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| **Description:** | *** THIS DOCUMENT SUPERSEDES TN 227429 *** - This webinar provided the results of an Electric Program Investment Charge (EPIC) research project focused on maximizing the energy efficiency of space conditioning systems. |
| **Filer:** | Cyrus Ghandi |
| **Organization:** | California Energy Commission |
| **Submitter Role:** | Commission Staff |
| **Submission Date:** | 3/29/2019 12:37:39 PM |
| **Docketed Date:** | 3/29/2019 |

# Development and Testing of the Next-Generation Residential Space Conditioner for California

CALIFORNIA ENERGY COMMISSION

## CEC EPC-14-021 EPIC Project Results and Technology Recommendations

**California Energy Commission**
**Electric Power Research Institute (EPRI)**
**Western Cooling Efficiency Center at University of California Davis**

March 27, 2019

# Project Funders and Partners with EPRI (Project Prime)

- Funders:



- Teaming Partners:




- Technology Provider:

# Project Funders and Partners with EPRI (Project Prime)

- Funders:

CALIFORNIA ENERGY COMMISSION

Commission Agreement Manager:
*Jackson Thach*

EPRI ELECTRIC POWER RESEARCH INSTITUTE

*Ammi Amarnath*, Project Manager

*Sara Beaini, PhD; Walt Hunt; Aaron Tam*

*Ron Domitrovic, PhD; Alekhya Vaddiraj*

- Teaming Partners:

PG&E Pacific Gas and Electric Company®

Applied Technology Services, San Ramon, CA

*Manny D'Albora, P.E. and Robert Davis, P.E.*

UC DAVIS UNIVERSITY OF CALIFORNIA

WCEC WESTERN COOLING EFFICIENCY CENTER

*Prof. Mark Modera, PhD, PE,* Director

*Curtis Harrington*

*Sreenidhi Krishnamoorthy, PhD*

*Robert Mcmurry, Caton Mande*

*Theresa Pistochini*

- Technology Provider:

DAIKIN Goodman Air Conditioning & Heating

*Ryohei Hinokuma*

Strategic Alliances Manager

# Webinar Agenda:
## Project Results and Technology Recommendations

| TOPIC | PRESENTER |
|---|---|
| Welcome & Background | *Jackson Thach, CEC and Ammi Amarnath, EPRI* |
| Project Overview: Scope, Features Tested, Summary Results | *Ammi Amarnath, EPRI* |
| Project Methodology | *Sara Beaini, EPRI* |
| Next-Generation Residential Space Conditioning System Evaluation Results | *Sara Beaini, Aaron Tam, EPRI*<br>*Curtis Harrington, WCEC* |
| Recommendations and Lessons Learned | *Sara Beaini, EPRI*<br>*Curtis Harrington, WCEC* |
| Technology Transfer | *Sara Beaini, EPRI* |
| Questions & Discussion | *All* |

# Project Overview: Scope, Features Tested, Summary Results

Ammi Amarnath

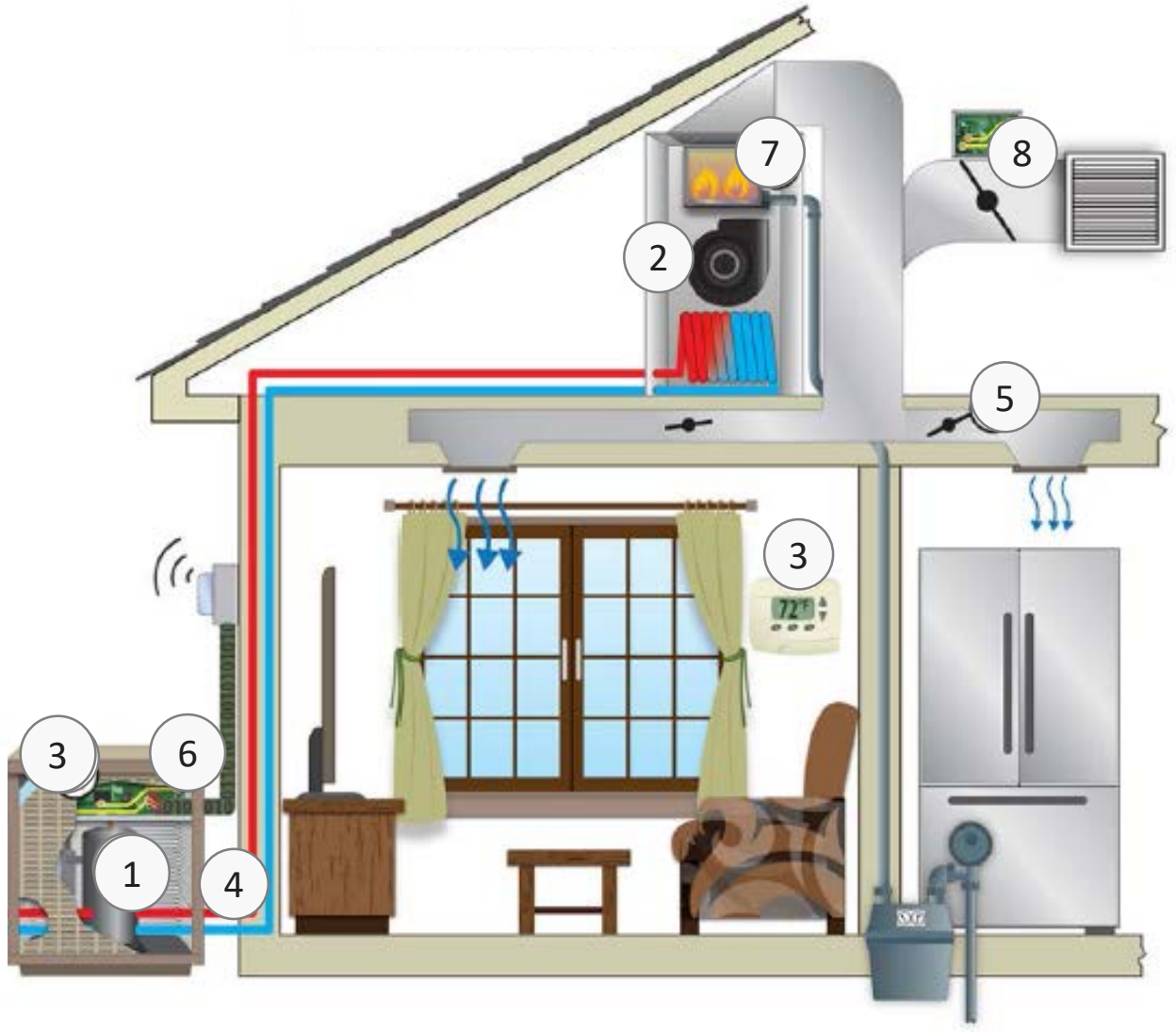
# Project Objectives: Next Generation Residential Space Conditioning System (Next-Gen RSCS) for California

- Develop *Variable Capacity Smart HVAC System*, *integrating* best energy-efficient technologies for California consumers - *Next-Gen RSCS*
- Test in independent labs to evaluate more energy-saving technologies
- Assess various configurations of Next-Gen system, optimized for CA consumer
- Field test system in 3 real-world operating environments to compare with traditional HVAC performance
- Technology transfer for stakeholders and public

# Next-Generation Space Conditioner Enhancing Technology Features

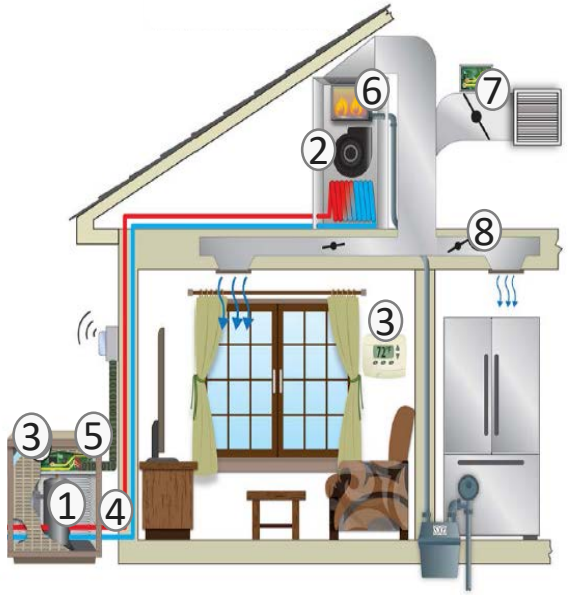
*multiple energy efficiency features integrated into single system*

1. Variable Capacity Compressor
2. Variable Speed Indoor Blower
3. Auto Demand Response
4. Alternative Refrigerant
5. Zonal Control
6. Fault Detection & Diagnostics
7. Dual Fuel (Intelligent Heating)
8. Integrated Ventilation Control



# Next-Gen RSCS Summary Results

- Variable Capacity Compressor and Variable Speed Indoor Blower
  - Next-Gen RSCS provides 22-32% cooling energy savings and over 90% of annual heating load without backup for CA.
- Auto Demand Response (DR)
  - Variable capacity heat pump maintains customer comfort during DR event.
- Alternative Refrigerant
  - R-32 improves cooling efficiency by 2-3% and peak demand reduction by 7-8% compared to R-410A across CA climate zones.
- Zonal Control
  - Zoning should be required for variable capacity heat pumps *with ducts in unconditioned space.*
- Fault Detection and Diagnostics (FDD)
  - FDD improves performance with potential, up to 55% efficiency savings (literature).
- Integrated Ventilation
  - Additional 1-4% cooling energy savings and 1% for heating using VCHP with heat recovery ventilator (HRV).
- Dual Fuel (Intelligent Heating)
  - Dual fuel functionality adds system versatility for future intelligent heating capability.

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# Project Methodology

Sara Beaini

# Technology Attributes Lab Tested in Phase 1 and Phase 2

| | Technology Attributes | EPRI | PG&E | WCEC |
|---|---|---|---|---|
| Phase 1 | Variable-Capacity Compressor | ✓ | ✓ | ✓ |
| | Variable-Speed Indoor Blower | ✓ | ✓ | ✓ |
| | Integrated Ventilation | ✓ | | |
| | Demand Response | ✓ | ✓ | |
| | Dual Fuel (intelligent heating) | | ✓ | |
| | Duct-loss assessment for single-zone | | | ✓ |
| Phase 2 | Alternative Refrigerants | ✓ (R-32) | ✓ (R-32) | |
| | Zonal Control | ✓ (R-32) | | |
| | Fault Detection & Diagnostics | | ✓ (R-410A) | |
| | Duct-loss assessment for multi-zone | | | ✓ (R-410A) |

**Technology Specifications**

- Outdoor Unit: 2-ton rated cooling capacity heat pump with inverter drive compressor
  SEER 19-21 / HSPF 9.6-10.0
- Furnace: 80,000 Btu/hr modulating burner, ½-hp variable speed blower, Rated AFUE 97
- Indoor Coil
- Smart Thermostat

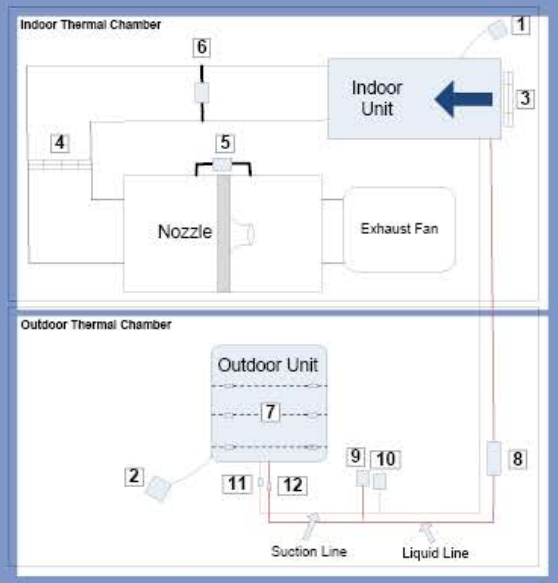
Daikin/Goodman residential heat pump units undergo testing at EPRI Thermal Laboratory, PG&E Applied Technology Services, and UC Davis Western Cooling Efficiency Center

Indoor Unit Setup at PG&E


EPRI Thermal Lab Environment Chambers

Outdoor Unit

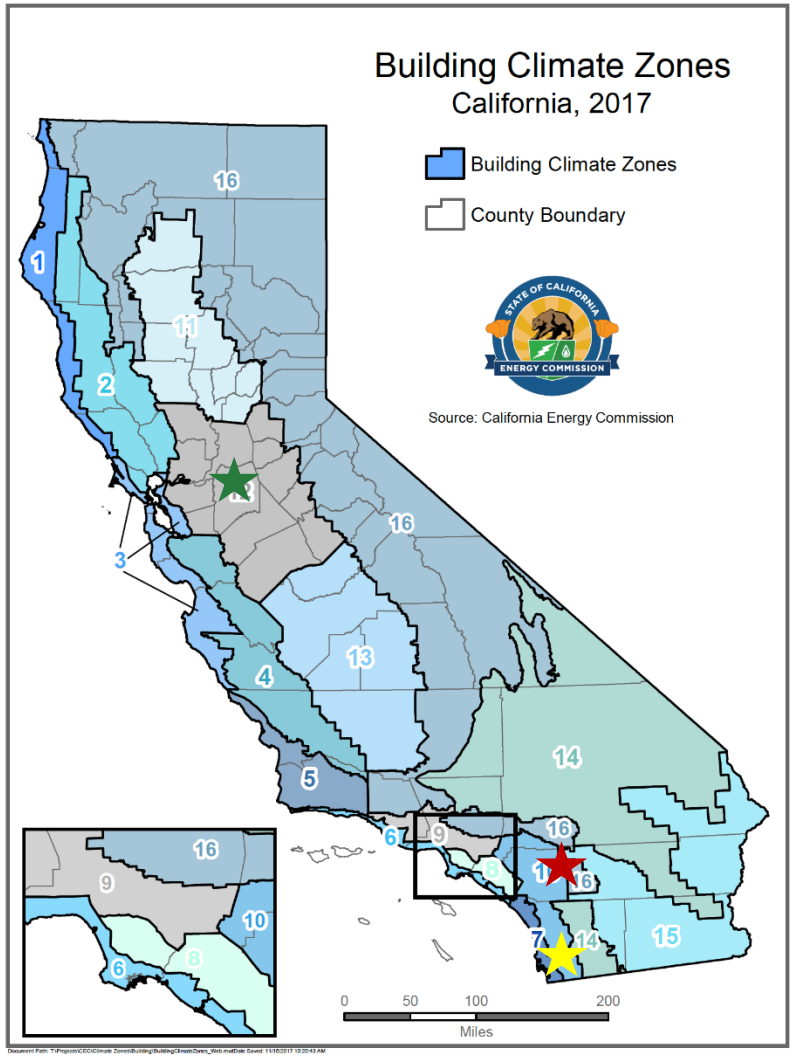
Ductwork Setup in WCEC Testing Chamber




Schematic of Test Setup

# Laboratory Evaluation: Phase 1 and Phase 2

# Phase 3 Field Evaluation




| Attribute/IOU | PG&E ★ | SCE ★ | SDG&E ★ |
|---|---|---|---|
| City | West Sacramento | Chino Hills | San Diego |
| Climate Zone | 12 | 10 | 7 |
| Area ($Ft^2$) | 2507 | 1850 | 1906 |
| Home Vintage | 2008 | 1993 | 1980 |
| Existing HVAC | Ducted AC with Gas Furnace | Ducted AC with Gas Furnace | Ducted AC with Gas Furnace |
| Location of Ducts | Attic | Attic | Attic |
| Existing AC Size (Tons) | 3-ton Condenser 4-ton AHU | 4 | 4 |
| Floors | 2 | 2 | 1 |
| Number of Bedrooms | 3 | 4 | 3 |
| Number of Residents | 4 + 1 pet | 4 + 1 pet | 1+3 pets |
| *Installed Size of Next-Gen RSCS* | *4- ton ducted split w/ gas furnace* | *4- ton ducted split w/ gas furnace* | *4- ton ducted split w/ gas furnace* |
| *New ducting* | *R-6* | *R-8* | *R-8* |
| *Number of Zones* | *4* | *3* | *2* |

# Technology Features Evaluated by Project Phase

| Technology | Phase 1 Lab Test | Phase 2 Lab Test | Phase 3 Field Test |
|---|---|---|---|
| Variable-Capacity Compressor | ✓ | | ✓ |
| Variable-Speed Blower | ✓ | | ✓ |
| Integrated Ventilation | ✓ | | |
| Demand Response | ✓ | | ✓ |
| Dual Fuel (intelligent heating) | ✓ | | ✓ |
| Duct-loss assessment for single-zone | ✓ | | |
| Alternative Refrigerants | | ✓ | |
| Fault Detection & Diagnostics | | ✓ | |
| Zonal Control | | ✓ | ✓ |
| Duct-loss assessment for multi-zone | | ✓ | ✓ |

# Field Installation: Host Sites

PG&E site

SCE site

SDG&E site

# Field Installation: System M&V

## Outdoor Unit

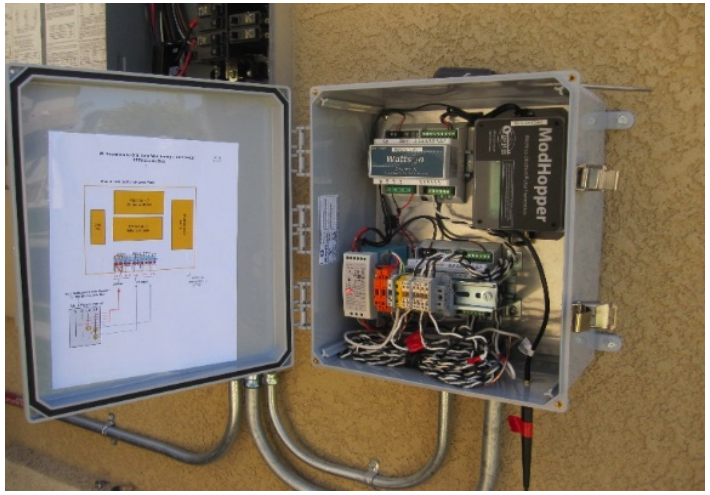
## Indoor Air Handling Unit

## EWC Controller


## Thermostat and sensors


## Attic Ducting

## EPRI M&V Box



# Next-Gen RSCS: Homeowner's Feedback

- Homeowners appreciate how much quieter the Next-Gen RSCS operates compared to previous singe speed AC unit
- Homeowners like how quickly it cools or heats the space
- Homeowners like having app-based controller with Thermostat to turn on specific zones
- Homeowners like  the ability to control temperatures in individual spaces (control zones independently
- Zonal control added complexity to the system use
  - Airflow was too forceful in certain zones, thus noisy in certain rooms
  - Adjusting weighting of the zones with Zonal Control board mitigated this effect

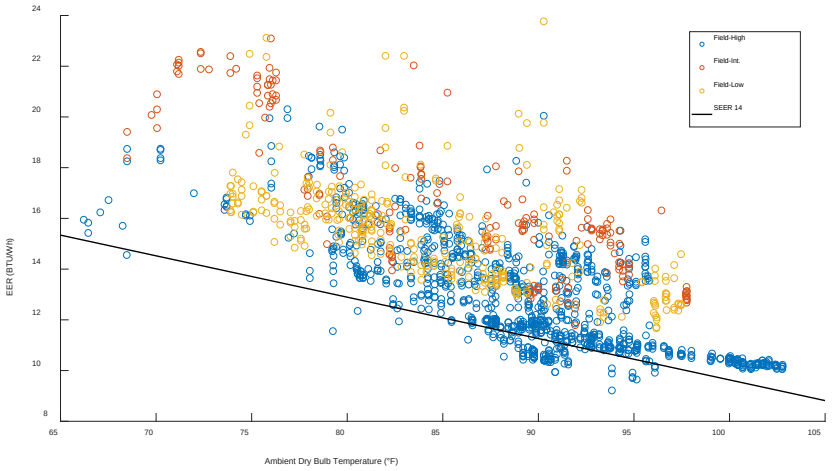
# Next-Gen RSCS Evaluation Results

Aaron Tam, Sara Beaini, Curtis Harrington

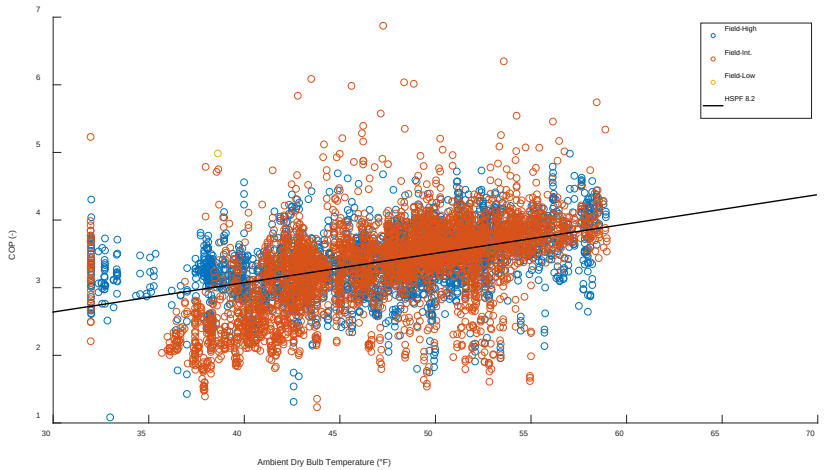
# Next-Gen RSCS Evaluation Results

- Variable Capacity Compressor and Variable Speed Indoor Blower

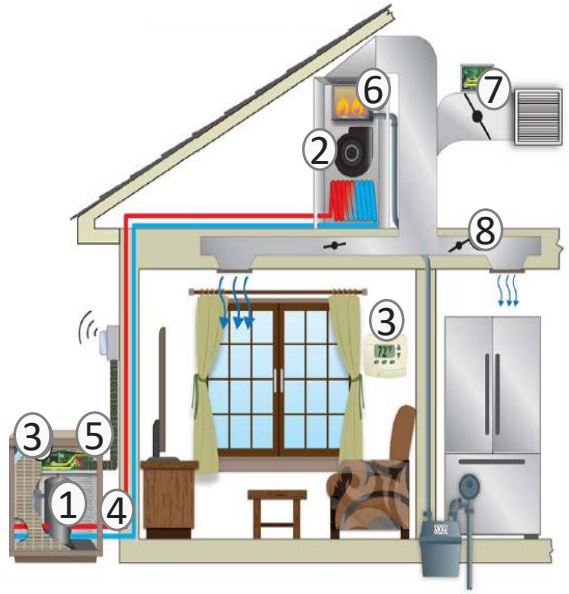
Variable capacity heat pump (SEER 21/HSPF 9.6) field data shows efficiency improvements over baseline (single speed SEER 14/HSPF 8.2)




Unit cooling efficiency results @ PG&E site




Unit heating efficiency results @ PG&E site

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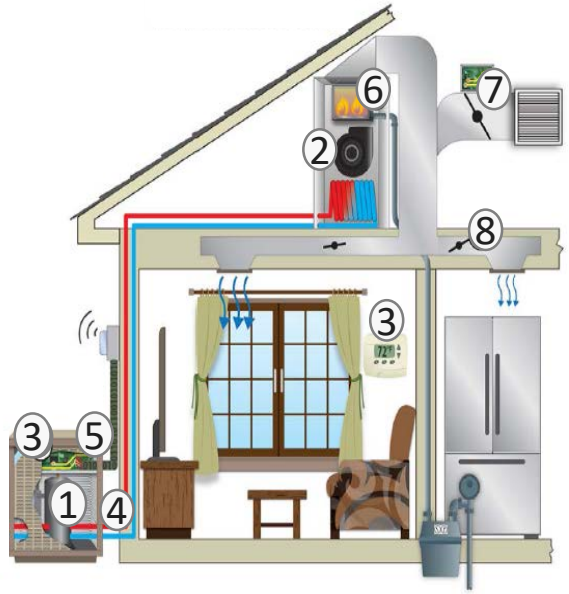
**Next-Gen RSCS provides 22-32% cooling energy savings and over 90% of annual heating load without backup for CA.**

# Next-Gen RSCS: Dual Fuel Heating Capability

- Dual Fuel Heating

*means electric variable capacity heat pump with natural gas furnace for back up*

- Key Metrics to Assess:
  - **Breakeven temperature**: *Temperature below which it is cheaper to provide heat with natural gas*
  - **Balance point**: *Temperature below which heat pump can no longer provide all the heating requirements of the space*

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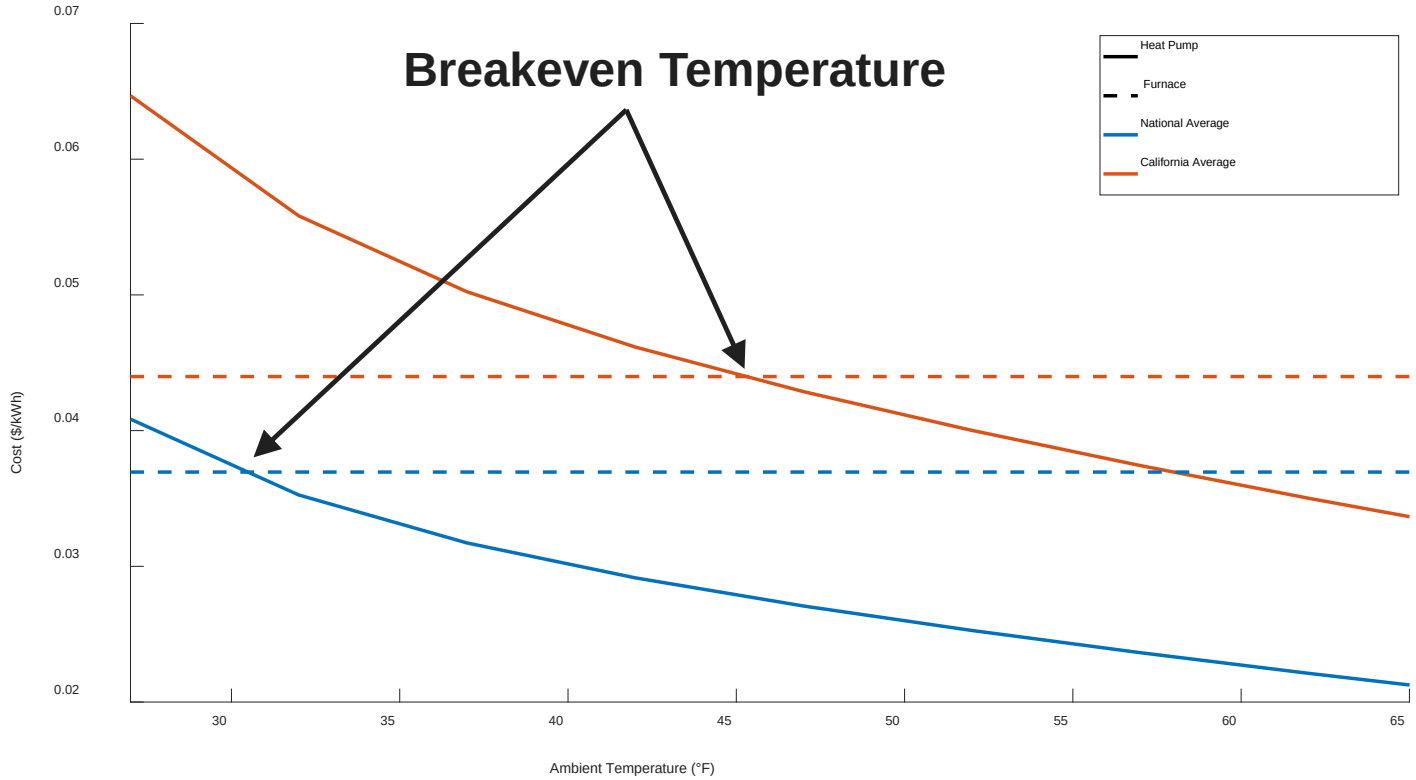
**Dual fuel functionality adds versatility to Next-Gen RSCS to provide intelligent heating capability in the future**

# Next-Gen RSCS: Dual Fuel Heating Capability – cont.

## Utility Rates Information

| | Electricity [$/kWh] | Gas [$/thm] |
|---|---|---|
| California Average | 0.19 | 1.25 |
| National Average | 0.12 | 1.05 |



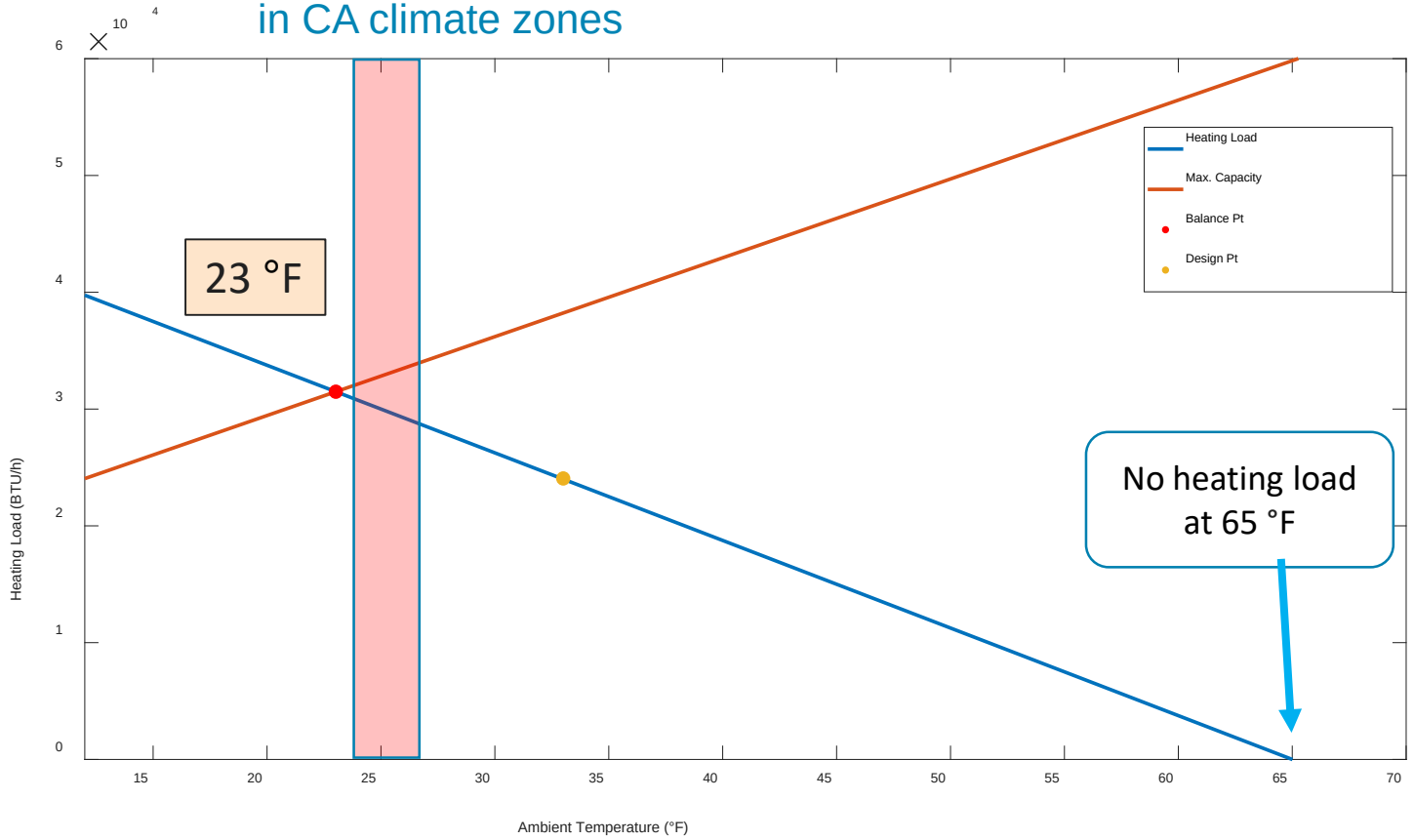

***Utility rates are primary drivers for incentivizing heat pump usage***

# Next-Gen RSCS: Dual Fuel Heating Capability – cont.

## Design Point for PG&E site

| | |
|---|---|
| Outdoor Temperature | 33°F |
| Indoor Temperature | 70°F |
| Heating Load | 24,000 Btu/h |

Average coldest temperature in CA climate zones

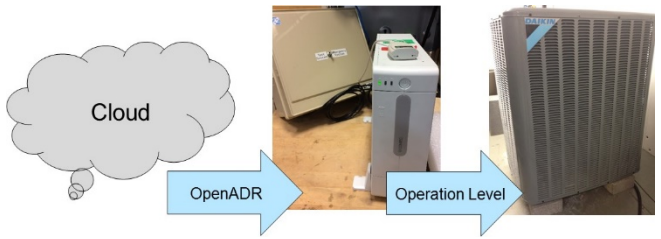



**Heat pumps are well suited for CA climate zones since they can meet almost all loads in the heating season *without backup***

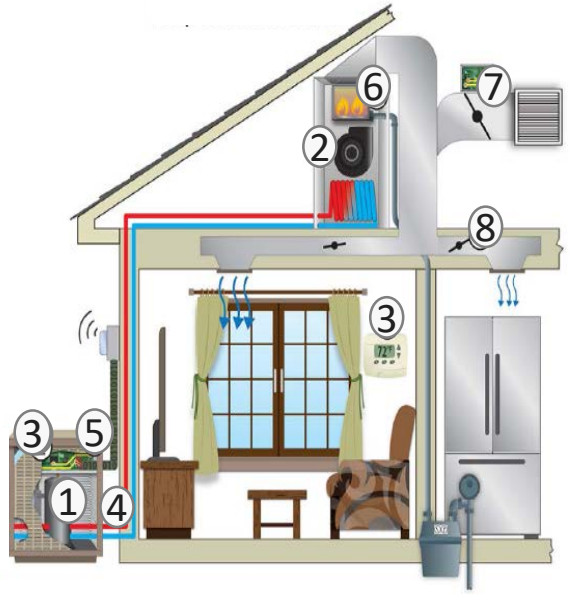
# Next-Gen RSCS Evaluation Results

## Auto Demand Response (DR)

- Variable Capacity Heat Pump can serve as a valuable and flexible DR resource
- Demonstrated ADR using OpenADR 2.0b
- Capacity reduction is less than the power reduction (non-linear)




| | Unit Power (W) | Percent Power Reduction | Approximate Cooling Capacity (Btu/h) | Percent Capacity Reduction |
|---|---|---|---|---|
| **Baseline Case** | 1,866 | - | 17,000 | - |
| **Event 1: 50% Power** | 928 | 50.3% | 10,500 | 38.2% |
| **Event 2: 30% Power** | 558 | 70.1% | 6,500 | 61.8% |

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**Variable capacity heat pump maintains customer comfort during demand response event.**

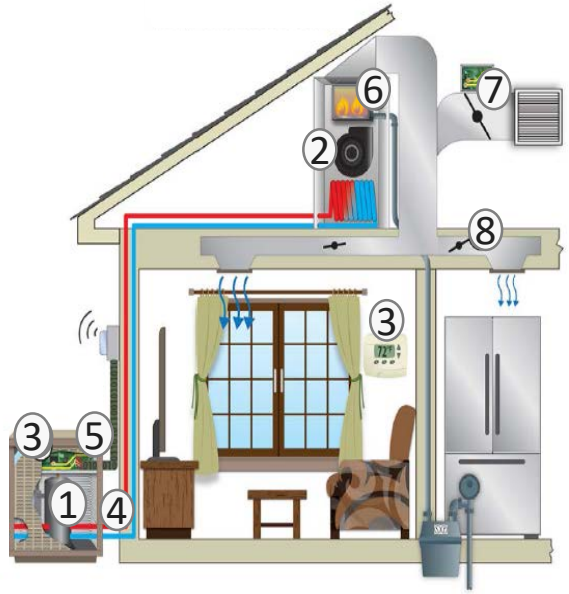
# Next-Gen RSCS Evaluation Results

- Alternative Refrigerant

## R-32 (GWP 675)

***Effective drop-in refrigerant in a Variable Capacity Heat Pump (VCHP) compared to R-410A (GWP 2100)***

- R-32 reduced system charge by 29% compared to R-410A.
- R-32 improved cooling performance by1.2 to 3.0% compared to R-410A.
- R-32 in HVAC equipment provided peak power reduction of 6.7%, 7.0% and 8.2% at 95°F, 105°F and 115°F compared to R-410A.
- R-32 increased heating capacity by 5% at 25°F and by 10% at 62°F, but COP was reduced by 2 to 4% compared to R-410A.

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**Lower GWP refrigerant improves Energy Efficiency.**
**Lower GWP refrigerant reduces refrigerant charge.**

# Comparison of R-32 and R-410A in Variable Capacity Heat Pump

## Equipment Cooling Efficiency Improvement for California Residences

| California Climate Zone | Representative City | VCHP R-410A | VCHP R-32 |
|---|---|---|---|
| 1 | Arcata | - | - |
| 2 | Napa | 32.3% | +1.8% |
| 3 | Oakland | 25.5% | +2.4% |
| 4 | San Jose | 29.6% | +2.5% |
| 6 | Los Angeles | 30.2% | +2.2% |
| 7 | San Diego | 28.3% | +2.2% |
| 8 | Long Beach | 29.9% | +3.0% |
| 10 | Riverside | 30.3% | +2.2% |
| 12 | Stockton | 28.6% | +2.5% |
| 13 | Fresno | 28.2% | +2.6% |
| 15 | Blythe | 22.4% | +2.7% |

22 – 32% cooling efficiency improvement with **R-410A VCHP**

*Additional 2 – 3% with* **R-32 VCHP**

## Equipment Cooling Peak Demand Reduction for Residences

| Outdoor Temperature (F) | VCHP R-410A | VCHP R-32 |
|---|---|---|
| 95 | 3.7% | 10.4% |
| 105 | 3.3% | 10.3% |
| 115 | 2.6% | 10.8% |

3 – 4% peak demand reduction with **R-410A VCHP**

*Additional 7 – 8% with* **R-32 VCHP**

**R-32 improves cooling efficiency by 2-3% and peak demand reduction by 7-8% compared to R-410A across CA climate zones.**

# Next-Gen RSCS Evaluation Results

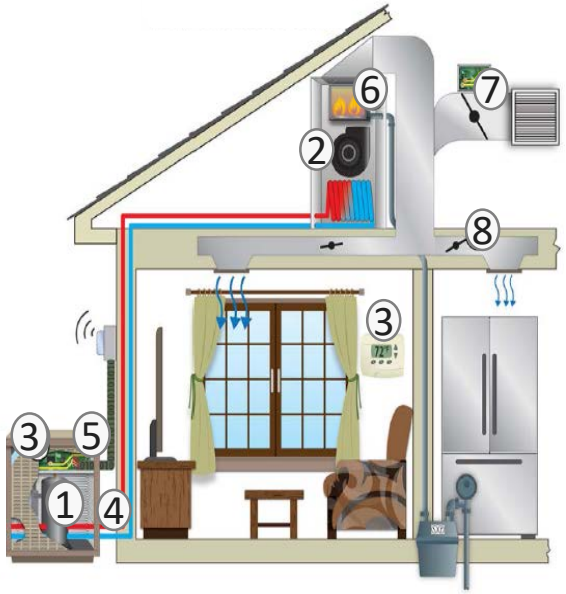
## Fault Detection and Diagnostics

*Ability to detect system degradation in performance and trigger diagnostics for service to remedy issues*

- Detectable faults were identified in both heat pump and furnace
- FDD system can provide up to 55% efficiency savings (literature)
- *Feature refinement needed to provide notification in advance of fault occurrence*

**Technician View**

**Homeowner View**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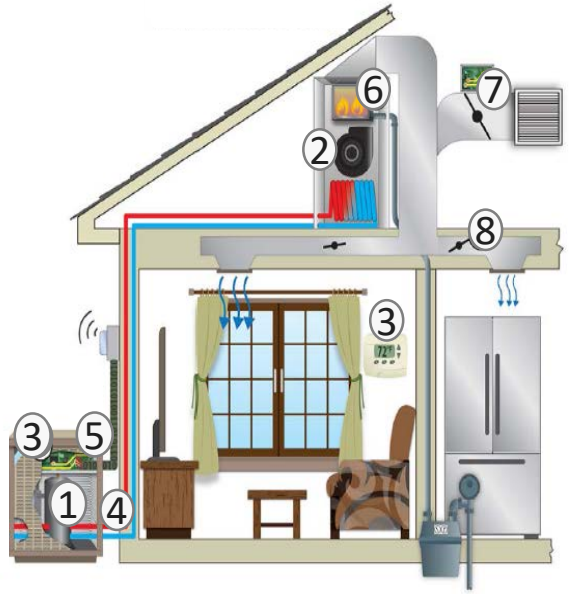
**Fault detection and diagnostics improves performance with up to 55% efficiency savings**

# Next-Gen RSCS Evaluation Results

## Integrated Ventilation

*Using heat recovery ventilator (HRV) to provide fresh air ventilation efficiently by exchanging heat between a fresh air and exhaust air stream*

| CA Climate Zone | City | Annual Energy Savings for Cooling Season | | Percentage of Modeled Annual Heating Load Satisfied by VCHP | |
|---|---|---|---|---|---|
| | | VCAC | VCAC + HRV | VCHP | VCHP + HRV |
| **1** | Arcata | - | - | | |
| **2** | Napa | 32.3% | +2.3% | 91.1% | +0.9% |
| **4** | San Jose | 29.6% | +1.8% | 94.2% | +0.7% |
| **10** | Riverside | 30.3% | +3.5% | 93.9% | +0.7% |
| **12** | Stockton | 28.6% | +3.2% | 88.6% | +1.3% |
| **13** | Fresno | 28.2% | +3.7% | 87.5% | +0.9% |
| **15** | Blythe | 22.4% | +3.6% | 87.5% | +1.0% |
| **16** | Bishop | 28.2% | +3.8% | 95.5% | +0.7% |

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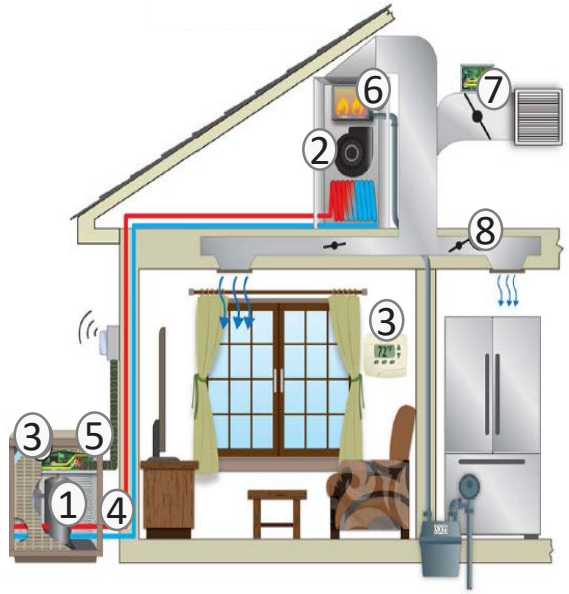
**Additional 1-4% cooling energy savings and 1% for heating using VCHP with Integrated Ventilation for CA climate zones**

# Next-Gen RSCS Evaluation Results

## Zonal Control

*Separating conditioned space into smaller zones, by using dampers within the ductwork and controlled with a thermostat or unit controller*

- Zoning should be required for variable capacity heat pumps (VCHP) with ducts in unconditioned space
- Require a *minimum of 2 zones* when installing VCHP **OR** place *ducts in **conditioned** space*
  - 2-zone equipment is well-established and poses few technical challenges
  - 2-zone systems would achieve much of the benefits
    - 39% better effectiveness at low speed vs. R-6 with no zoning
- Optimal zoning for the full range of operating speeds can be challenging
  - Coordination is needed between zone controller and fan speed

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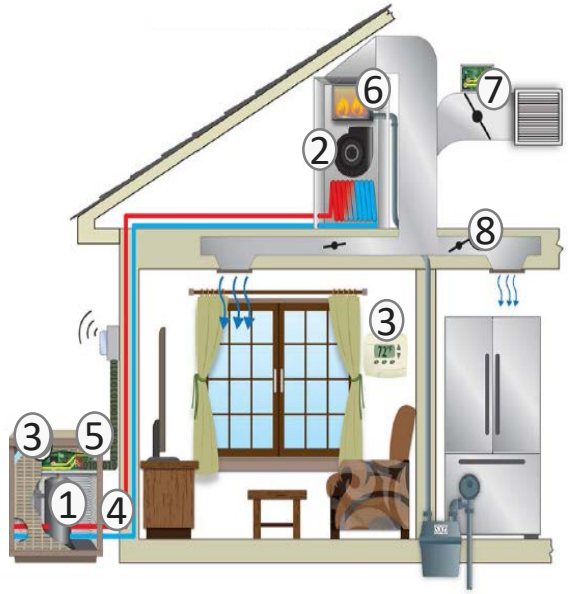
**Zoning should be required for variable capacity heat pumps *with ducts in unconditioned space.***

# Next-Gen RSCS Evaluation Results

## Duct Delivery Effectiveness

*How well ducts deliver the conditioned air to ducted space*

- Duct loss assessment with variable capacity heat pump
  - Actual duct design for a 2-ton single-family system
  - Ducts located in unconditioned space (same temp as outdoor)
  - Standard new-construction duct insulation – R-6
  - No duct leakage

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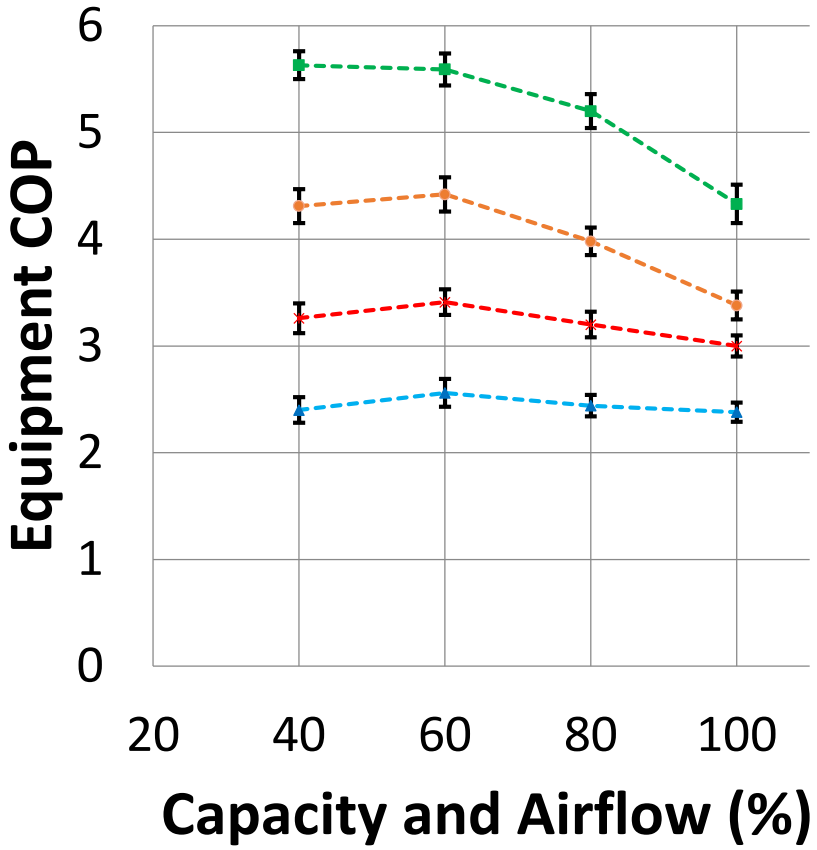
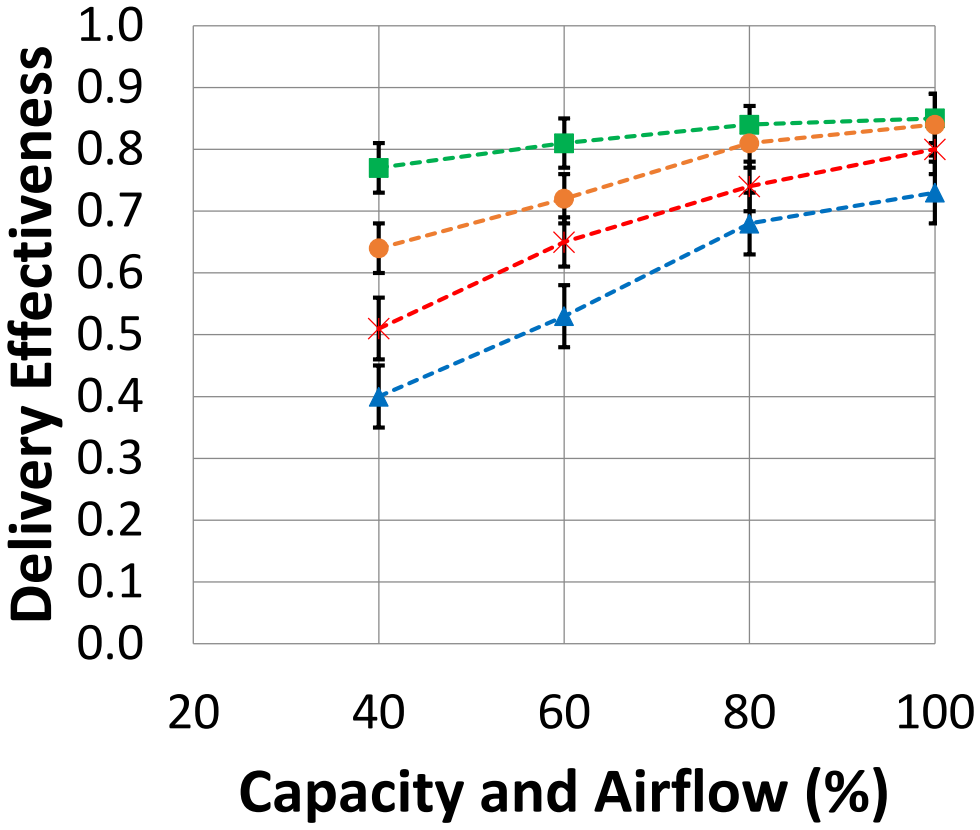
**Maximum System COP depends on outdoor/attic temp**

# Equipment COP and Duct Efficiency vs. Compressor and Fan-Speed




Duct-zone temperatures:

- 85°F
- 95°F
- 105°F
- 115°F

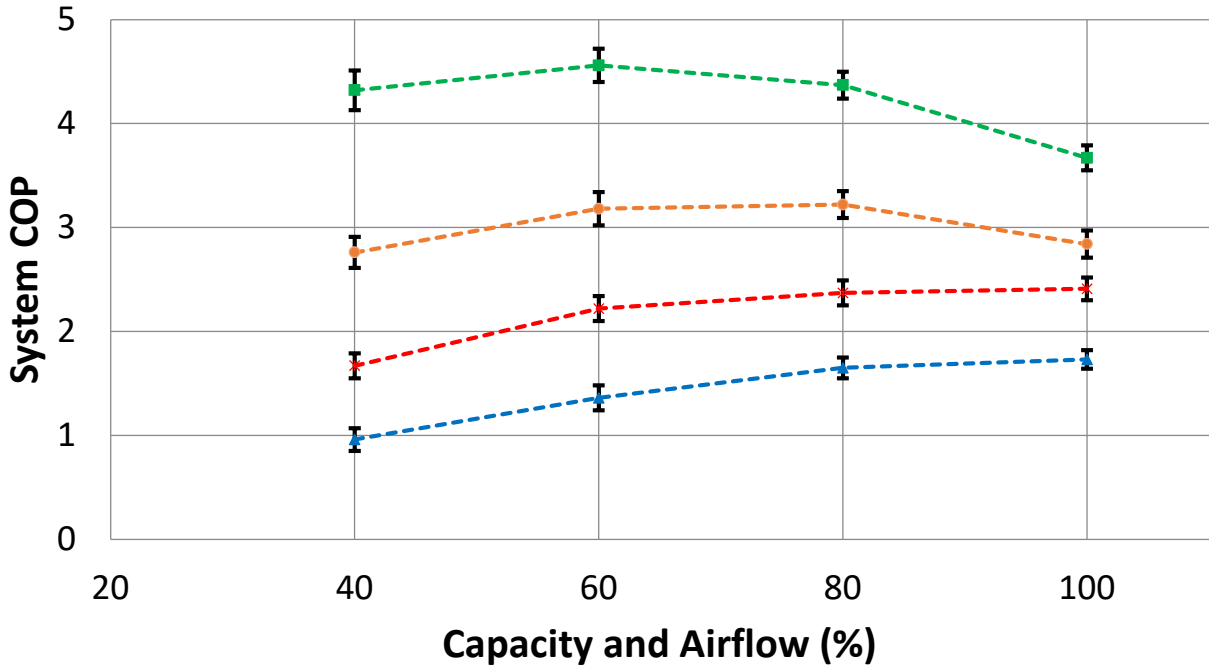



**Equipment performance increases as speed is reduced**

**Delivery effectiveness decreases as speed is reduced**

# System COP

- System COP = Equipment COP x Delivery Effectiveness
  - *System COP describes overall efficiency including equipment and ducts*
- Maximum System COP depends on outdoor/attic temperature



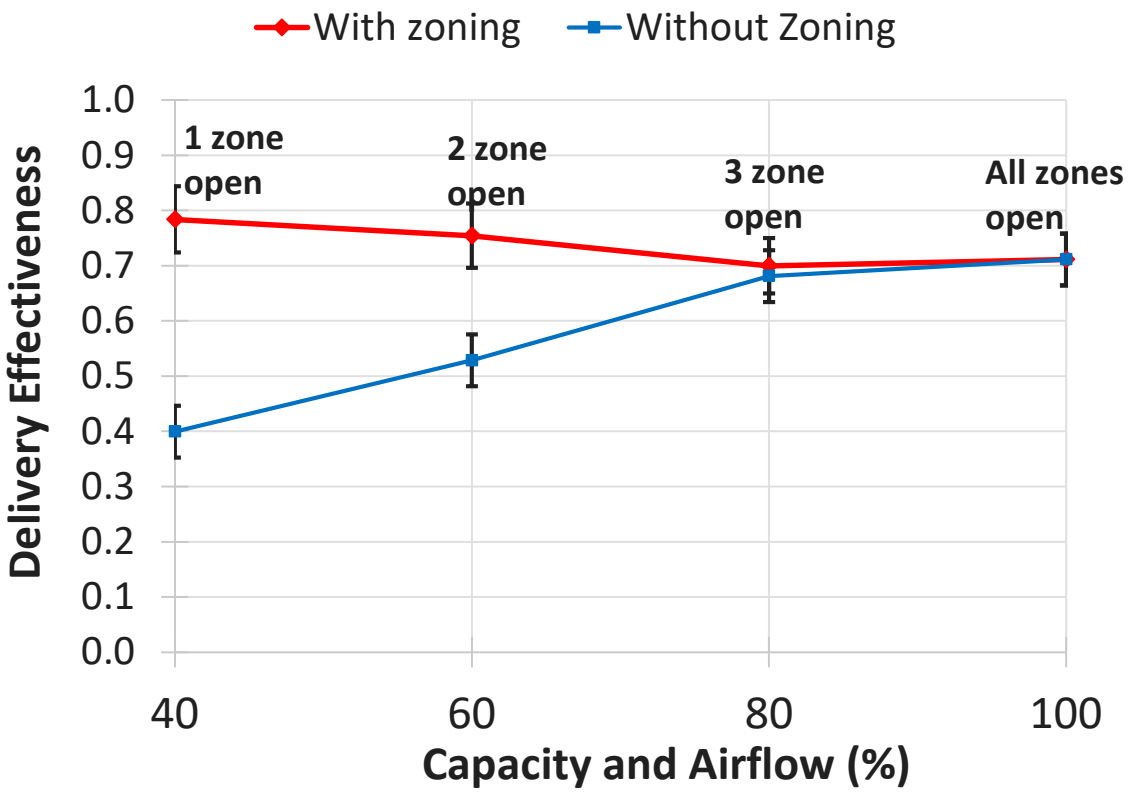

Duct-zone temperatures:

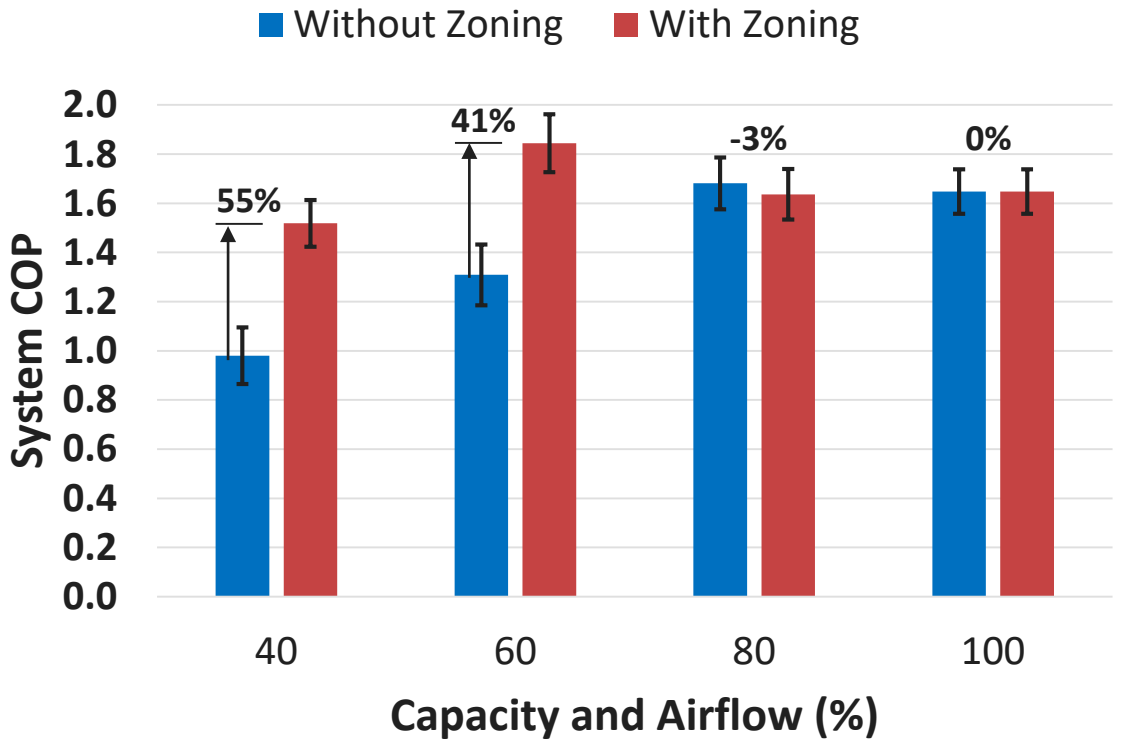
- 85°F
- 95°F
- 105°F
- 115°F

**Optimal speed at high temperatures is 100%**

# Impact of Adding Zoning: (Attic: 115°F, Indoor: 75°F)

- 95% more cooling delivered when zoned at low speed
- 40-55% better system efficiency at low speed

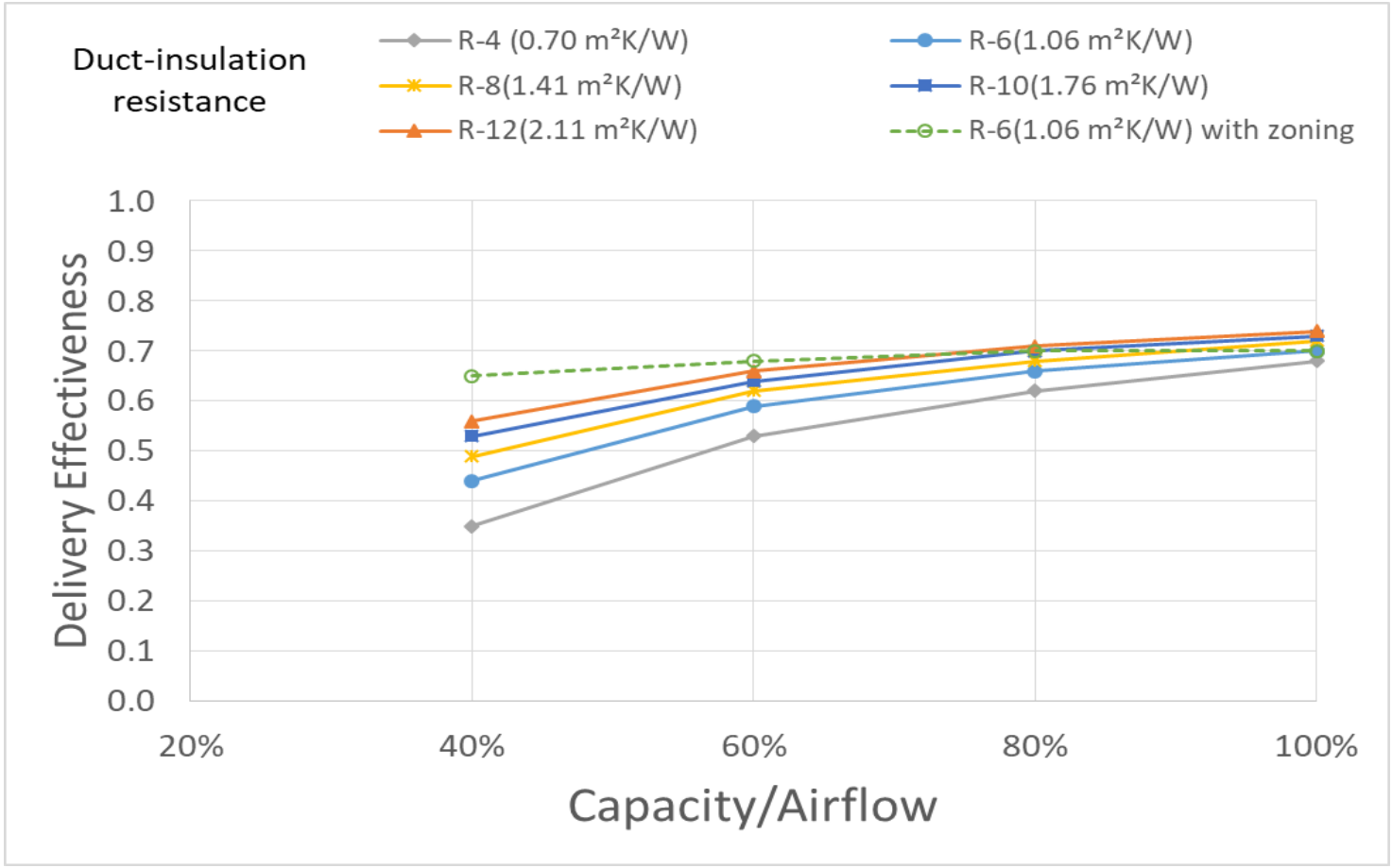



**Zoning can significantly reduce duct losses at low speed**

# Zoning versus Adding Insulation: (Attic: 115°F, Indoor: 75°F)

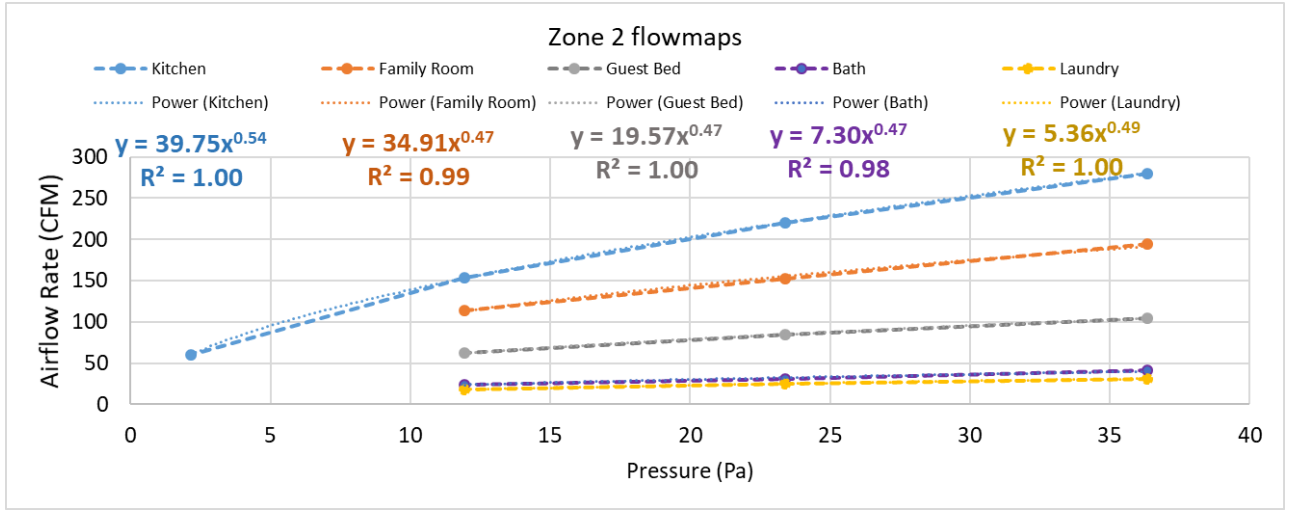
- R-6 with zoning had best performance
- All had similar effectiveness at high speed
- R-12 had 20% higher effectiveness than R-4 at low capacity



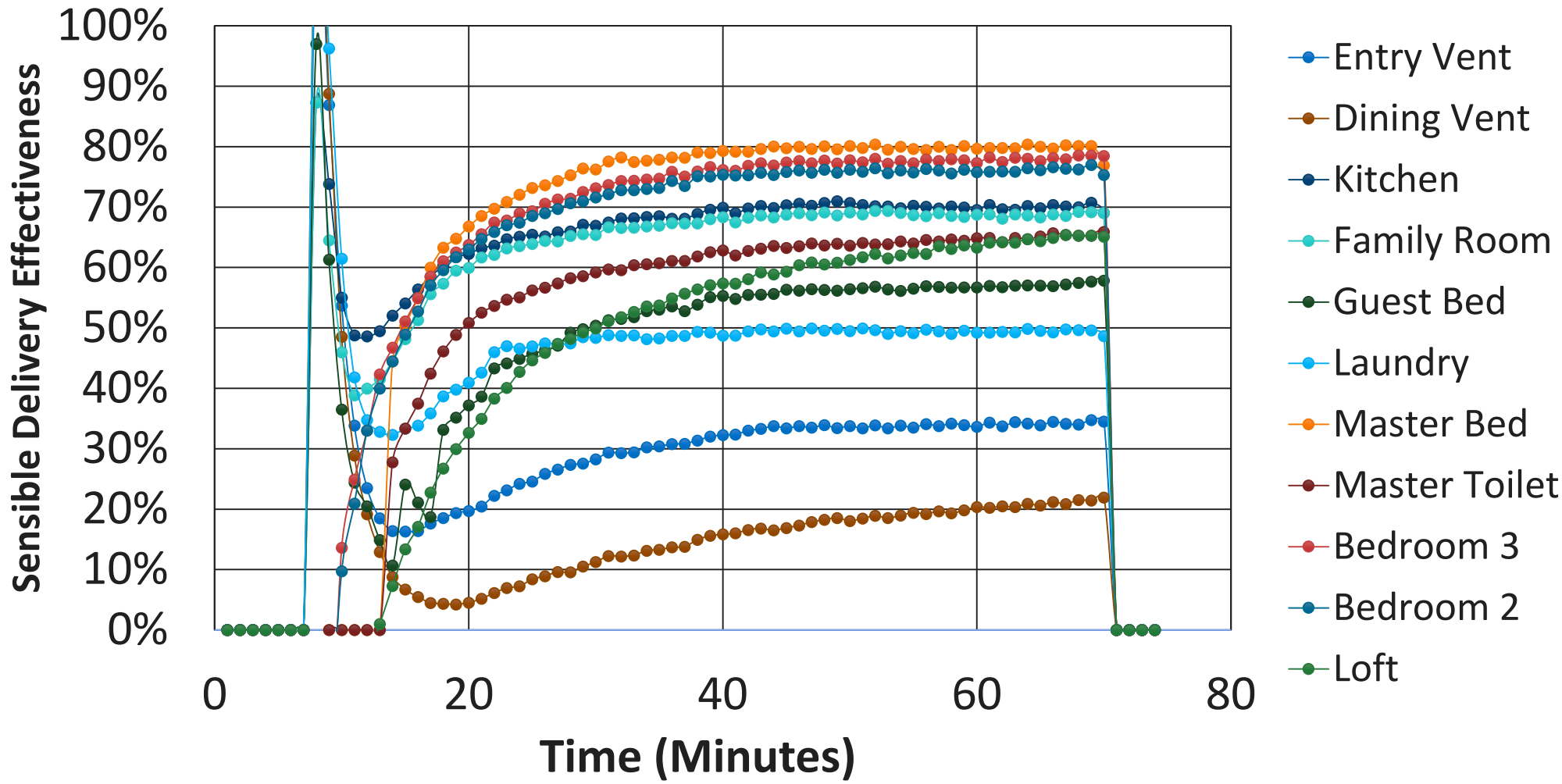
# Field Evaluation of Duct Losses

- Delivery effectiveness for each grill monitored
  - Temperature at each grill
  - Temperature/Relative Humidity at equipment
  - Airflow mapped for each grill
  - Indoor and outdoor unit power

Allows us to develop flow map for ducting system



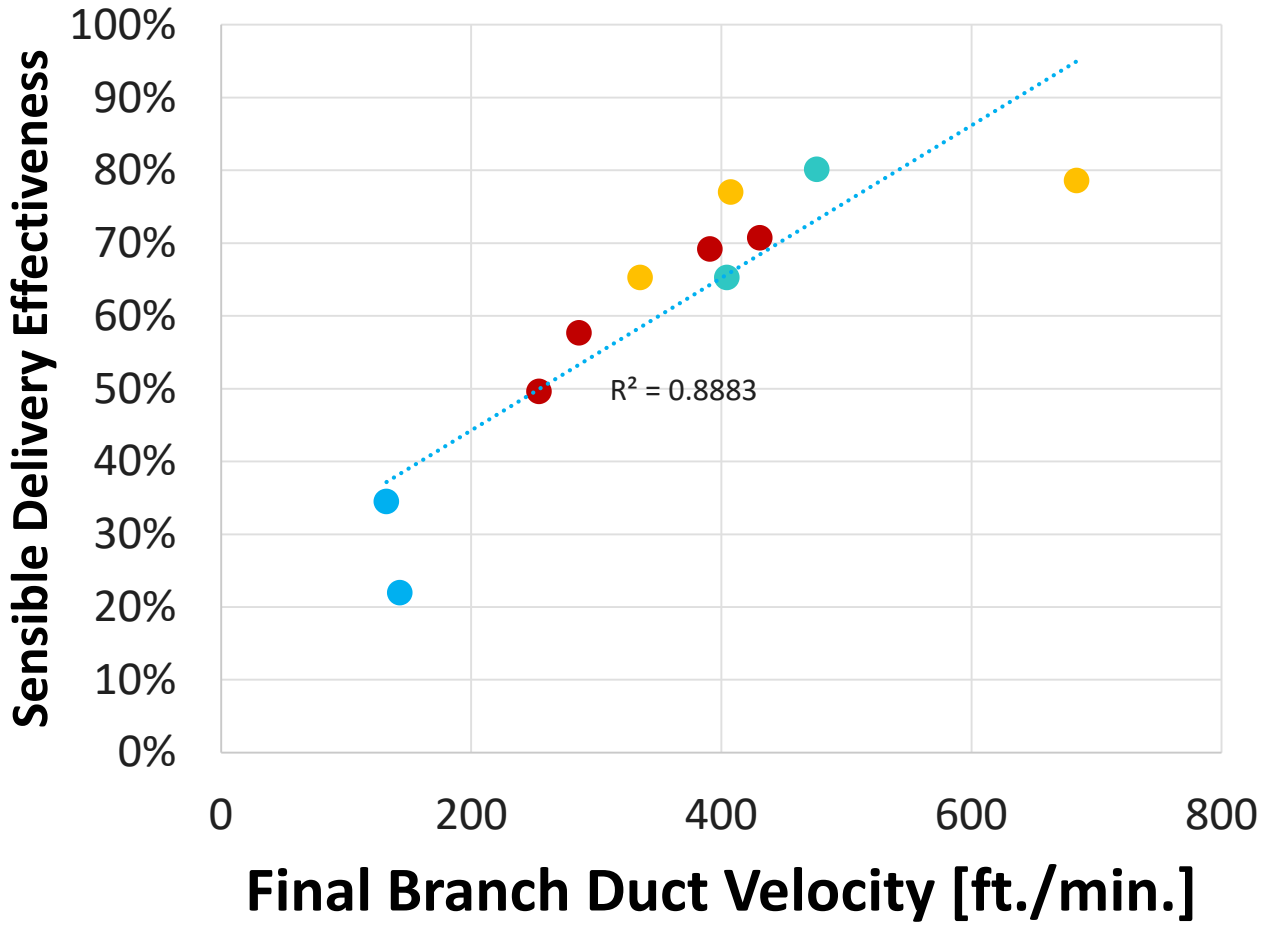
# Delivery Effectiveness for Each Grill




**Delivery effectiveness varies between grills and ranged from 20-80%.**

# Impact of Duct Velocity and Delivery Effectiveness

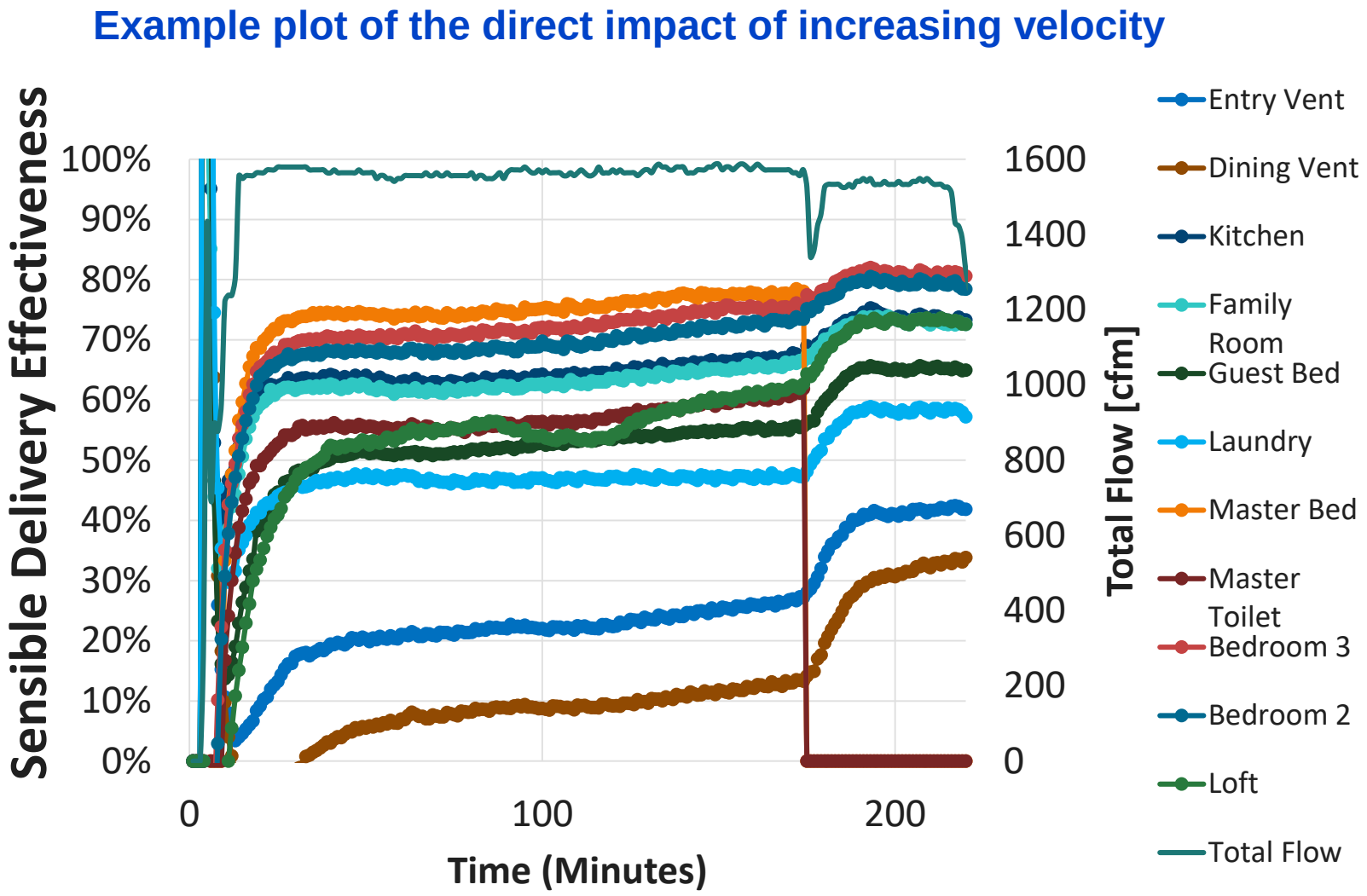
- Velocity is good indicator of effectiveness
- Lower velocity resulted in lower effectiveness
- Typical max velocity in res. = 600 ft/min




**50% reduction in fan speed results in only 30% reduction in delivered capacity**

# Higher Velocity Resulted in Higher Delivery Effectiveness

- Zone 3 closed (Master Bed, Master Toilet) at ~175 minutes
- Airflow stayed relatively constant
- Remaining active grills had an increase in delivery eff.
  - 25% increase in velocity
  - 10% increase in delivery effectiveness



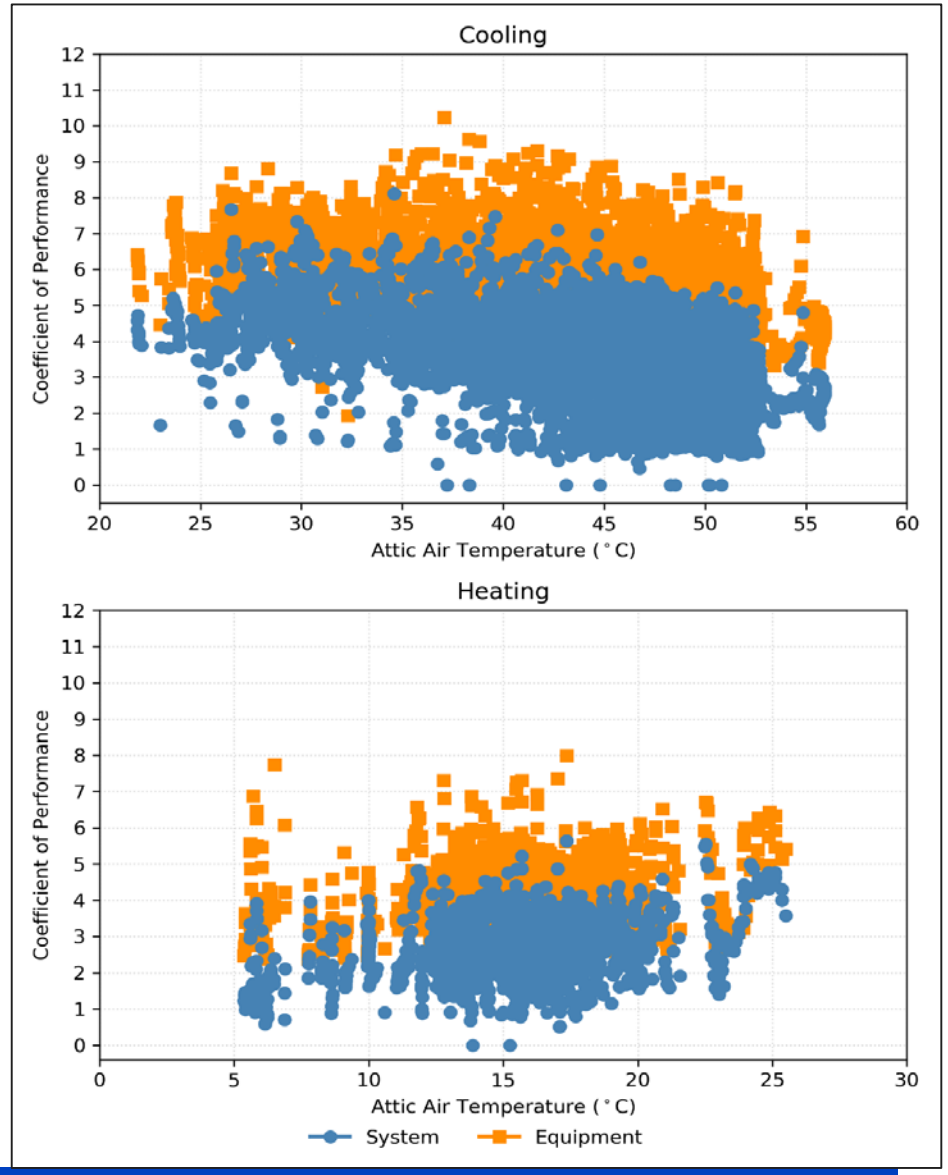
# Equipment and System COP (SDG&E)

## Cooling Data

- Average Equipment COP = 5.2
- Average System COP = 3.4
- Delivery Effectiveness = 65%

## Heating Data

- Average Equipment COP = 3.8
- Average System COP = 2.6
- Delivery Effectiveness = 68%




**Delivery effectiveness was good but not optimal**

# Recommendations and Lessons Learned

Sara Beaini, Curtis Harrington

# Next-Gen RSCS: Key Takeaways

- **Variable-speed systems have tremendous possibilities**
  - Allow control of ratio of cooling and dehumidification
  - Ducts in unconditioned spaces can significantly impact VCHP system performance
  - Duct location and insulation will impact choice of control algorithms

- **Best Solution:  Variable-speed systems with zoning**
  - Combination of variable speed and zoning addresses equipment/duct interactions
  - Facilitates energy-efficient demand response programs
  - Increased duct insulation can also reduce equipment/duct interactions

# Suggestion: Configure the Next-Gen RSCS into Different Models

| Next-Gen RSCS Energy Efficiency Technology Feature | Efficiency/Cost Savings Potential compared to SEER 14 single speed without that feature | Base Model | Intermediate Model | Premium Model |
|---|---|---|---|---|
| Variable-Capacity Compressor & Blower | 22% to 32% in this study | ✓ | ✓ | ✓ |
| Fault Detection & Diagnostics | Up to 55% from the literature | ✓ | ✓ | ✓ |
| Demand Response | | ✓ | ✓ | ✓ |
| Zonal Control | Up to 50% savings at 40% system capacity | ✓ | ✓ | ✓ |
| Dual Fuel (intelligent heating) | Up to 22% for cases run | | ✓ | ✓ |
| Integrated Ventilation | 1-4% seasonal cooling energy savings | | | ✓ |
| Alternative Refrigerants | 1.2% to 3% for cooling | | | ✓ |

**A request to the manufacturers to configure different models of Next-Gen RSCS for different market segments/climates/demographics**

# Opportunities for Future R&D

- Examine cost effectiveness of each feature in California
  - Develop model to evaluate energy and demand cost savings for each feature and corresponding incremental equipment cost for all California climate zones for representative housing, demographics and occupancy situations
- Zonal Control
  - Adding more zones (ex. 3-4) adds further complexities that need to be addressed in the design stage of the ducting work, with proper sizing with variable capacity heat pump
  - Zone controllers could incorporate feedback on airflow to avoid over-pressurizing smaller zones
- Codes and Standards (Title 24 and ASHRAE)
  - Examine ways to limit the heat transfer to ducts in unconditioned spaces such as attics (ex. adding insulation, zonal control and duct sizing)

# Opportunities for Future R&D…continued

- Provide Heating Controller (Intelligent Heating)
  - Similar to demand response controller but receives signal based on efficiency preference, economics (utility prices), environmental factors (carbon footprint of fuel source)
- Dual fuel heat pump
  - Is a high efficiency furnace warranted for California climates (with limited heating hours and where some of those hours can be served by the electric heat pump)?
- Fault Detection and Diagnostics
  - Refine sensitivity of the controls to small changes in system performance → anticipate maintenance, halt system degradation as early as is possible
  - Thoroughly test in the laboratory by simulating incrementally small changes in selected parameters to examine the sensitivity of the controls to identifying gradual degradation in performance
- Alternative Refrigerants
  - Address technology and regulatory needs for the use of R-32 (GWP 675) (or equivalent) as a drop-in refrigerant for R-410a (GWP 2100) systems

# Technology Transfer

Sara Beaini

# Technology Transfer to Stakeholders

- *Leveraging Utility Energy Efficiency and Demand Response Programs for Commercialization and Market Transformation*
- Focused workshop with utilities and key stakeholders in early 2019
- EPRI Advisory Meetings with Utility Members
- EPRI Energy Efficiency and Demand Response Symposia
- EPRI Electrification Conference and Exposition 2018
- EPRI Next-Generation Heat Pump Deployment Initiative
- Supporting AHRI 1380 Standard for Automated Demand Response for VCHP
- Supporting future California Title 24 Building Standards
- Presentations at key industry meetings and conferences:
  - CEC EPIC Symposia
  - ACEEE 2018
  - ASHRAE 2019
  - etc…

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- Daikin/Goodman and EWC Controls
- Host Site Participants

- Morton Blatt, Dean Kato
- Technical Advisory Committee

# Questions & Discussion

# Together...Shaping the Future of Electricity

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# Other Resources

More Information About this Project & Final Report-
http://innovation.energy.ca.gov/SearchResultProject.aspx?p=30005&tks=636892844467435460

More Information about EPIC Program-
https://www.energy.ca.gov/research/epic/

More Information about Natural Gas Research Program-
https://www.energy.ca.gov/naturalgas_research/

More Information about EPRI and WECEC-
https://www.epri.com
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