# A Bottom-Up Approach to Sustained Curtailment and Comfort for Controlled Demand Response

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# Outline

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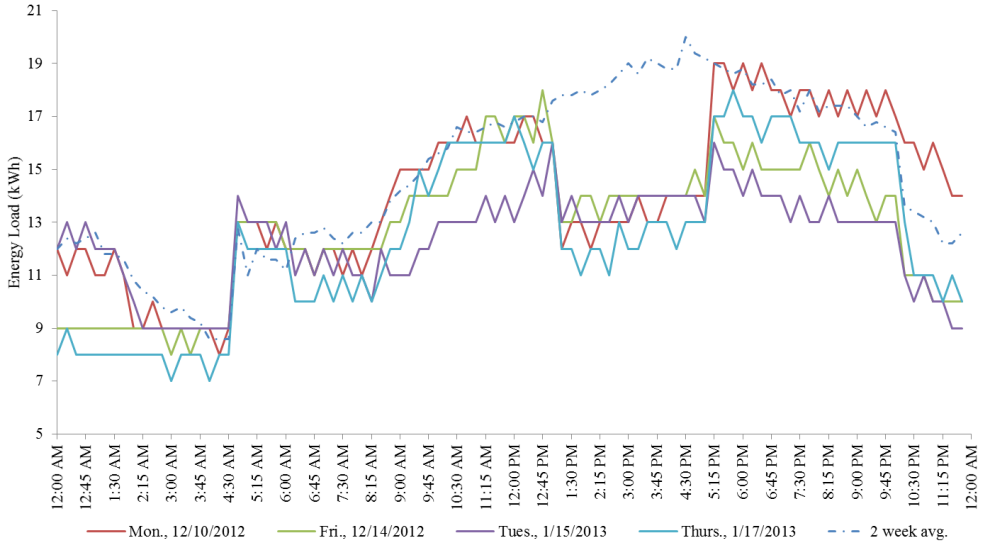
# Introduction

- **Demand Response** (DR) is an efficient method for utilities to deal with peak demands in **smart grids** as it helps avoid the high costs of buying energy from the open market in the event that demand surpasses the generation capacity



# Introduction

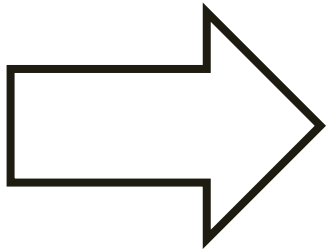
- Several approaches to DR exist:
  - **Incentive based**, e.g., reduce prices outside peak periods
  - **Voluntary**, e.g., participants voluntary register to participate in DRs
  - **Direct Load Control (DLC)**, e.g., utilities directly control the clients' appliances
  - **Mixed**

- Most rely on **aggregated** or **individual** appliance metered **consumption data**

# DR Challenges

Predict curtailment & achieve it through customer selection

Maximizing human comfort



How do we simultaneously achieve these contradictory goals?

# Issues & Approach

- **Human comfort** (weekly or monthly DR events)
- Meter data **may not** accurately **capture** curtailment during DR
  - Consumption may increase/show no change due to other factors contributing to energy consumption (temperature, other appliances, etc.)

**Our solution** combines:

- **DLC** by calculating curtailment based on **equipment** based **models** with a
- Smart **customer reselection** during consecutive DR events
  - Affects a **small pool** of customers **different** each time

# When to use it

When utilities:

1. Know the amount of energy it needs to save (without necessarily reaching the optimal minimum consumption) during peak demand

2. Have information over the individual equipment consumption and mechanical characteristics

3. Building level consumption is metered but no apparent curtailment is visible

4. Can achieve the curtailment in a surgical manner without affecting a large pool of customers.

# Current Solutions

- Statistical methods based on machine learning algorithms most common
  - **But**, require large amounts of historical data and **cannot** distinguish a building's sources of curtailment
- Previous bottom-up approaches primarily focus on residential settings
  - Our focus is on large buildings with numerous occupants and various destinations
- No integrated solutions focusing on achieving curtailment and maximizing human comfort

# Experiment Test bed

- The USC Smart Grid employs **Fully-Automated Demand Response** strategies on the University of Southern California (USC) University Park Campus.

- **Strategies** are implemented during the peak electricity usage period on the USC campus: **1:00-5:00PM**.

- Currently **36 buildings** are involved in DR experiments with historical **building level consumption** data being recorded for more than **6 years** now (at 15-minute intervals).

# DLC Methods

## Global Temperature Reset (GTR)

- Facility management operators remotely establish a wide **temperature range for each zone** to operate within
- GTR takes advantage of the thermal inertia of a building, which makes it less susceptible to rapid temperature fluctuations

## Variable Frequency Drive (VFD)

- Achieves energy curtailment by **directly limiting the fan** variable **drive speed** for air handling units
- The benefit of lowering the fan speed is enhanced by the non-linear relationship between fan speed and power, represented by the power fan law

# DLC Experiments

## 1. Curtailment Correlation Analysis

- Approximately 40 real life experiments for 8 buildings during the Spring & Fall
- Two baseline methods compared: Southern California Edison and Week Before
- Only considered VFD

## 2. Relative Performance (RP) & Human Comfort

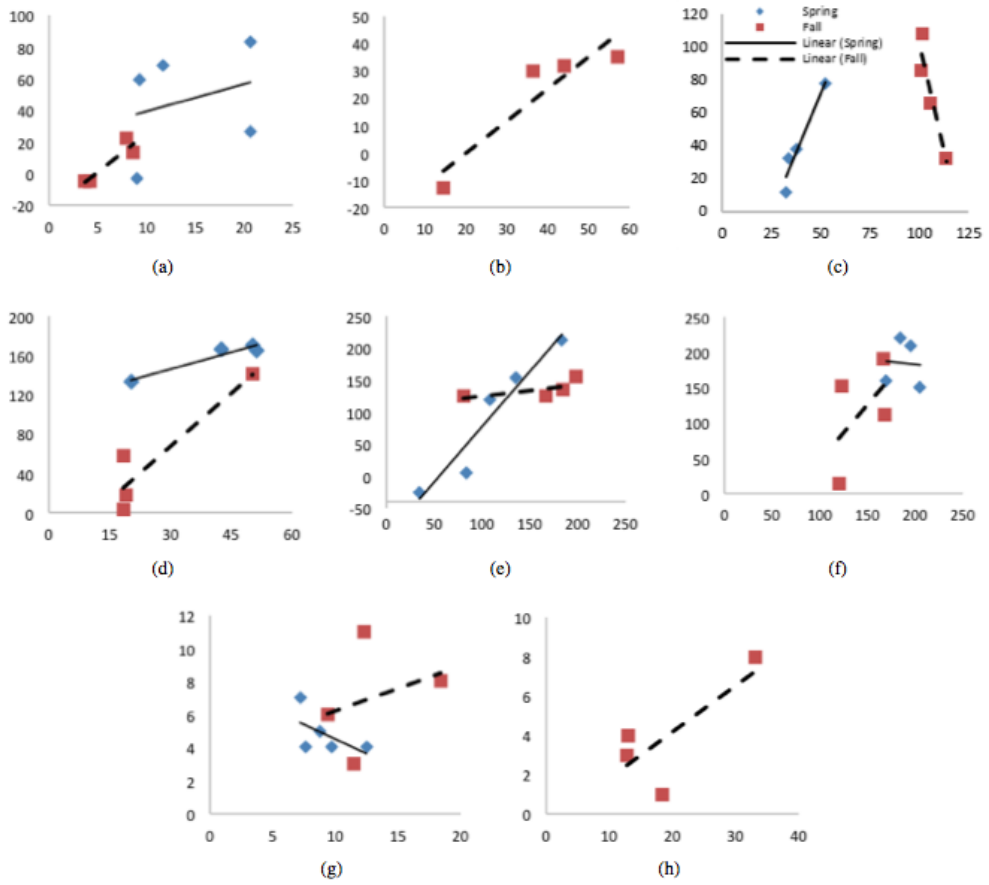
- 50 consecutive simulated DR events where the heterogeneity of the aggregated RP at each particular time *t* was calculated
- RP computed differently for GTR and VFD
- Human comfort directly linked to RP

# Building Selection for RP

- **Random** picks k random buildings and applies the same curtailment to each
- **RandomAggregated** picks k random buildings favoring those with higher aggregated RP
- **BestK** picks the first *k* buildings and applies the same curtailment to each
- **Proportional** curtails each of the first k buildings proportionally to the so far aggregated RP
- **Threshold-local** & **Threshold-global** target RP instead of curtailment by placing a limit on the RP reduction of each building
  - *-local: limit is set 0.00001 of the aggregated comfort of the least impacted building
  - *-global: limit set to 0.00001 of the total aggregated comfort

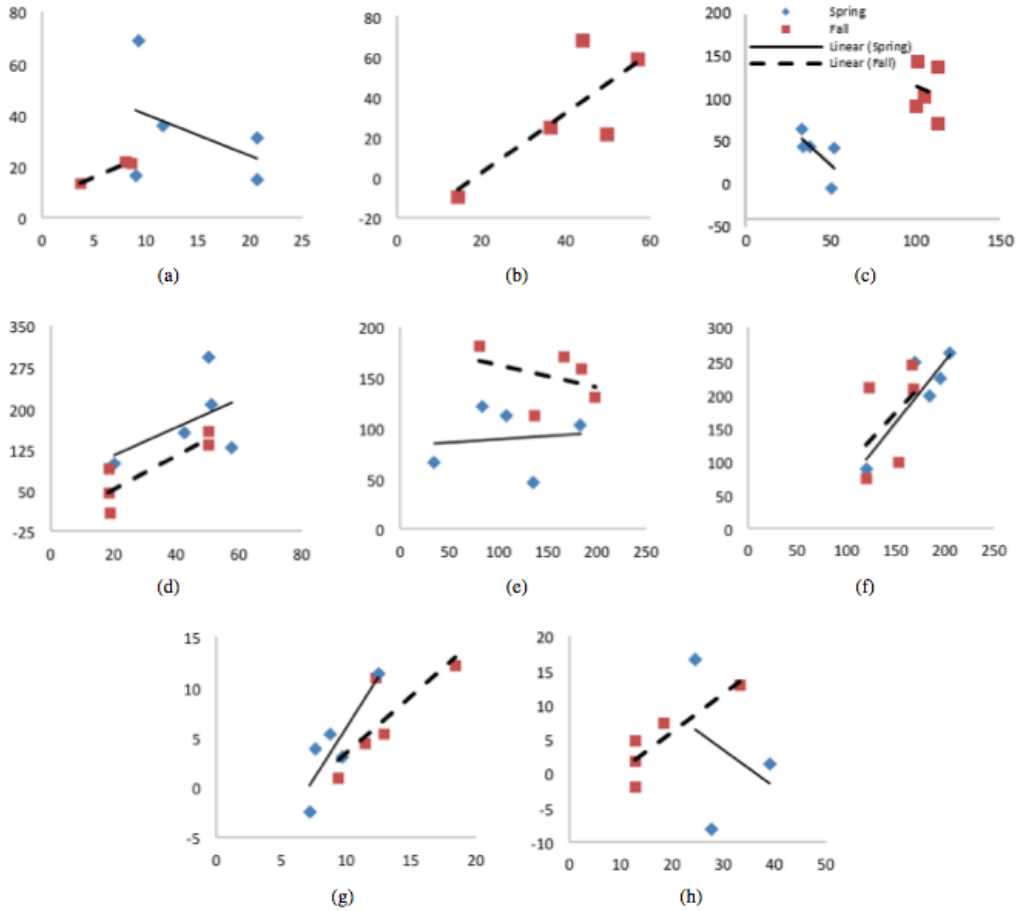
# Results: Correlation between building and equipment level curtailment

Week Before Baseline



# Results: Correlation between building and equipment level curtailment

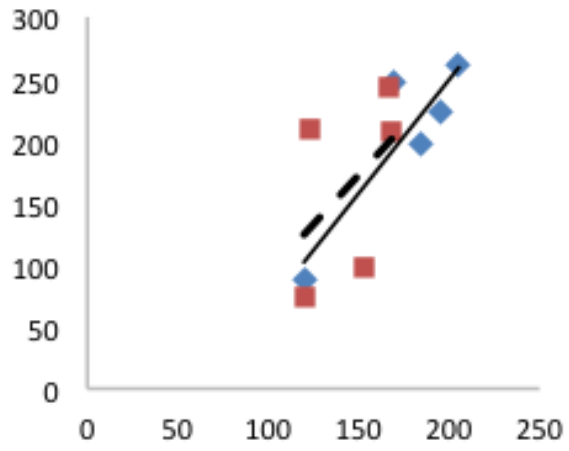
SCE ISO Baseline



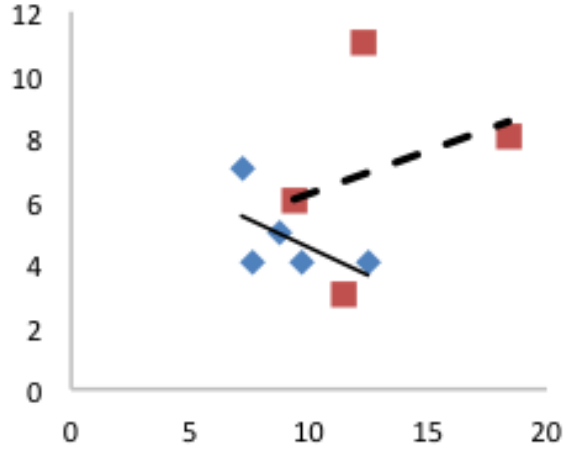
# Results: Correlation between building and equipment level curtailment

Regardless of the baseline method, two types of correlation are evident:

**Strong correlation (R > 0.9 and m > 0)**




**No correlation (R < 0.9)**



# Correlation Analysis

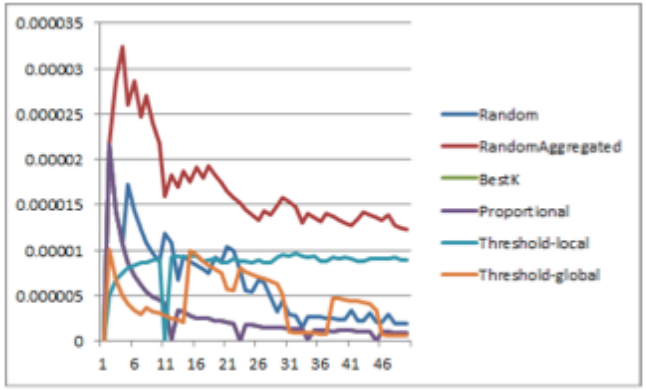
- **Week before** baseline: 50% strong positive correlations (for both Spring and Fall experiments)
- **SCE ISO** baseline:  less correlations, i.e., 25% for Spring and 37.5% for Fall

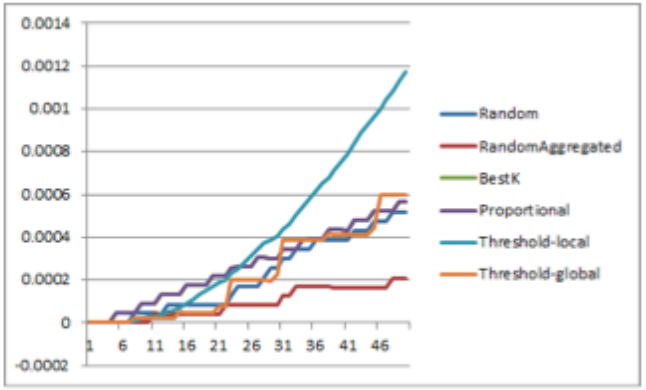
**Key points**:

- SCE is less efficient as campus consumption is specific to each day due to class schedule, holidays, etc. which is also linked to the different seasonality performance
- For the uncorrelated cases either the particular behavior is not indicative of the normal behavior or other factors such as an increased consumption impact the global consumption
- No relationship between the correlation and the building type

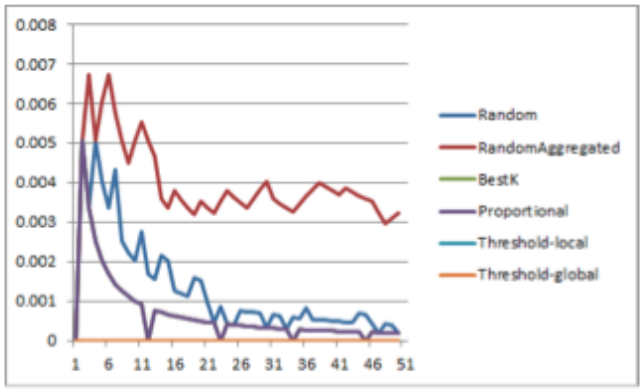
Strong case for a bottom-up approach based on equipment modeling

# Results: RP

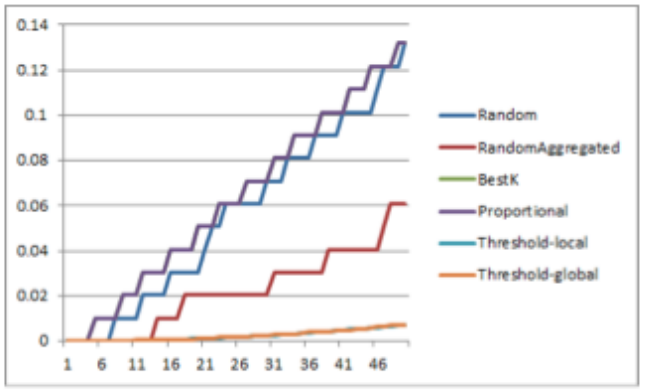



VFD




(a) Heterogeneity of aggregated RP.




(b) Distance from the optimal RP.

GTR

# RP Analysis

- Efficiency varies based on DLC method
  - **VFD**:
    - **BestK** and **Proportional**: best homogeneity and fastest convergence
    - **RandomAggregated**: worst homogeneity but closest to the optimal RP
  - **GTR**:
    - **Threshold-global** and **Threshold-local** to be the best (nearly identical) candidates in terms of homogeneity and closeness to optimality
      - More buildings selected with less impact on the RP (fine grained control)

RP oriented strategies are more suited but their efficiency depends on the level of control we have over them

- trade number of selected customers with impact on individual customers

# Conclusion

- The bottom-up analysis proved **a degree of correlation** to exist between **equipment-level level energy curtailment** and **overall building-level curtailment**

- Fast and **efficient heuristics** shown to be an effective method for **scheduling DR strategies** and **participants** to **maximize human comfort**

- **Successfully combined these two methods**, despite their contradictory objectives, maximum curtailment and human comfort can be realized

# Thank you! Questions?

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