Data-Driven Management for a Sustainable Energy Grid

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Work with Ram Rajagopal, James Sweeney, June Flora, and Sam Borgeson

Outline

- **Context: Energy Program Targeting**
- A Structural Temperature Response Model
- Applications

Energy Program Targeting

Problem:

Identify, engage and incentivize willing and responsive users to improve consumption behavior

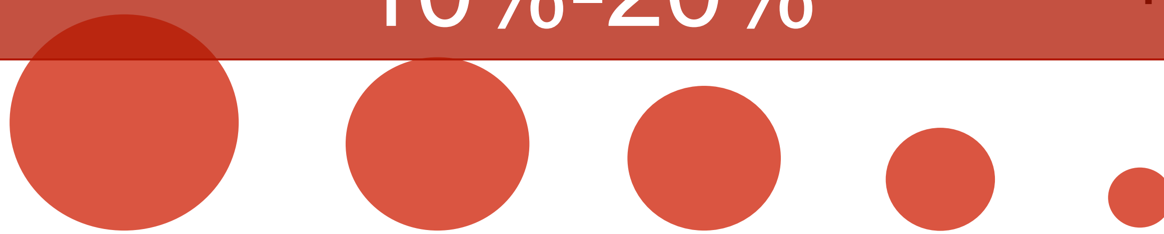
Timescale of Intervention

Energy Efficiency (EE)

Demand Response (DR)

Program yield today: 10%-20%*

Months

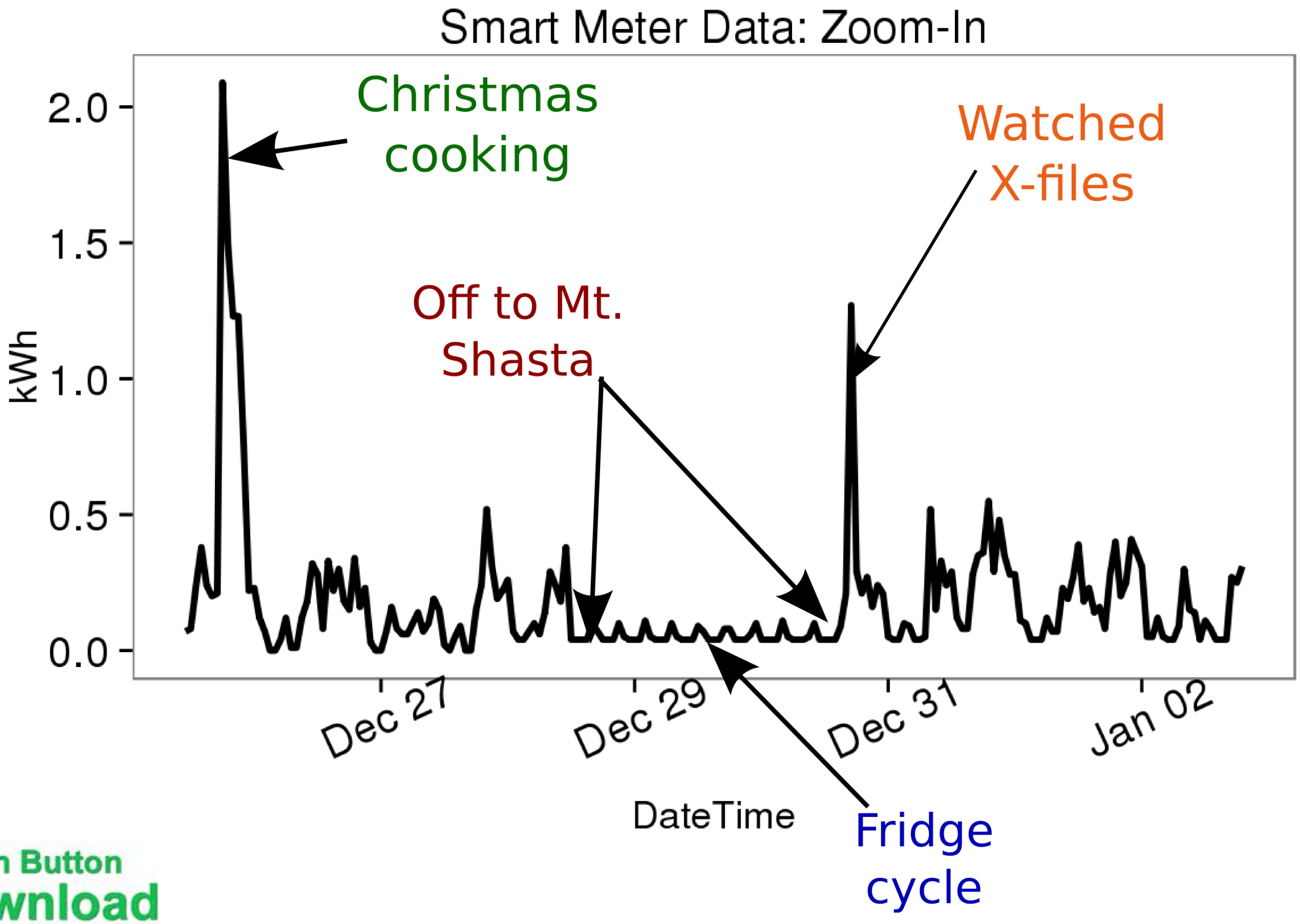


15 min

$$\text{yield} = \frac{\text{Achieved Reductions}}{\text{Potential Reductions}}$$

(*ACEEE, 2011)

Understanding Consumption



Green Button
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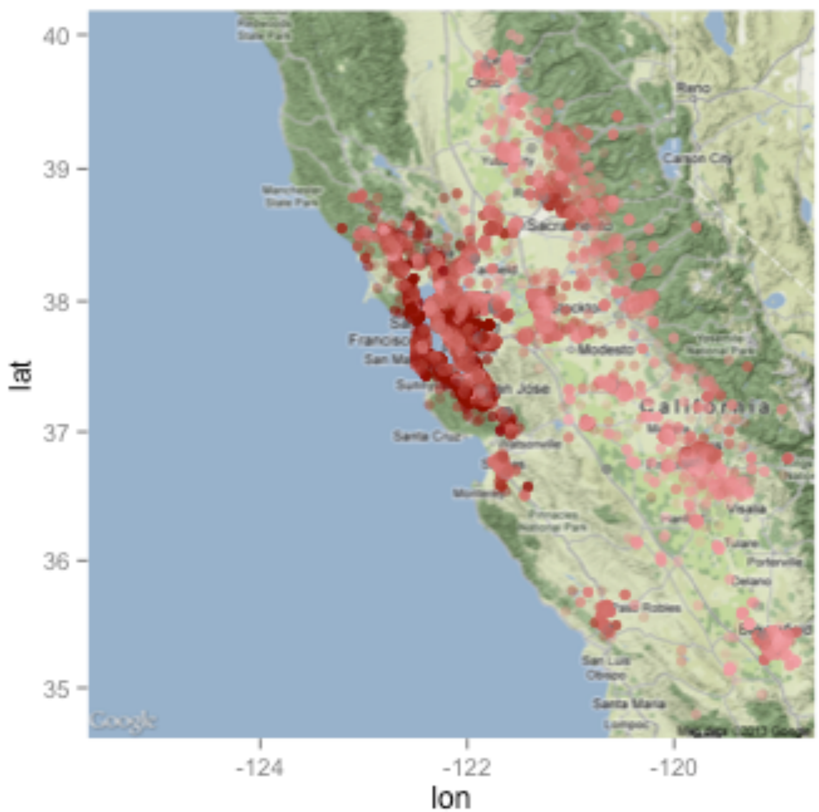
Data Snapshot: Time Series

- **Consumption:**
  - PG&E: 120,000 CA users, **43M days,** hourly
  - Google: 1000 US users (trial experiment)
- **Weather**: scraped off www.wunderground.com



Google Questionnaire

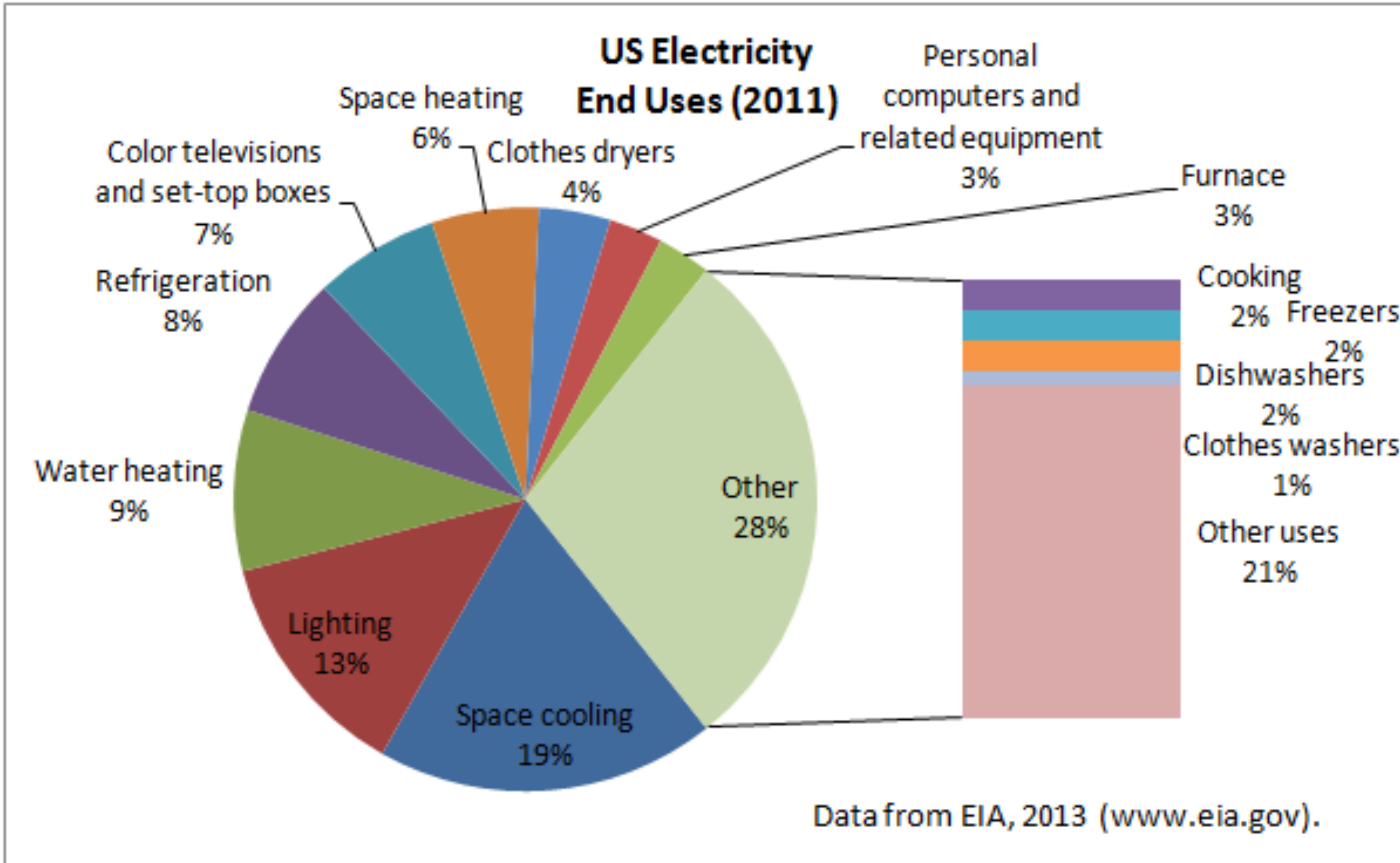
Appliance Questions	**% Yes**
Have clothes dryers?	63%
Has more than 1 fridge?	26%
Has spa, hot tub, or pool?	8%
Has washing machine?	92%
Has more than one computer?	**95%**
Has plasma TV?	26%

Lifestyle/Occupancy	**% Yes**
Do children under 5 live in household?	33%
Do non-employed people live in household?	30%
Do elderly people live in household?	2%
Do you work from home?	18%

+100 more questions on appliances, lifestyle, attitudes toward energy use…

Thermal Electricity Demand

HVAC (Heating + Cooling) = 25% of total electricity use



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Albert, A., Rajagopal, R. Thermal profiling of residential energy consumers. *Review and Resubmit, IEEE Transactions on Power Systems, 2013.*

The "Nest" Targeting Problem

Whom to offer *Nest* thermostat rebates to?

$$\Delta E = 1^\circ F \times \frac{dE}{dT}\left[\frac{\mathrm{kWh}}{{}^\circ F}\right]$$

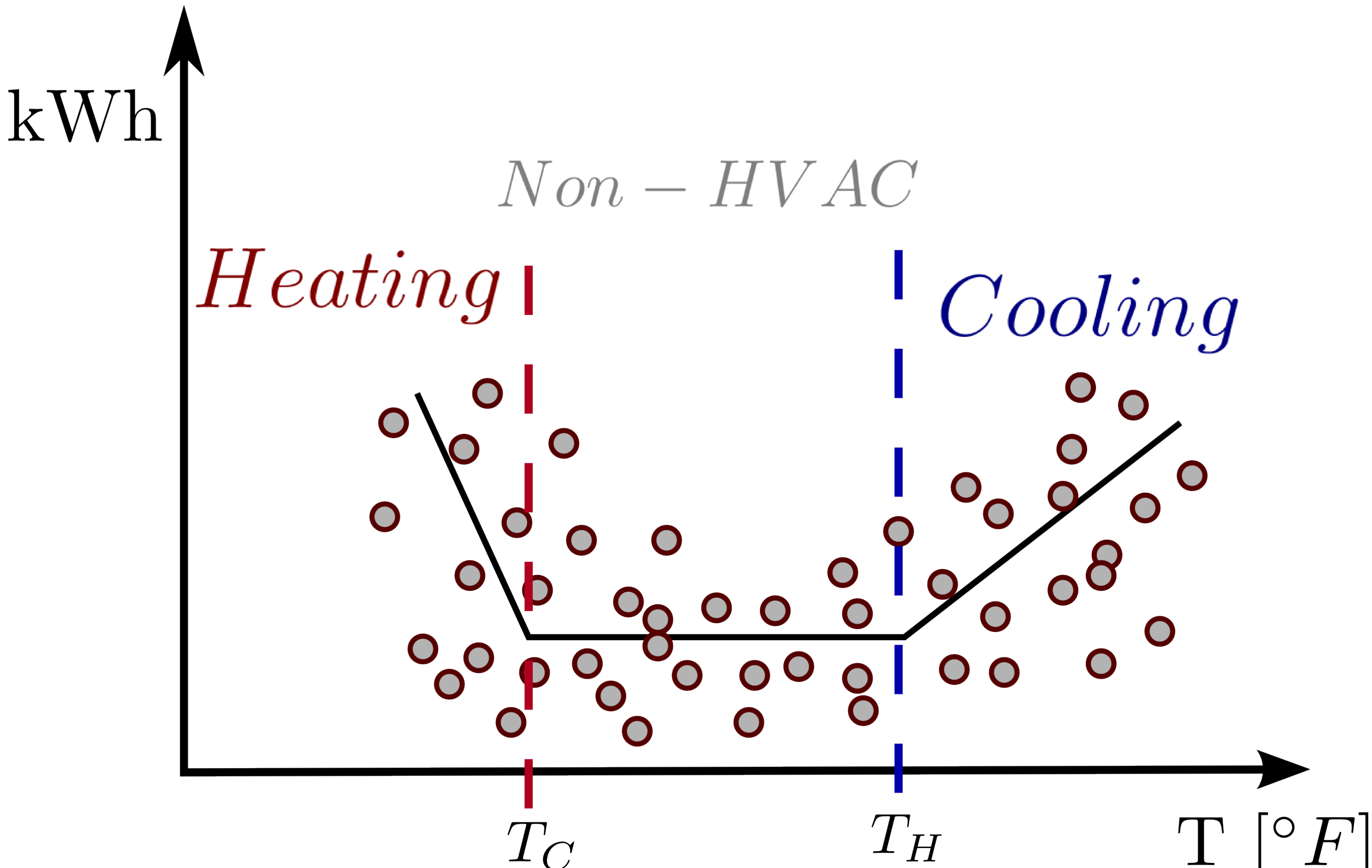
Consumption Averted

Temperature Setpoint Change

Consumpti
on
Response
Rate

- Occupancy, lifestyle, building thermal mass…

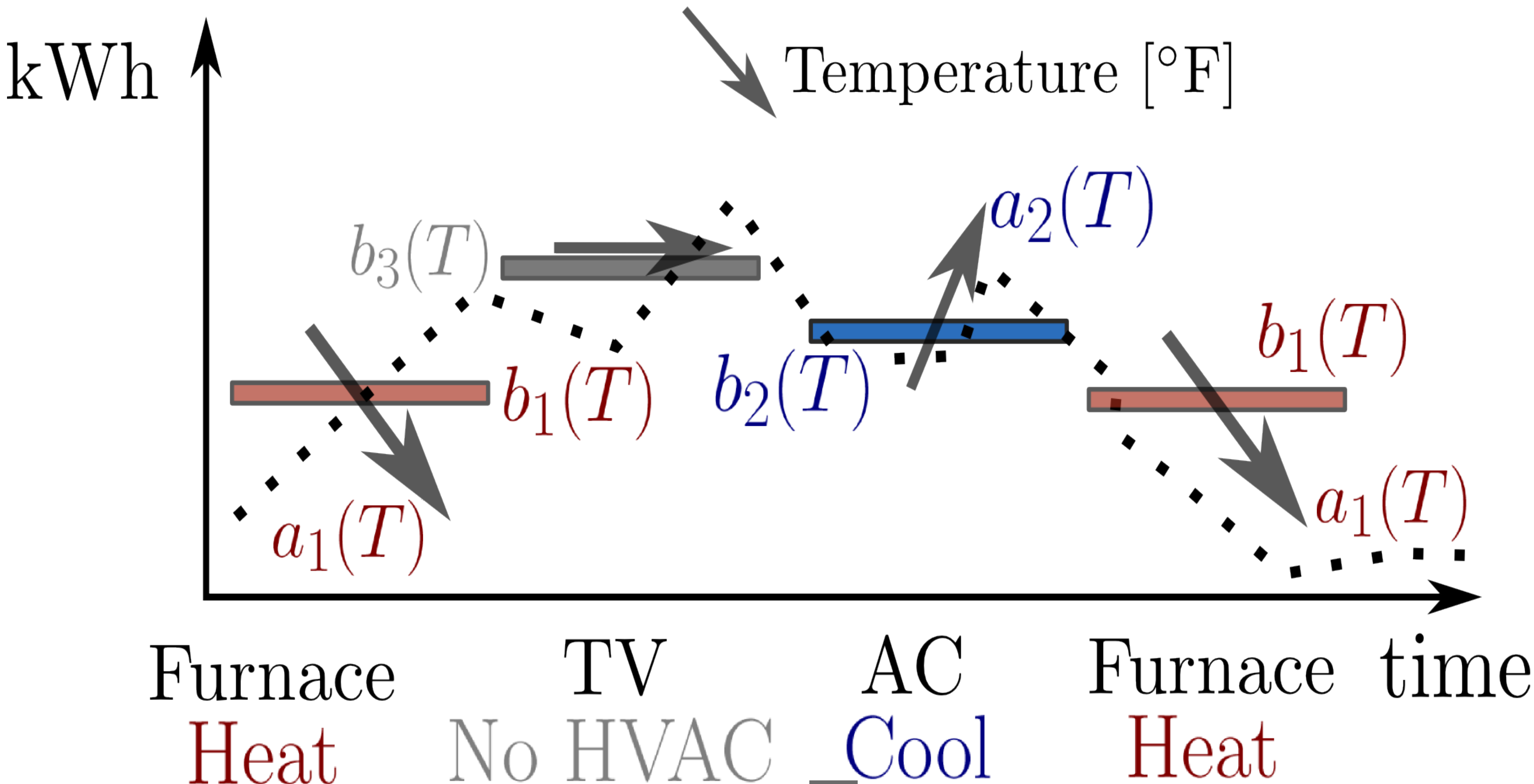
Structuring Thermal Consumption



- Behavioral response model to identify the right users

Thermally-Sensitive Occupancy States

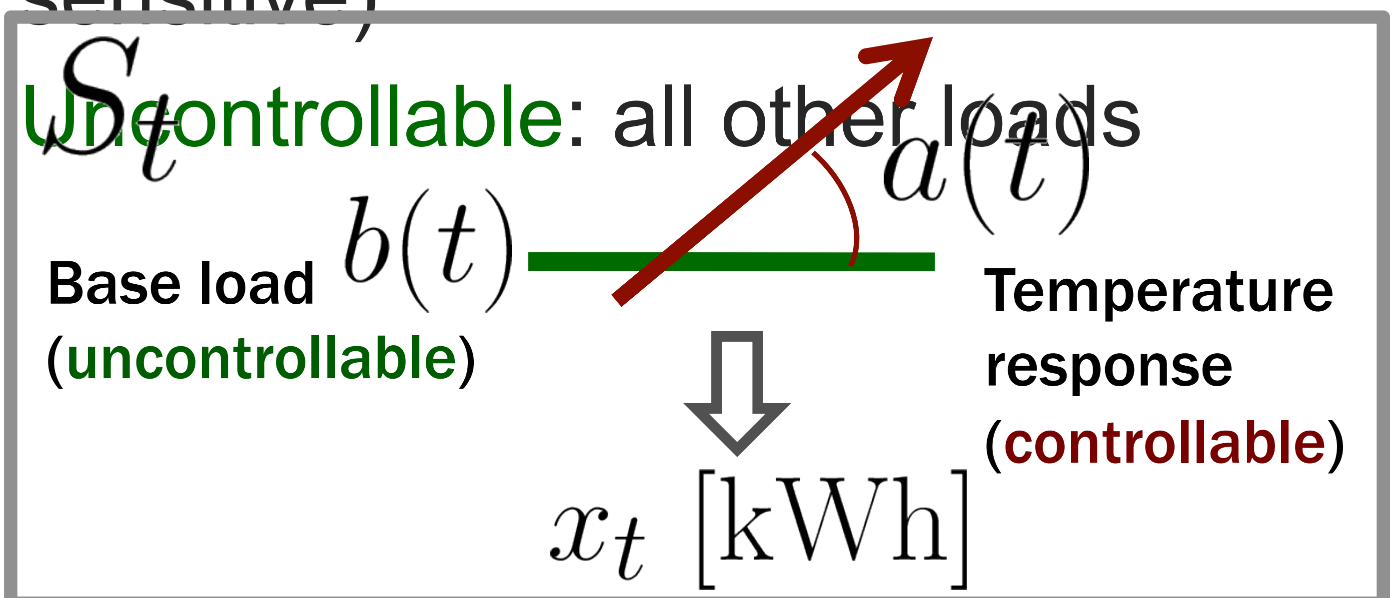
Intuition



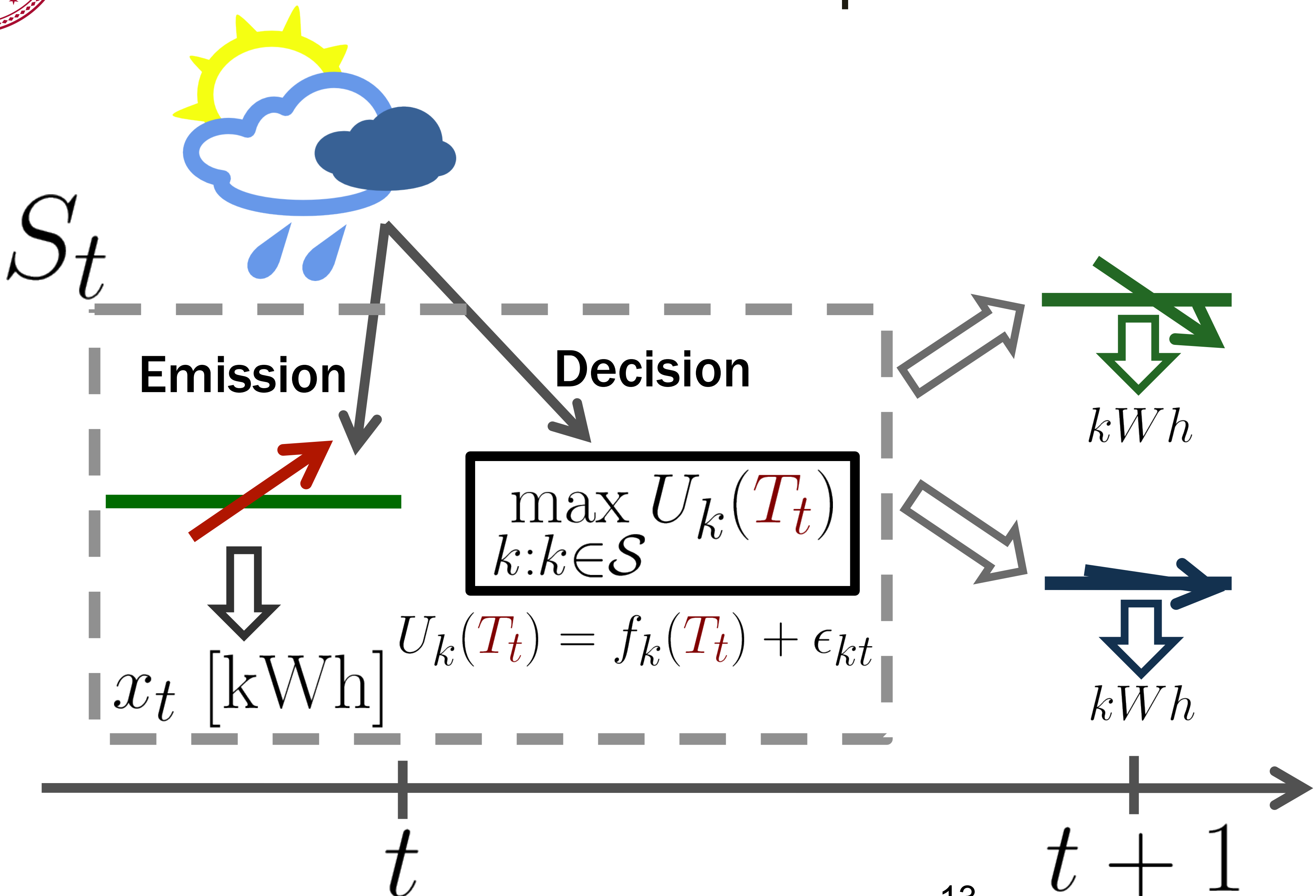
Hidden Markov Model

Coarse Thermal Disaggregation

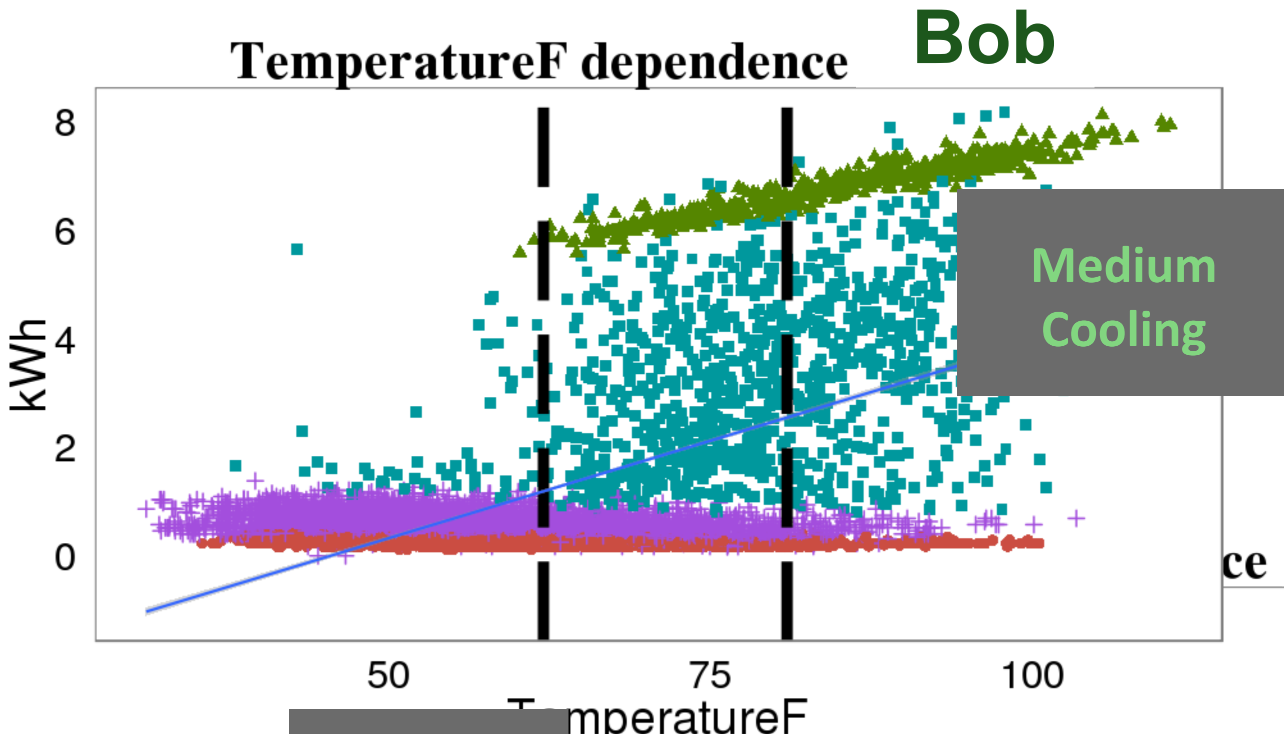
- Decompose consumption into two parts:
  - Controllable: HVAC (temperature-sensitive)
  - Uncontrollable: all other loads

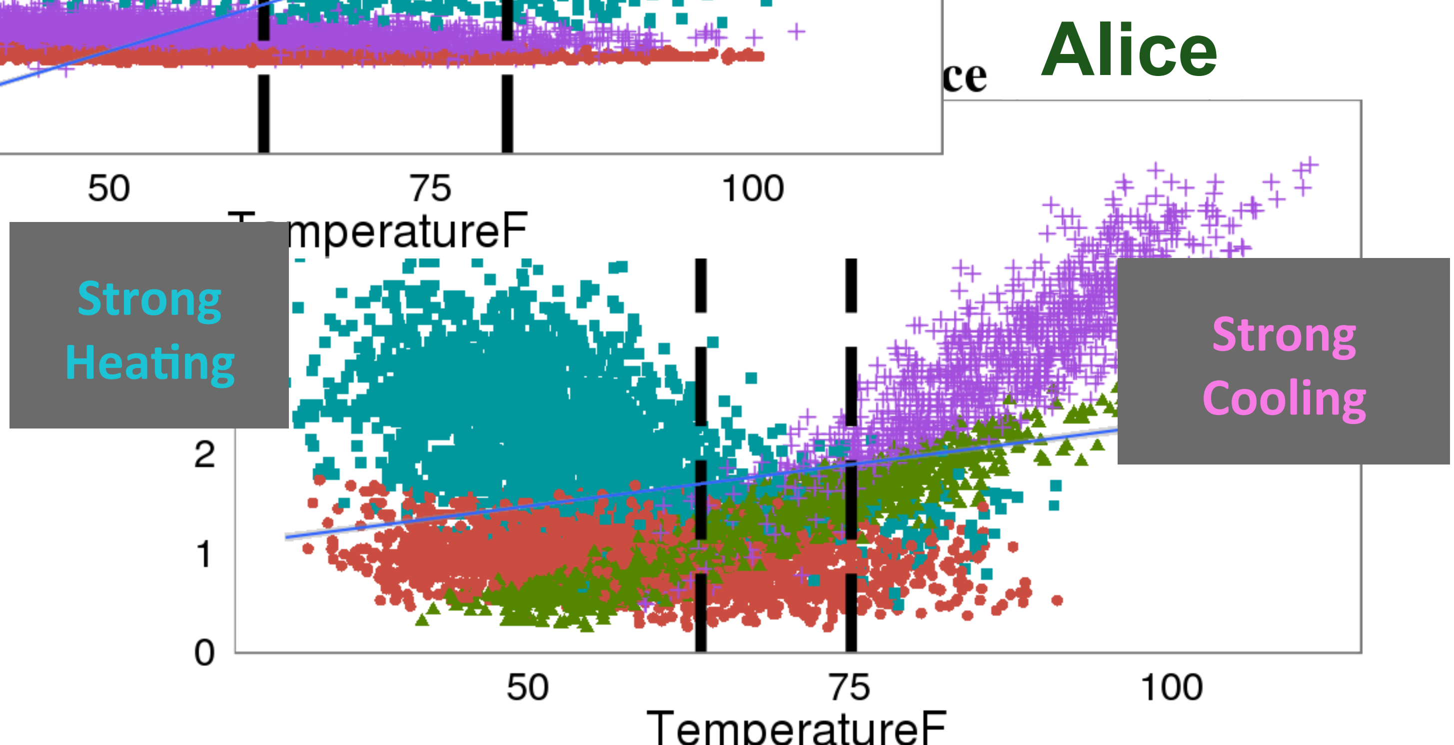


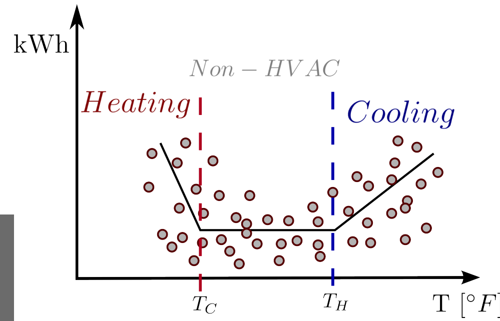
A Structural Thermal Response Model



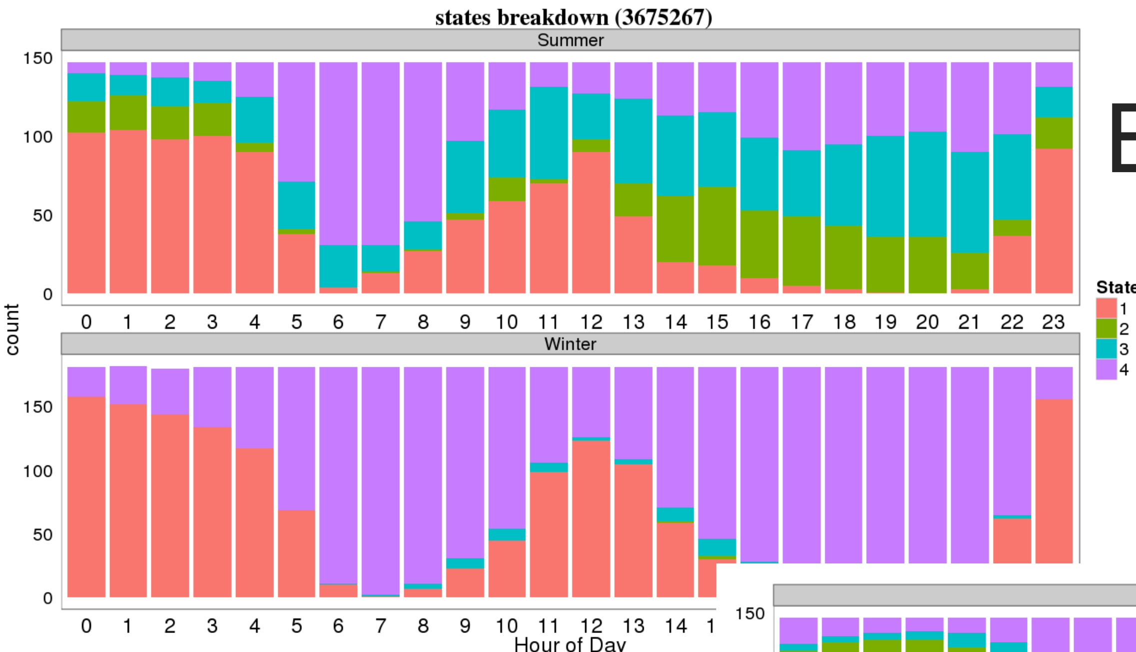
Alice and Bob



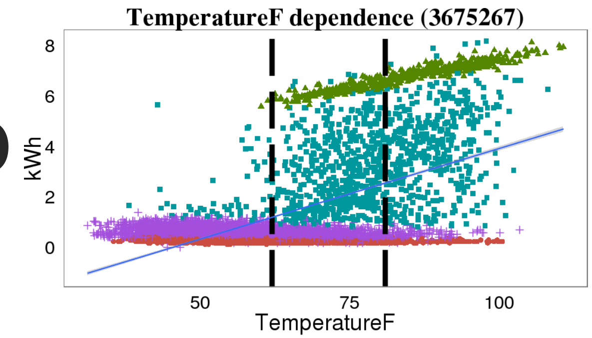


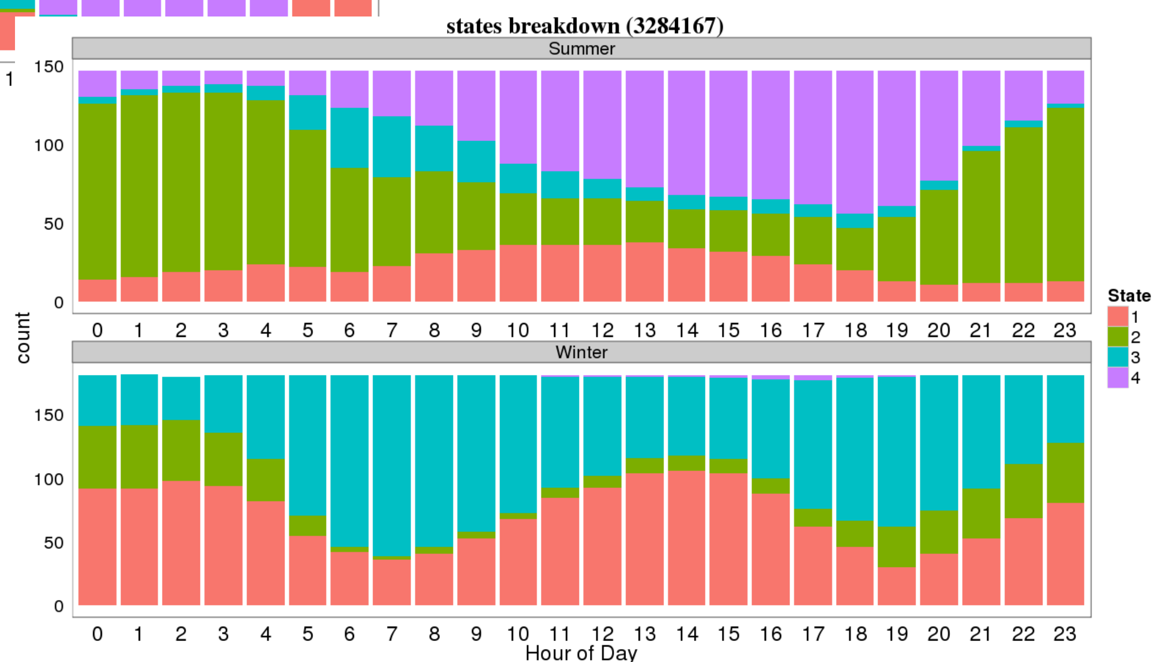


Seasonal and Daily Profiles

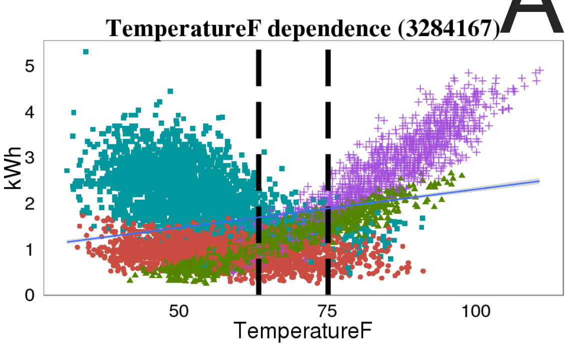


Bob





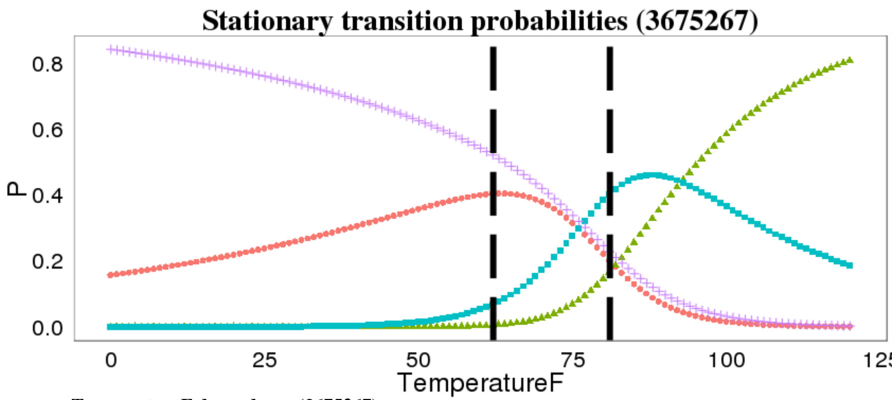
Alice

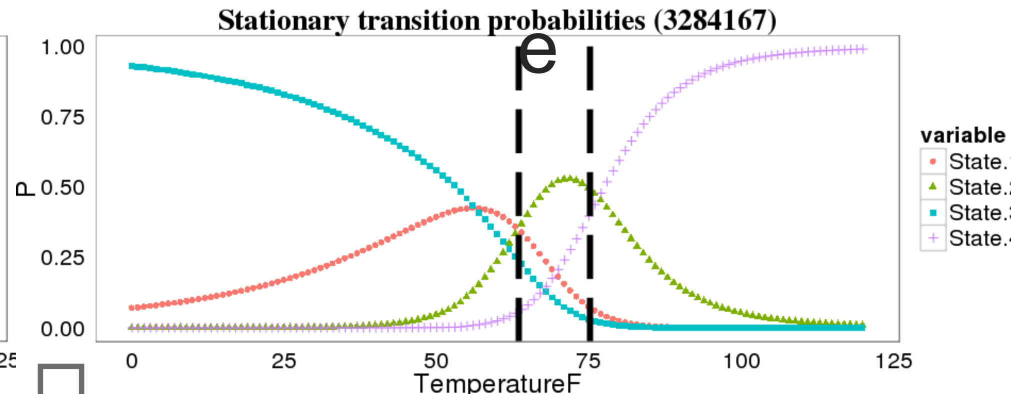


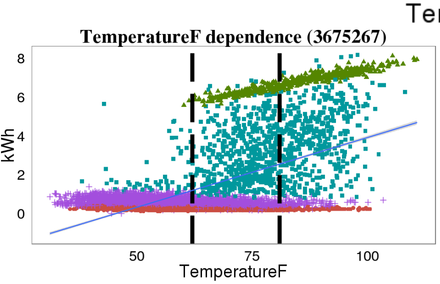
Effective Thermal Sensitivity

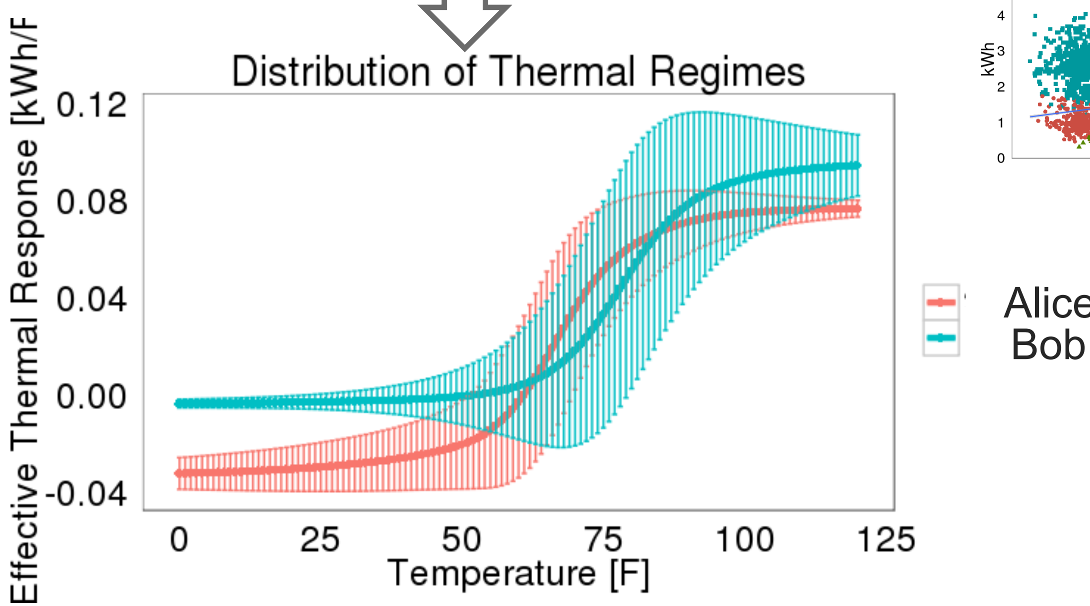
Bob

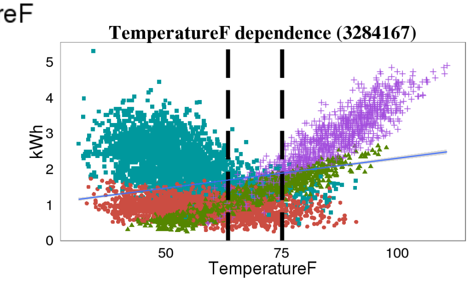
Alic
e











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- Context: Energy Program Targeting
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Applications

So we have response models. Now what?

Albert, A. Managing a portfolio of thermally-sensitive energy consumers. *Working paper (targeted at Marketing Science – special issue on Big Data)*.

User Model

Targeting Rebates (EE)

Thermal Selection (DR)

Thermal Segmentation

Bakersfield, CA

Bakersfield

City in California

Bakersfield is a city near the southern end
Kern County, California. It is roughly equid
Angeles, which are 110 miles to the north

Wikipedia

Area: 143.6 sq miles (371.9 km²)

Weather: 60°F (16°C), Wind W at 0 mph

Population: 358,597 (2012)

- ~2000 users , 1 year of data, hourly readings
- Hot, arid climate: predominant AC usage

158
17
Drey T.
Hungry Valley, CA

I don't know how anyone lives in this city! I drove through it at 9:30pm and it was 96 degrees! Lawd have mercy! I would have hung myself by now!

Good lord!

Was this review …?

Useful 5 | Funny 10 | Cool 2

Simple "Nest Targeting"

Identify user subset that are most sensitive to cooling

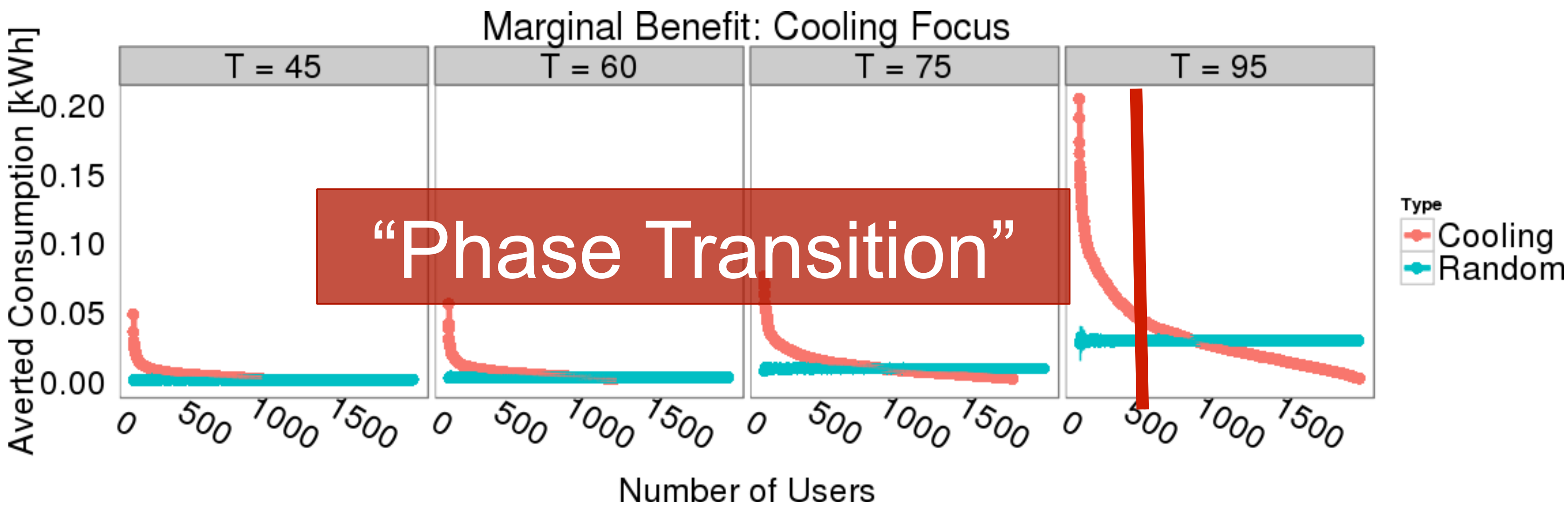
$$\max_{\mathbf{x}} \mathbb{E}\left[\sum_i x_i \beta_1(T)\right]$$

$$s.t. \sum_i x_i = N$$

$$x_i \in \{0, 1\}$$

Simple "Nest Targeting"

Identify user subset that are most sensitive to cooling



Applications

So we have response models. Now what?

Albert, A., Rajagopal, R. Smart meter driven segmentation: what your consumption says about you. *IEEE Transactions on Power Systems*, *28 (4), 2013.*

User Model

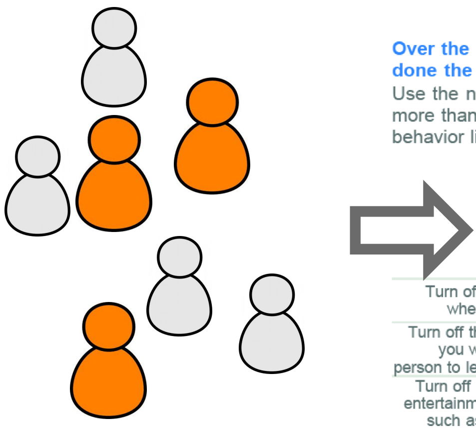
Targeting Rebates (EE)

Thermal Selection (DR)

Thermal Segmentation

Learning about the User

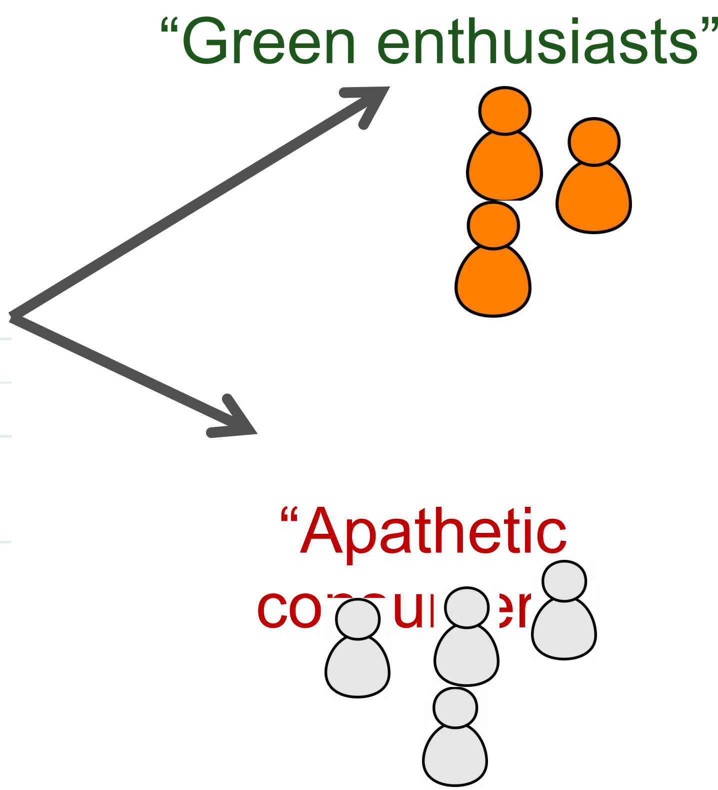
Old way: programs at utilities generally use questionnaires to perform “psychographic” market segmentation



Over the past three months, how often have you or your household members done the following? *

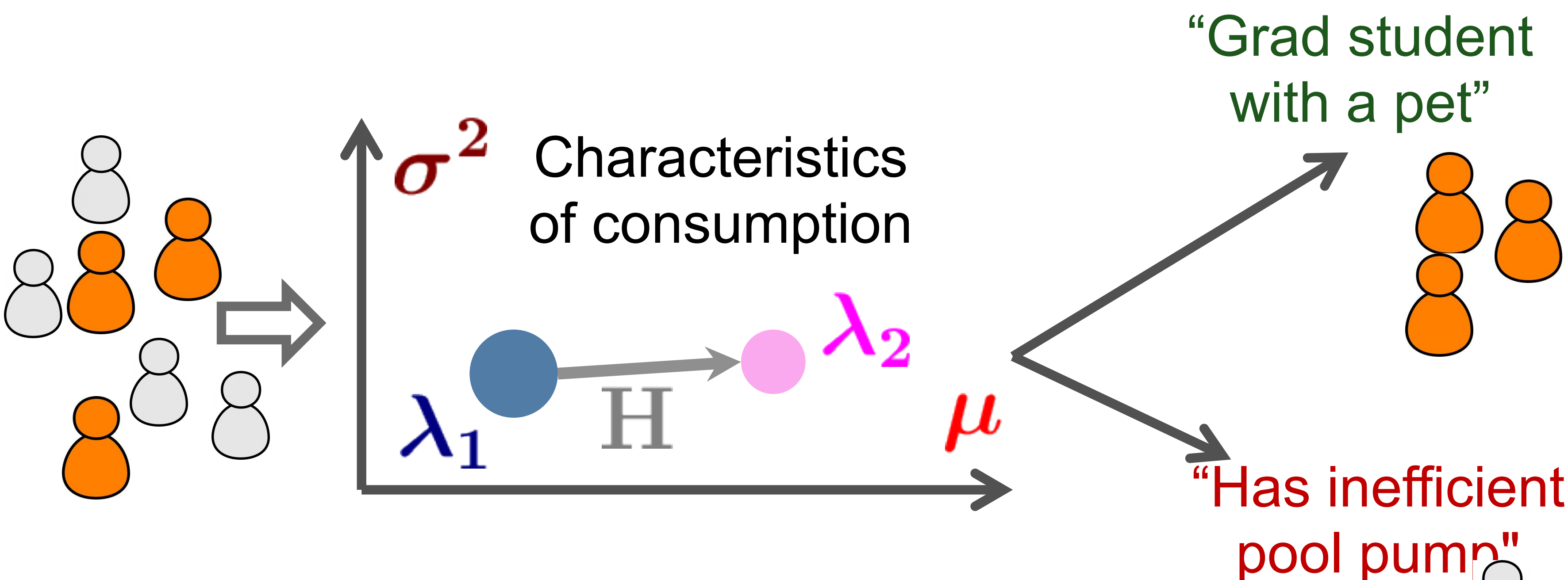
Use the not relevant category when the appliance indicated is in an area that serves more than one household or if you or no one in your household does performs the behavior listed

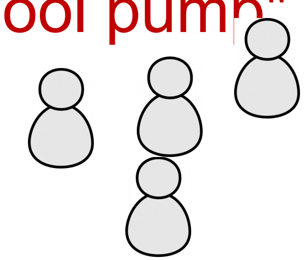
	Not relevant	Rarely (less than 25% of the time)	Occasionally (25% - 50%)	Often (50% - 75%)	Almost always (more than 75% of the time)
Turn off computers when not in use	○	○	○	○	○
Turn off the TV when you were the last person to leave a room	○	○	○	○	○
Turn off gaming and entertainment devices such as, Xbox and DVD players when you were the last person to leave a room	○	○	○	○	○



Learning about the User

New way: actually use the data to make lifestyle inferences: Classification



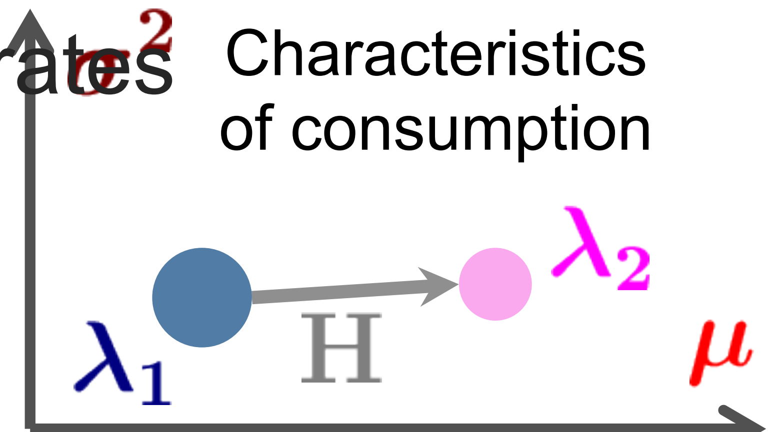


"Dear Adrian, people who consume like you can get an efficient pet lamp that consumes 50% less and can save you $100 a year. Here's a coupon if you'd like to purchase it from our preferred partners."

Consumption Features

$$\mathrm{kWh} = f(\mathrm{Occupancy\ Patters}, \mathrm{Weather})$$

- Magnitude – base loads, rates
- Duration– typical duration
- Variability – entropy



Classifier

AdaBoost [Freund & Schapire, 1996]

User Characteristics

Performance vs Random Guessing

Are consumption characteristics informative of user attributes?

Question	Improvement over random guessing*
Clothes Dryers	**19%**
Washing Machines	**19%**
Central AC Units	**17%**
Individual Under 5 (Infants)	**11%**
Unemployed Residents	**10%**
Work from home	**7%**

*5-fold cross-validation out-of-sample results

Accounting for empirical distributions in the

User and Consumption Characteristics

- **Appliances**: state base loads and variances
  - variance: indication of occupant activity
  - washing machines
  - hot tubs/spas…
- **Lifestyle**: state variability
  - small children (under 5)
  - unemployed members of household

Thank You!

*“Half the money I spend on advertising is wasted;
the trouble is I don’t know which half.”*

John Wanamaker, Philadelphia, PA.

Now we have data to tell which half.