Laboratory Evaluation: Setup and Results

Experimental Setups

The experimental setup for each of the three laboratories, EPRI, PG&E and WCEC, consisted of environmental thermal chambers (either a single two-zone chamber, or two separate chambers side-by-side). One zone/chamber served as a simulated "indoor room", where the indoor unit with gas furnace was setup, and the other as an "outdoor space", where the outdoor unit was setup. The "indoor room" was conditioned to maintain the required return air conditions to the test unit and its airflow apparatus was used to measure the supply airflow from the indoor coil. The "outdoor space" was used to maintain the required air conditions to the outdoor components and its airflow apparatus was used to measure the outdoor unit exhaust airflow. Conditioning equipment located on the roof of these chambers is capable of heating, cooling, dehumidification and humidification of air. Each chamber includes a variable-speed blower on the outlets of each airflow station that could be set to maintain the desired outlet static pressures or airflow rates and compensate for the added resistance of the flow measurement system and ductwork.

HVAC testing was conducted in accordance with American Society of Heating Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 37-2009. Air-side and refrigerant-side measurements were conducted which allowed for air-side and refrigerant-side capacity calculations. An exhaust fan on the indoor setup allowed for the external static pressure on the indoor unit to be adjusted in accordance with the assumed external static pressure curve. Laboratory measurements included return air conditions, supply air conditions, outdoor air conditions, indoor airflow, external static pressure, indoor and outdoor unit power, refrigerant suction and discharge temperature and pressure, and refrigerant mass flow.

For the WCEC lab setup, the air, after being conditioned by the indoor unit, passes into a supply plenum that is designed to split the flow into four trunk ducts, some of which later split into branches. Phase I testing was set up as a single zone with no zonal control equipment. Sizing of the supply (and return) ducts (plastic flex ducts with R = 1.1 K m2/W) was guided by 2013 Title 24 Residential Compliance Standards for a single-story home that utilizes a 2-ton A/C unit. Trunk sections carrying air to Zones 1 and 3 were split into two branches each, terminating at four grilles total. The trunk section carrying air to Zone 4 split into three branches/grilles. The trunk section for Zone 2 delivered air at a grille downstream directly without splitting into branches. The grilles for all the zones were installed on a 72” x 40” x 20” wooden plenum box. A 10’ rubber flex-duct was attached to one side of the wooden box and ducted into the indoor environmental chamber to deliver all the air leaving the grilles. All duct sections were arranged on shelves to prevent direct thermal contact between ducts and a significant effort was made to make the duct-sections airtight. The exhaust air from the condenser unit was ducted out of the outdoor chamber. A reasonable airflow was maintained through the chamber to minimize the impact of duct losses on the temperature of the chamber.

Although Phase 1 and Phase 2 laboratory testing was conducted independently to evaluate the system performance and operation, a set of similar cooling performance data was conducted to serve as benchmarking points, with similar outdoor, indoor, and external static pressure conditions (see *Table 2*). Although efforts were made for similar equipment operation across the three labs for this set of tests, indoor unit airflow differed across the three labs due to general equipment setup and the laboratories approach used to evaluate the variable capacity space conditioning equipment. Considering the differences in the setups across the three laboratories, the results of similar test conditions represent only slight discrepancies across the three laboratory setups.

Table 2: Comparison of Steady-State Performance across the 3 Laboratories (each color denotes a lab)

Test Mode	Outdoor Air $T_{DryBulb}$	Room Air $T_{DryBulb}$	Room Air $T_{WetBulb}$	Air Flow	Ext. Res.	Capacity	Power (kW)			COP
	°F	°F	°F	CFM	IW	Tons	Indoor Unit	Outdoor Unit	Total	Equip
Cooling High	**95**	**80**	**67**	758	0.45	1.98	0.18	1.74	1.92	3.63
				579	0.45	1.88	0.14	1.70	1.84	3.59
				822	0.45	1.97	0.24	1.74	1.98	3.51
Cooling Interm.	**95**	**75**	**62**	534	0.22	0.89	0.07	0.65	0.72	4.33
				472	0.30	0.92	0.08	0.67	0.76	4.27
				527	0.21	0.93	0.08	0.67	0.75	4.36
Cooling High	**115**	**75**	**62**	753	0.46	1.38	0.18	2.09	2.27	2.13
				577	0.45	1.42	0.14	2.11	2.25	2.23
				822	0.45	1.56	0.24	2.16	2.40	2.28

Overview of Laboratory Evaluation Results (Phase 1 and Phase 2)

The following reviews the key results from the laboratory evaluation for each of the eight features of the Next-Generation Residential Space Conditioning System:

Variable Capacity Space Conditioning with R-410A

The test plan for steady-state performance was based on Air Conditioning, Heating and Refrigeration Institute (AHRI) Standard 210/240-2008 for both cooling and heating mode. Dynamic testing, or load-based testing, was also conducted to evaluate the performance of the variable capacity heat pump (VCHP). Load-based laboratory evaluation consists of imposing a thermal load on the indoor zone and allowing the unit controller to determine the appropriate output of the system. In load-based evaluations, the indoor zone is not maintained at steady-state conditions by the test setup, but rather the unit itself is responsible for maintaining appropriate conditions based on the unit setpoints and imposed load. Load-based evaluations are similar in nature to calorimetric testing, which is used to evaluate certain types of HVAC equipment. As opposed to steady-state testing, which fixes the level of operation, load-based testing allows the unit controls to modulate and adjust the unit output in response to the imposed thermal load on the indoor zone. Load-based evaluations examine the control system of the variable capacity unit and provide a more complete understanding of overall real-world operating performance under certain scenarios of operation. Key findings include:

a. Enables 22-32% cooling energy savings across California climate zones compared to a 14 SEER single-speed system as a baseline.
b. The Next-Gen RSCS can provide the heating capacity needs to satisfy over 90% of annual heating load without requiring the use of back-up heating, for most of the 16 California climate zones modeled.
c. Cooling and heating part-load efficiencies are better than full-load efficiencies at mild temperatures (between 35°F and 90°F).
d. Higher part-load efficiency corresponds to higher SEER/HSPF values.
e. VCHP is able to modulate and the system operation matches well with an imposed dynamic load.

Auto Demand Response (ADR)

The demand response setup utilized an OpenADR2.0 infrastructure. A cloud-based service issued a Demand Response (DR) event start-time, time duration, and payload value to the test unit's DR computer hardware. After receiving the DR signal, the computer hardware adjusted the unit's operation accordingly based on a predetermined upper limit. The upper limit refers to the load capabilities of the equipment, and does not directly refer to the operation level of the system. The results of two ADR events are shown in Table 3. For the 60% test case, the power reduction of the HVAC system was approximately 50%, while the power reduction of the 30% test case was approximately 70%. During both the 60% and 30% test cases, the variable capacity unit continued to provide a level of cooling capacity to the space, where the thermal comfort level of the room was not compromised proportionally to the power reduction achieved. Key findings were:

a. Demonstrated VCHP's capability as a flexible demand response resource
b. During ADR events, VCHP's capacity reduced non-linearly with reduced power.

Table 3: Summary of ADR testing with VCHP for 2 different compressor speed reduction settings: 30%, 60%

	Unit Power (W)	Percent Power Reduction	Approximate Cooling Capacity (Btu/h)	Percent Capacity Reduction
Steady at 90%	1,866	-	17,000	-
60% DR Event	928	50.3%	10,500	38.2%
30% DR Event	558	70.1%	6,500	61.8%

Integrated Ventilation Control

To improve overall building performance and energy usage, building envelope improvements have been made in residential building codes and energy efficient construction practices. Improving the insulation and tightness of the building envelope can significantly reduce the natural ventilation and exchange of fresh air within the occupied space. ASHRAE 62.2 "Ventilation and Acceptable Indoor Air Quality in Residential Buildings" outlines proper fresh air requirements for residential applications. Multiple forms of mechanical ventilation have been developed to provide the occupied space with necessary levels of fresh air.

Using the results of the laboratory assessment for VCHP with the heat recovery ventilator (HRV), an energy model was developed which compared the performance of VCHP and HRV to a baseline system in both the cooling and heating modes for all 16 California Climate Zones. For the energy model comparison, the baseline system was assumed to consist of a 14 SEER air-conditioner, forced air ventilation, and a natural gas 80% AFUE furnace. Key findings were:

a. Compared to baseline system, the use of a heat recovery ventilator with a VCHP provides an additional 1-4% cooling savings for California Climate Zone 10 (cooling design condition of 101°F and a heating design condition of 35°F).
b. Modeling results for the heating season showed that the capacity of the Next-Gen RSCS system (without backup) could be increased by around 1% in cooler California Climate Zones (Zones 1,2, 11, 12, 13, 14, 15 &16) when using an HRV.

Zonal Control

Zonal control (i.e. maintaining individual temperature set-points in different zones of a building) is a strategy that is fairly commonplace in most commercial U.S. buildings (F. Jazizadeh, et al., 2014), while the majority of single-family houses in the United States have HVAC systems typically controlled by a single, centrally located thermostat (Alles, 2006). In addition to the obvious advantage of increasing occupant comfort (Foster and Moses, 1993), a zone-based temperature control strategy has good potential to reduce energy use, given that the energy wasted for heating or cooling unoccupied spaces of a typical US home accounts for 15.9% of the total primary energy use (Meyers et al., 2010). Previous research on zonal control fails to quantify the improvement in delivery effectiveness of the duct system and system efficiency (equipment plus ducts) when used together with variable-capacity/airflow equipment. Key findings from the laboratory evaluation of VCHP with zonal control were:

a. Zoning allows for potential load reduction on the HVAC system when implementing temperature offsets in unoccupied zones. For example, a 10% load reduction corresponded with a 12.8% HVAC power reduction, while a 20% load reduction resulted in a 25.7% HVAC power reduction.
b. Efficiency impact is largely dependent upon on the temperature offset for unoccupied zones and the subsequent load reduction on the HVAC system.

Dual Fuel (Intelligent Heating)

This feature employs an electric heat pump (VCHP) with a high-efficiency gas furnace for backup heating. Calculations were performed to assess the economics of dual fuel heat pumps in selected locations in California. It was found that, in certain situations, the Next-Gen RSCS Dual Fuel Heat Pump (DFHP) can provide attractive savings compared to a gas furnace. The fact that operation of the DFHP can be adjusted as utility prices vary, allows the homeowner to benefit from future changes in utility prices that might affect the ratio of electricity to gas prices. The assurance that the homeowner will be able to experience the lowest future heating costs possible, is an important attribute of dual fuel heat pump capability and increases the value of this feature to potential purchasers of the Next-Gen RSCS.

Laboratory testing was performed that confirmed the functionality of the dual fuel heat pump concept in all possible modes of operation. These modes of operation were as follows: The furnace operated exclusively when the outdoor temperature was below the heat pump breakeven temperature. The heat pump operated exclusively when the outdoor temperature was above the heat pump breakeven temperature and above the heat pump balance point. When the outdoor temperature was above the heat pump breakeven temperature but below the heat pump balance point, the Next-Gen RSCS would cycle between the heat pump and the furnace with the heat pump being the primary source of heating and the furnace providing backup.

Fault Detection and Diagnostics (FDD)

Both the heat pump and the furnace have an extended list of faults that are detectable and which can aid in the repair and maintenance of the system. The testing of the FDD capabilities was limited in scope to primarily those faults that were thought to be the most likely to occur during normal usage. Thirteen of the 51 listed fault codes for the heat pump were triggered, as well as 5 of the 25 codes listed for the furnace, all of which were detected. Two key findings were:

a. The Next-Gen RSCS FDD system was very good at correctly identifying the cause of a fault condition when the fault event occurred.
b. The FDD system was not as good at alerting the user that a fault was occurring or notifying that a fault was on the verge of occurring (experiencing degradation) and should be attended to for optimal performance and preventive maintenance. This capability may be present with the existing components, and may just require a more sophisticated software upgrade. This

change should retain some conservatism such that the system will not trigger too many alerts, so that the end user stops paying attention and does not take action.

Alternative Refrigerant: Variable Capacity Space Conditioning with R-32

The performance of the Next-Gen RSCS variable capacity heat pump (VCHP) using R-32 as a drop-in replacement refrigerant was evaluated following similar test conditions for the VCHP using R-410A. It should be noted that the VCHP system has been designed for R-410A. Accordingly, the system was not optimally tuned for the differences in pressure and temperature of the R-32 refrigerant. Key findings include:

a. R-32 demonstrated an ability to be an effective, low Global Warming Potential (GWP) replacement for R-410A in the VCHP from an equipment performance and functionality perspective. The usage of R-32 in HVAC equipment offers a potential mechanism for peak power reduction in the warmest California climates.
b. In the Cooling mode, trends observed in the R-32 variable capacity heat pump are comparable to the trends observed for R-410A. At 95°F outdoor temperature, where nominal capacity is determined, the minimum output of the R-32 system was 29% of the maximum capacity. In R-410A testing of the variable capacity system, the minimum capacity was 30% of the maximum capacity at 95°F. The R-32 variable capacity system demonstrated increased efficiency at part-load operation, and the relative increase in efficiency from maximum to part-load operation increased with decreasing outdoor temperature.
c. The retrofit of R-410A to R-32 resulted in cooling efficiency increases of 6-9%, 1-3%, and 2-3% for maximum, intermediate and minimum operation, respectively.
d. With R-32 in the VCHP, the peak cooling performance improved by 6.7% – 8.2%. For residential equipment ranging from 2 – 4 tons, the R-410A variable capacity heat pump provides a potential peak reduction of 80 – 200W over a baseline 14 SEER system. Implementation of R-32 in the variable capacity heat pump provides an additional potential peak reduction of 125 – 475W depending upon equipment size.
e. For heating mode, R-410A and R-32 in the variable capacity heat pump yielded similar performance at maximum operation with COPs ranging from 2.4 to 3.5 from 15°F to 47°F, respectively at maximum heating operation.

Duct Loss Assessment with Variable Capacity Conditioning

Variable capacity systems have longer run times and therefore will have greater duct losses due to heat transfer, than comparably sized single speed (on-off) systems, when ducts are not in the conditioned space. These losses can offset variable capacity system modulation savings accruing under part load conditions. Tests were run for single zone and multizone configurations to assess the effect of duct losses on variable capacity system operation. Adding more insulation to ducts or keeping a portion of them in conditioned spaces will render the variable-capacity/variable-speed cooling technologies to be more beneficial.

Single-zone configuration

Key findings were:

a. VCHP connected to a duct system shows significant part-load energy-saving potential.
b. Reducing the fan and compressor speeds has more of an impact on distribution losses in the duct system when the indoor wet-bulb temperature is lower because of higher sensible

cooling. Since the duct losses occur through sensible heat gains, a larger percentage of total cooling produced is lost through the ducts. The result also implies that duct losses play a more significant role in the hot and dry California climates compared to hot and humid climates.

c. Mathematical modeling of the system with ducts agrees with 5% accuracy with experimental data and can be used to understand design-choice impacts. This model can be used to assess the impact of duct location and climate on duct losses and system performance with variable speed equipment.

Multi-zone configuration

Zonal control and variable capacity offers a potentially effective integration of two technologies for improved efficiency. The efficiency impact of zoning is largely dependent upon on the temperature offset for unoccupied zones and the subsequent load reduction on the HVAC system. Laboratory testing demonstrated altered variable capacity performance and functionality with the implementation of zoning. The data collected describes the performance characteristics of the system operating when—a) varying compressor speed and indoor fan speed together, and b) varying indoor fan speed while holding compressor speed fixed. Key findings include:

a. Adding zonal control to a variable-speed heat pump improves the System COP during cooling operations.
b. There is a tradeoff with higher fan power for zoned operation which creates an optimal zoning that does not necessarily coincide with the zoning that achieves the highest delivery effectiveness. In general, the optimal number of zones for maximizing System COP increases as the capacity/airflow percentage is increased.
c. Zoning is more effective at higher duct-zone temperatures. This is because the percentage increase in delivery effectiveness is higher due to zoning when the duct-zone temperatures are hotter, whereas the additional blower power consumption due to zoning is independent of temperature.
d. For very hot duct-zone temperature, the heat pump equipment using R-410A is capable of operating at lower capacities/air flow rates using a zoning mechanism that yields a System COP value comparable to the maximum System COP when operating without zoning. While lowering the capacity/air-flow rates hurt the System COP for hotter duct-zone conditions when operating without zoning. This result implies that in very hot climates, zoning can be employed in variable-capacity equipment to respond to demand-response events from the utility without compromising on efficiency.

Field Evaluation

The objective of the field evaluation is to assess the performance of Next-Gen Residential Space Conditioning System installed at residences with American-style ducting, and determine the energy efficiency benefits from the individual and collective technology features. Three residential host sites were selected, one in each of the three California IOU service territories (PG&E, SCE, SDG&E), to install and test the same Daikin/Goodman model VCHP units with refrigerant R-410A. The host sites were selected based on the CEC's recommended climate zones to provide qualitative and quantitative assessment of the VCHP in both heating and cooling mode. Table 4 summarizes the specifications of the three residential host sites and **Error! Reference source not found.** summarizes which features will be evaluated in each home. The new systems were installed in March 2018. The Measurement and Verification test plan will be presented at the ACEEE Summer Study with any preliminary results available by that time.

Table 4: Specifications of Residential Host Sites for Phase 3 Field Evaluation

CA IOU	City	Climate Zone	Area Sq. Footage	Vintage	Ducted HVAC system w/ Gas Furnace	Location of Ducts	Original AC unit size	Floors
PG&E	West Sacramento	12	2500	2008	Yes	Attic	3-ton outdoor; 4-ton indoor	2
SCE	Chino Hills	10	1850	1993	Yes	Attic	4-ton	2
SDG&E	San Diego	7	1906	1980	Yes	Attic	4-ton	1

Table 5: Variable Capacity Heat Pump Technology Attributes To Test at each Host Site

Technology Attribute	PG&E (2 story)	SCE (2 story)	SDG&E (1 story)
Variable-Capacity Compressor	Yes (4-ton outdoor unit, 5-ton indoor unit)	Yes (4-ton)	Yes (4-ton)
Variable-Speed Blower	Yes	Yes	Yes
Demand Response	Yes	Yes	Yes
Dual Fuel (intelligent heating)	Yes	Yes	Yes
Alternative Refrigerants[1]	No	No	No
Fault Detection & Diagnostics[2]	No	No	No
Integrated Ventilation[3]	No	No	No
Zonal Control	3 zones with R6 ducts	3 zones with R8 ducts	2 zones with R8 ducts
Duct-loss assessment	Single-zone, Multi-zone		

System Benefits and Discussion

Per California's Energy Efficiency Strategic Plan, HVAC is the single largest contributor to peak power demand in the state, comprising up to 30 percent of total demand in the hot summer months. The Next-Gen RSCS' combined technologies could significantly reduce peak demand. Variable-capacity systems have the unique attribute of going to a state of higher operating efficiency when the compressor speed is reduced. For a Demand Response event, a reduction in compressor speed provides a reduction in power draw, but with a correspondingly smaller reduction in cooling capacity. Per the Strategic Plan, the CEC estimates that a peak demand reduction of 1,096 MW could be achieved through high-efficiency HVAC installations

[1] R-32 was tested in the lab phase of the project. Since the use of R-32 has not been approved yet by the regulatory bodies, we cannot test R-32 in residential homes for the field test of the project. We rely on the lab testing for demonstration of the system performance.

[2] The laboratory testing of Fault Detection and Diagnostics (FDD) showed that the FDD alerts would occur when the unit was at the verge of breakdown/shut-down. Thus, the manufacturer has taken this information to improve upon their control algorithm for alert notifications. The model available for the field installation would not have any adjustments made from the laboratory results. We don't want to jeopardize the integrity of the new units installed in the homes if we were to test the FDD feature.

[3] All the approved host sites are pre-2013 construction, meaning they don't have ventilation requirements per Title 24 -2013 standards. Thus, if we were to evaluate the Integrated Ventilation feature (adding Heat Recovery Ventilator (HRV), there wouldn't be a meaningful baseline comparison. Instead adding an HRV to these homes would increase their energy consumption. Thus, we will rely on lab results that provide the energy savings for each CA climate zone by adding HRV to homes that have standard ventilation requirement (post 2013).

by 2020. Highlights of the preliminary results and benefits associated with the Next-Gen RSCS evaluated in this project are:

- Next-Gen RSCS' perform at higher system efficiency when operating at lower speed settings than rated levels.
- Next-Gen RSCS with demand response capability enables utilities to reduce peak demand.
- More efficient control strategies are needed for heat pumps connected to ductwork located in an attic for hot and dry California climate zones. The system balance is affected by the duct-zone temperatures, which invites the need for revising ducting standards.
- The Next-Gen RSCS has demonstrated its versatility with intelligent heating (dual fuel) capability and integrated ventilation configuration.
- Until legislative action is taken to approve of R-32 as a refrigerant for residential HVAC systems, the laboratory findings can be added to the literature, detailing experimental results evaluating a variable capacity heat pump system, designed for R-410A, but tested with R-32 as a drop-in refrigerant, and assessing its performance in both heating and cooling mode.
- Understanding the functionality and utility of Zonal Control with a variable capacity heat pump system can provide targeted energy savings. Recognizing that the variable capacity system performance is altered with zoning, the system efficiency with zoning is largely dependent upon on the temperature offset for unoccupied zones. This can be better evaluated during field demonstration.
- A variable capacity heat pump connected to a ductwork system in a multi-zone configuration has higher system COP when operating under zoned conditions, compared to non-zoning for the same capacity/airflow percentage and duct-zone temperature. Additionally, the benefit of zoning is realized at higher duct-zone temperatures.
- Fault Detection and Diagnostic (FDD) systems are helpful tools that can be used to improve HVAC unit performance. FDD's benefit customers by alerting them when an issue is taking place that could result in an incipient fault. This can permit the user or contractor to conduct preventive maintenance or take remedial measures to avert the fault condition.

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