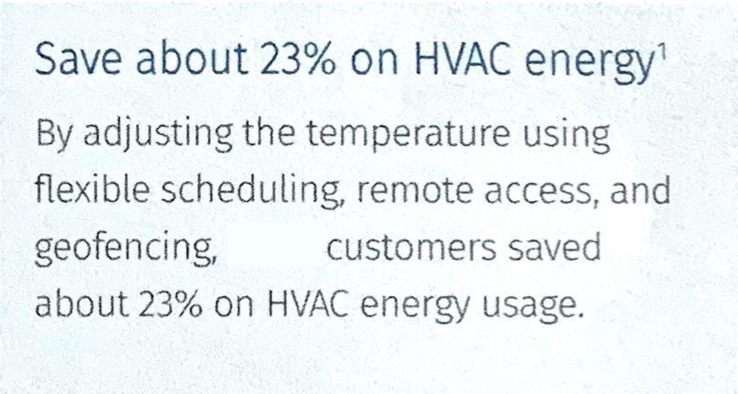
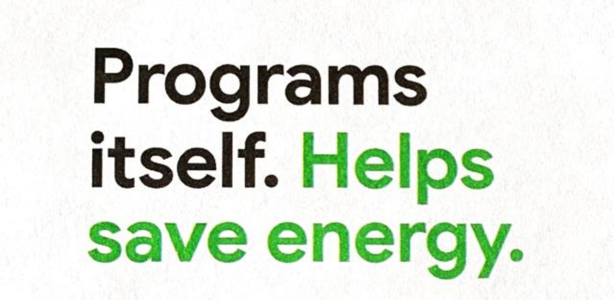
Benchmarking Smart Thermostats

MANUFACTURERS’ LITERATURE





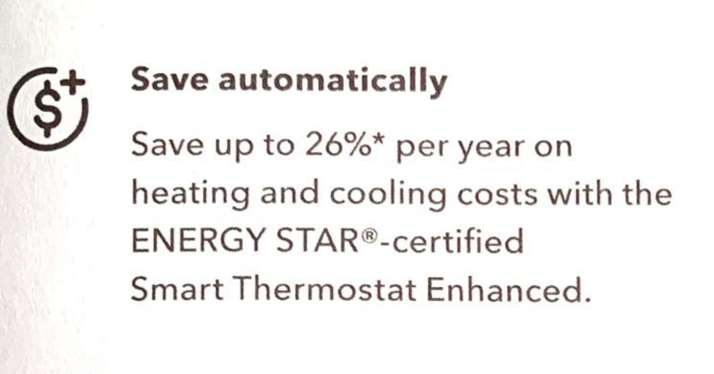


Photo by Kyle Benne, NREL

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Project Summary

Objective and Outcome

Our goal is to estimate the performance of commercially available smart thermostats relative to conventional thermostats with fixed setpoints. If successful, the resulting tool will help EPA ENERGY STAR® and other rating and incentive programs evaluate new thermostat products before they go to market.

Photos by Kyle Benne, NREL

Team and Partners

NREL: Project management, software and model development

LBNL: BOPTEST support, requirements, analysis

EPA: Domain experience, requirements, analysis

Stats

Performance Period: FY23-FY25

DOE budget: $400k/year

Milestone 1: Fixed capacity HVAC (Q4FY23)

Milestone 2: Variable capacity HVAC (Q4FY24)

Milestone 3: Pilot Demonstration (Q4FY25)

Evaluating thermostats is challenging

Manufacturers' literature…

- "Save about 23% on HVAC energy"
- "Save up to 26% per year"
- "Automatic energy savings"
- "Helps save energy"

EPA ENERGY STAR® has the challenge of certifying products that deliver savings to consumers.

ENERGY STAR

The problem is

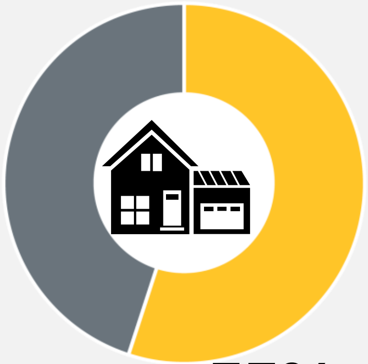
- This only works for a **limited number of HVAC system types.**
- Products **need 12 months of field data** before they can be recognized.

Woman from Pond5.com, Li Wentao Molang Shijue Co., photo of smart thermostat selection by Kyle Benne, NREL

But the possibility is enticing

Single Family Home Energy Use

$2,188 per year on energy costs



45% other

55% Heating and Cooling

$1,203 per year on heating and cooling

\+

Smart Thermostat

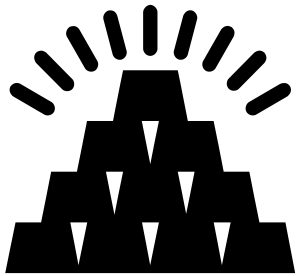
Inexpensive and often simple installation.

Based on some savings estimates, could **payback in under 2 years.**

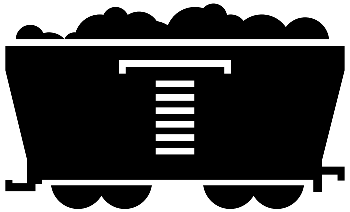
x

74 million single family homes in U.S.

=



Money saved



Energy saved (equivalent to millions of coal cars)

* Source: U.S. Energy Information Administration, Office of Energy Consumption and Efficiency Statistics, Forms EIA-457A and EIA-457C of the 2015 Residential Energy Consumption Survey.

EPA's ENERGY STAR program is helping to unlock the opportunity

- Controls CAN save energy – but do they? **Use field data!**
- Thermostat service provider is ENERGY STAR partner, so rely on thermostat telemetry, not meter data.

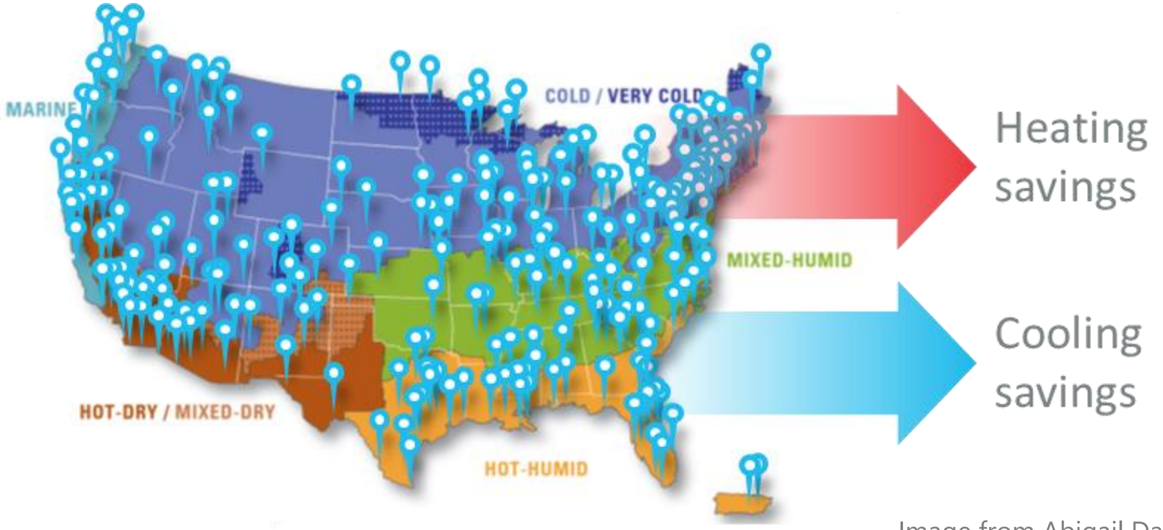


Image from Abigail Daken, EPA

- 12 months of retrospective data from >1000 thermostats: Wiring, Indoor temperatures, HVAC system run times; combine with public weather data.
- Derive % run time reduction from actual setbacks compared to no setback for each home, for heating and cooling.
  - Average in each climate zone to get regional savings.
  - Weighted average of regions gives national savings.
- 5 years of semi-annual resubmissions show reasonably stable results.

EPA has success, but some key challenges remain

- Note that the certified product is hardware + service/software, because the algorithms applied to control the thermostat are critical to savings.
- **Success:** Approximately 1/3 of US households can now get rebates for an ENERGY STAR thermostat!
- But the ENERGY STAR savings metric is not perfect:
  - Retrospective data requires substantial deployment – locks out new entrants from incentives based on ENERGY STAR certification. ☹
  - Assumes linear relationship between HVAC run time (proxy for energy use) and indoor-outdoor temperature difference: definitely untrue for variable speed heat pumps
  - Cannot capture savings other than from set back

Our idea is that simulation can help address key challenges

Photo by Bethany Sparn, NREL

- Test thermostats in conjunction with **any type of HVAC equipment**.
- **Isolate** the effects of the thermostat from all **other variables**, using controlled experiments.
- **Test a broad set of conditions** that may not exist in the field data.
- Test different thermostats **under identical conditions**.

The benefits of Building Energy Modeling have been captured for many building technologies, but they are less realized for control technologies.

We’re assembling DOE’s toolchain to bring simulation to bear

ResStock	Spawn of EnergyPlus	BOPTEST Building Optimization Performance Test	KPIs
• Gives us a large probabilistic sample of U.S. homes based on OpenStudio and EnergyPlus	• Gives us realistic HVAC equipment and control models using Modelica	• Simulated “drive pattern” like an auto dynamometer • Can protect manufacturers IP • Large scale simulation	• Equipment runtime • Energy consumption • Peak powers • And others

”The innovation is assembling existing technologies into a new solution designed to answer the question, 'Do smart thermostats save energy?'"

We began by generating (many) energy models

An automated workflow generates a large set of BOPTEST test cases, each representing a probabilistic home in the U.S.

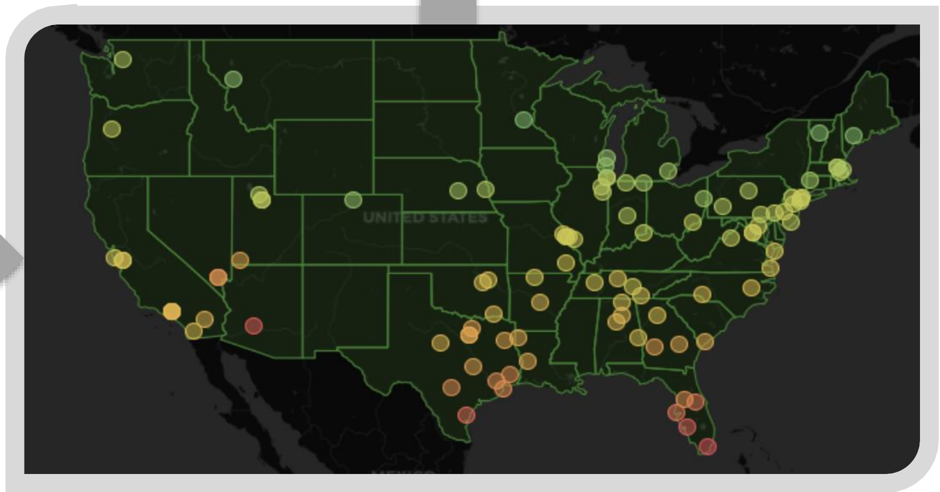
Test cases are stored within the BOPTEST Service, which is deployed to the cloud.

BOPTEST
Building Optimization Performance Test
Service on AWS

Spawn of EnergyPlus

ResStock

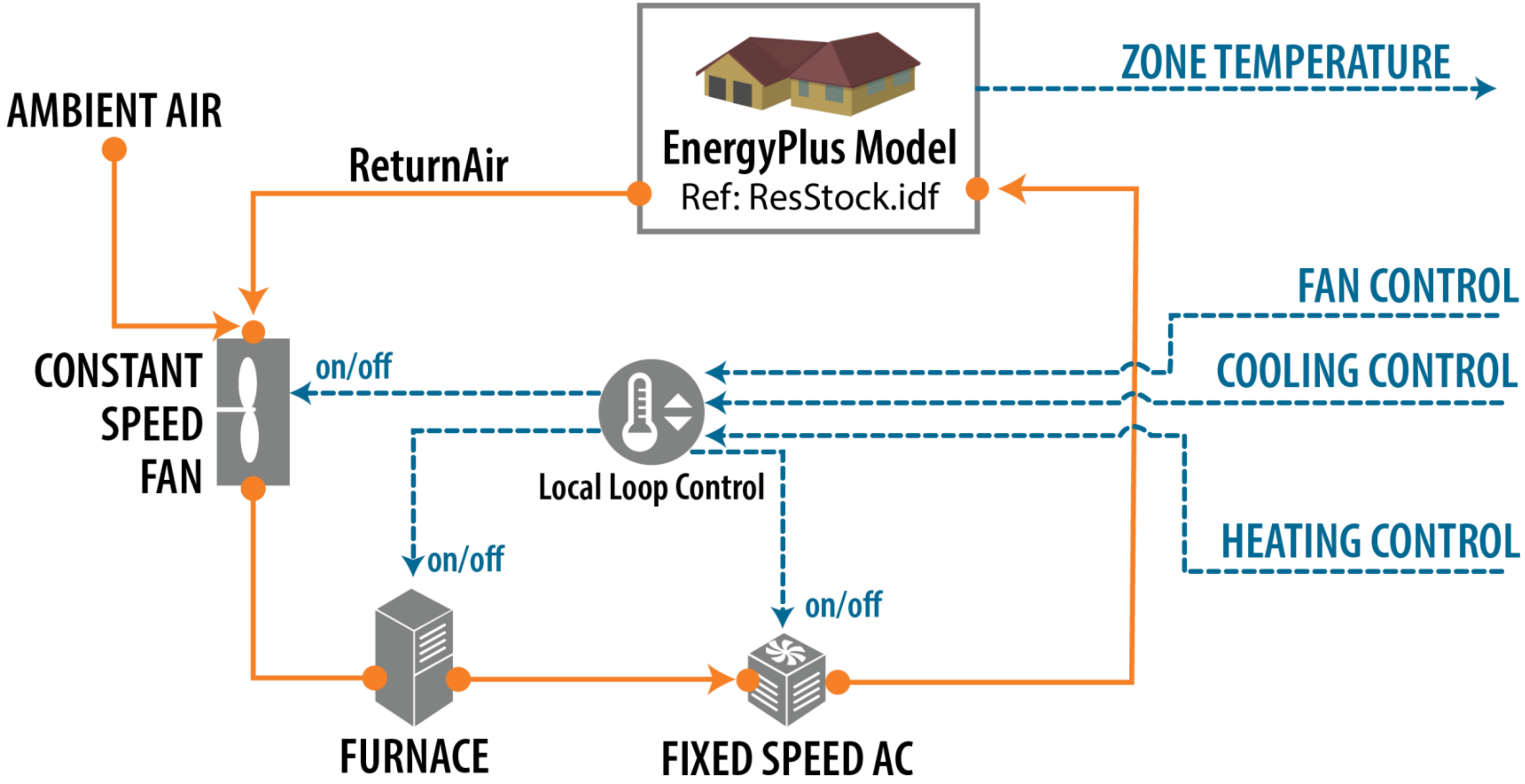
Test-Case-Factory



http://api.boptest.net/testcases/

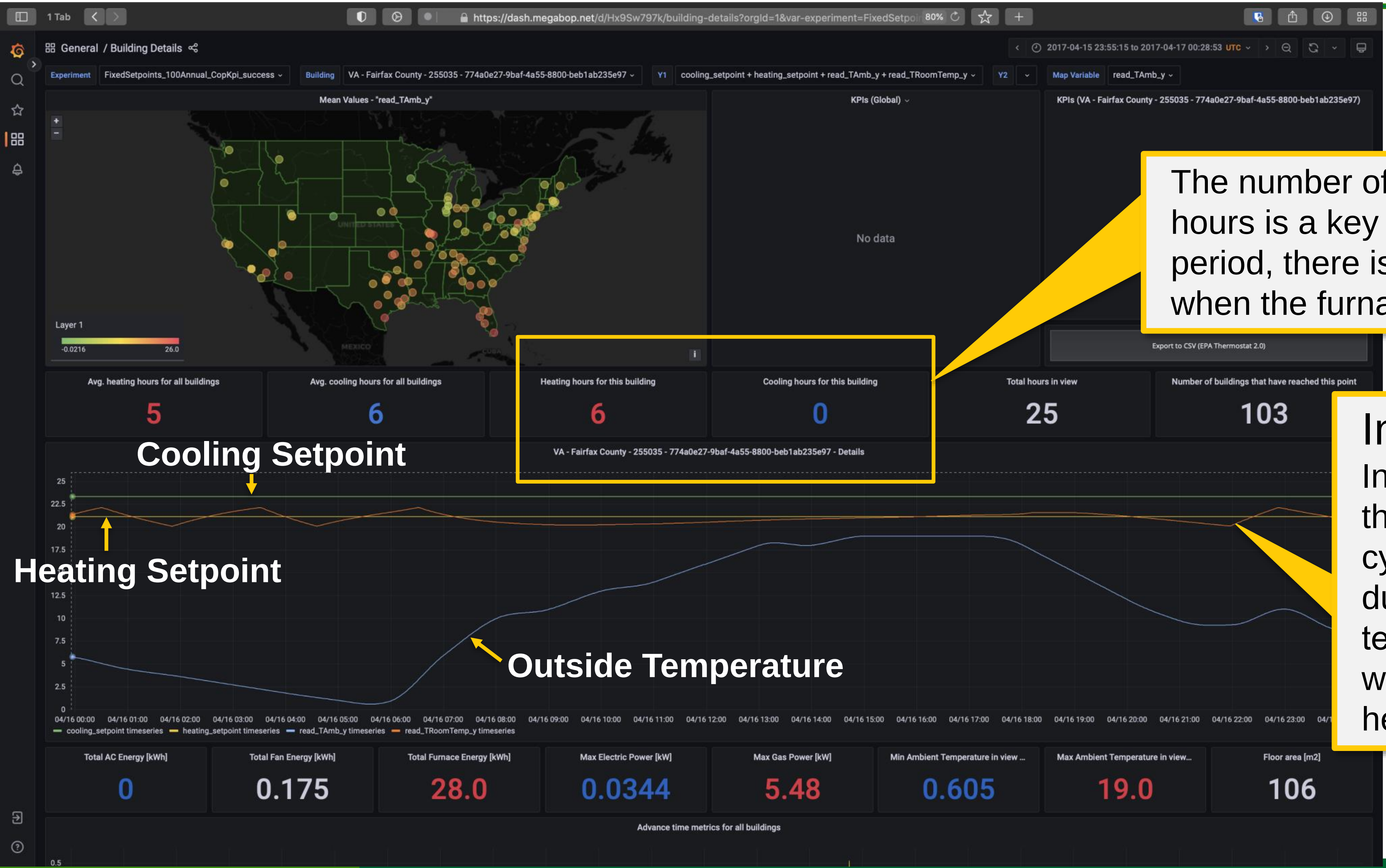
What are the characteristics of the energy models?

- Each ResStock model has a single conditioned living space, with optional attic and garage.
- Internal loads and occupancy are generated stochastically.
- Each model's **form and fabric** is uniquely defined based on a variety of **statistical data sources**.



In this iteration, we modeled **a constant efficiency gas furnace, single speed AC**, and **constant speed fan**.

Results are collected in a large database



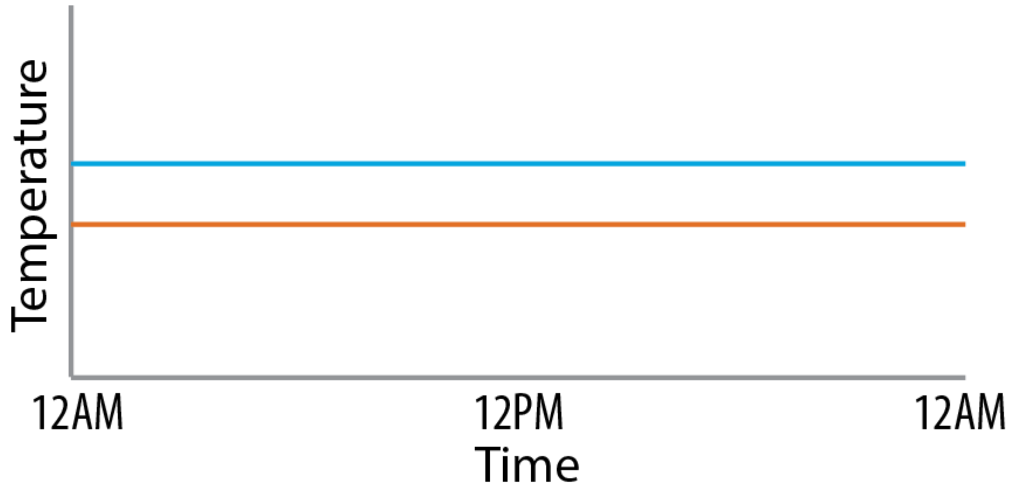
The number of heating and cooling hours is a key metric. In this 25-hour period, there is a total of 6 hours when the furnace is running

Indoor Temperature

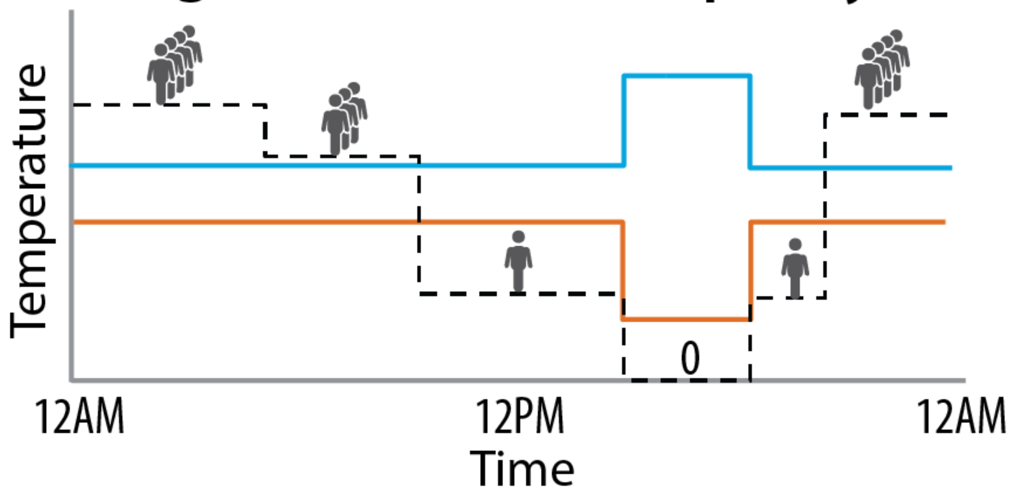
In this instance, we see the effects of the furnace cycling at nighttime, while during the day the indoor temperature is “floating” within the deadband of the heating setpoint.

So far, we’ve evaluated four generic thermostat algorithms

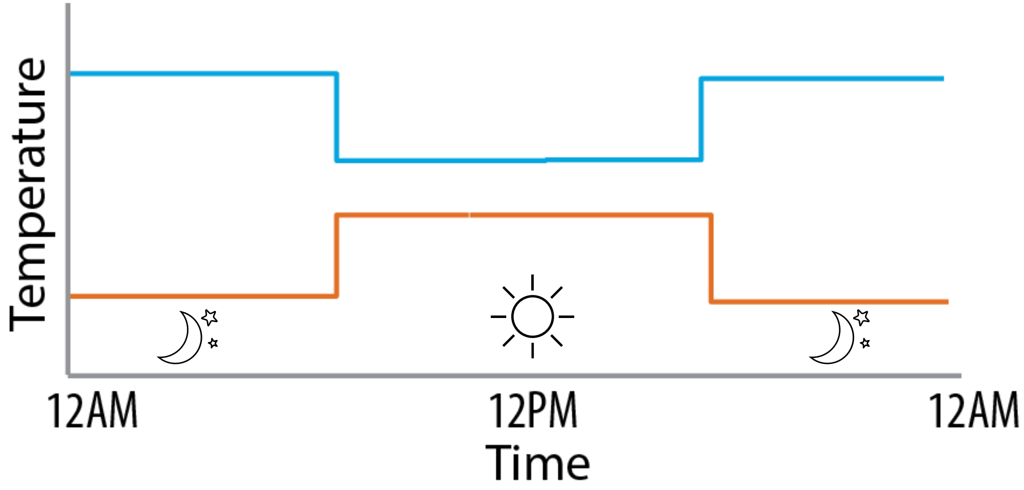
Algorithm “A” – Hold



Algorithm “B” – Occupancy



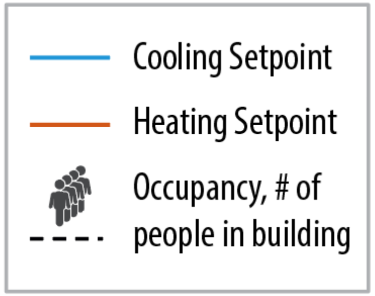
Algorithm “C” – Night Setback



Algorithm “D” = “B” + “C”

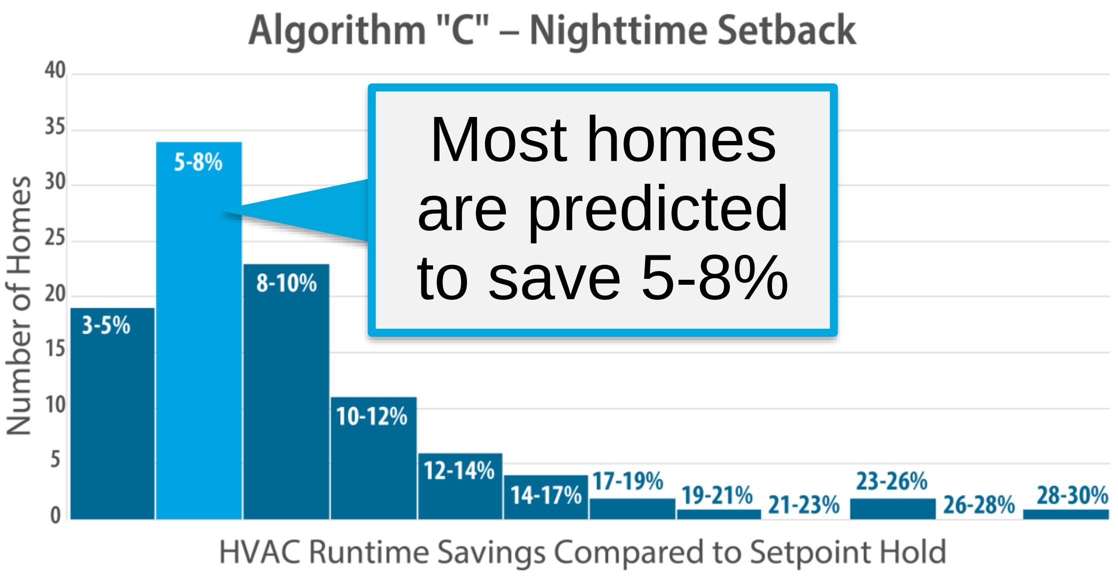
Occupancy sensing and night set-back

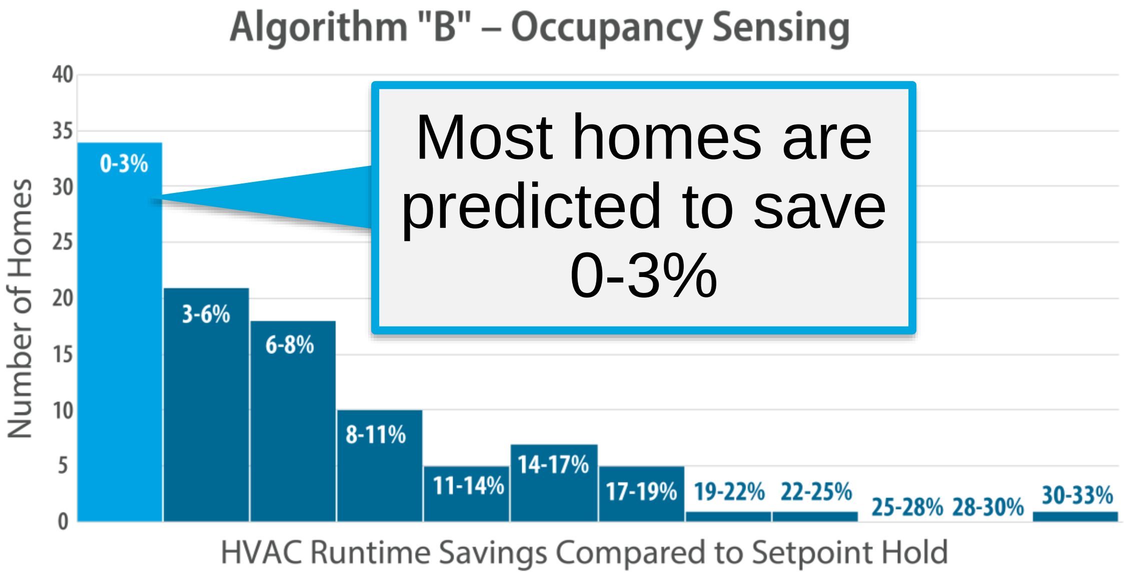
This approximates a typical default smart thermostat algorithm

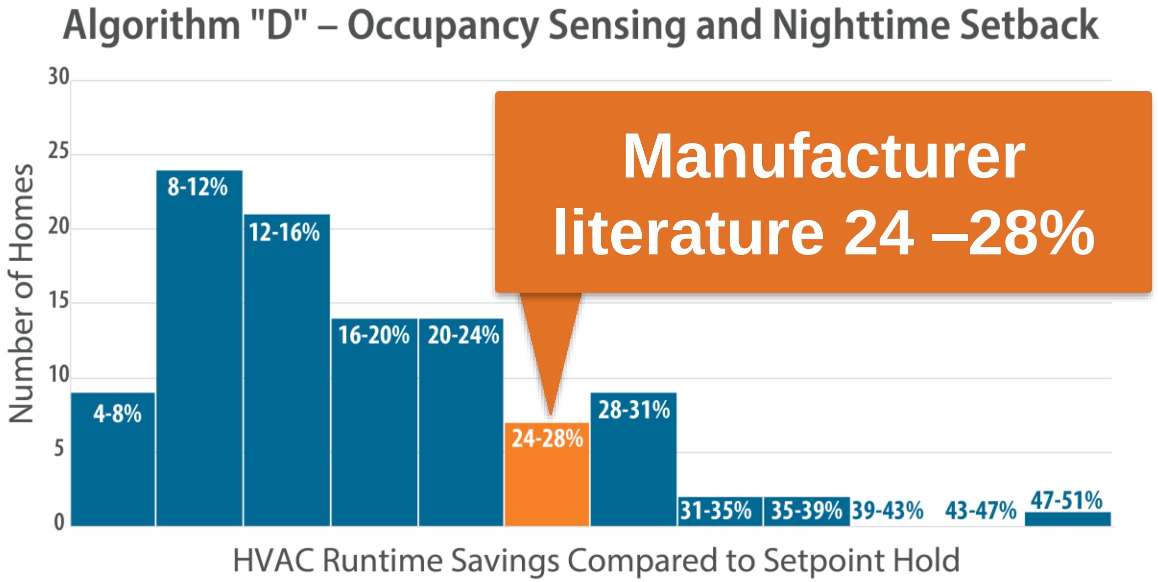


Early results support manufacturers' literature, but with nuance

- More advanced thermostat algorithms combine savings.
- Algorithm "D" combines the savings from occupancy sensing and nighttime setback.



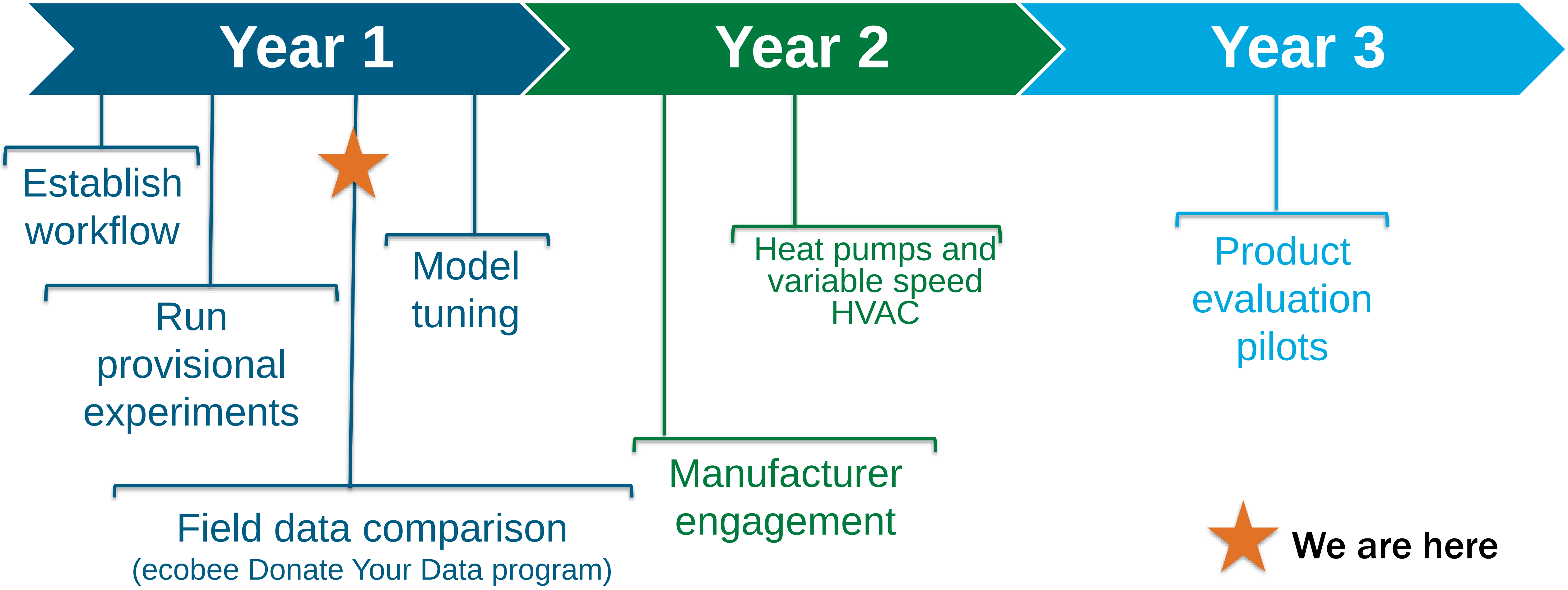




We have a process, but we're still working through questions

- Do we understand "Local loop" control logic within heat pump equipment well enough to properly model it? (We have the technical capability)
- How does the local loop control interact with the thermostat and are we capturing it properly?
- How can we capture the occupant interactions with the thermostat?
- Our simulated living spaces have uniform temperature (fully mixed volume); considering the tradeoffs, are modeling enhancements a priority?
- These are a few of our known unknowns, what aren't we thinking about that might be commonly overlooked?

What’s next?



In parallel, we and others are continuously improving the enabling pieces, Spawn, BOPTEST, et al.

Thank You

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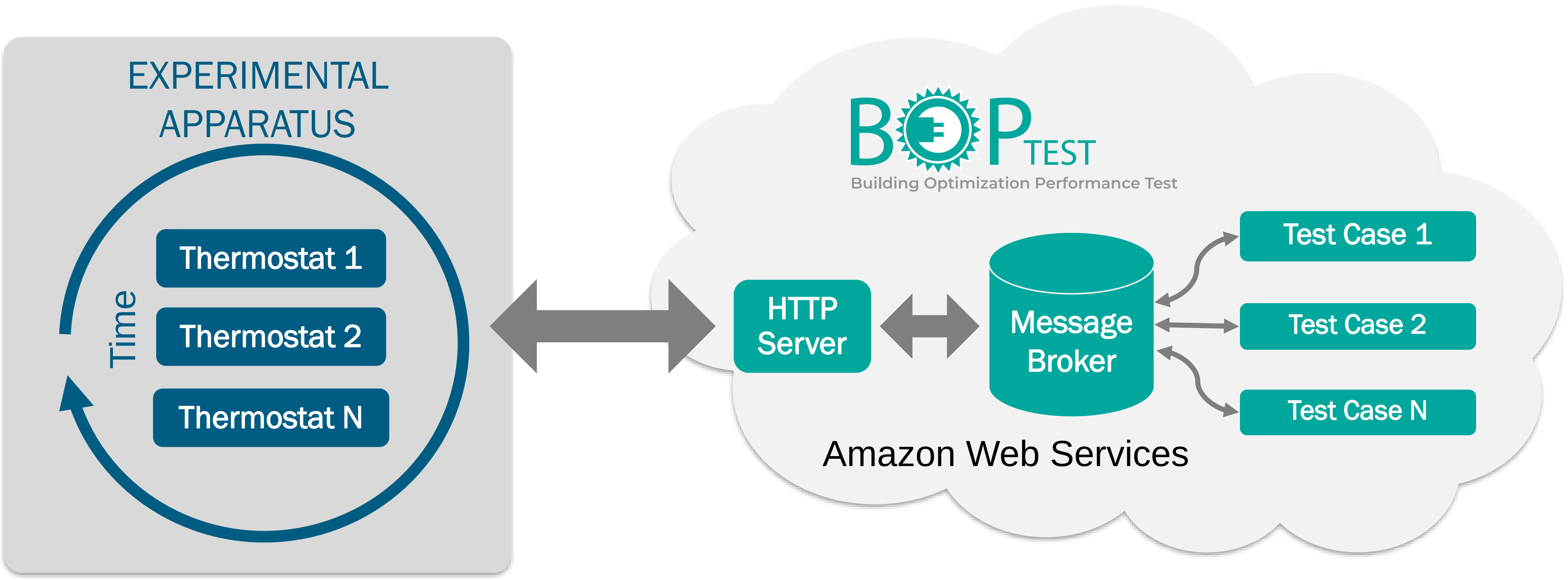
REFERENCE SLIDES

One more thing…



- We've adopted the "Alfalfa" architecture. (Poster here at Peer Review)
- The software enables us to do large scale "co-simulation" if we choose.
- We can answer questions such as what happens to the cumulative demand curve if the thermostats receive a signal to load shed.

Project Execution

	FY2023				FY2024				FY2025			
Planned budget	$400,000				$400,000				$400,000			
Spent budget	$200,000				$0				$0			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Past Work												
Q1 Milestone: Experiment 1 Design (constant speed)	◆											
Q2 Milestone: Experiment 1 Results (constant speed)		◆										
Current/Future Work												
Q3 Milestone: Experiment 2 Design (constant speed revision)			◆									
Q4 Milestone: Experiment 2 Results (constant speed revision)				◆								
Go/No-Go 1: Viability of initiial simulation results				◆								
Q1 Milestone: Experiment 3 Design (variable speed)					◆							
Q2 Milestone: Experiment 3 Results (variable speed)						◆						
Q3 Milestone: Experiment 4 Design (variable speed revision)							◆					
Q4 Milestone: Experiment 4 Results (variable speed revision)								◆				
Go/No-Go 2: Viability of variable speed simulation results								◆				
Q1 Milestone: Experiment 5 Design (commercial test)									◆			
Q2 Milestone: Experiment 5 Results (commercial test)										◆		
Q3 Milestone: Experiment 6 Design (commercial test revision)											◆	
Q4 Milestone: Experiment 6 Results (commercial test revision)												◆

Team

NREL: Jermy Thomas, Jiazhen Ling, Kyle Benne

Software development, building energy modeling, project management

LBNL: David Blum, Alan Meier, Leo Rainer

BOPTEST support, requirements, analysis

EPA: Abigail Daken

Domain experience, requirements, analysis

Special Thanks

ecobee:

Answering our questions, providing field data