Anomaly Detection in Premise Energy Consumption Data

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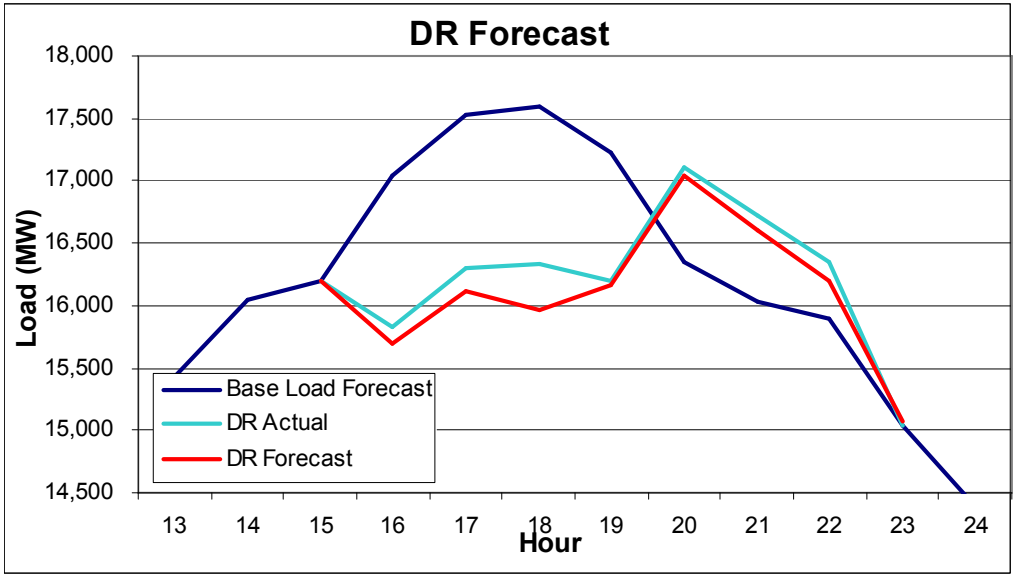
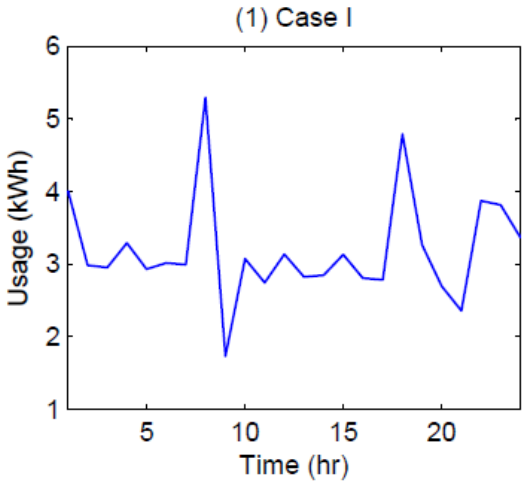
Demand Response Estimation

- **Critical X's:** weather, Temperature, seasons, days of week, devices, time…
- **X's are gathered from:**
  - AMI data
  - Real time weather forecasts
  - Historical data
- **Methods:**
  - Sampling Methods
  - Categorization Techniques
  - Empirical Methods
  - Regression techniques
  - Bayesian methods
  - Artificial Intelligence – Neural Nets, SVM,…

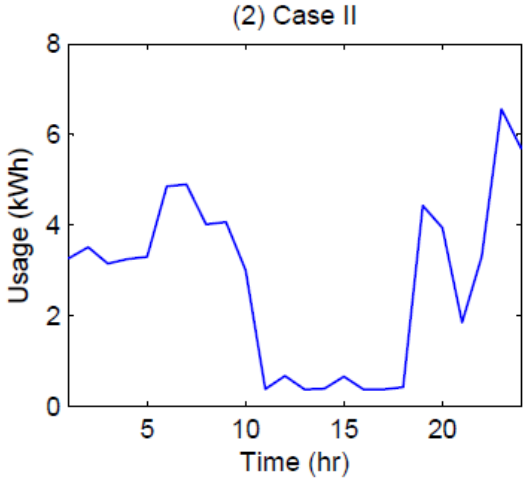


- 2 Error Sources:
  - Base Load Forecast
  - Response Estimate

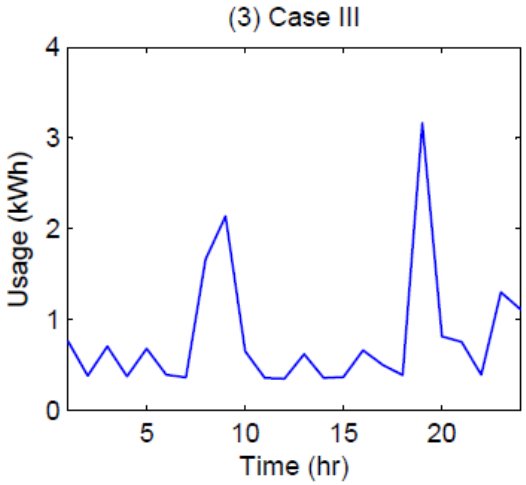
Typical Household Load Patterns



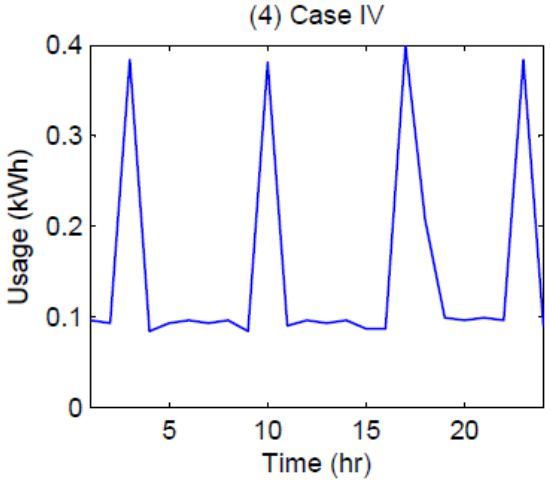
Weekend with heating/AC



Weekday with heating/AC



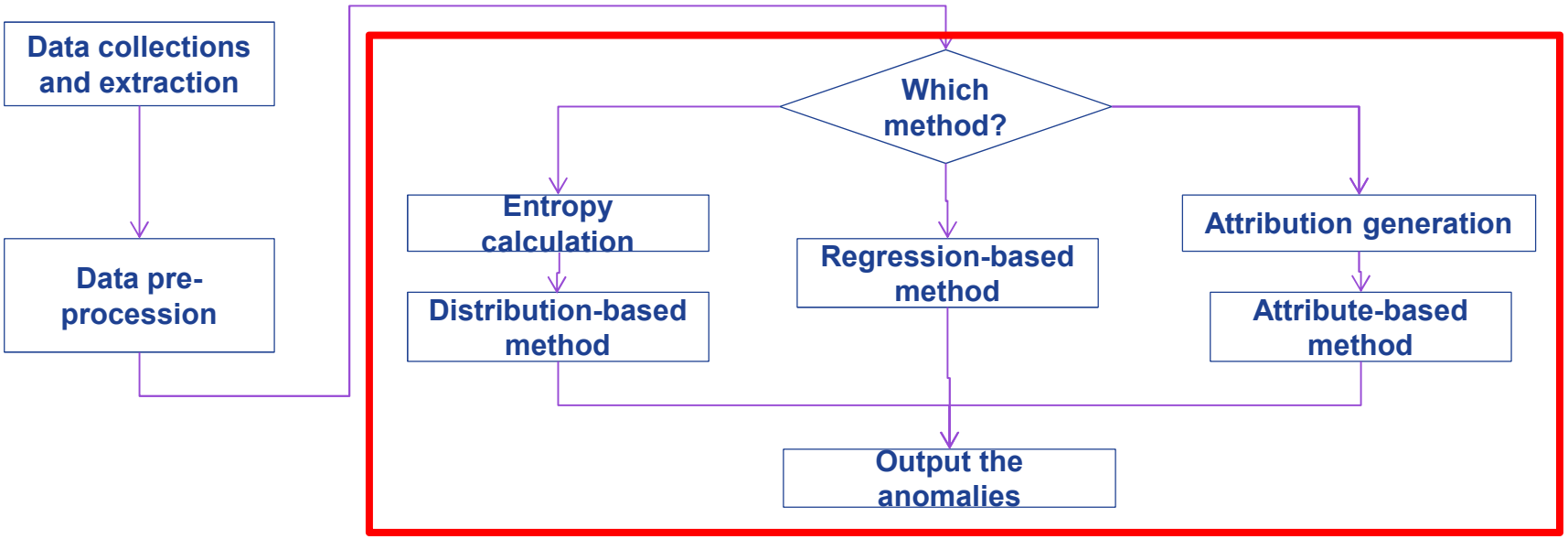
Weekday without heating/AC



Anomaly

Proposed Methods for Anomaly Detection

- **Regression-Based Anomaly Detection**
- **Distribution-Based Anomaly Detection**
- **Attribute-Based Anomaly Detection**



Regression-based Anomaly Detection

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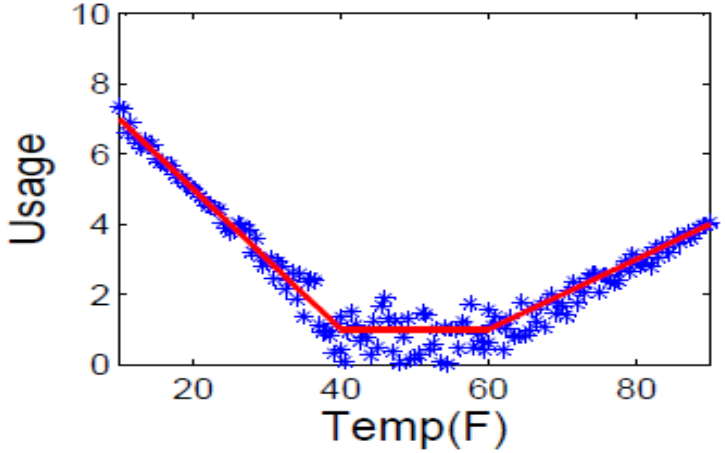
Algorithm:

1. Piecewise regression: 1, 2, and 3 piece linear functions
2. F test: determine the best model $f(X)$
3. Estimate energy consumption $\hat{Y} = f(X)$
4. Calculate ratio $R = \frac{\hat{Y}}{\cdot\cdot}$, mean $\bar{R}$, and standard



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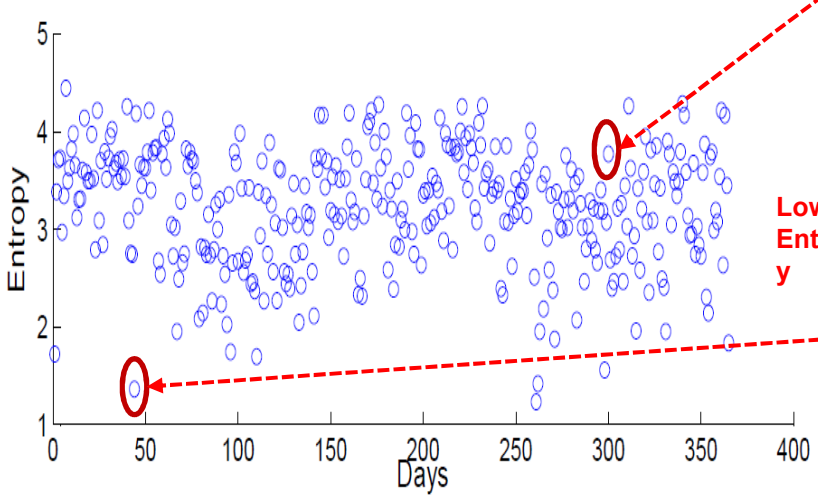
Distribution-based Anomaly Detection

In information theory, entropy is a measure of the uncertainty associated with a random variable.

$$H(x) = \sum_{i=1}^{n} p(x_i) log_b p(x_i)$$

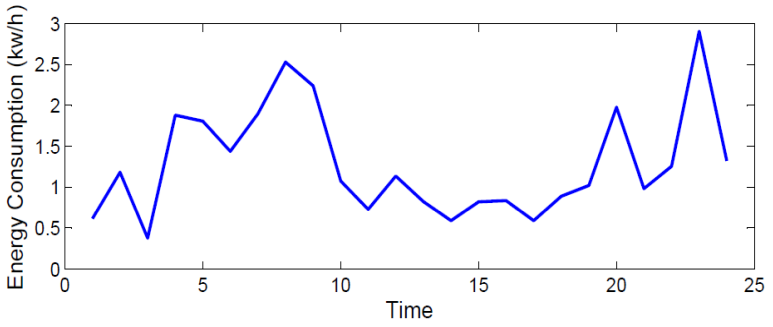
E(Abnormal) < E(Normal)

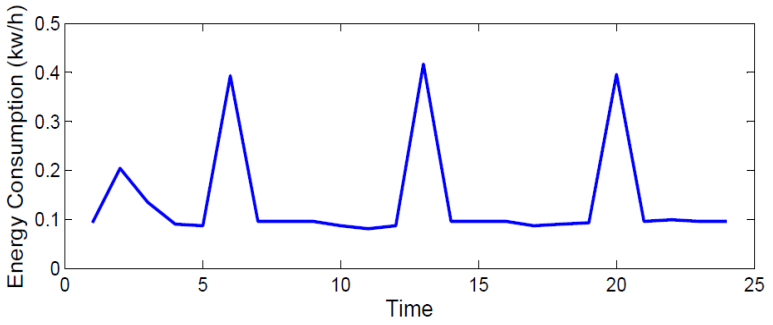


High Entropy

Low Entropy

Normal Weekday





Abnormal Weekday

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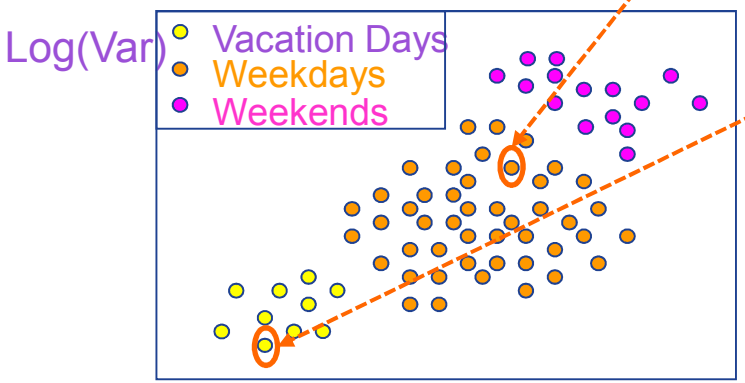
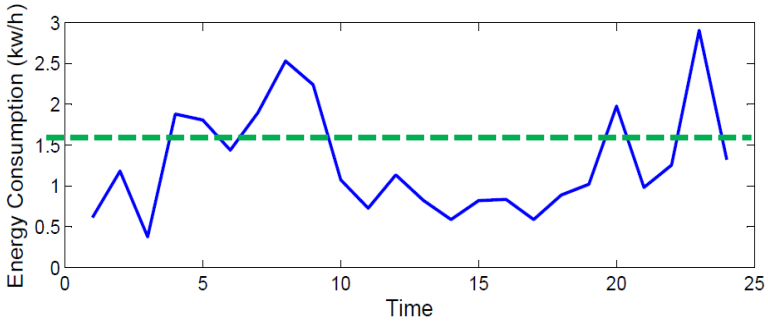
Attribute-based Anomaly Detection

Attributes generated from daily consumption data are:

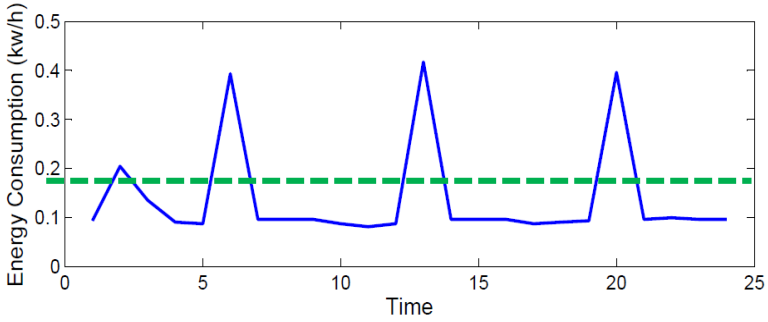
- mean
- Variance
- Maximum
- range (=maximum - minimum)
- ratio (=maximum/minimum).



Normal Weekday



High usage mean and peak



Low usage mean and peak

Vacation Weekday

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Raw Data

2 sets of raw data

- Single customer data
  - Detailed usage
  - 8 months

Time	A/C Down Condensing Unit	A/C Up Condensing Unit	Air Handler Downstairs	Air Handler Upstairs	Computer Room	Dishwasher	Dryer(Gas)	Entertainment Center	Microwave	Other	Range	Pool Pump	Refrigerator	Main	Washer	Indoor Temperature Downstairs	Indoor Temperature Upstairs	Weather Temp
1/1/2010 0:00	0	0	0	0	0.03	0	0	0.01	0	0.01	0	0	0.06	0.1	0	281.97	283.64	53.6
1/1/2010 0:15	0	0	0	0.06	0.03	0	0	0.01	0	0.01	0	0	0.01	0.1	0	282.07	283.53	53.6
1/1/2010 0:30		0	0	0	0.03	0	0	0.01	0	0	0	0	0.02	0.05	0	282.01	283.64	53.6
1/1/2010 0:45	0	0	0	0.05	0.03	0	0	0.01	0	0.02	0	0	0.07	0.18	0	282.14	283.71	53.6

- 9-customer data
  - Some information is missing
  - 90 days

ab	name	'Laurel'		
	main	<2160x1 double>	0.0412	1.8768
	dryer	<2160x1 double>	0	0.3203
	microwave	<2160x1 double>	0	0.5240
	range	<2160x1 double>	0	0.5240
	refrigerator	<2160x1 double>	0.0053	0.0920
	washer	<2160x1 double>	0	0.5240
	waterheater	<2160x1 double>	0	0.5240
	others	<2160x1 double>	-0.3030	1.4485
ab	time	''		

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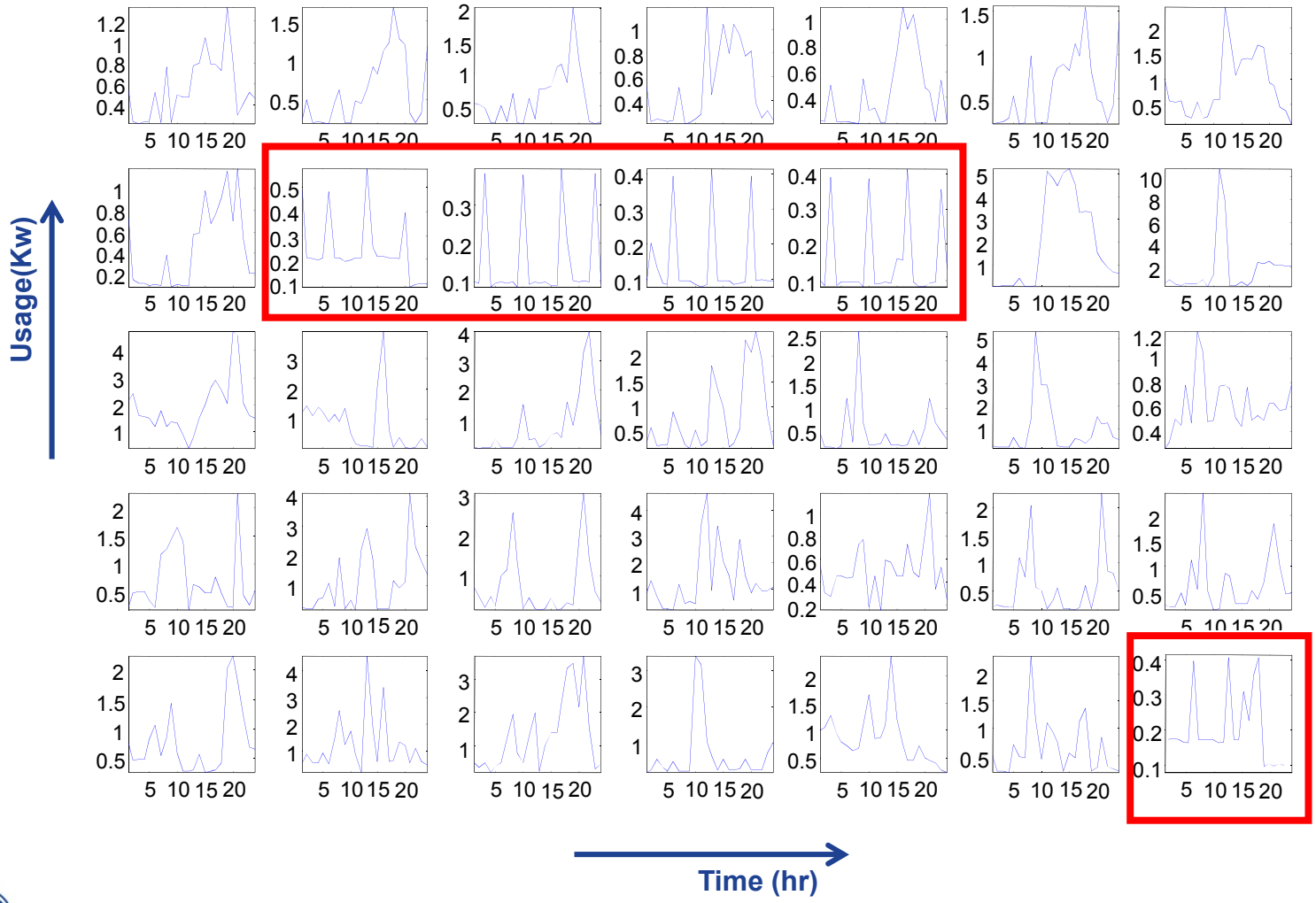
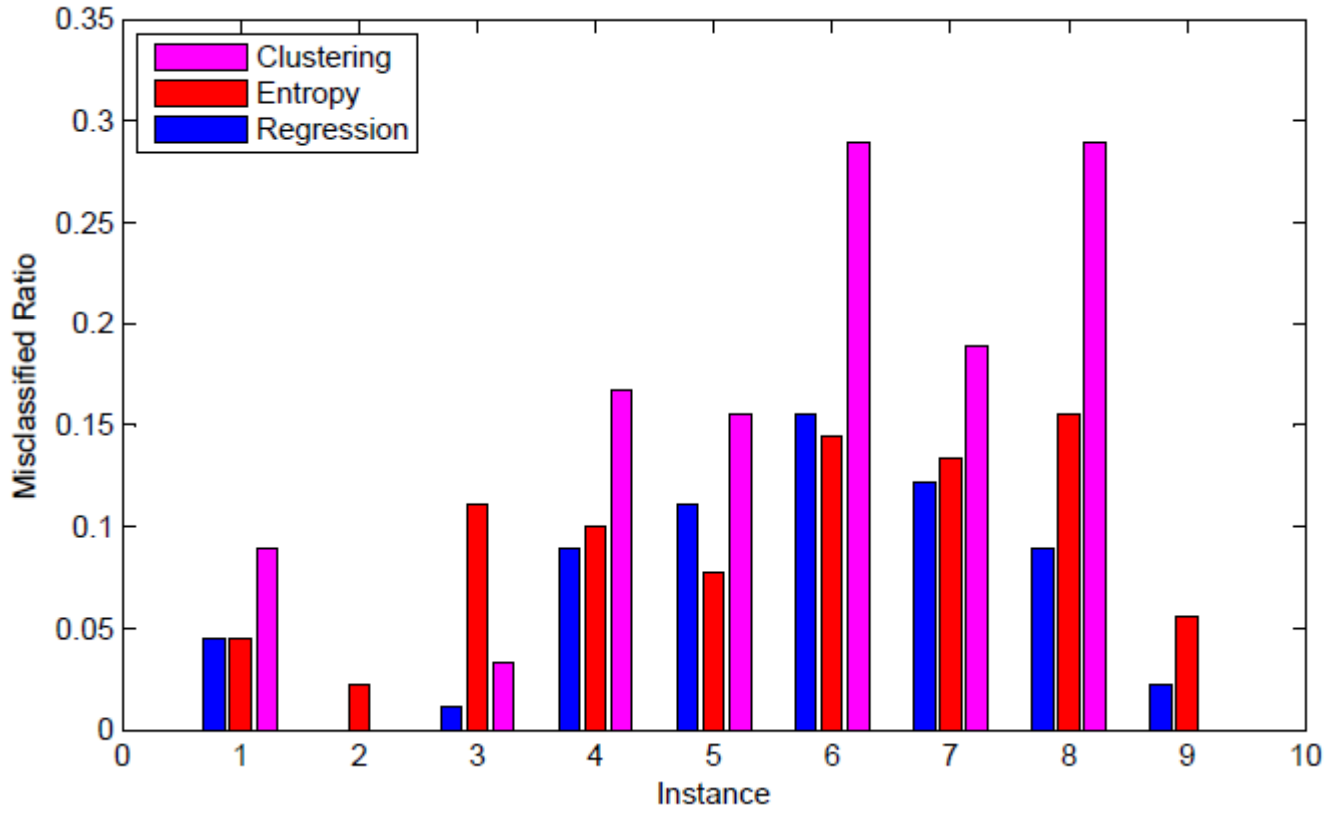
Abnormal Days Detection

(use statistics, machine learning, etc. to detect days with abnormal behavior/responsiveness in nonevent days or during DR events)



Simulation Results: 9-customer Data

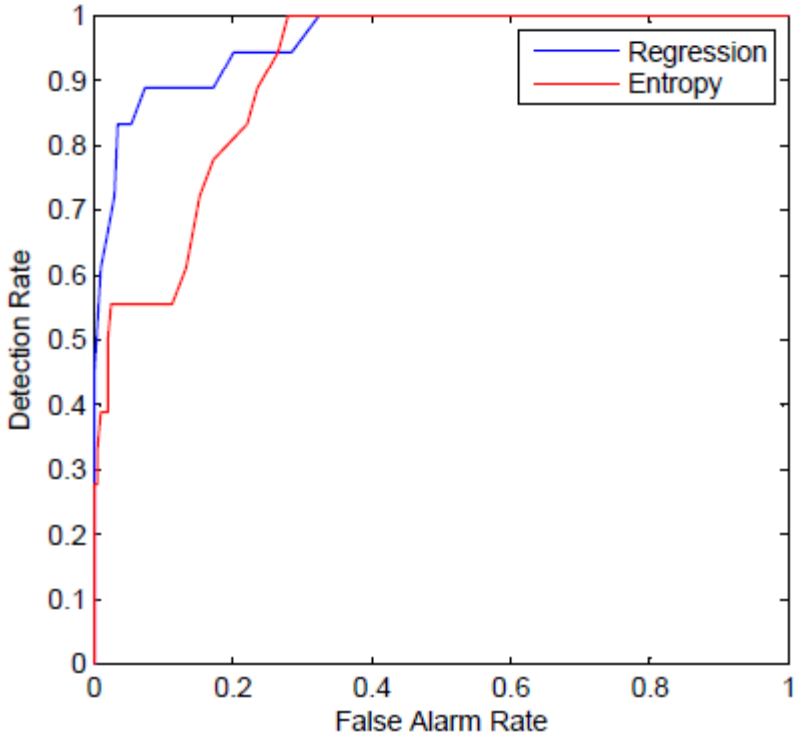


Simulation Results: Single-customer Data

Detection Results

	Detection Rate	False Alarm Rate
Regression	88.89%	7.35%
Entropy	55.56%	9.80%
Clustering	72.22%	30.88%

ROC Curve



Conclusions

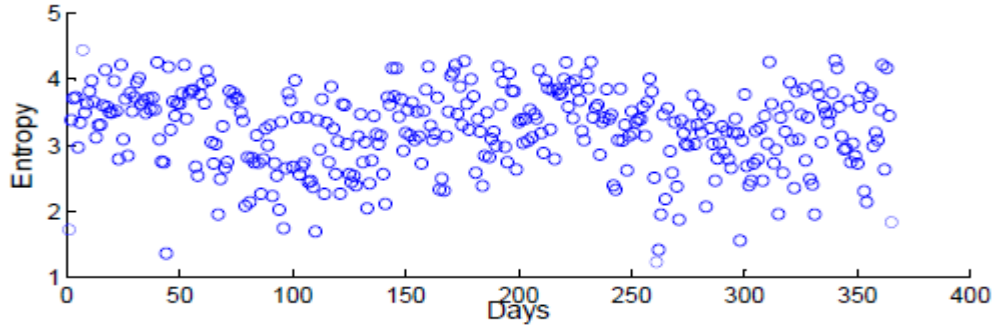
- Anomaly detection achievable in demand response estimation.
- Proposed Regression-based, distribution-based, and attribute based methods can be used.
- Data mining on each customer's power consumption profile is required for algorithm selection and parameter tuning

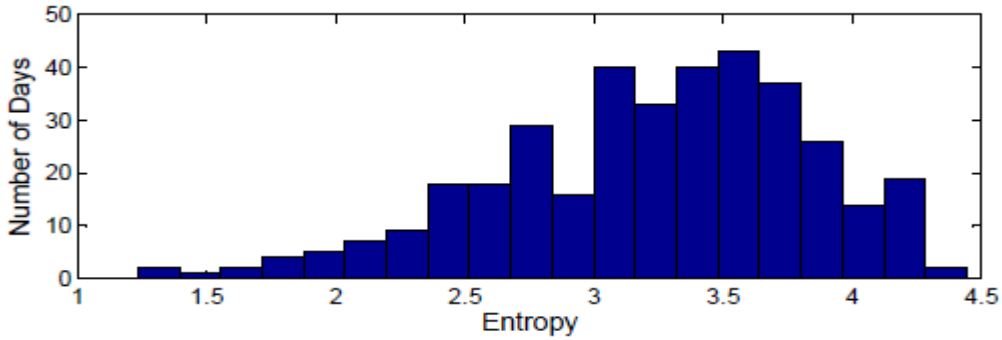
Backup

Distribution-based Anomaly Detection cont.

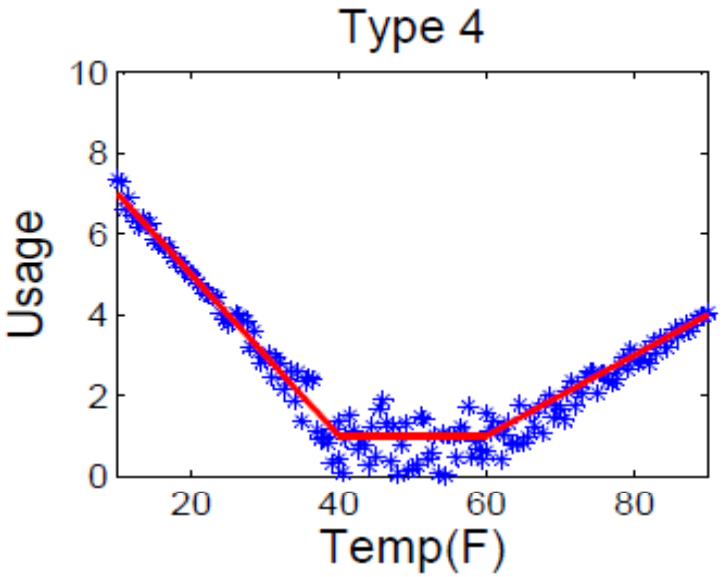
Algorithm:

1. Normalize energy consumption data
2. Calculate entropy H for each daily profile, mean $\bar{H}$, and standard deviation σ_H
3. Identify day i as an anomaly day if $H_i < \bar{H} - \alpha \cdot \sigma_H$





Piecewise Regression



3 Piece Regression

$$y = \begin{cases} a_1 x + b_1 & if\ x < c_1 \\ a_2 x + b_2 & if\ c_1 \le x \le c_2 \\ a_3 x + b_3 & if\ x > c_2 \end{cases}$$

$$a_1 c_1 + b_1 = a_2 c_1 + b_2$$

$$a_2 c_2 + b_2 = a_3 c_2 + b_3$$

Attribute-based Anomaly Detection cont.

Algorithm:

1. Generate attributes from raw energy consumption data
2. Run k-Means clustering n times using random start point and select the best one output
3. Identify the cluster with the smallest mean usage as anomaly days

Different Anomaly Detection Methodologies

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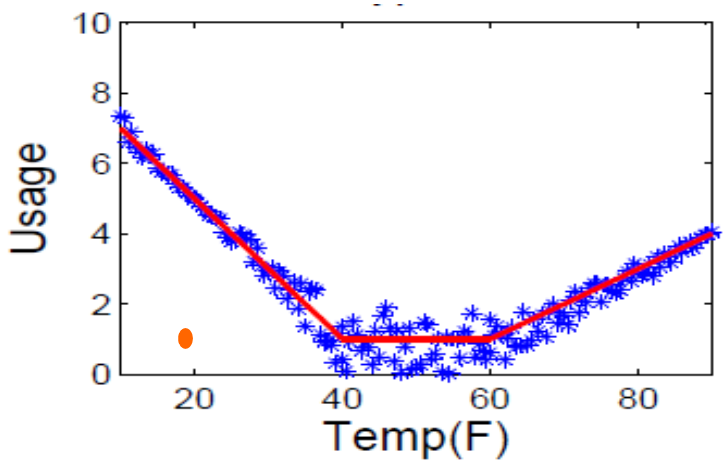
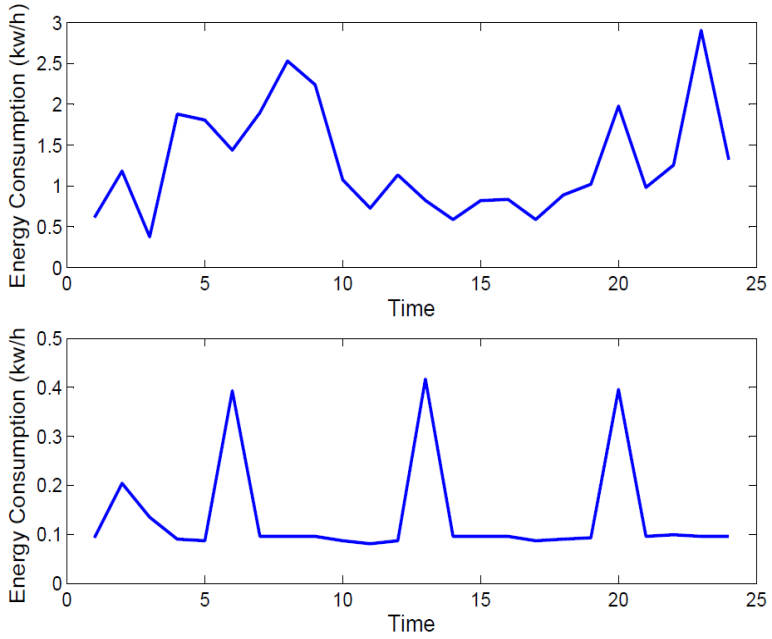
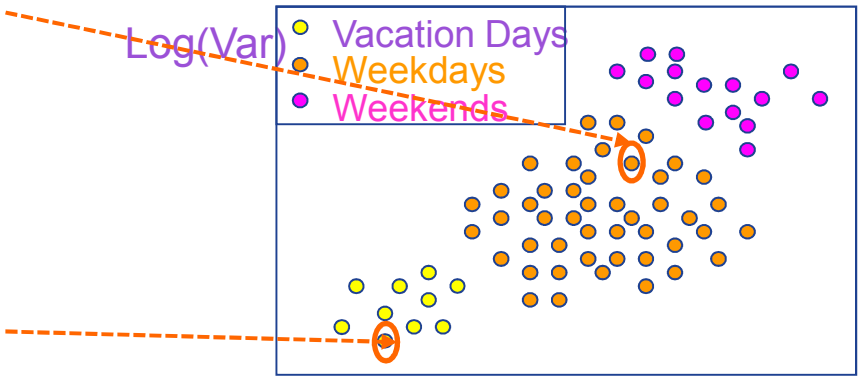
Regression based



Distribution based



Attribute based



Demand Response (DR) Process