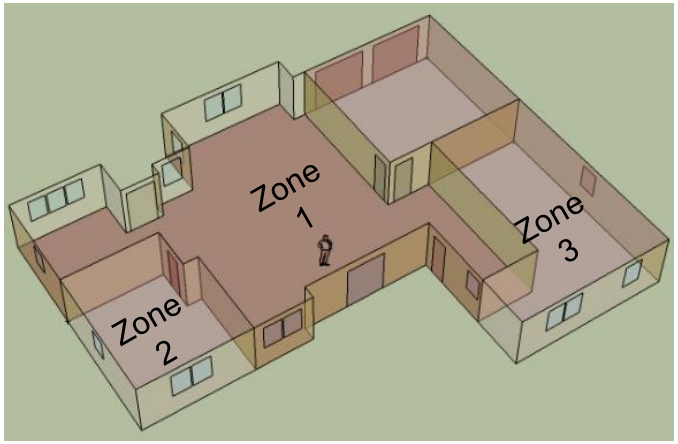
U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Integrated HVAC Control Methods for Mini-Split Heat Pumps in Existing Homes


```
/** Begin: Mini-Split Heat Pump Set Point *
 * ================================================
 * MSHP set point = MSHPsp = Ti -[(SO + AO) + (NO*NF
 * Ti = Desired indoor space temperature (Central Sy
 * SO = Standard temperature offset = 5
 * AO = Additional Offset = (To-Tio)/Trd
 * To = Outdoor temperature
 * Tio = Desired indoor temperature during occupied
 *       into stage 2 when recovering from daytime s
 * Trd = Temperature Response Denominator = 4
 * NO = Night offset = -1
 * NF = Nightime flag = 1 during sleeping hours or 0
 * ================================================
 */
var tempSet = nestData.target_temperature_f; //76; /
var standardOffset = 5; //SO
```



University of Central Florida, Florida Solar Energy Center
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Project Summary

Timeline:

Start date: October 1, 2017

Planned end date: September 30, 2019

Key Milestones:

1. Document persistence of supplemental mini-split savings. December 2018
2. Demonstrate ability to maintain whole house comfort with supplemental mini-split. December 2018
3. Complete design of integrated controller. December 2018

Budget:

Total Project $ to Date (March 31, 2019):

- DOE: $163,358
- Cost Share: $21,124

Total Project $:

- DOE: $283,479
- Cost Share: $31,495

Key Partners:

MITSUBISHI ELECTRIC
Cooling and Heating Solutions

Project Outcome:

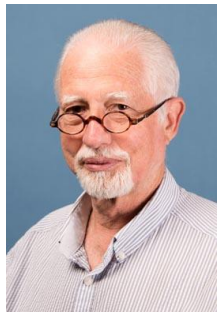
Develop and demonstrate an integrated controller that coordinates operation of an existing central space conditioning system with a single, centrally located mini-split heat pump. Control algorithm minimizes EUI by prioritizing mini-split runtime, and invokes central system to ensure comfort in bedroom zones and during peak load. *Project goal is to enhance space conditioning energy savings beyond simple addition of a mini-split by 10%, contributing to MYPP Goal of reducing EUI by 40% in existing homes.*

Team

FLORIDA SOLAR ENERGY CENTER™
Creating Energy Independence


Eric Martin


Karen Fenaughty


Danny Parker


Tom Cummings


Lixing Gu, PhD


Bereket Nigusse, PhD

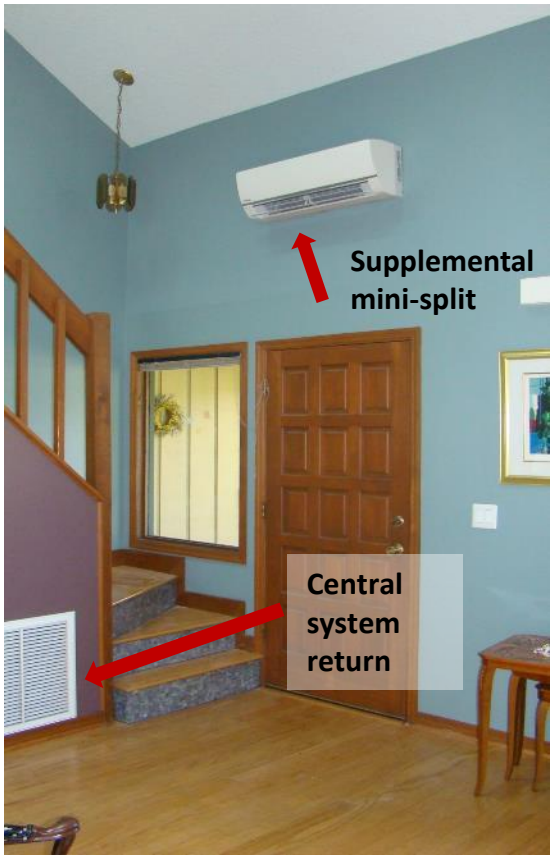
- Involved in several prior studies investigating performance of variable capacity space conditioning systems.
- Data and participants from one such prior study leveraged for the current project.
- Instrumental in developing, field testing, and overcoming market barriers for many new high performance housing technologies.
- EnergyPlus expertise.

MITSUBISHI ELECTRIC

- Cost sharing partner, providing mini-split heat pumps and in-kind support related to:
  - Equipment selection
  - Available control platforms/strategies
  - Commercialization

Challenge

- **Need for cost effective equipment retrofit to reduce space conditioning energy when existing system is not at end of life.**
- **Provide capacity modulation to accommodate a staged deep retrofit's steadily declining conditioning loads.**
  - Without the potential discomfort of installing an under-sized central system (unable to meet thermostat set points) at the beginning of the retrofit.
  - Without the potential discomfort associated with keeping the progressively oversized central system (short cycling and poor moisture control).

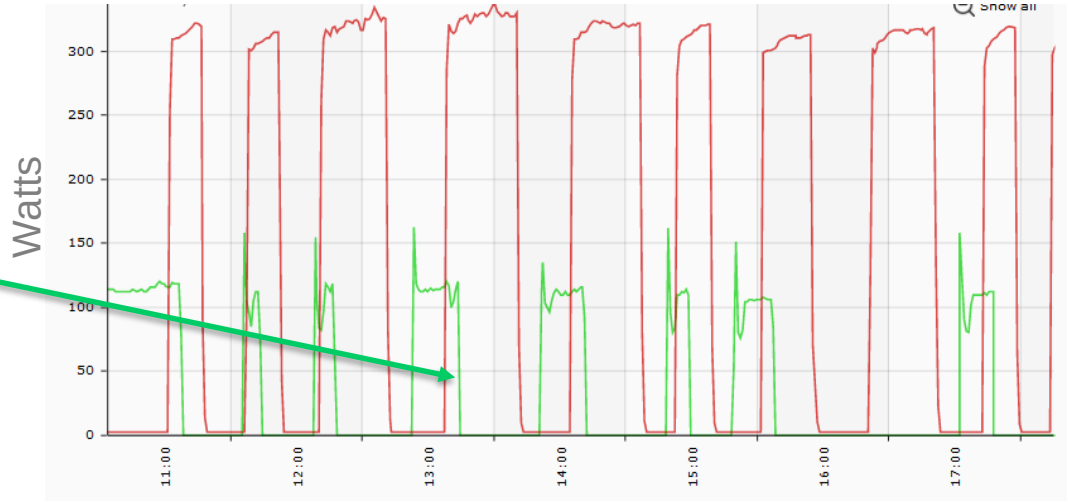


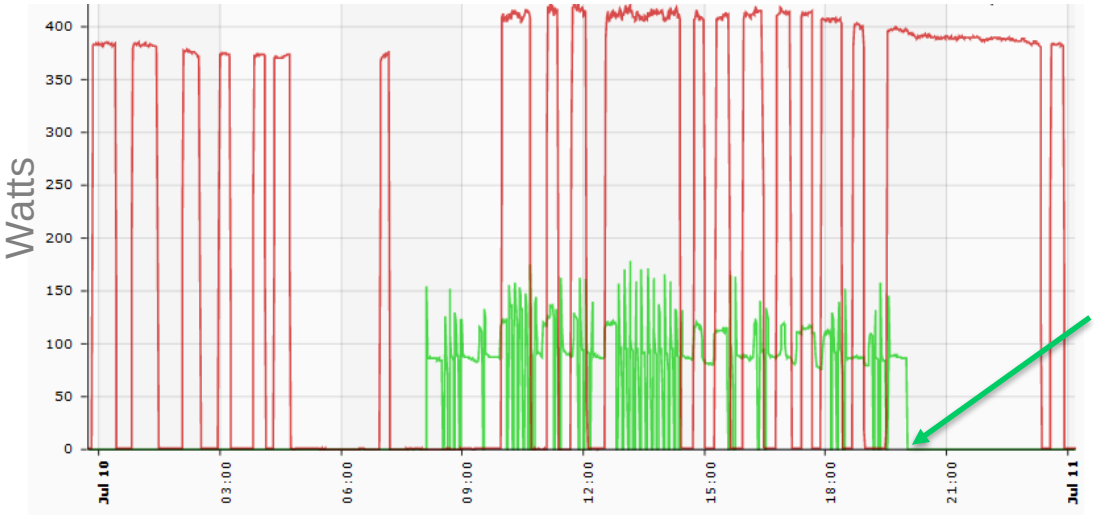
- **Building America Research to Market Plan: "Validate/Demonstrate Smart HVAC and Advanced Dehumidification Systems."**
  - Market availability of systems "capable of efficiently and consistently conditioning low load homes."

Bigger Challenge – Optimize Energy Savings

Mini-split not addressing as much of the conditioning load as it could and competing thermostats cause mini-split to short-cycle.

We aim to reduce central system runtime by maximizing mini-split capacity and runtime.



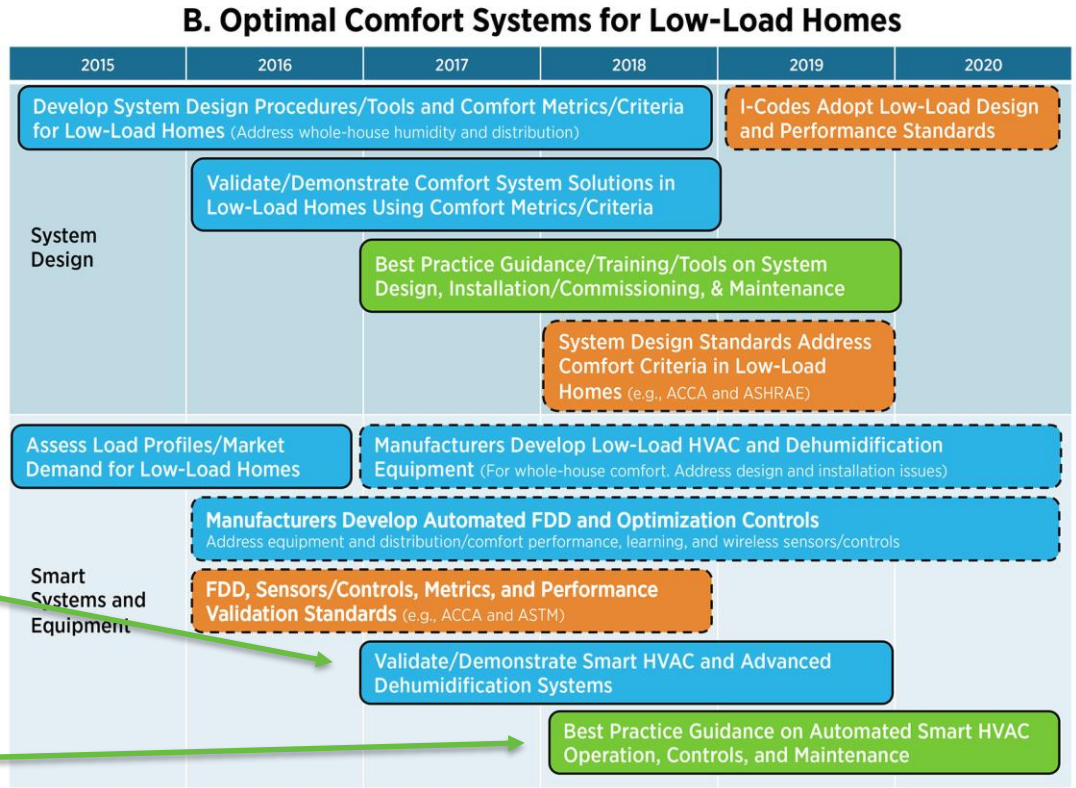


Too much mini-split runtime can cause limited central system engagement creating nighttime comfort issues in bedrooms not directly served . Occupants often respond by turning mini-split off at night.

We aim to maximum night-time mini-split use, while keeping bedrooms comfortable.

Approach

- Early stage research to develop and demonstrate an integrated controller that coordinates operation of an existing central space conditioning system with a single, centrally located mini-split heat pump.
- Evaluating and experimenting with 13 homes from previous Building America project with supplemental 1-ton mini-split.
- "Validate/demonstrate smart HVAC and advanced dehumidification systems."
- "Best practice guidance on automated smart HVAC."



Impact

- **Market for ductless heat pumps continues to grow at 10%-30% per year.**
- **Part of this growth is due to incentives available for peak demand reduction and electrification of heating for future renewable integration.**
- **Modeling efforts and pilot studies show potential for 20-80% heating/cooling savings from addition of supplemental mini-split.**
  - Savings vary widely based on baseline system and occupant interaction.
- **Larger scale program evaluations show that mini-splits only used for 50-60% of potential operating hours.**
  - Finding: Lack of a control decreases potential energy savings by 25-75%.
- **Desire to structure future incentives according to presence of advanced control.**
  - NYSERDA is funding a controls demonstration project.
  - Draft control specifications already emerging.
- **Results from past FSEC Building America study indicate ~$300 price point for an integrated controller, assuming it generates an additional 10% savings beyond simply adding a mini-split.**

Progress

- Mid stage in our research.
- Manually optimized set points in 3 homes w/1-ton Panasonic system.
- Installed new 1-ton Mitsubishi systems in 3 homes.
- Evaluating an integrated controller in 4 homes.

ID	Advanced Control Method	Year Built	Living Area (ft^2)	AC Size (tons)	Manual J Peak Load (tons)	AC SEER
1	None	1993	1856	3.5	3.5	13
2	None	2006	2328	5.0	4.5	13
3	Optimized Set Points	1984	1594	3.0	3.0	12
4	Optimized Set Points	1982	2231	4.0	3.0	13
5	None	1981	1628	3.5	2.5	13
6	None	1980	1946	3.5	3.0	14
7	Integrated Control	1986	1978	3.5	3.5	15
8	Optimized Set Points & Integrated Control	1995	2050	5.0	2.5	12
9	None	1999	1390	2.5	2.0	10
10	None	1987	1520	3.0	2.0	15.5
13	Integrated Control	1988	2554	5.0	4.5	16
14	Integrated Control	1981	1559	3.0	2.5	17
15	Optimized Set Points & Integrated Control	1991	1951	4.0	n/a	17

Progress

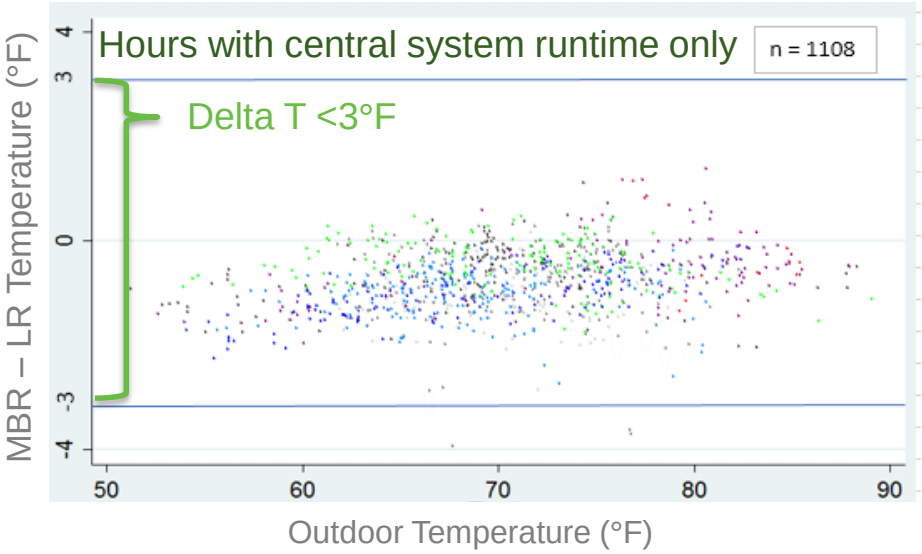
- **Evaluated persistence of cooling energy savings from simple addition of a supplemental mini-split.**
  - Evaluated in 3 sites with 2-3 year history of supplemental mini-split.

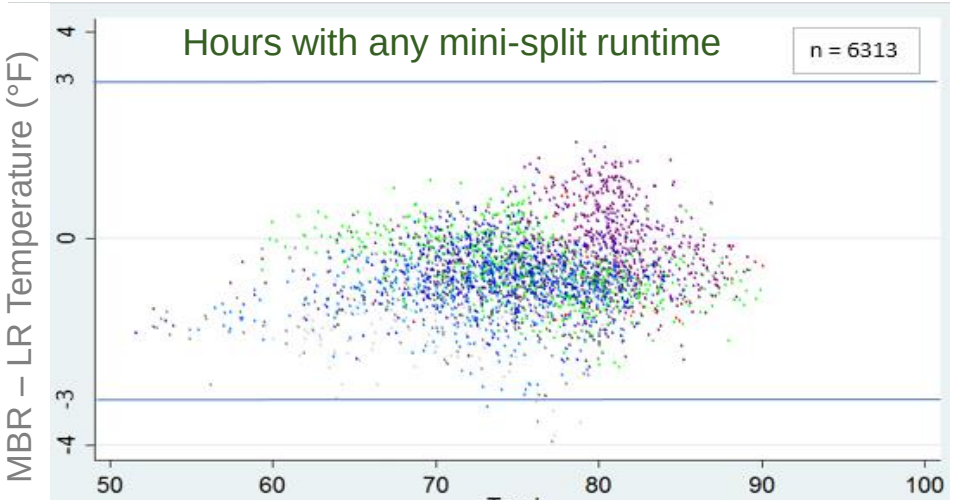
Site	Post Year 1	Post Year 2	Post Year 3
4	30%	23%	24%
8	38%	51%	41%
15	28%	34%	N/A

  - Very short-term evaluation of cooling energy savings at 3 new installations: 14%, 34%, and 39%.
- **Evaluated whole house comfort: Short term pre vs. post supplemental mini-split.**
  - Evaluated cooling season room-to-room thermal distribution pre and post supplemental mini-split in 3 sites (July and August).
  - Used ACCA Manual RS guidelines: Cooling hour Delta T not to exceed 3°F.
  - Find excursions are almost non-existent both pre and post; exception was in unoccupied spare bedroom and observed in both pre and post.

Progress

- **Ability to maintain whole house comfort: Long-term by runtime condition.**
  - Evaluated one year of cooling season room-to-room thermal distribution.
  - Used ACCA Manual RS guidelines: Cooling hour Delta T not to exceed 3°F.
  - Difference between master bedroom and living room Delta T against outdoor temperature.
    - No clear differences in room-to-room Delta T with and without mini-split.
    - The largest excursions occur when the central system is running and in cooler months.
    - Rarely does the Delta T exceed the ACCA Manual RS guideline of 3°F, whether the supplemental mini-split was running or not.





warmer months pinkish

cooler months blueish

Progress

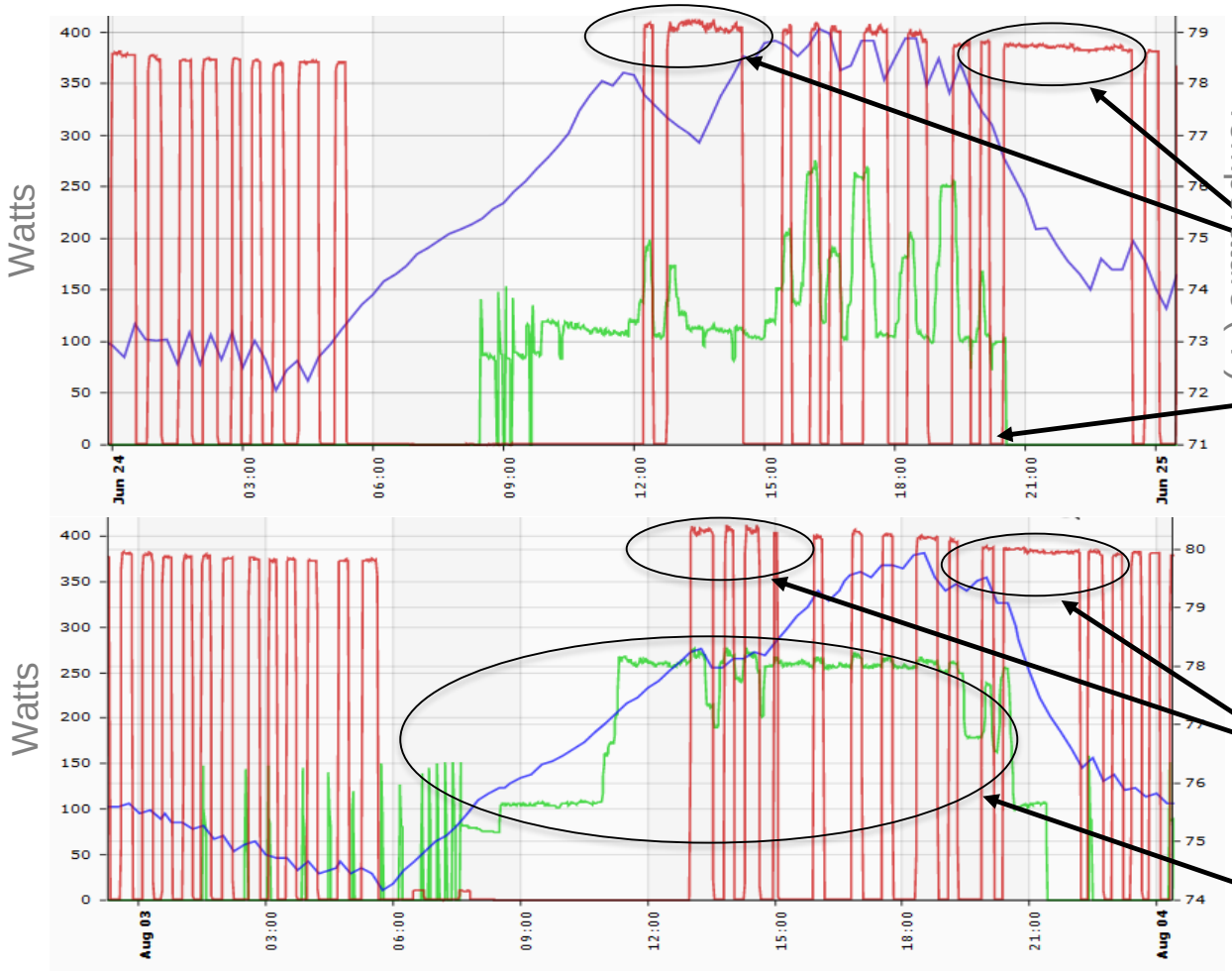
- **Integrated Controller Design Experiments: Manual Set Point Optimization**
  - Experimented with 3 homes from previous project.
  - Adjusted set points of both systems to reduce overall HVAC energy.
  - Introduced central system fan cycling during sleeping hours to compensate for lack of distribution when only mini-split is running.
  - Example: Initially 17% cooling energy savings, comfort adjustment yielded 11%.

Site 4	Mini-split (kWh/Day)	Central (kWh/Day)	Total HVAC (kWh/Day)	Living Room Temp (°F)	Outdoor Temp (°F)
Pre-Intervention	1.6	34.9	36.4	74.5	82.8
Adjustment 1	1.9	28.4	30.3	74.8	82.1
Adjustment 1 Net	(0.4)	6.5	6.1	(0.3)	0.7
Adjustment 1 Savings	(24%)	19%	17%		
Adjustment 2	2.2	30.4	32.6	74.7	81.8
Adjustment 2 Net	(0.6)	4.5	3.8	(0.2)	0.9
Adjustment 2 Savings	(40%)	13%	11%		

  - Re-evaluated at 3 months found 8% and 10% cooling energy savings and rare Delta T temperature excursions above 3°F, and no worse with adjustment.
  - 16% cooling energy savings at a third site with intentional zoning.

Progress

- **Integrated Controller Design Experiments: Set point adjustment at Site 4.**



Before adjustment

Central system:

77/78°F @8:00a;

73°F @8:30p

Long central runtimes

Mini-split:

74°F @8:30a to 8:30p

No mini-split 8:30p to 8:30a

After adjustment 2

Central system:

15 min central system fan cycling 8p to 8p

Reduced central runtime

Mini-split:

71°F, constant on

More aggressive mini-split

Progress

- **Integrated Controller Design: Hardware**
  - Smart thermostat platform
    - Nest for central system
    - Sensibo for mini-split
  - Homeowner enters desired comfort into Nest as a programmable set point schedule.
  - Nest remote temperature sensor used in master bedroom.
    - Nest set to read master bedroom temperature during sleeping hours, and activate central system to maintain nightime bedroom comfort.

Progress

- **Integrated Controller Design: Software Algorithm**
  - Read Nest set point schedule and automatically adjust the mini-split set point.
  - Read/write to/from smart thermostats through server via thermostat internet connectivity and open API.
  - Daytime: central system only operates if central zone set point cannot be satisfied with mini-split.
  - Sleeping hours: Bedroom set point first attempted to be satisfied with min-split. If not 1) invoke fan cycling, 2) invoke central system.

```
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 * ========================================================================
 * MSHP set point = MSHPsp = Ti -[(SO + AO) + (NO*NF)]
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 * Trd = Temperature Response Denominator = 4
 * NO = Night offset = -1
 * NF = Nightime flag = 1 during sleeping hours
 * ========================================================================
 */
var tempSet = nestData.target_temperature_f; //7
var standardOffset = 5; //SO
var est = Math.floor((OUTDOOR_TEMP - tempSet)/tem
var nightOffset = -1; //NO
var night = (isDaytime()?0:1); //NF
var new_sms_target_temp = nestData.target_tempera
console.log([new Date], JSON.stringify({
 "AMBTMP": OUTDOOR_TEMP,
 "Est":est,
 "SetSensibo": new_sms_target_temp,
```
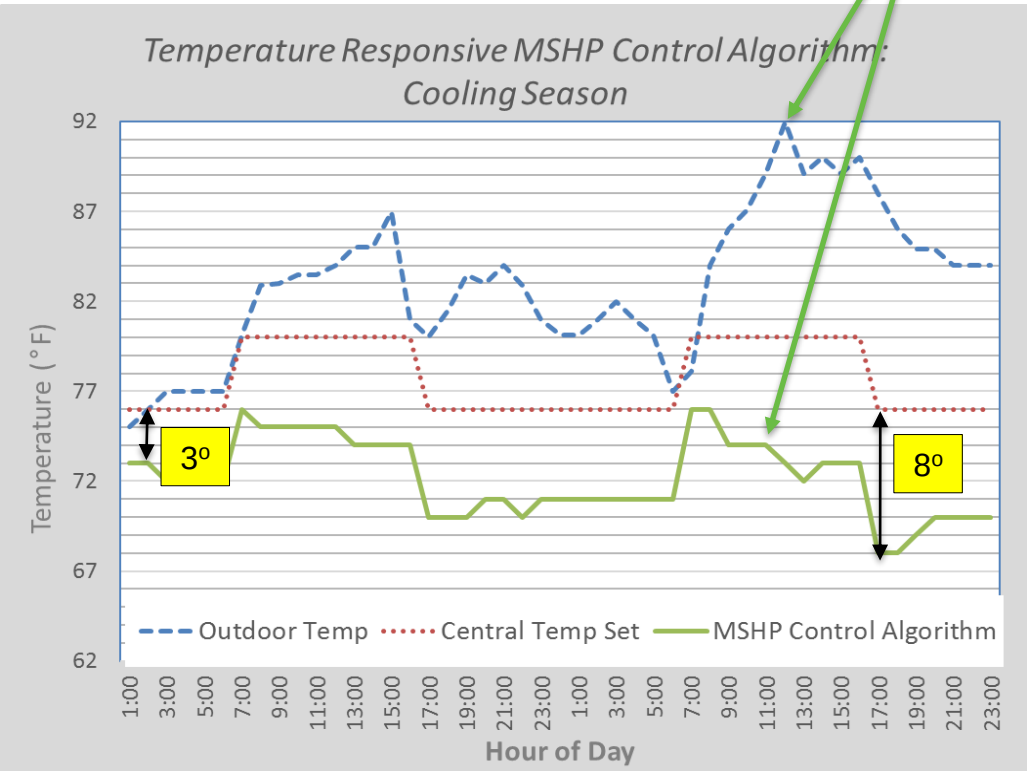

Outdoor temperature is considered in algorithm: mini-split cools more aggressively on warmer day



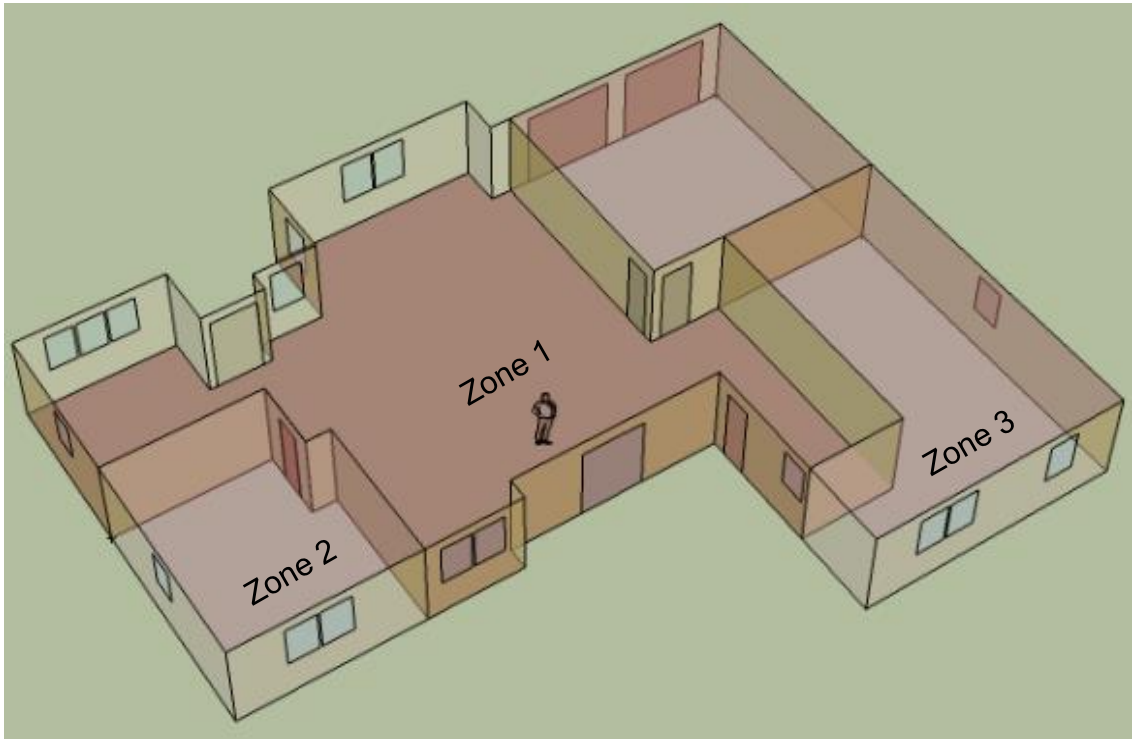
Stakeholder Engagement

- **Developing *Building America Solution Center* content geared towards southeastern contractors covering design, installation, and control considerations for supplemental mini-split.**
- **Engaging with utilities, regional efficiency organizations, and manufacturers through coordination and contributions to other ongoing projects to increase impact:**
    - PNNL: modeling and lab home experimentation of integrated controls in the northwest.
    - NYSERDA: 12 home demonstration project of integrated controls in northeast.

Remaining Project Work

- **Complete Controller Experiments**
  - Finalize controller algorithm and implement, test and refine.
  - Collect data and evaluate results for energy savings and comfort.
- **Conduct Central System End of Life Simulations**
  - Develop multi-zone EnergyPlus model and conduct simulations to estimate life cycle cost considerations of choices for central system replacement.

- Capacity?
- Efficiency?
- Ducted vs. ductless?



Thank You

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Eric Martin, PI and Karen Fenaughty, Co PI
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REFERENCE SLIDES

Project Budget

Project Budget: Budget Period 1 funds spent on IRB and Research Plan development and approval, benchmarking baseline performance, and controller design. Budget Period 2 funds are being spent on controller refinement and validation.

Variances: No variances from the original planned budget.

Cost to Date: 58% of the budget has been expended to date (3/31/2019).

Additional Funding: A portion of the cost share has been provided by Mitsubishi.

Budget History					
October 2017– December 2018 (Budget Period 1 - past)		January 2019– September 2019 (Budget Period 2 - current)		FY 2020 – N/A (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$163,409	$18,148	$120,070	$13,347		

Project Plan and Schedule

Initial delay in Institutional Review Board protocol review caused slippage of two early stage milestones. Installation of new mini-splits intentionally delayed for more baseline data collection.