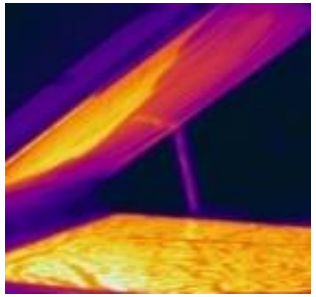
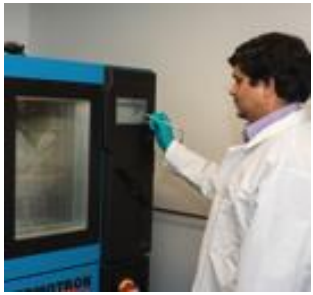
Communicating Thermostats: Opportunities and Challenges





Kurt Roth, Bryan Urban, Michael Zeifman, and Joana Abreu

April 7, 2016

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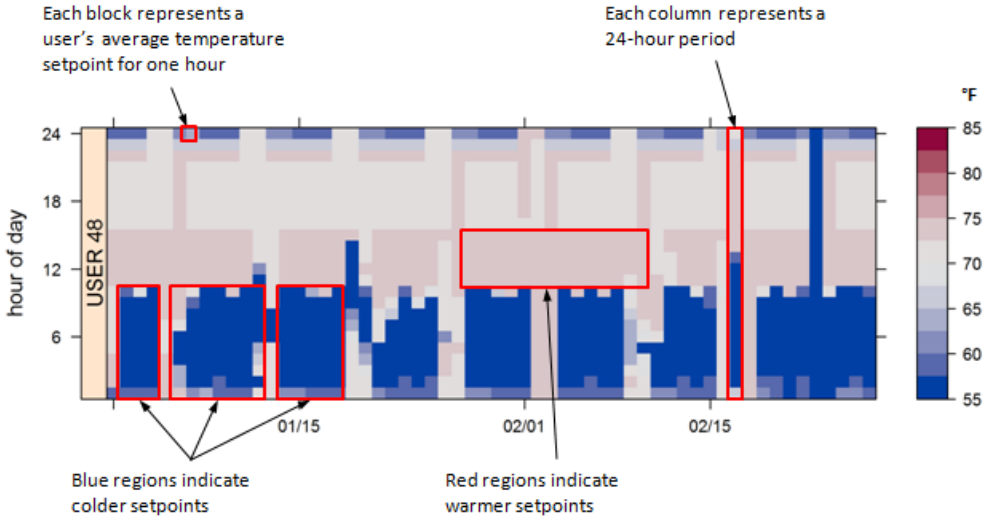
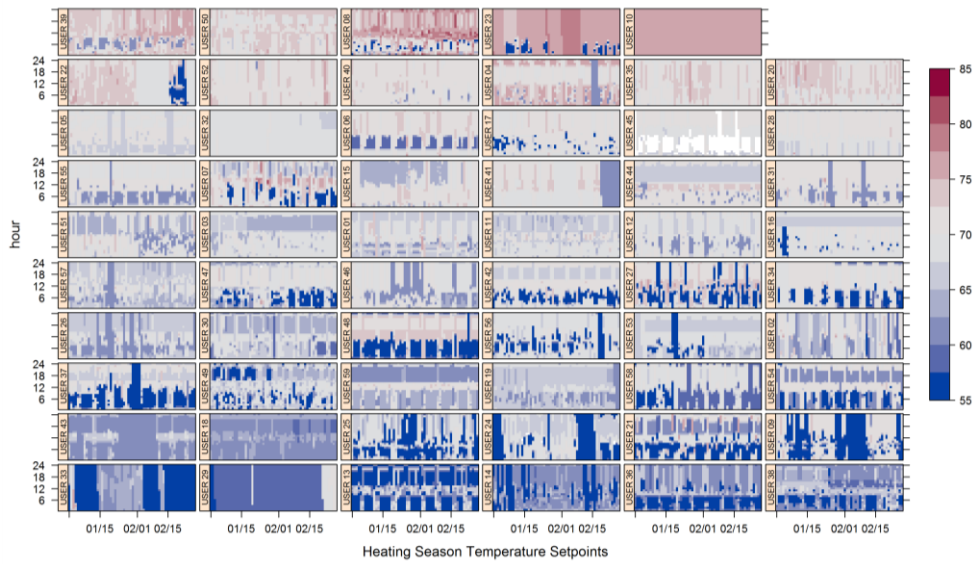
So many data ...





Source: Urban and Roth (2014)

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... and so many potential opportunities!

- Tailored behavioral interventions: Tips, feedback, etc.
- DR potential
- Automated Quality Assurance (QA) for retrofits
- Remote evaluation, measurement, and validation (EM&V)
- Retrofit opportunities
- Fault detection and diagnostics
- Etc.

Source: http://muppet.wikia.com

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But what is feasible given the relative lack of context and messiness of the real world?

- Thermostat placement
- HVAC system type
  - Electric vs. fuel-fired
  - Furnace vs. boiler
    - Hot water vs. steam
  - Fixed vs. variable capacity
- Number of zones
- Supplemental heating systems
- Building thermal mass
- Multi- versus single-family
- Etc.

Source: http://muppet.wikia.com

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Temperature Data: Based on thermostat transfer function

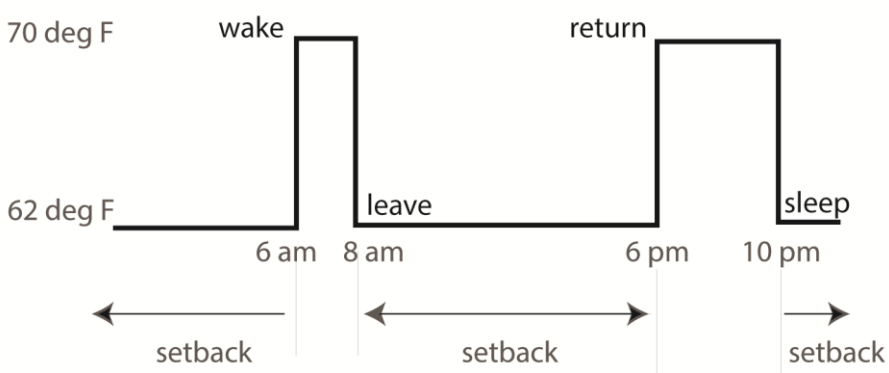
Experiment Settings: Four Combinations

Setpoints

- Constant : 70°F
- Variable : 70°F/62°F

Blinds

- Opened/Closed
- Opened/Closed



Source: Fraunhofer CSE.

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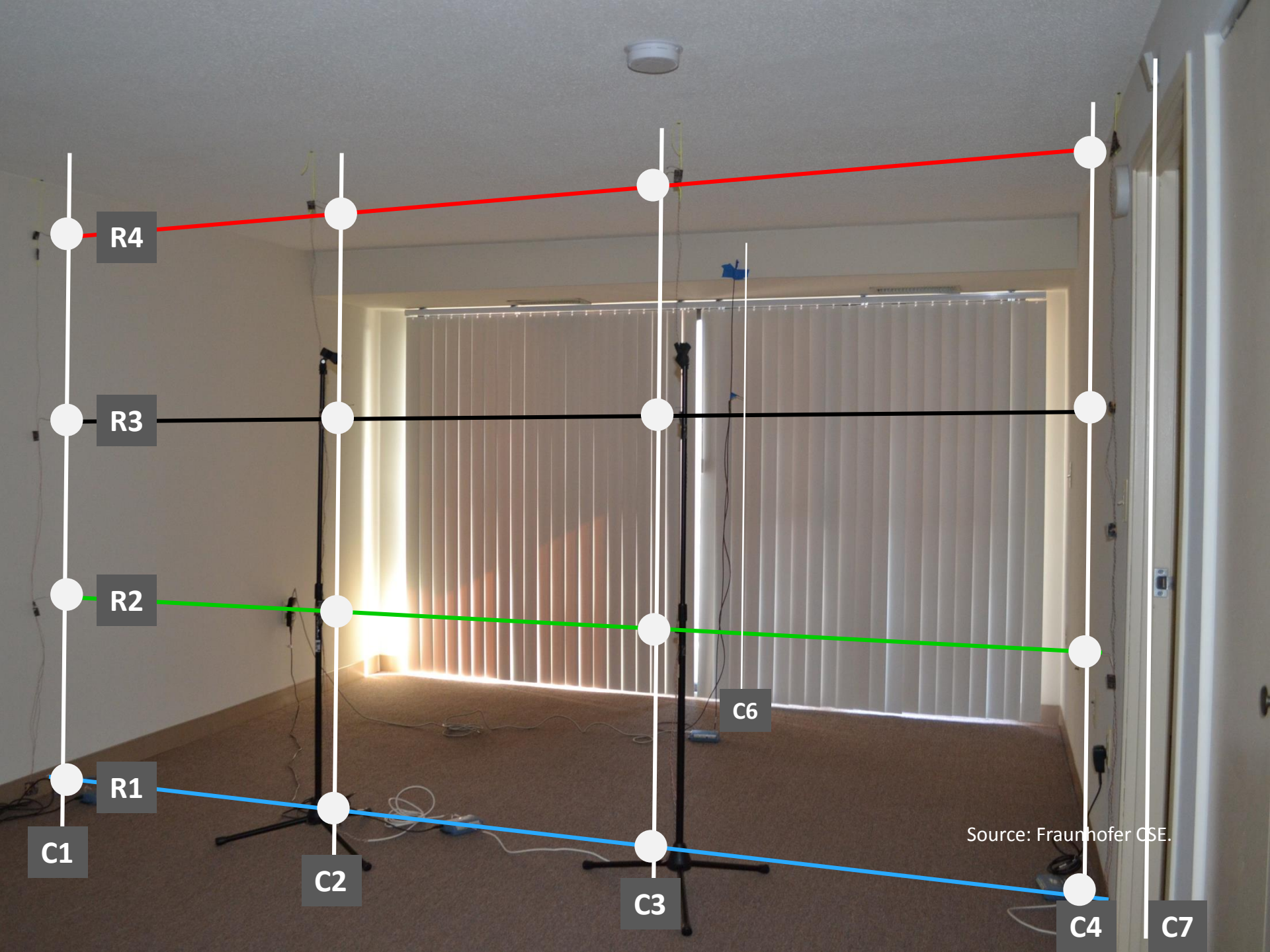
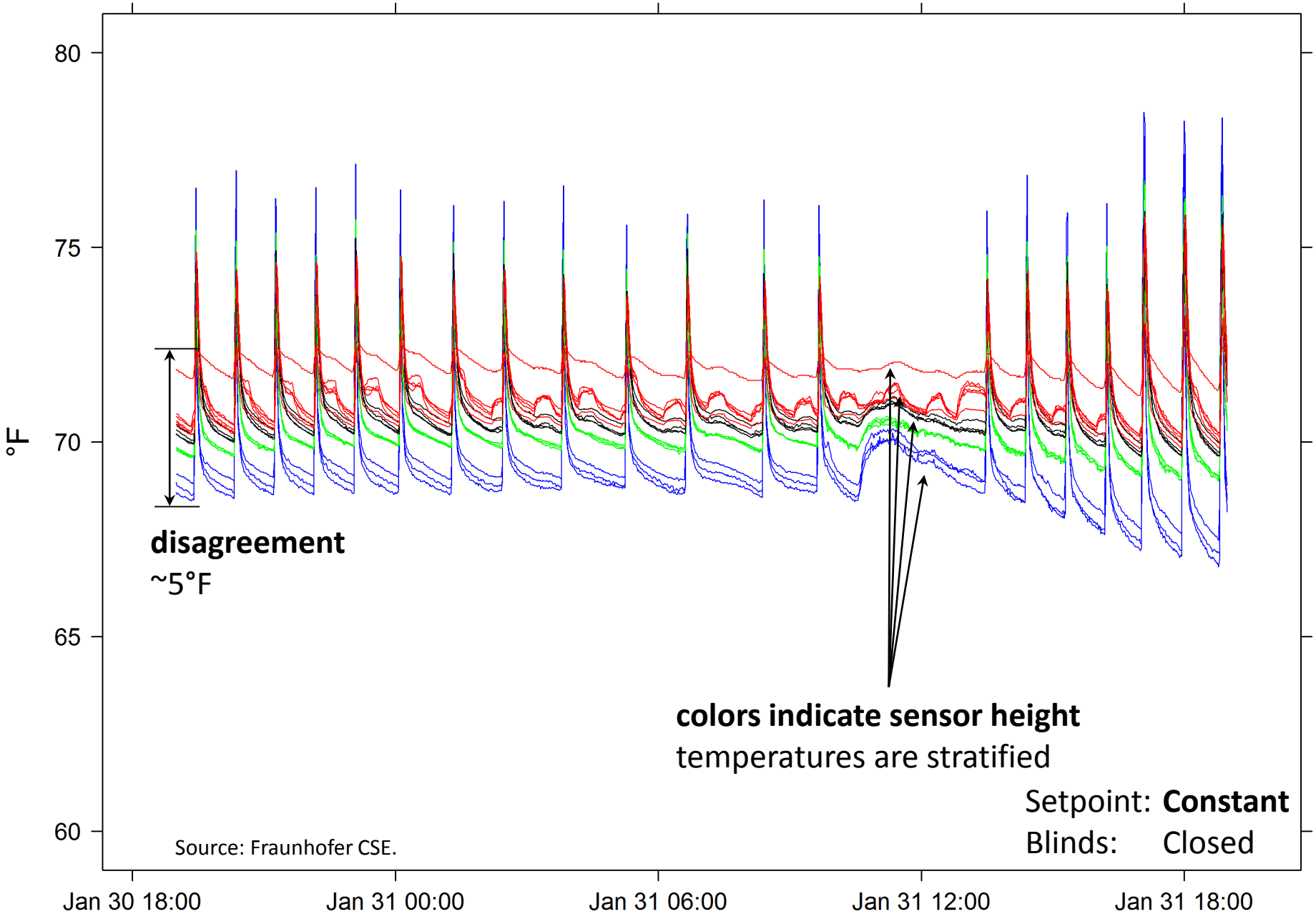
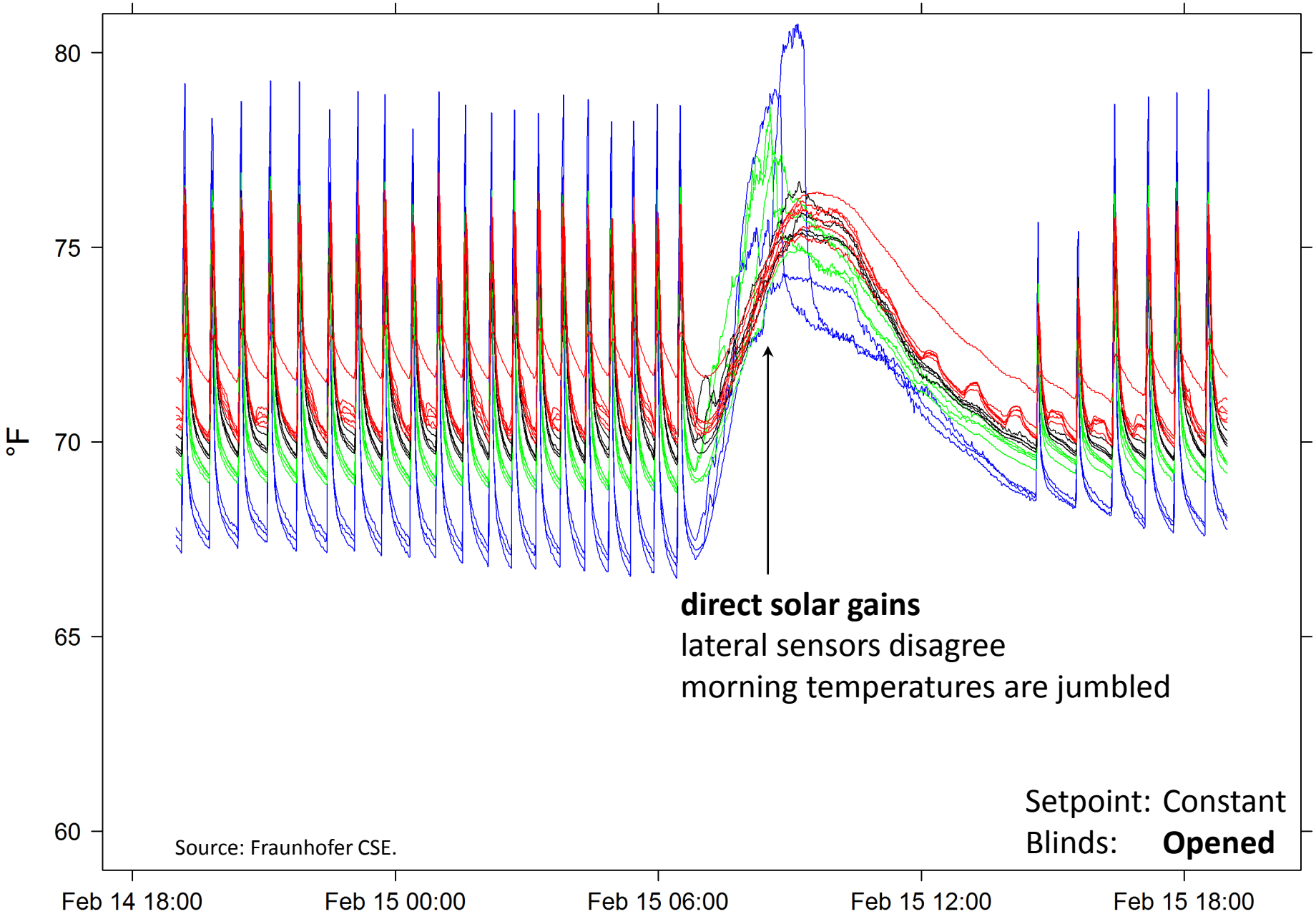
Source: Fraunhofer CSE.

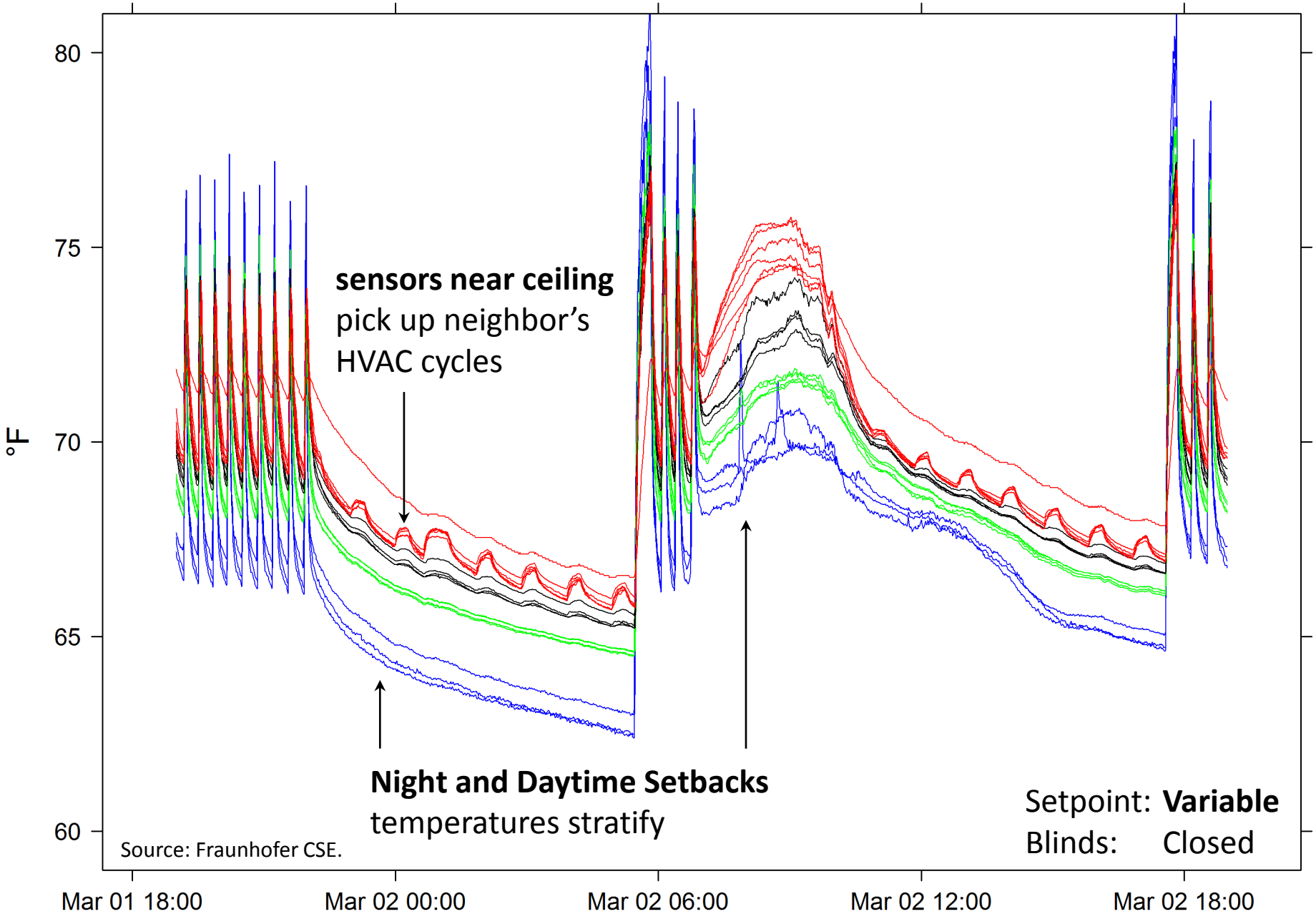

R4
R3
R2
R1
C1
C2
C3
C4
C6
C7
Source: Fraunhofer CSE.

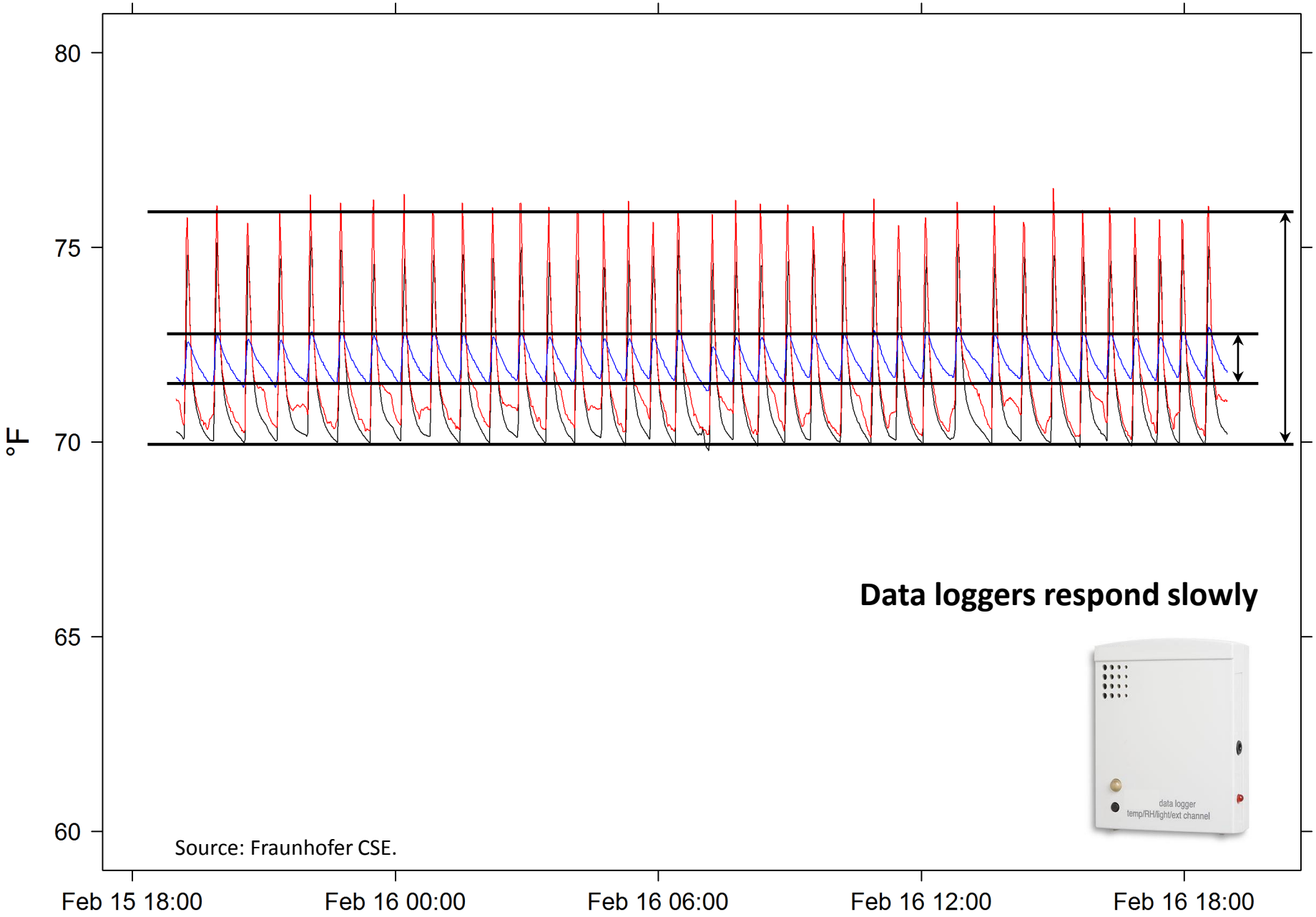
Source: Fraunhofer CSE.

Source: Fraunhofer CSE.


80
75
70
65
60
°F
Jan 30 18:00
Jan 31 00:00
Jan 31 06:00
Jan 31 12:00
Jan 31 18:00
disagreement
~5°F
colors indicate sensor height
temperatures are stratified
Setpoint: Constant
Blinds: Closed
Source: Fraunhofer CSE.

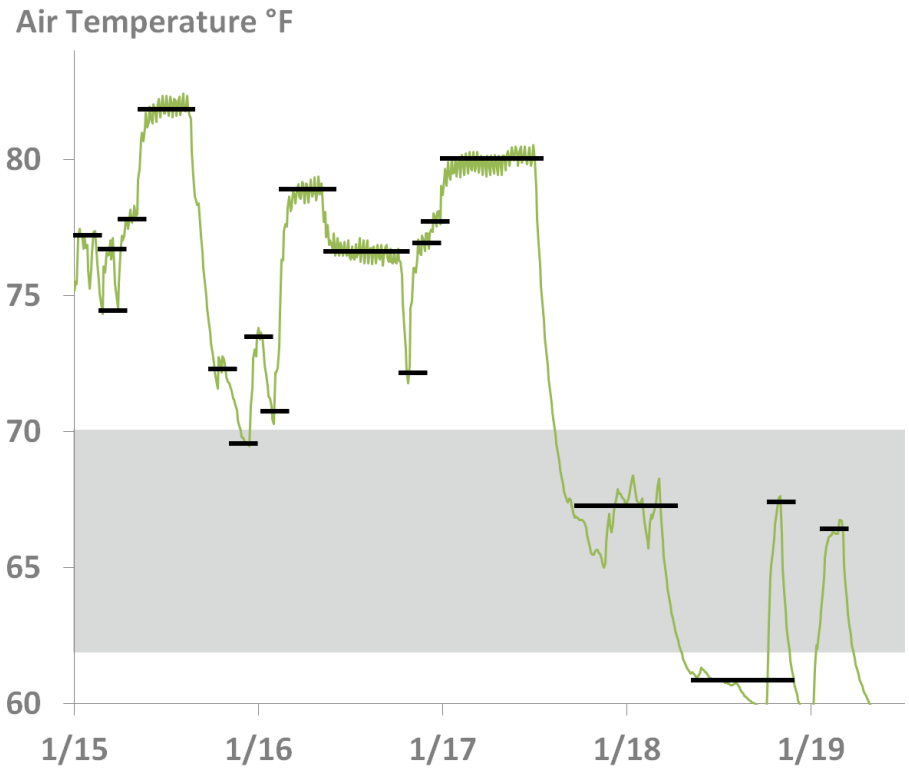

80
75
70
65
60
°F
Feb 14 18:00
Feb 15 00:00
Feb 15 06:00
Feb 15 12:00
Feb 15 18:00
direct solar gains
lateral sensors disagree
morning temperatures are jumbled
Setpoint: Constant
Blinds: Opened
Source: Fraunhofer CSE.


80
75
70
65
60
°F
Mar 01 18:00
Mar 02 00:00
Mar 02 06:00
Mar 02 12:00
Mar 02 18:00
sensors near ceiling
pick up neighbor's
HVAC cycles
Night and Daytime Setbacks
temperatures stratify
Setpoint: **Variable**
Blinds: Closed
Source: Fraunhofer CSE.


80
75
70
65
60
°F
Feb 15 18:00
Feb 16 00:00
Feb 16 06:00
Feb 16 12:00
Feb 16 18:00
Data loggers respond slowly
data logger
temp/RH/light/ext channel
Source: Fraunhofer CSE.

Behavioral Opportunities

- Setback depth and frequency
- Observed changes in setpoint behavior
  (requires longer history)
- Identify if/how often people are using auto-away features
  (requires occupancy data)



Source: Fraunhofer CSE.

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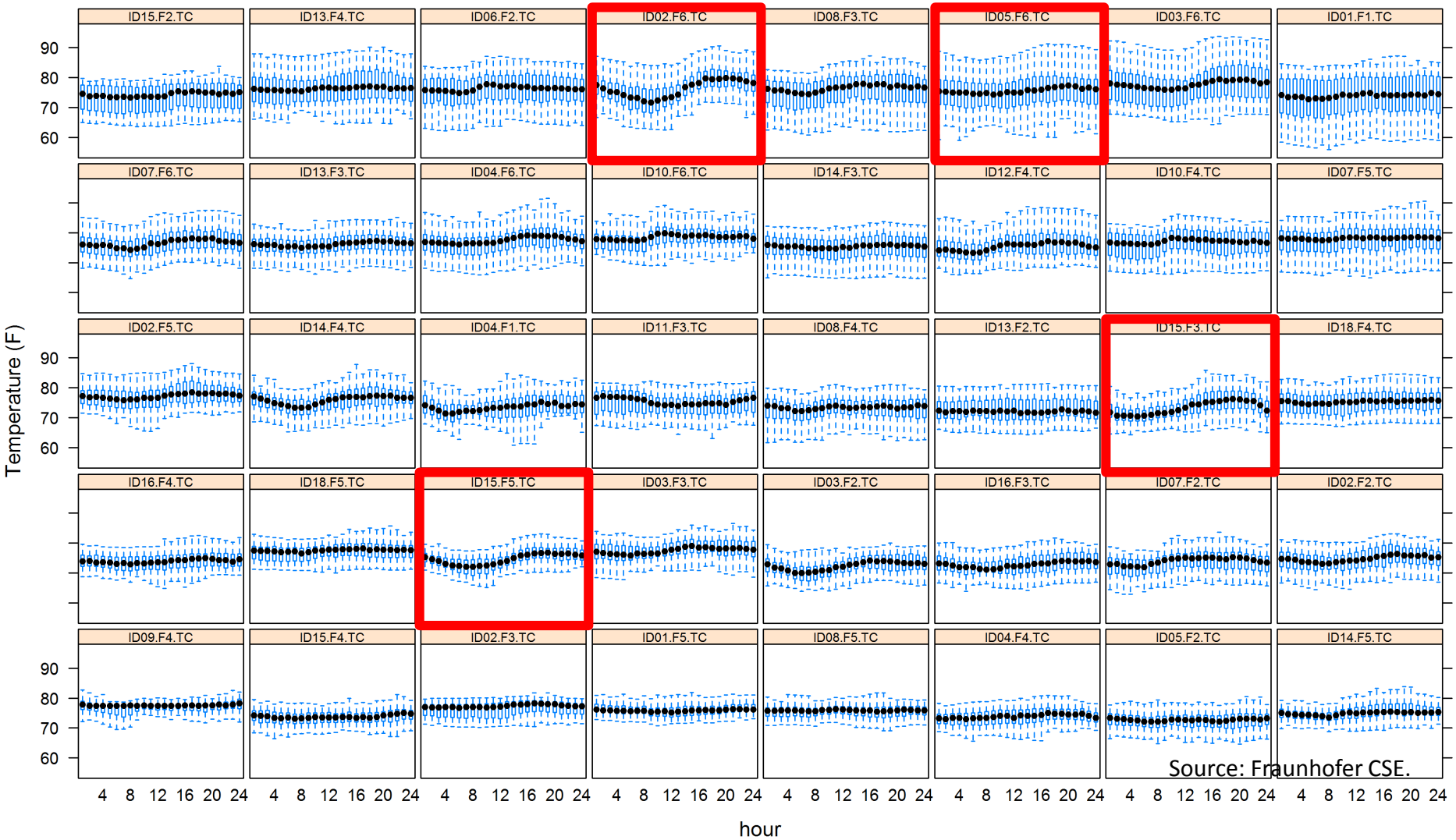
DR Potential

Daily Temperature Profiles – BY APARTMENT – SUMMER

= visual evidence of a routine setback schedule

Variance



Source: Fraunhofer CSE.

Retrofit QA / Remote EM&V: Ground truth is known.

Before

After

Source: Fraunhofer CSE.

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Identifying Retrofit opportunities: Easy to conceive approaches, not straightforward in practice – but ground truth *not* known.

???

???

Source: Wiki Historian N OH of English Wikipedia

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Identifying Retrofit opportunities: Easy to conceive approaches, not straightforward in practice – Ground truth *not* known

???

???

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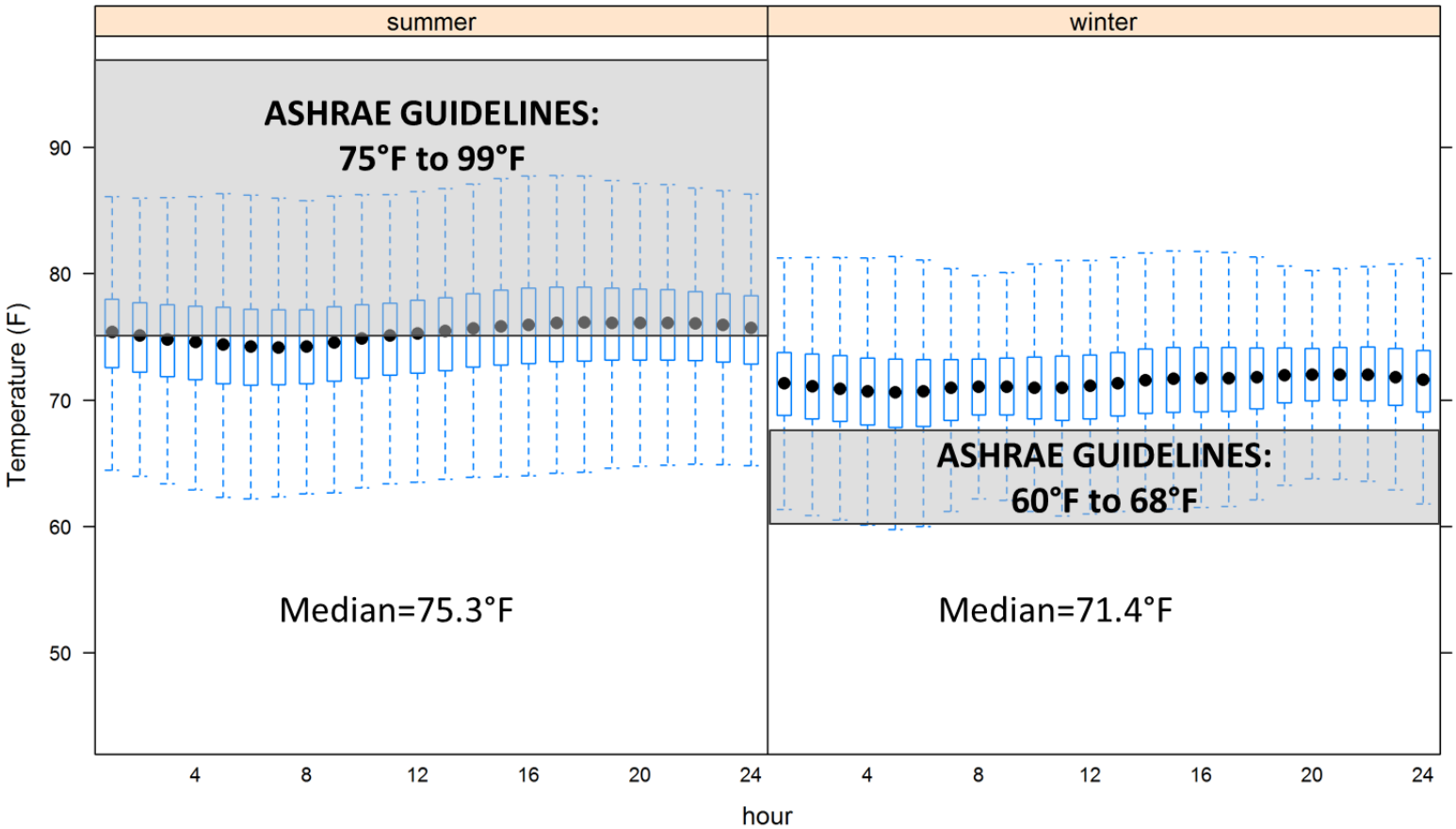
Understand Actual Household Behaviors
Example: Performance baselines for energy simulations



Source: Urban et al. (2012)

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Crucial to understand situations where drawing inferences CT data is more problematic

- Thermostat placement
- HVAC system type
  - Electric vs. fuel-fired
  - Furnace vs. boiler
    - Hot water vs. steam
  - Fixed vs. variable capacity
- Number of zones
- Supplemental heating systems
- Building thermal mass
- Multi- versus single-family
- Etc.

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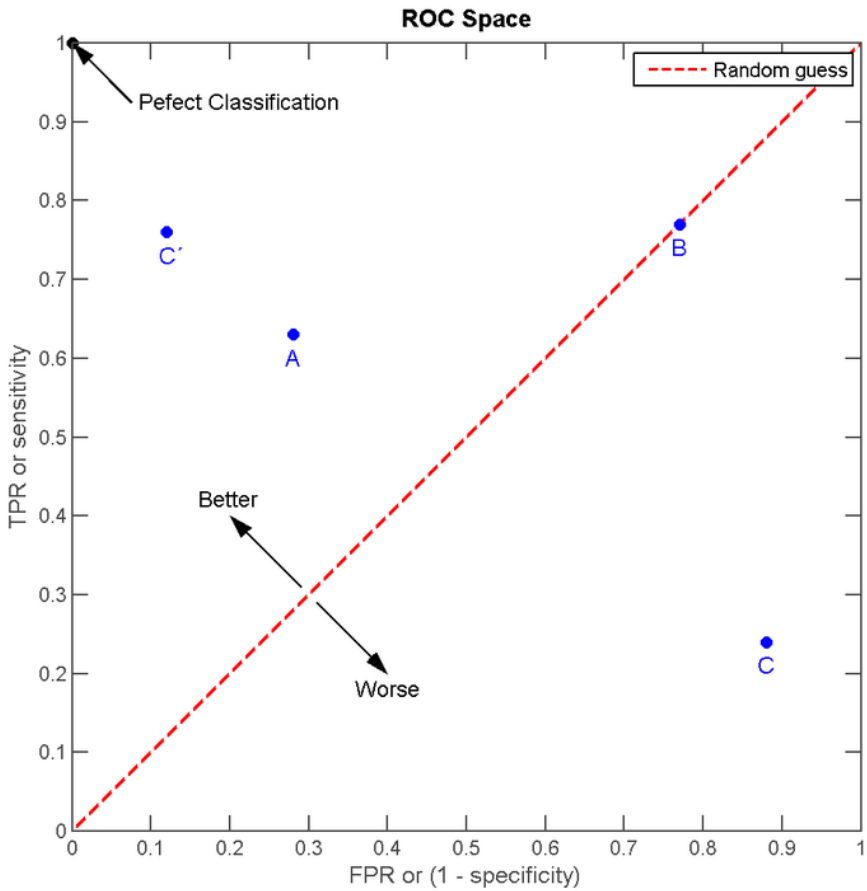
Performance evaluations should not just be evaluated on false positive rate, but also reflect false negatives.



Source: Wikipedia.

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Many thermostat manufacturers are willing to share data – but data formats are all over the map!

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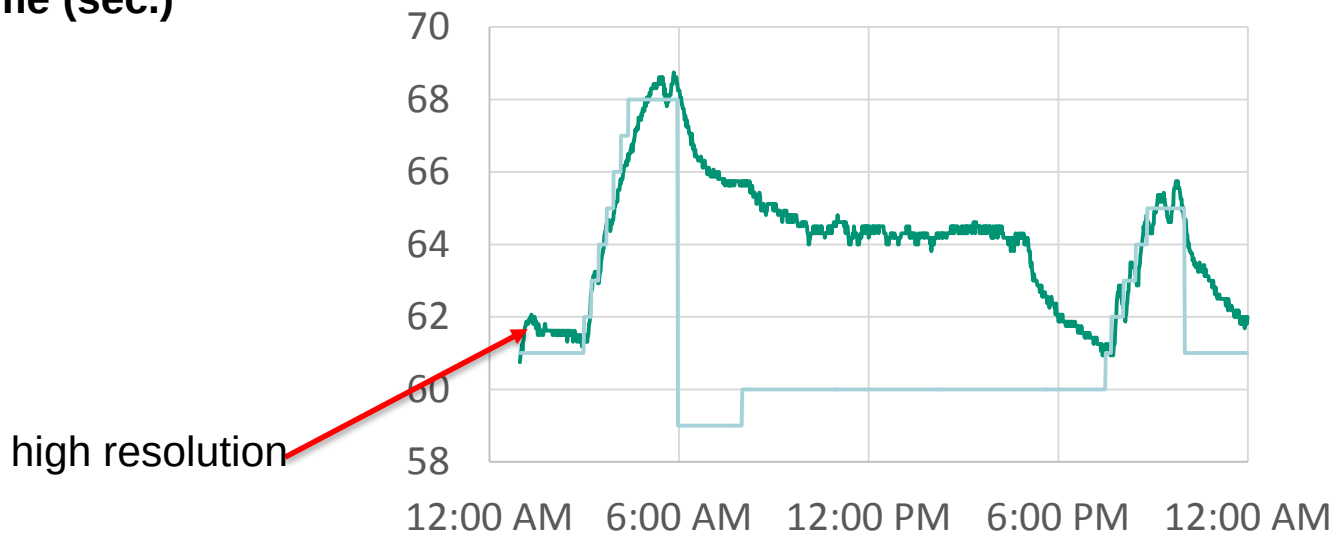
Manufacturer 1

Time	Temp.		Settings						Setpoints		Codes					
Date/Time	Room Temp	Runtime	Hold	Fan	Auto Available	Equipment Type	Critical Fault	Mode	Heat Setpoint	Cool Setpoint	Y1	Y2	W1	O	G	W2
3/1/2016 0:58	60.75	0	Inactive	Auto	Yes	AC	None	Heat	61	82	Off	Off	Off	Off	Off	Off
3/1/2016 0:59	60.93	0	Inactive	Auto	Yes	AC	None	Heat	61	82	Off	Off	Off	Off	Off	Off
3/1/2016 1:00	61	0	Inactive	Auto	Yes	AC	None	Heat	61	82	Off	Off	Off	Off	Off	Off
3/1/2016 1:01	61.12	0	Inactive	Auto	Yes	AC	None	Heat	61	82	Off	Off	Off	Off	Off	Off
3/1/2016 1:02	61.25	0	Inactive	Auto	Yes	AC	None	Heat	61	82	Off	Off	Off	Off	Off	Off
3/1/2016 1:03	61.06	0	Inactive	Auto	Yes	AC	None	Heat	61	82	Off	Off	Off	Off	Off	Off
3/1/2016 1:04	61.31	0	Inactive	Auto	Yes	AC	None	Heat	61	82	Off	Off	Off	Off	Off	Off

Runtime (sec.)



Source: Fraunhofer CSE.

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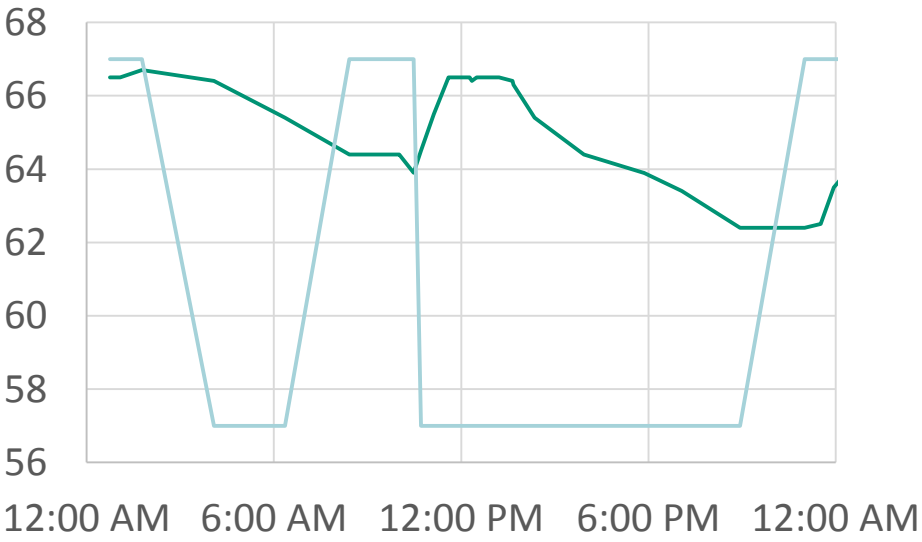
Manufacturer 2

Time | Temp. | Running | Weather | Mode | Setpoints

Device	Timestamp (UTC)	Inside Temperat	Operating State	Forecast Low	Forecast High	Thermostat Mode	Cool Setpoi	Heat Setpoin
1200	1/12/2016 17:50	61.8	0	24	36	1	83	57
1200	1/12/2016 14:41	62.4	0	24	36	1	83	57
1200	1/12/2016 14:03	63.4	0	24	37	1	83	57
1200	1/12/2016 13:40	64.3	0	24	37	1	83	57
1200	1/12/2016 13:30	64.4	0	24	37	1	83	57
1200	1/12/2016 13:46	64.4	1	24	37	1	83	57



Source: Fraunhofer CSE.

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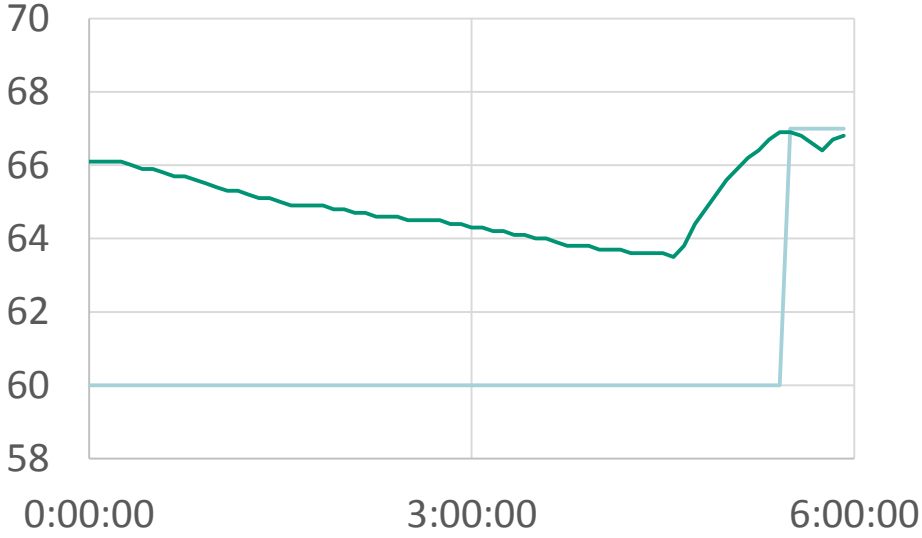
Manufacturer 3

Time		Mode				Setpoints		Temp.		Weather		Runtime		
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)
12/7/2015	0:00:00	heat	heatOff		Sleep	82	60	66.1	38	39.7	6	0	0	0
12/7/2015	0:05:00	heat	heatOff		Sleep	82	60	66.1	38	39.7	6	0	0	0
12/7/2015	0:10:00	heat	heatOff		Sleep	82	60	66.1	38	39.7	6	0	0	0
12/7/2015	0:15:00	heat	heatOff		Sleep	82	60	66.1	38	39.7	6	0	0	0
12/7/2015	0:20:00	heat	heatOff		Sleep	82	60	66	38	39.7	6	0	0	0
12/7/2015	0:25:00	heat	heatOff		Sleep	82	60	65.9	38	39.7	6	0	0	0



Source: Fraunhofer CSE.

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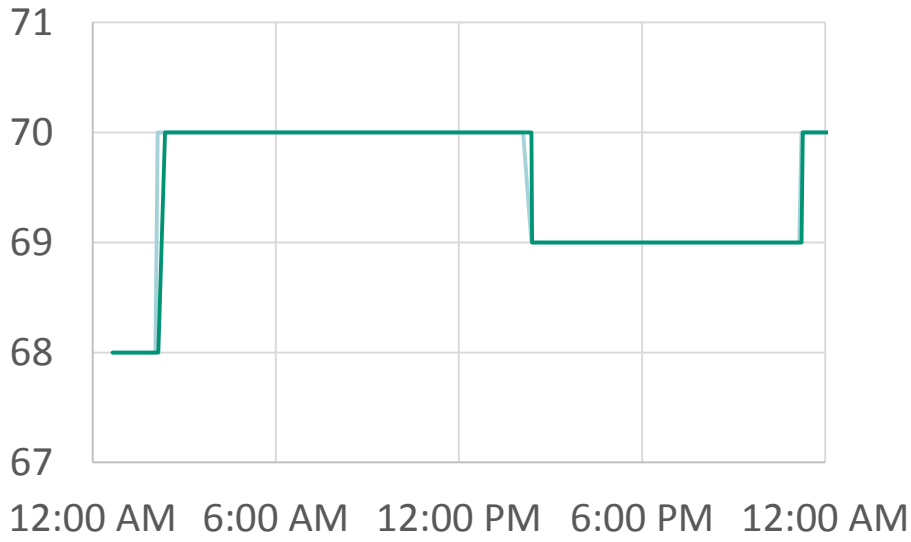
Manufacturer 4

Time	Mode		Setpoints		Temp.		Rel. Humidity	Weather		Schedule Setpoints	
TimeStamp	Mode	Program Status	CoolSetpoint	HeatSetpoint	DispTemperature	OutdoorTemp	Indoor Humidity	OutdoorHumidity	SchedCoolSp	Sched HeatSp	StatSenseDispTemp
1/1/2016 0:39	Heating	Permanent Hold	73	68	68	39	39	75	73	69	68
1/1/2016 0:54	Heating	Permanent Hold	73	68	68	37	39	82	73	69	68
1/1/2016 1:09	Heating	Permanent Hold	73	68	68	36	39	81	73	69	68
1/1/2016 1:19	Heating	Permanent Hold	73	68	68	36	40	81	73	69	68
1/1/2016 1:39	Heating	Permanent Hold	73	68	68	38	40	76	73	69	68
1/1/2016 2:03	Heating	Permanent Hold	73	68	68	38	40	76	73	69	68



Source: Fraunhofer CSE.

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Manufacturer Data Formats: All Over the Map

Thermostat	Data Frequency	Runtime Precision	Temp. Precision	Rel. Humidity	Local Weather
#1	1 min.	seconds per minute	0.01°F	none	none
#4	variable (minutes)	TBD.	1°F	to 1%	outdoor temp and humidity
#3	5 min.	seconds per 5 minutes	0.1°F (avg. over period)	to 1%	wind speed, outdoor temp
#2	variable state change or ΔT>1°F	seconds on/off	0.1°F (avg. over period)	TBD.	forecast low/high temp.

Source: Fraunhofer CSE.

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Needed: A standard for data specification and access control, e.g., Green Button for communicating thermostats.

- What data to collect
- Time resolution
- Precision and accuracy

Answers will vary depending on what the data are used for!

- Data access and sharing control
  - Real-time versus historical data

p.s. Same thing needed for connected devices!

Source: DOE.

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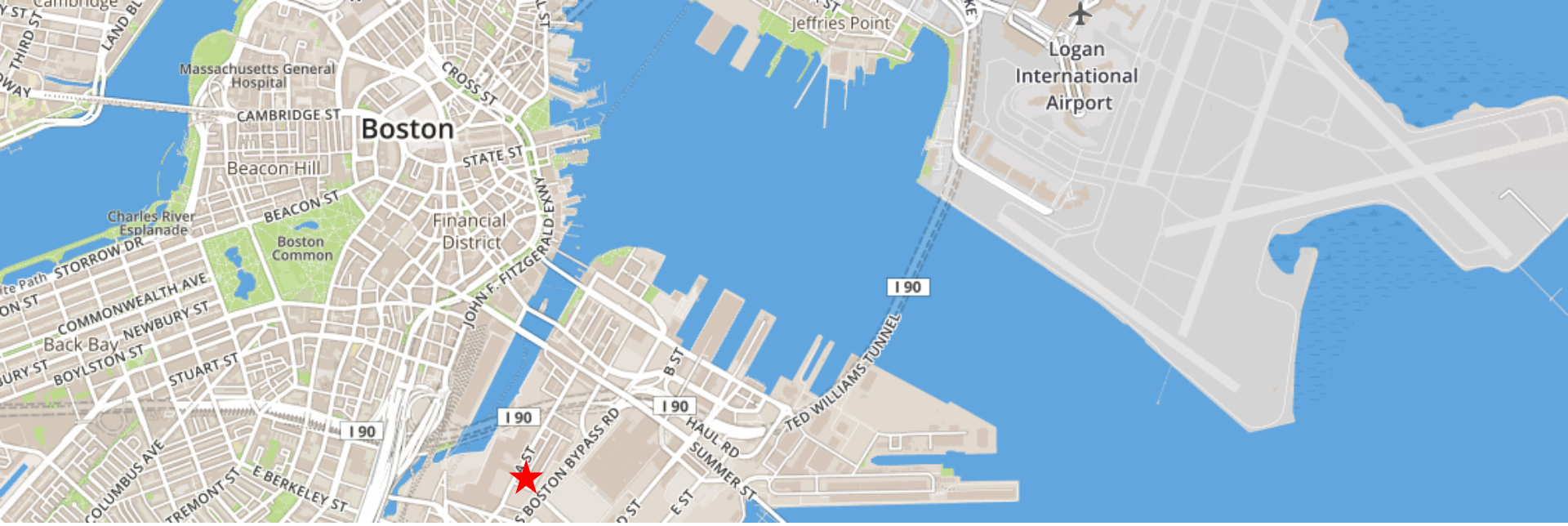

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