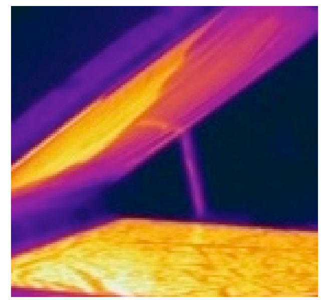
Buildings, Energy and Behavior: Sapiens Happens



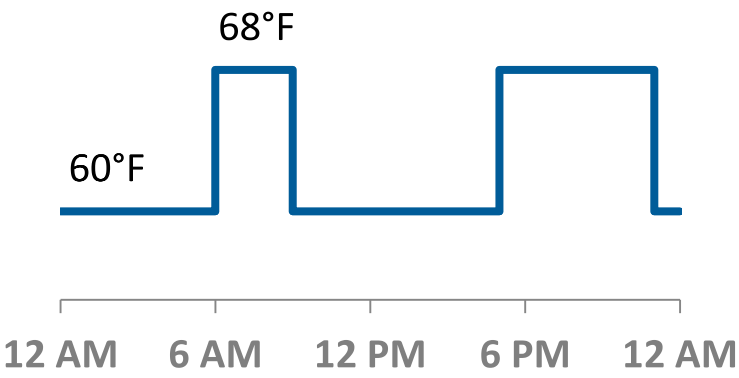
Kurt Roth, Ph.D.

EIA Conference

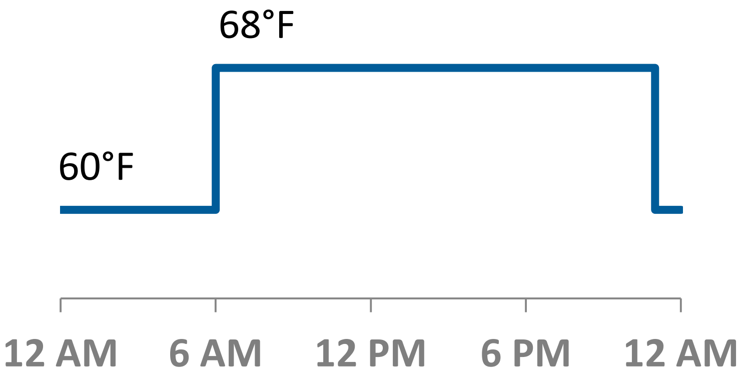
June 26, 2017

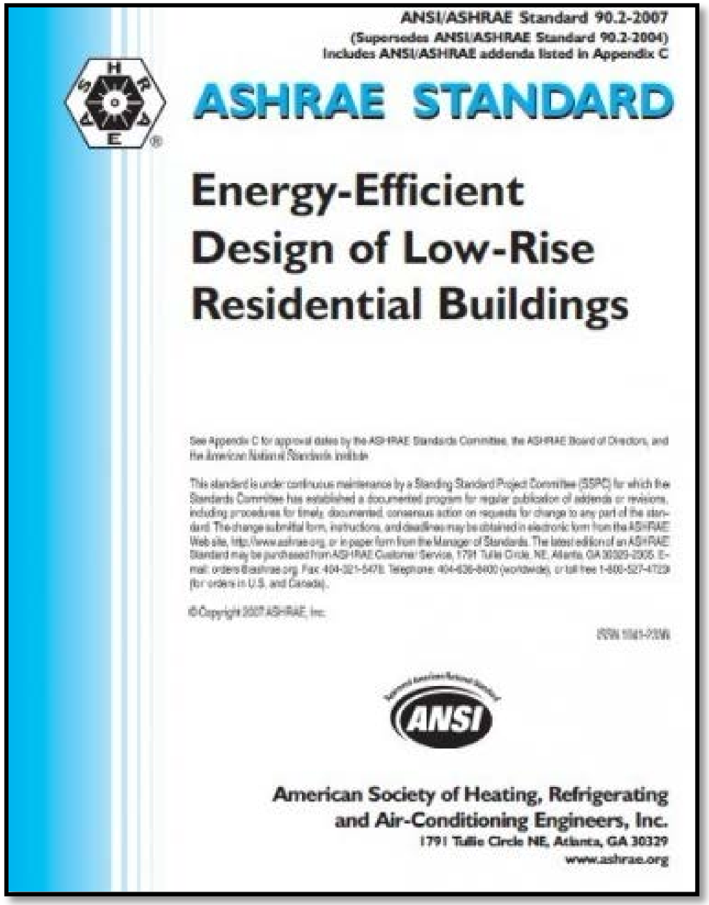
IMPACT OF BEHAVIOR ON BUILDING ENERGY CONSUMPTION

Sleeping Zone



Single Zone or Living Zone





ANSI/ASHRAE Standard 90.2-2007
(Supersedes ANSI/ASHRAE Standard 90.2-2004)
Includes ANSI/ASHRAE addenda listed in Appendix C

ASHRAE STANDARD

Energy-Efficient Design of Low-Rise Residential Buildings

See Appendix C for approval dates by the ASHRAE Standards Committee, the ASHRAE Board of Directors, and the American National Standards Institute.

This standard is under continuous maintenance by a Standing Standard Project Committee (SSPC) for which the Standards Committee has established a documented program for regular publication of addenda or revisions, including procedures for timely, documented, consensus action on requests for change to any part of the standard. The change submittal form, instructions, and deadlines may be obtained in electronic form from the ASHRAE Web site, http://www.ashrae.org, or in paper form from the Manager of Standards. The latest edition of an ASHRAE Standard may be purchased from ASHRAE Customer Service, 1791 Tullie Circle, NE, Atlanta, GA 30329-2305. E-mail: orders@ashrae.org. Fax: 404-321-5478. Telephone: 404-636-8400 (worldwide), or toll free 1-800-527-4723 (for orders in U.S. and Canada).

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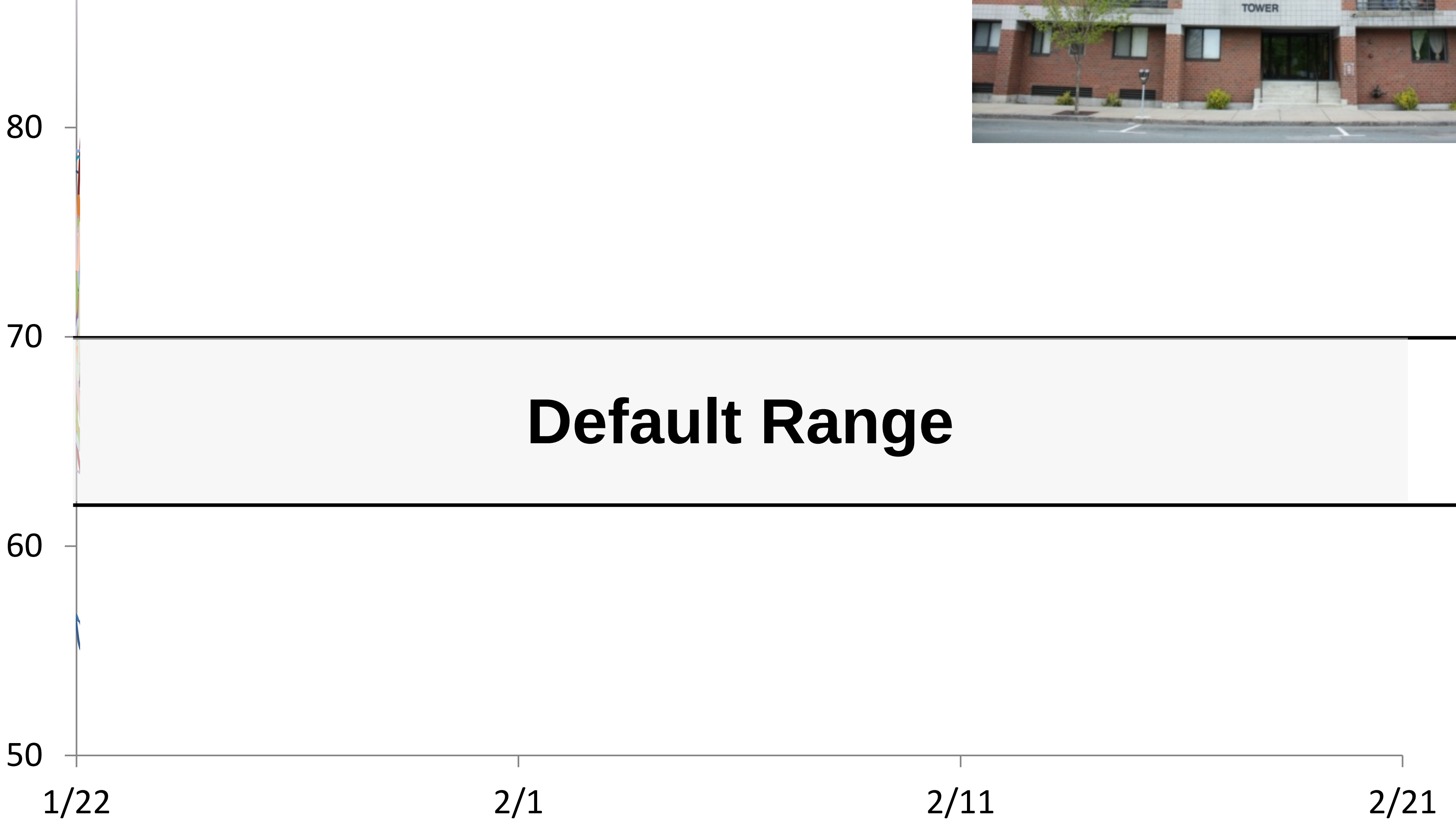
ANSI

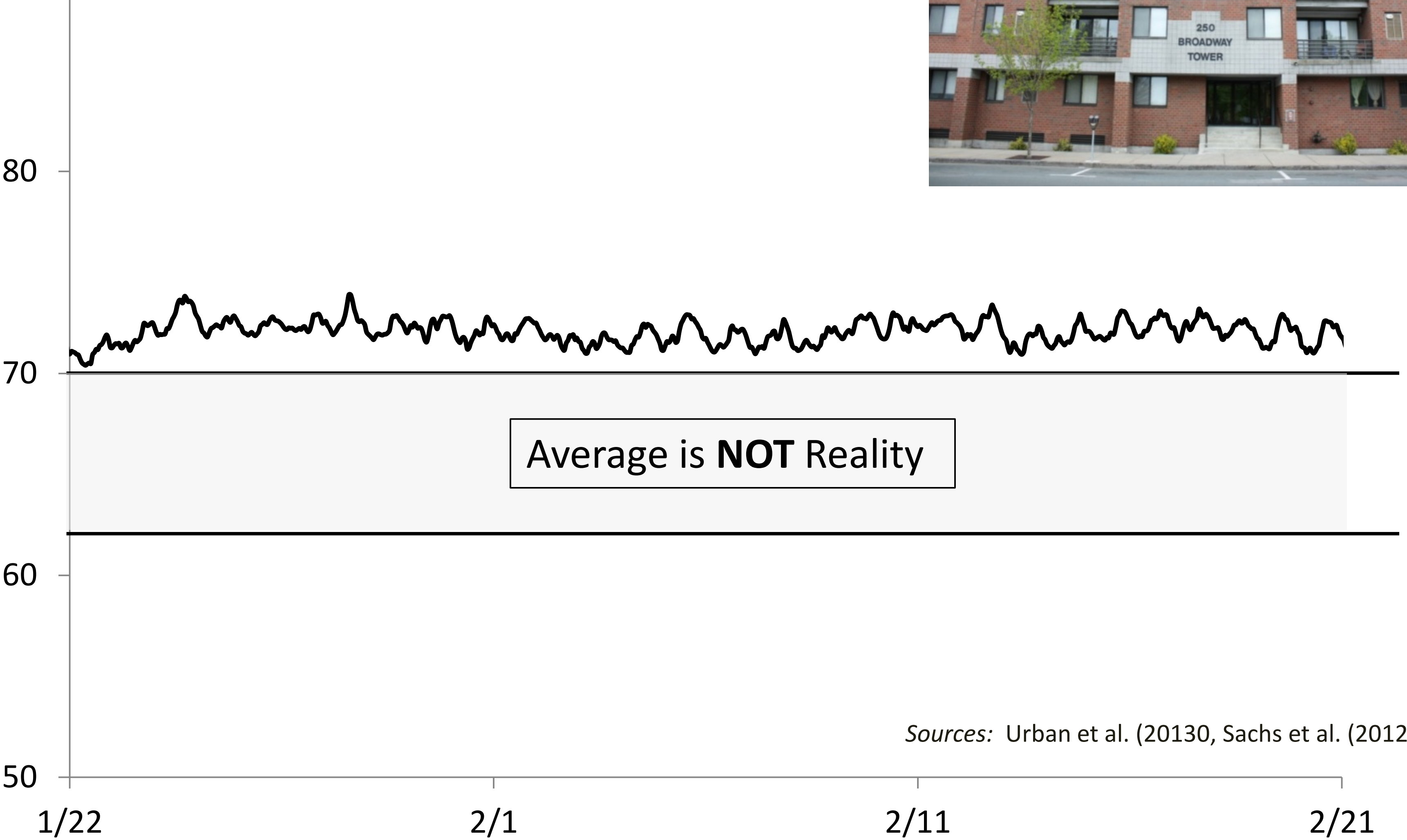
American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.
1791 Tullie Circle NE, Atlanta, GA 30329
www.ashrae.org

Source: ASHRAE (2007).

Measured Air Temperature (n=67)

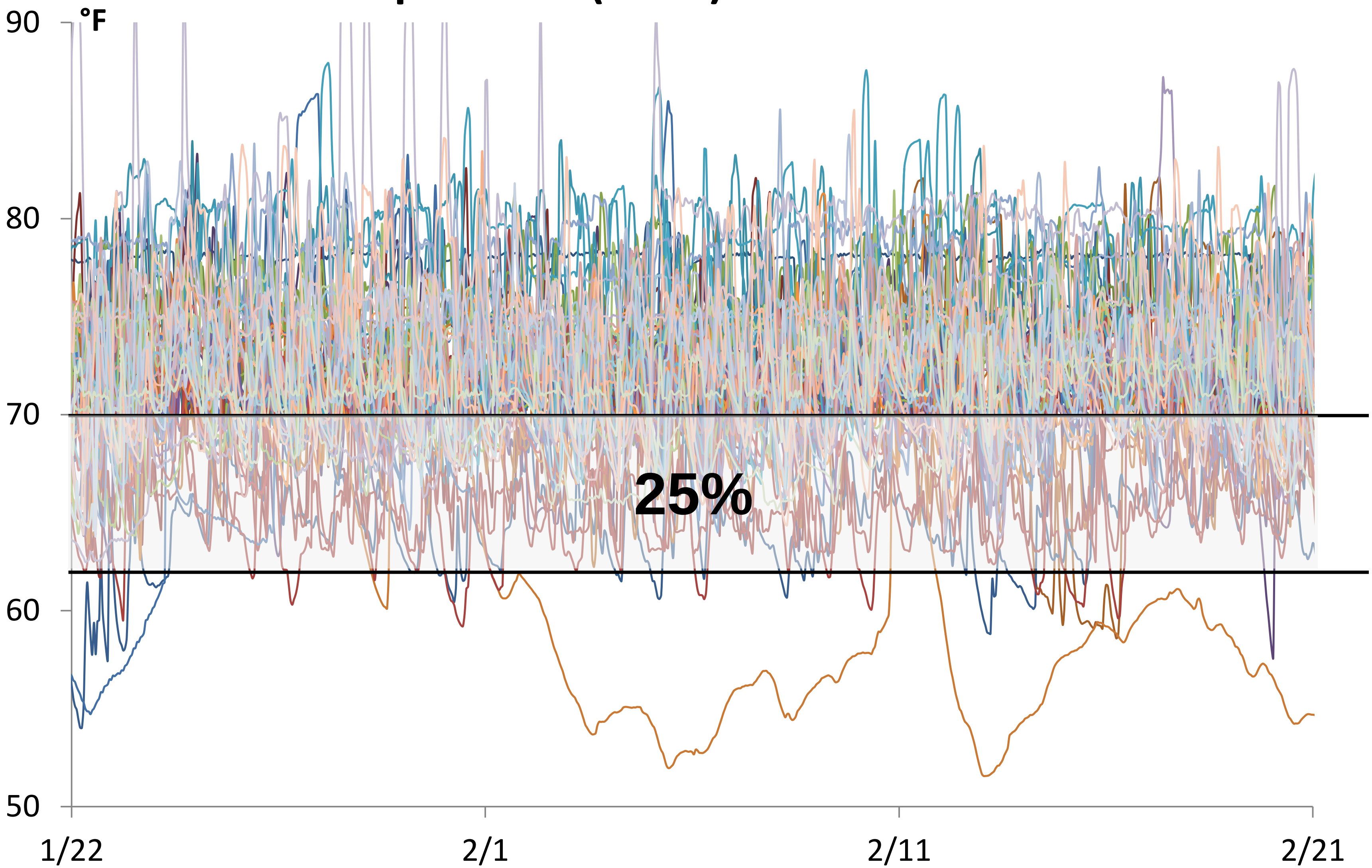


Average Air Temperature over 67 Appts.

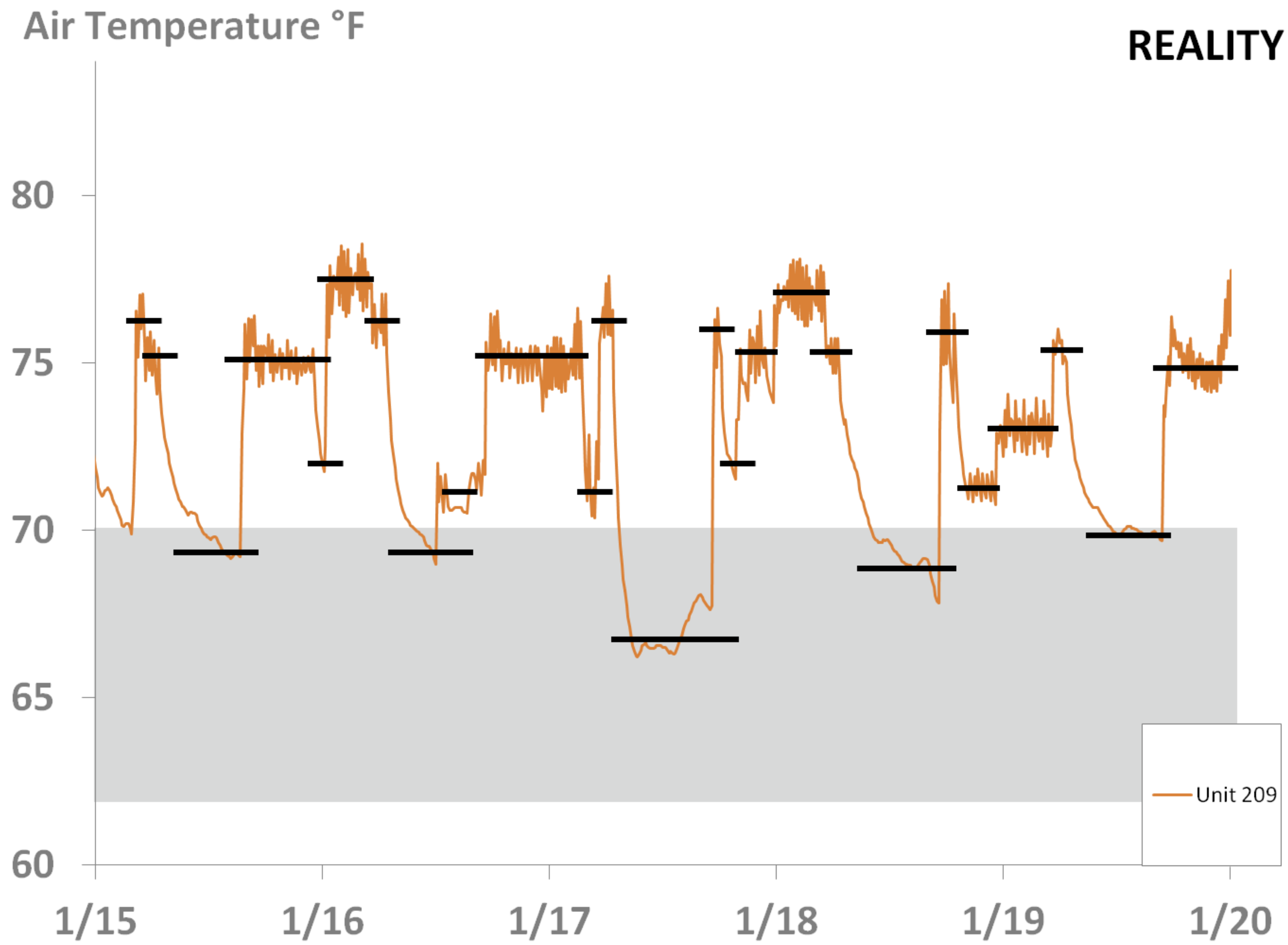


Sources: Urban et al. (20130, Sachs et al. (2012).

Measured Air Temperature (n=67)



Sources: Urban et al. (20130, Sachs et al. (2012).



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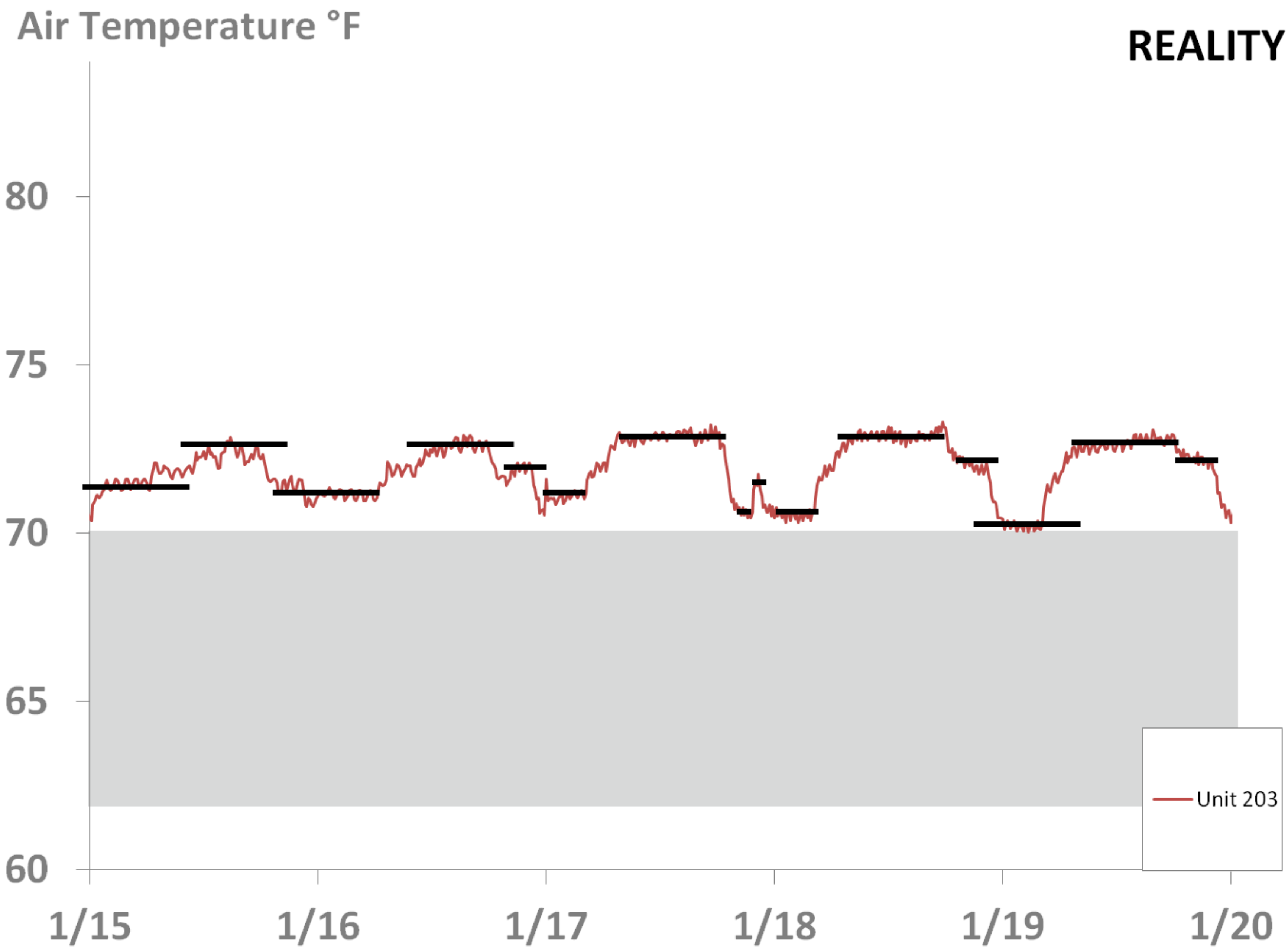
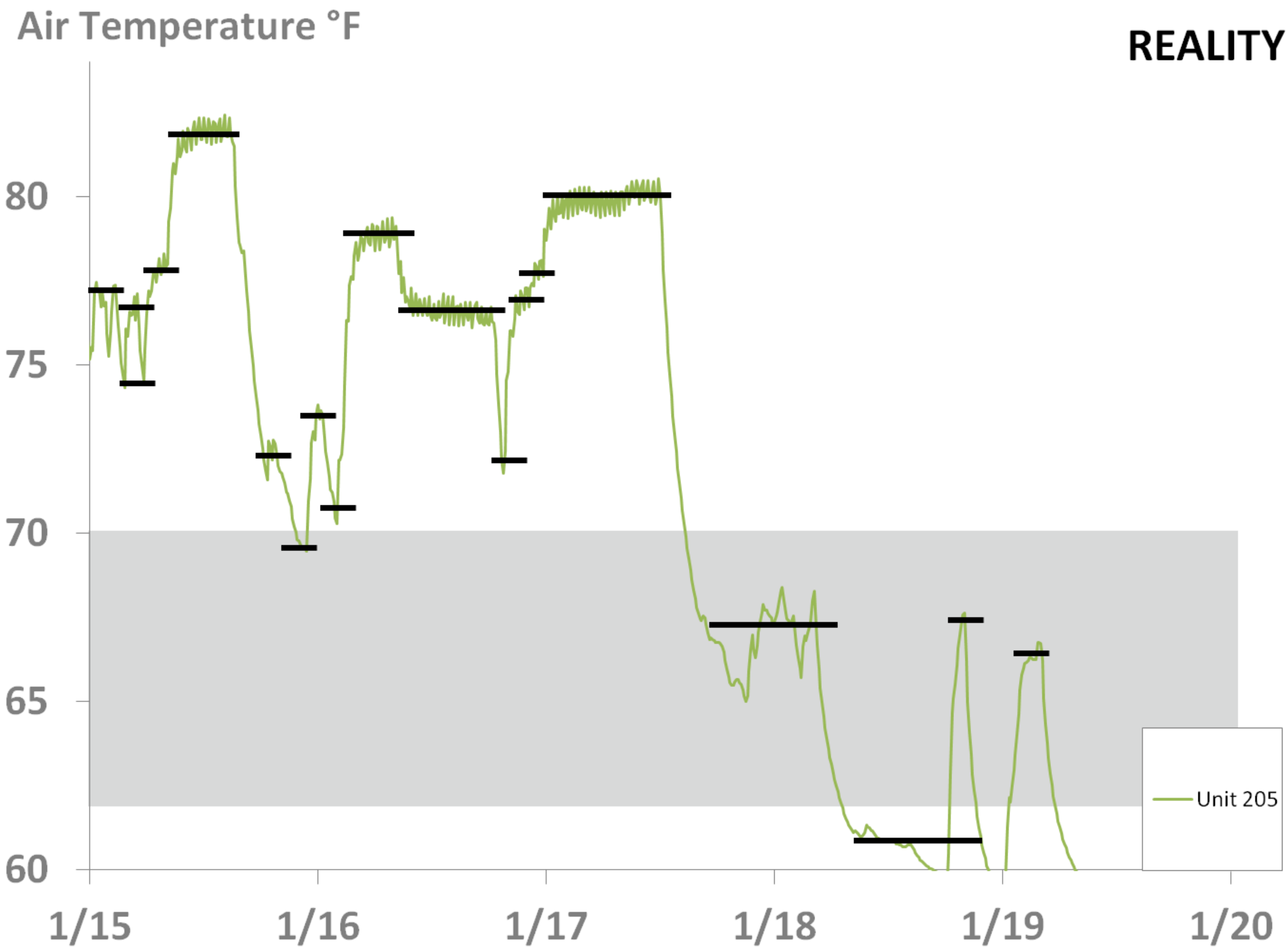
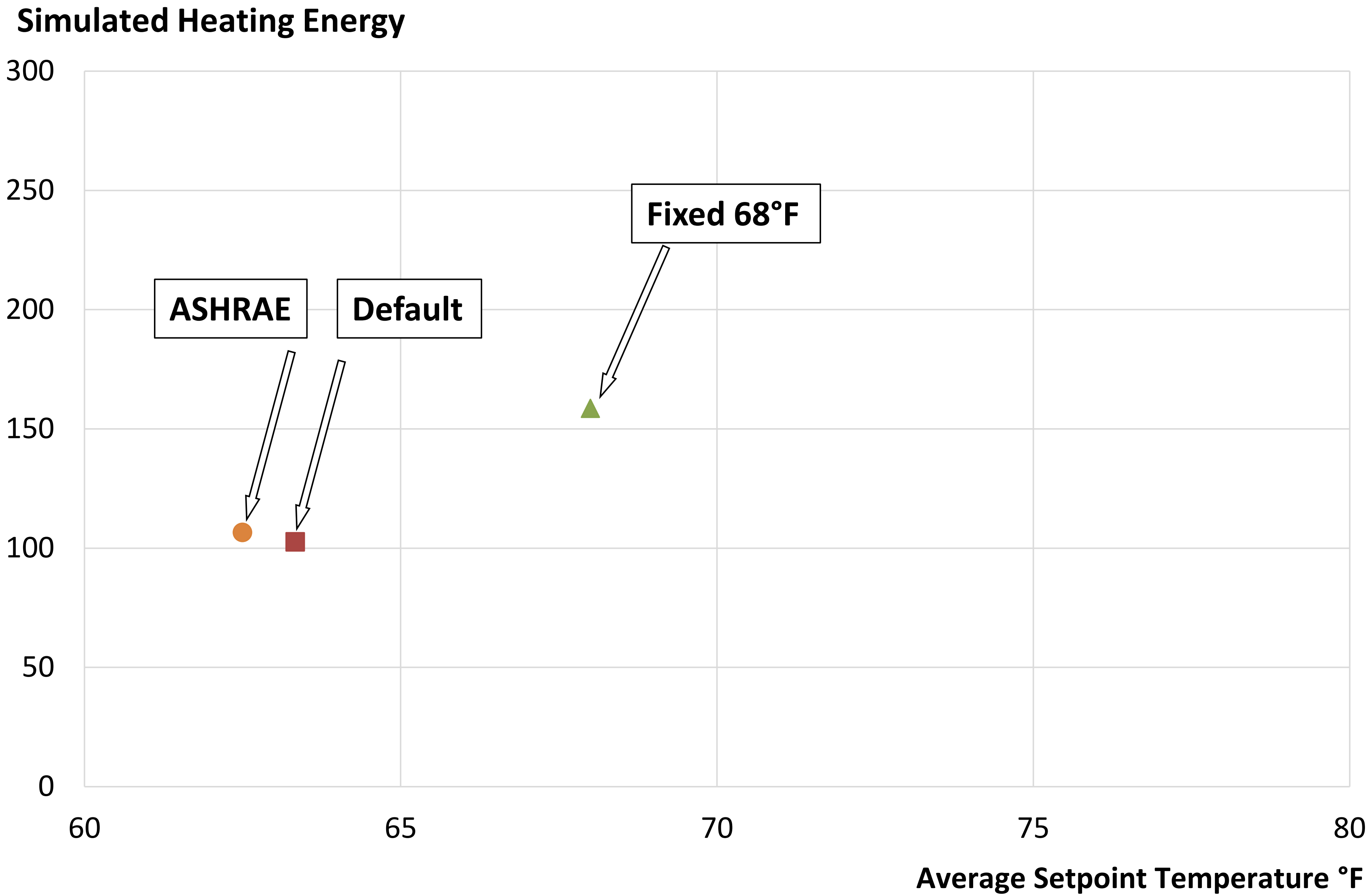


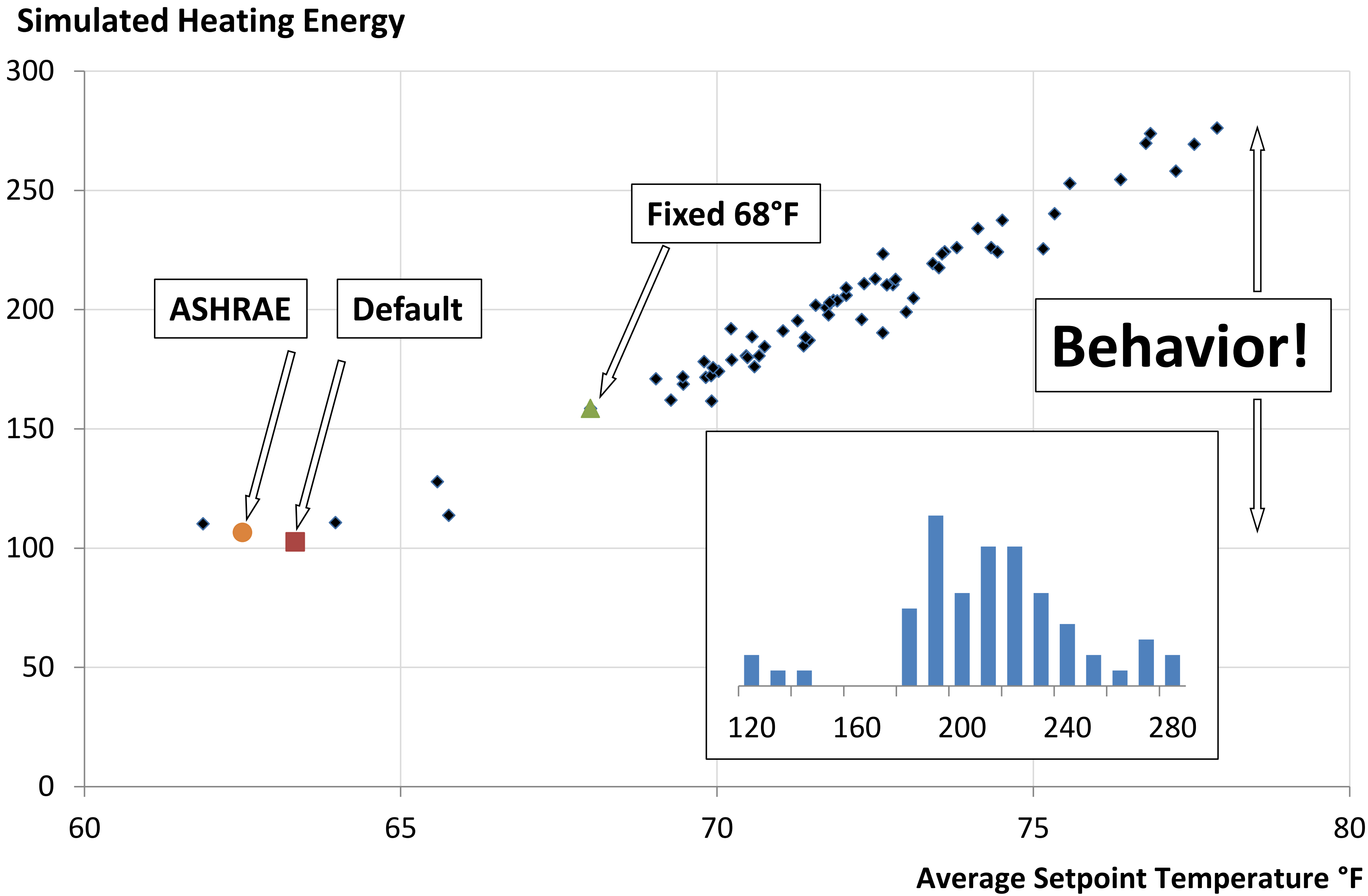
Sources: Urban et al. (20130, Sachs et al. (2012).



Sources: Urban et al. (20130, Sachs et al. (2012).



Source: Urban et al. (2013)



Source: Urban et al. (2013)

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Behaviors happens in the context of technology!

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Example: Programmable thermostats & Energy Saving

Energy savings due to programmable thermostats:

- Programmable thermostats **save** energy
  - 6% and 3.6% savings in a billing analysis of 7,000 and 25,000 households, respectively
  - 9% savings in a survey of 2,300 respondents
- Programmable thermostats **do not** save energy
  - No significant savings in billing and survey analysis of 299 households
  - No savings and/or some increases

Sources: RLW Analytics (2007), Michaud et al. (2009), Tachibana (2009), Nevius & Pigg (1999), Cross & Judd (1996), Conner (2001), Parker 2000)

Fraunhofer DOE-Building America Project: Field Evaluation of Programmable Thermostats

- Conventional Wisdom: Thermostat usability likely responsibility for inconsistent PT savings
- Our reaction: Sounds good – what happens in homes??

Project approach:

- Recruited multifamily building with 90 households
- Randomly installed high usability and basic thermostats
- Installed non-intrusive sensors to monitor temperatures and HVAC activity throughout winter
- Analyzed data to evaluate thermostat use

Image Source: Honeywell

Building AMERICA U.S. Department of Energy

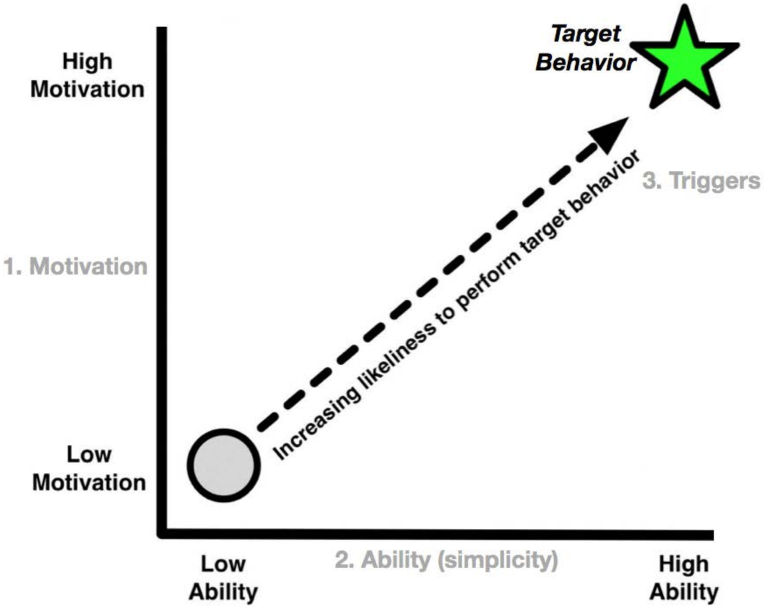
Fraunhofer USA

Findings:

- **Negligible** use of nighttime setback in both groups
- **Comfort trumps energy:** average 72ºF at night
- Suggests high usability alone is not sufficient for savings

Why???

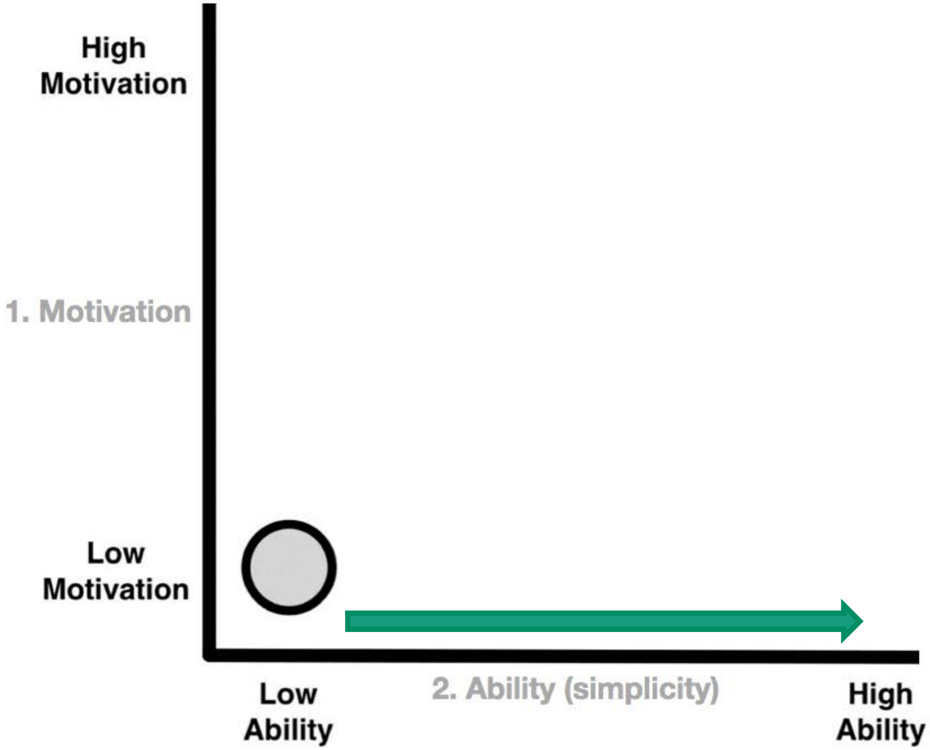
- Factors underlying behavior Change:
  - Ability
  - Trigger
  - Motivation



Sources: Sachs et al. (2012), Fogg (2009).

Thermostat behavior change: ability is NOT enough!

- Three main factors:
  - Ability
  - ~~Trigger~~
  - ~~Motivation~~



Sources: Sachs et al. (2012), Fogg (2009).

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NEW DATA SOURCES = NEW OPPORTUNITIES

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New data sources can be used to reduce building energy consumption by shaping different types of behavior:

1. Operational behaviors

2. Purchasing behaviors

3. Installer behaviors

Operational Behaviors and communicating thermostats: Temperature set-point optimization and occupant feedback

- People-centric control – give them comfort when they want it, and optimize HVAC operation around that
- Nudge people toward more efficient set point schedules

Image Source: Nest.

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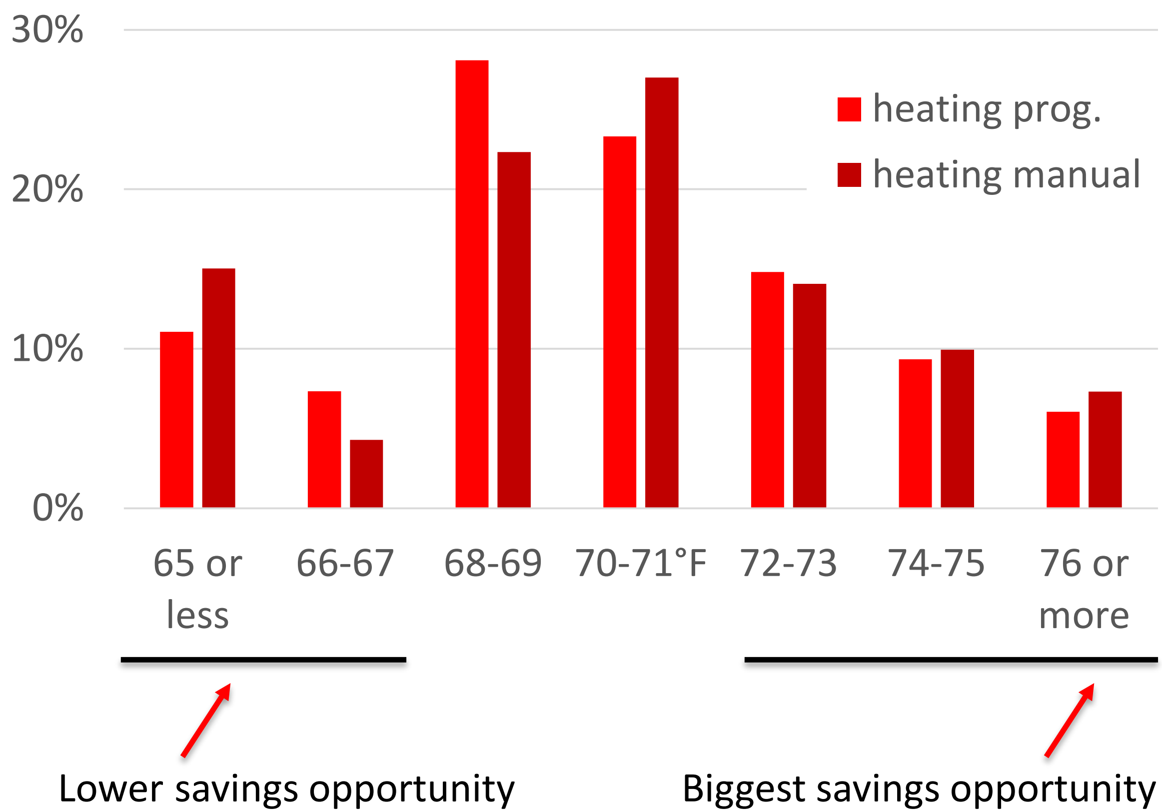
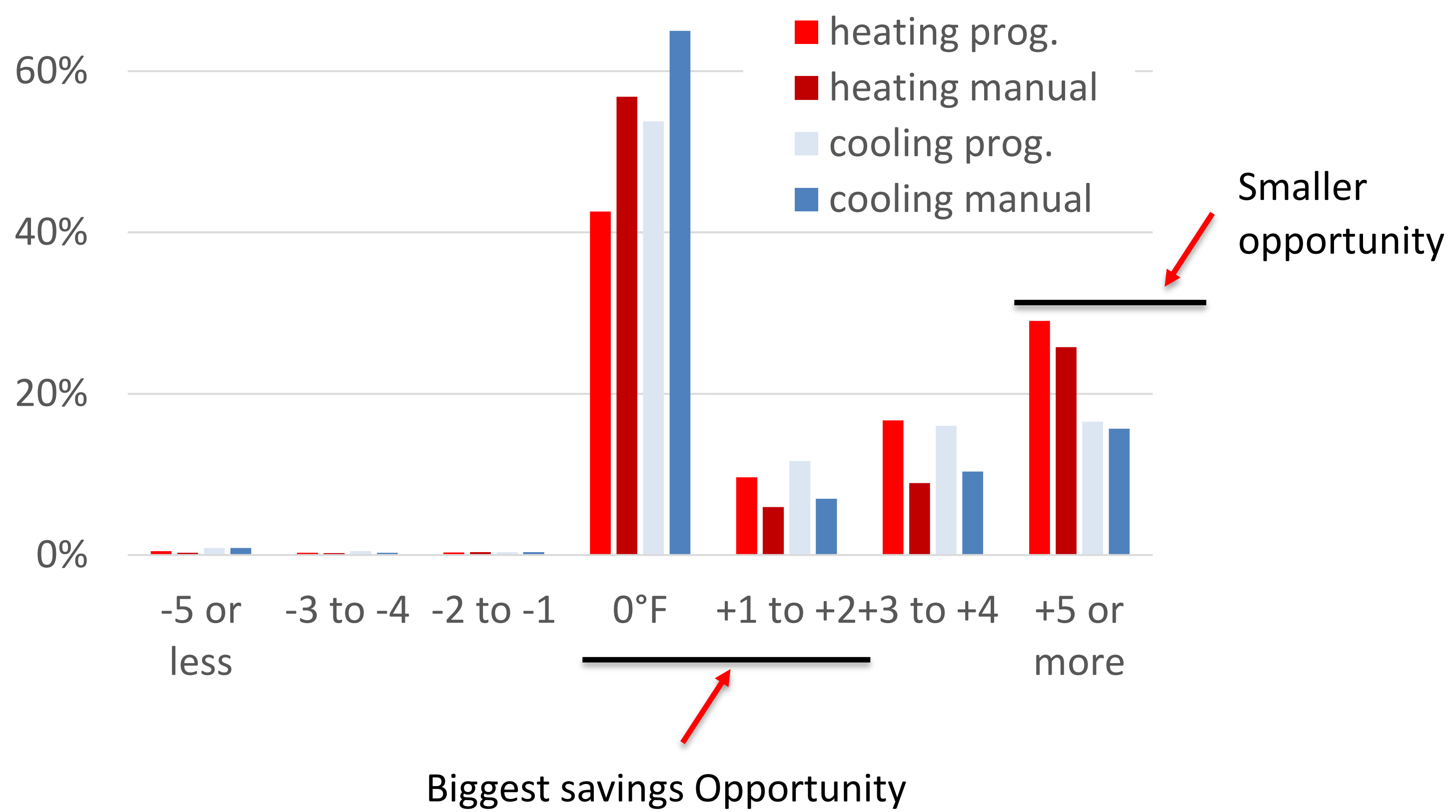
Customize based on heating setpoint preferences



Source: DOE/EIA RECS 2009

Customize based on setback depth when away



Source: DOE/EIA RECS 2009

Purchasing Behaviors and communicating thermostats: Remote home energy assessments

Date	Time	System Setting	System Mode	Calendar Event	Program Mode	Cool Set Temp (F)	Heat Set Temp (F)	Current Temp (F)	Current Humidity (%RH)	Outdoor Temp (F)	Wind Speed (km/h)	Cool Stage 1 (sec)	Heat Stage 1 (sec)	Fan (sec)
3/29/2016	0:00:00	auto	heatOff		Sleep	82	63	70	39	43.8	16	0	0	0
3/29/2016	0:05:00	auto	heatOff		Sleep	82	63	69.9	39	43.8	16	0	0	0
3/29/2016	0:10:00	auto	heatOff		Sleep	82	63	69.8	40	43.8	16	0	0	0
3/29/2016	0:15:00	auto	heatOff		Sleep	82	63	69.8	40	43.8	16	0	0	0
3/29/2016	0:20:00	auto	heatOff		Sleep	82	63	69.8	40	43.8	16	0	0	0
3/29/2016	0:25:00	auto	heatOff		Sleep	82	63	69.7	40	43.8	16	0	0	0
3/29/2016	0:30:00	auto	heatOff		Sleep	82	63	69.6	40	42.7	22	0	0	0
3/29/2016	0:35:00	auto	heatOff		Sleep	82	63	69.4	40	42.7	22	0	0	0
3/29/2016	0:40:00	auto	heatOff		Sleep	82	63	69.3	40	42.7	22	0	0	0
3/29/2016	0:45:00	auto	heatOff		Sleep	82	63	69.1	40	42.7	22	0	0	0
3/29/2016	0:50:00	auto	heatOff		Sleep	82	63	69	40	42.7	22	0	0	0
3/29/2016	0:55:00	auto	heatOff		Sleep	82	63	68.9	40	42.7	22	0	0	0
3/29/2016	1:00:00	auto	heatOff		Sleep	82	63	68.9	40	42.7	22	0	0	0
3/29/2016	1:05:00	auto	heatOff		Sleep	82	63	68.8	40	42.7	22	0	0	0
3/29/2016	1:10:00	auto	heatOff		Sleep	82	63	68.7	40	42.7	22	0	0	0
3/29/2016	1:15:00	auto	heatOff		Sleep	82	63	68.6	40	42.7	22	0	0	0
3/29/2016	1:20:00	auto	heatOff		Sleep	82	63	68.6	40	42.7	22	0	0	0
3/29/2016	1:25:00	auto	heatOff		Sleep	82	63	68.5	40	42.7	22	0	0	0
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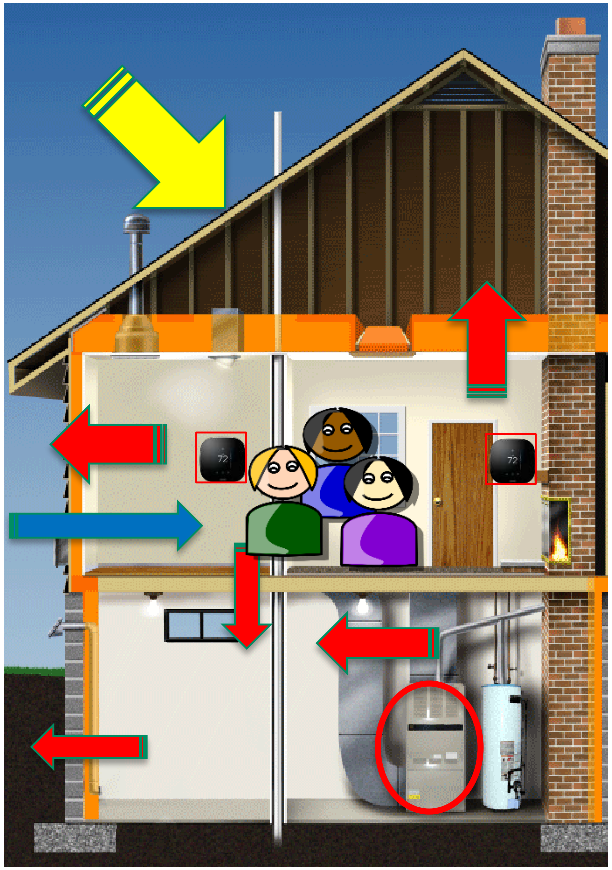
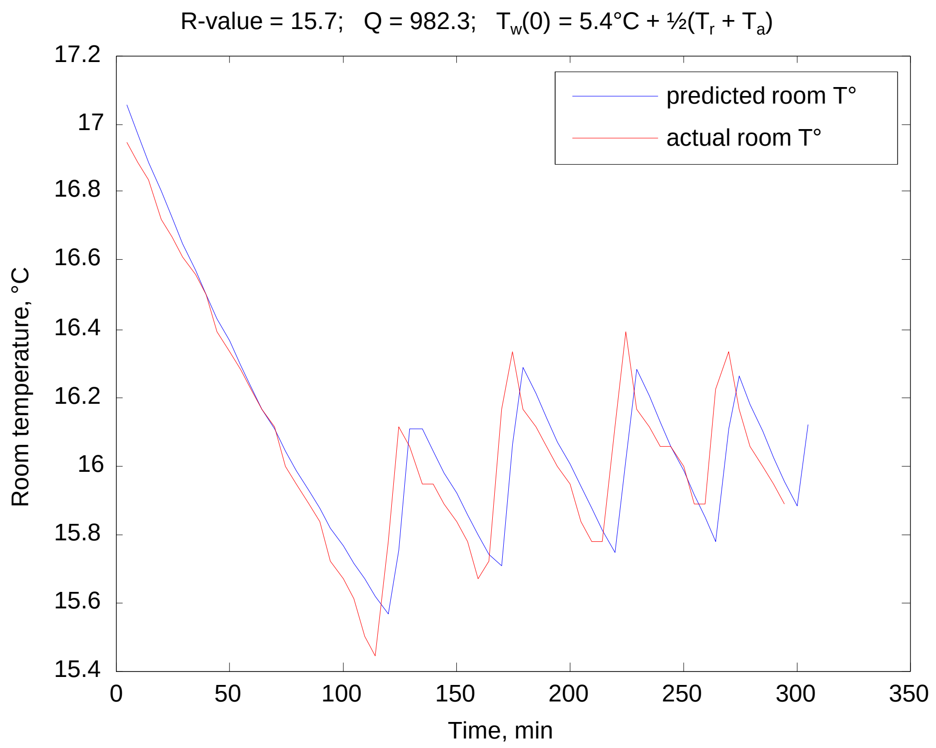
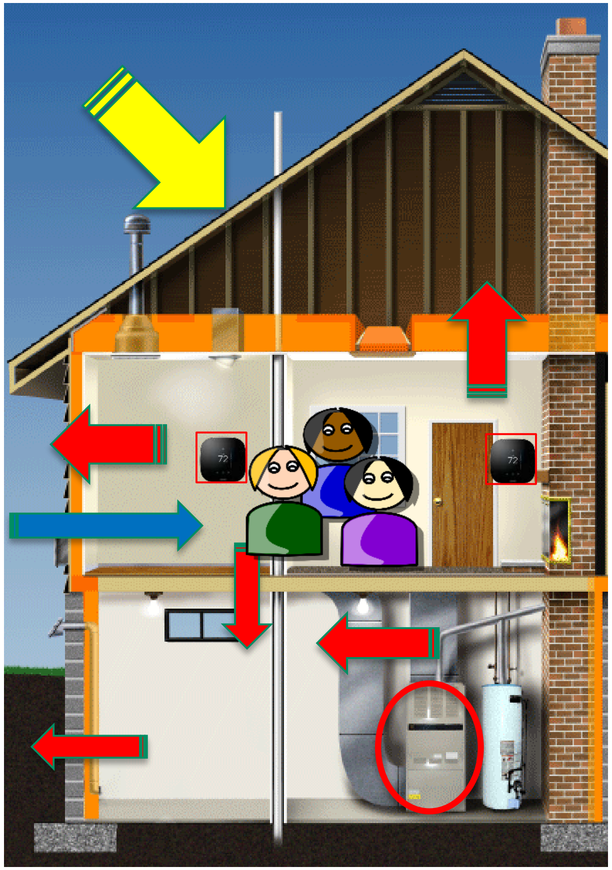
3/29/2016	1:35:00	auto	heatOff		Sleep	82	63	68.4	40	42.6	19	0	0	0
3/29/2016	1:40:00	auto	heatOff		Sleep	82	63	68.4	40	42.6	19	0	0	0
3/29/2016	1:45:00	auto	heatOff		Sleep	82	63	68.3	40	42.6	19	0	0	0
3/29/2016	1:50:00	auto	heatOff		Sleep	82	63	68.2	40	42.6	19	0	0	0
3/29/2016	1:55:00	auto	heatOff		Sleep	82	63	68.2	41	42.6	19	0	0	0
3/29/2016	2:00:00	auto	heatOff		Sleep	82	63	68.1	41	42.6	19	0	0	0



Source: Roth and Zeifman (2017).

Fraunhofer DOE-Building America project developing algorithms using CT data to model home thermal response …





Source: Roth and Zeifman (2017).

Ultimately enabling:

- Identify household-specific retrofit opportunities
- Calculate household-specific energy savings potentials
- Provide targeted energy efficiency offerings to households
- Increase uptake of EE retrofits

*By insulating your home, you can reduce your heating bill by **$183** per year …*

Image Source: S. Edwards-Musa.

Installation Behaviors and communicating thermostats: Remote performance monitoring

- For homeowners:
  - Are expected retrofit savings being achieved?
  - If not, why??
    - Poor retrofit implementation?
    - Operational fault?
    - Increased comfort?
- For utility EE programs:
  - Deliver for customers
  - Enable early identification of systematic problems, e.g., condensing boiler supply water temperature reset schedules
  - Potential for customer engagement

Use home electric interval (e.g., hourly) data to:

- Identify and target homes that are good candidates for EE and DR programs
- Identify and target homes for energy efficiency or demand response programs
- Perform remote EM&V
- Diagnose or predict HVAC faults

Image Source: Itron.

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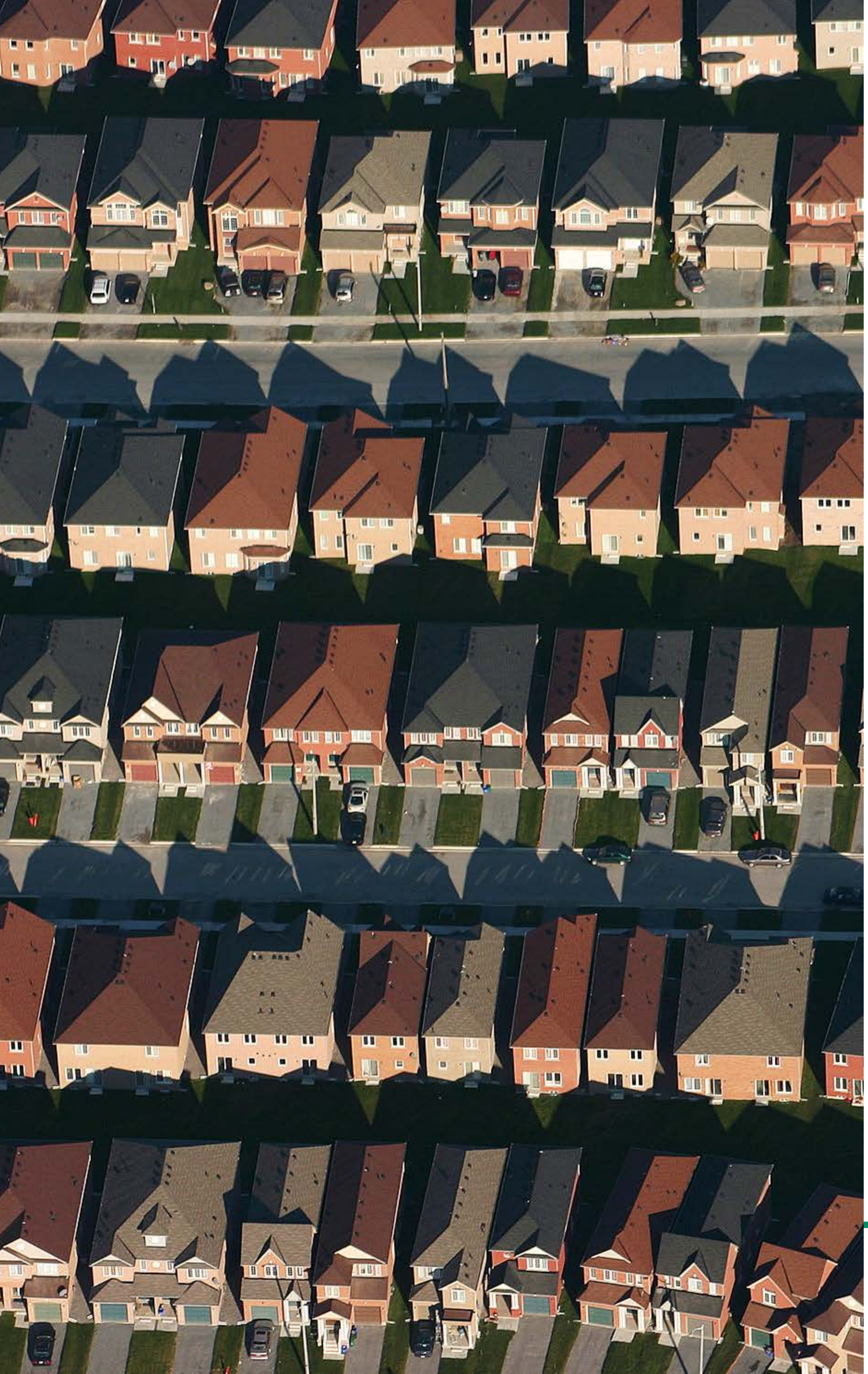

Example: Analysis of West Coast utility residential behavioral EE and DR pilot

Fraunhofer hypothesis:

- Likelihood to participate in EE and DR programs reflects energy-related attitudes and beliefs
- Energy-related attitudes affect energy-related behaviors
- Energy-related behaviors impact electricity consumption pattern

Thus: Households likely to participate have similar electricity consumption patterns

Sources: Zeifman (2014, 2015)

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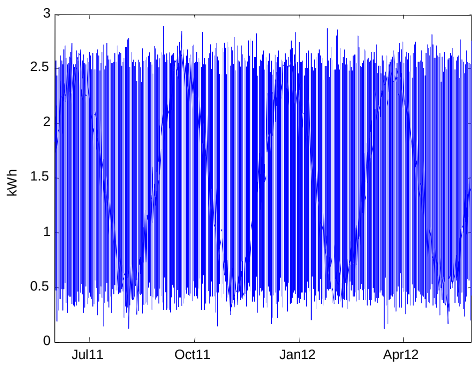
Field Data Description

- Pool 1: Smart meter data on ~5,600 households that enrolled in the Program (out of 470,000 eligible households, or 1.2%)
- Pool 2: Smart meter data on ~32,000 households resided just outside the eligible area (still same city and microclimate zone)
  - Hourly electricity consumption for ~18 months (1 year before the Program) of each household
  - Zip code of each household
- Pool 1 seems to be similar to Pool 2
  - Socio-economic data do not differ significantly (US Census by zip code)
  - Average hourly electricity consumptions do not differ significantly

Sources: Zeifman (2014, 2015)

Approach: Applied nonlinear machine learning (NML) algorithms

- Black box system: inputs –> NML algorithm –> output
  - *Input:* Year's worth of hourly electricity consumption data
  - *Output*: Binary (likely to enroll / unlikely to enroll)
- Algorithm cannot tell what visible signal/household features correlate with enrollment propensity, just whether a household is more or less likely to enroll.



Household hourly kWh data

NML algorithm

Score 1: Will enroll

Score 2: Won't enroll

If Score 1 > Score 2 = Enrolled
If Score 2 > Score 1 = Not Enrolled

Sources: Zeifman (2014, 2015)

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Algorithm Testing

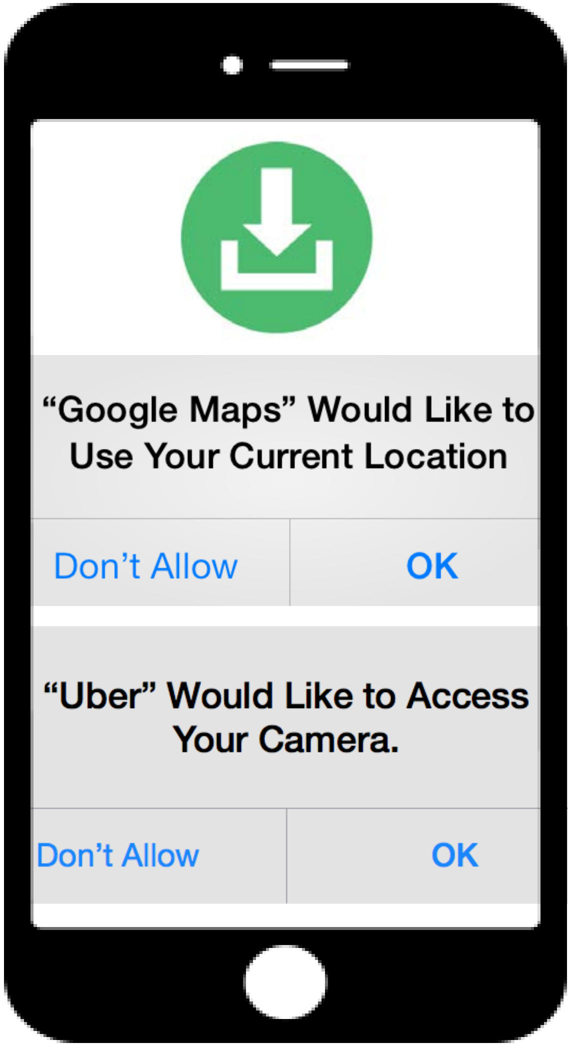
- Classify a random sample of 2,000 enrolled households and 2,000 not enrolled households not used for training
- Repeat the process of training and testing using random samples (multiple cross-validation)
- Random chance = 50% prediction accuracy.

Samples used	Enrolled households	Not enrolled households
Training samples	92.4±1.1 %	91.7±1.3 %
Testing samples	91.2±1.1 %	90.5±1.4 %

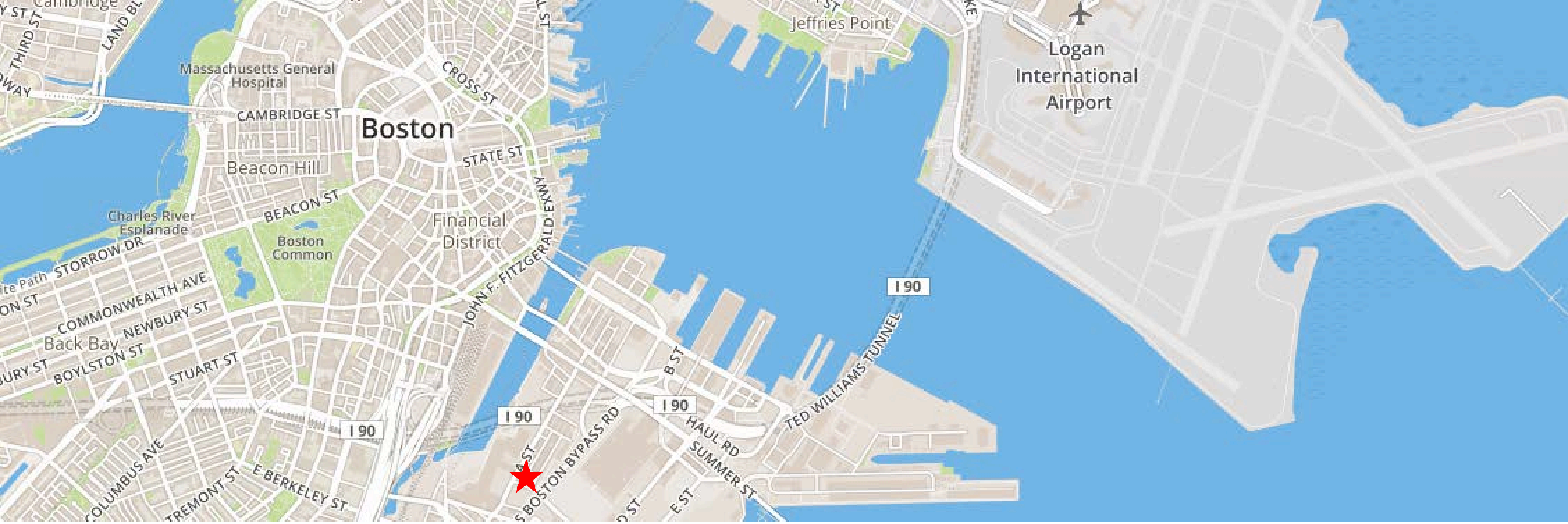
Algorithm predicted what households would enroll with an accuracy ~five times greater than chance

Sources: Zeifman (2014, 2015)

NEED: Common Data Sharing Frameworks



In short, Sapiens happens!



Contact

Kurt Roth
Director
Building Energy Systems
kroth@cse.fraunhofer.org

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