SuAT

Architecture & Sustainable Building Technologies
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Robust Exploratory Data Analysis for Actualized Building Energy Performance

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Frontiers in Energy Research Presentation

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/ ITA
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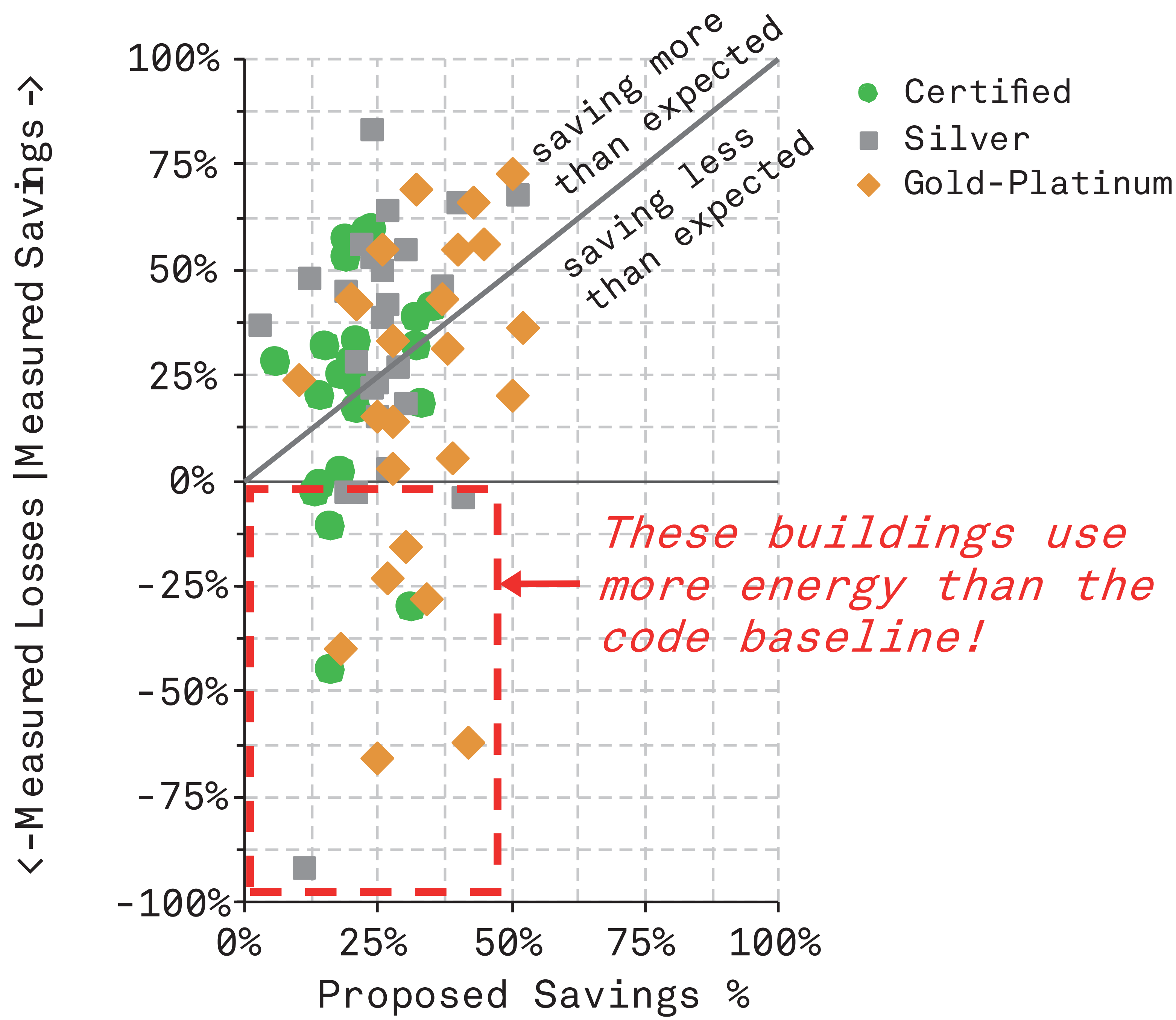
Swiss Federal Institute of Technology Zurich

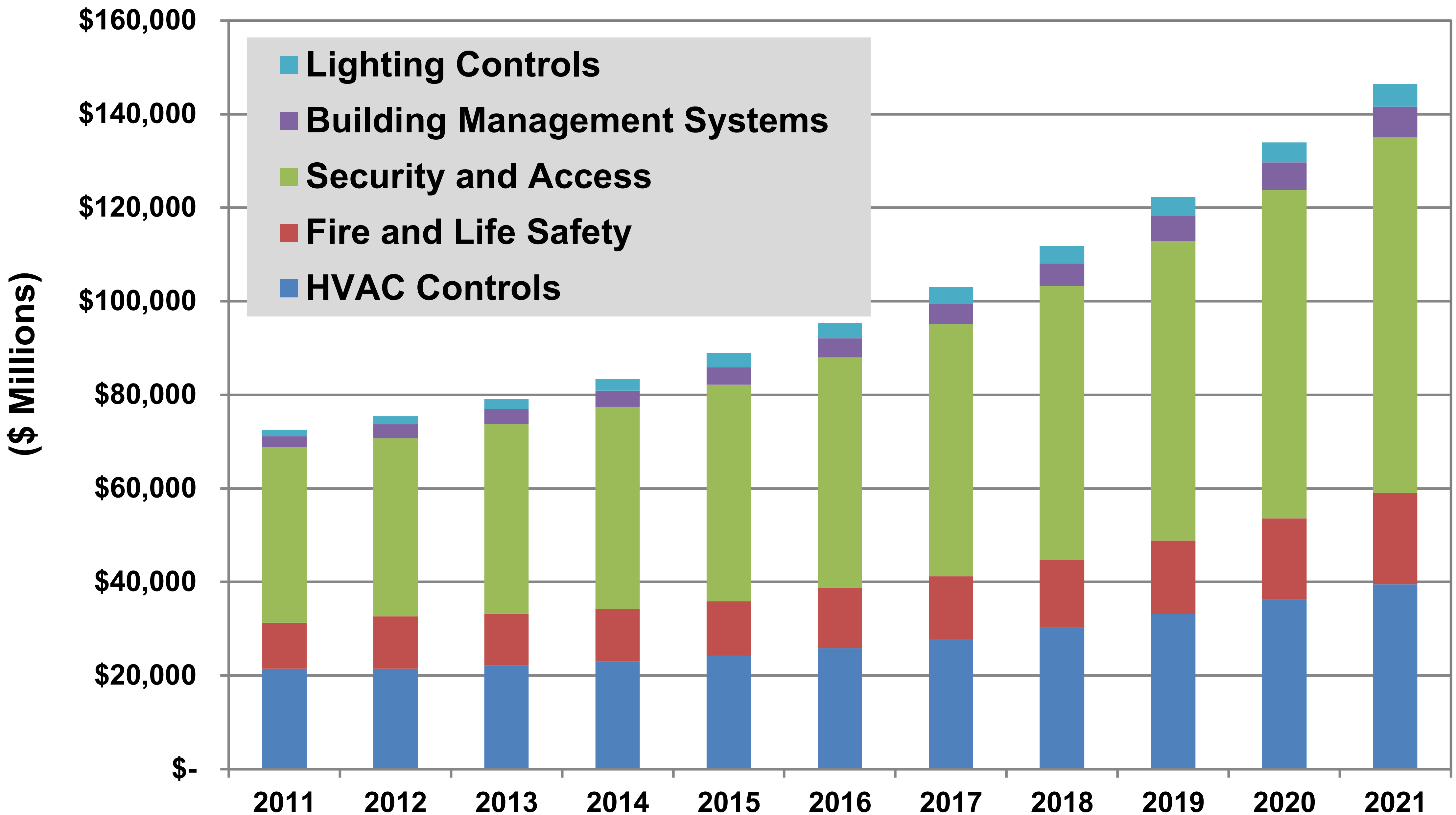
Performance Realization of High Performance Buildings is a Problem



Measured versus Proposed Savings Percentages.
Adapted from "Energy Performance of LEED for new construction buildings" study (Turner & Frankel 2008)

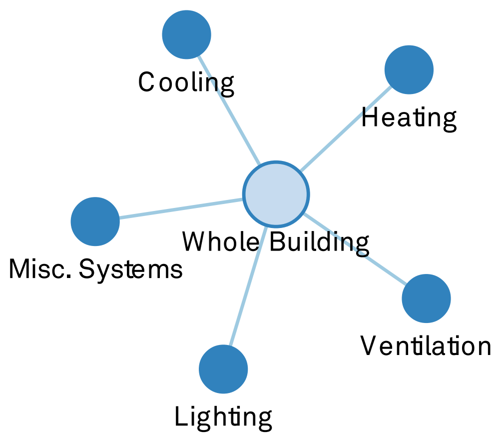
Other studies have shown similar performance gaps (Demanuele et al. 2010; Dasgupta et al. 2012; Menezes et al. 2012; Osaji et al. 2013)

Data measurement systems are creating more and more data



BAS Market Size by Control System, World Markets: 2011-2021.
"Commercial Building Automation Systems" (Emmerich & Bloom 2012)

Conventional Top-Down Analysis



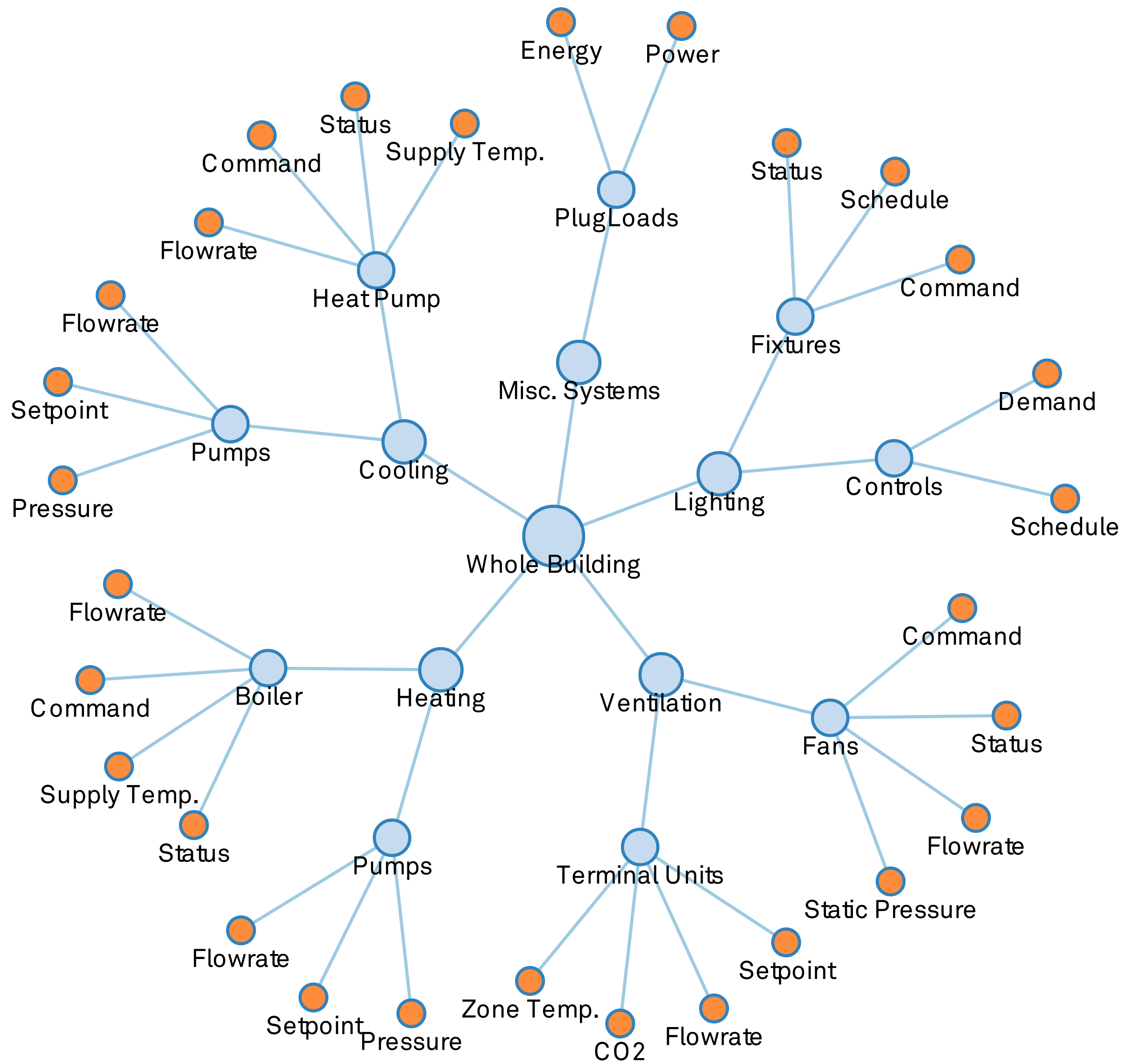
Benchmarking (Mills et al. 2008)

Performance Tracking (Friedman et al. 2011; Greensfelder et al. 2010)

Energy Information Systems (Granderson et al. 2011)

Provides only basic indicators of performance

Conventional Bottom-up Analysis



Commissioning techniques
(Milesi-Ferretti & Choiniere 2012; Mills 2009; Bynum et al. 2008)

Fault Detection and Diagnostics
(Samouhos 2010; Katipamula & Brambley 2005)

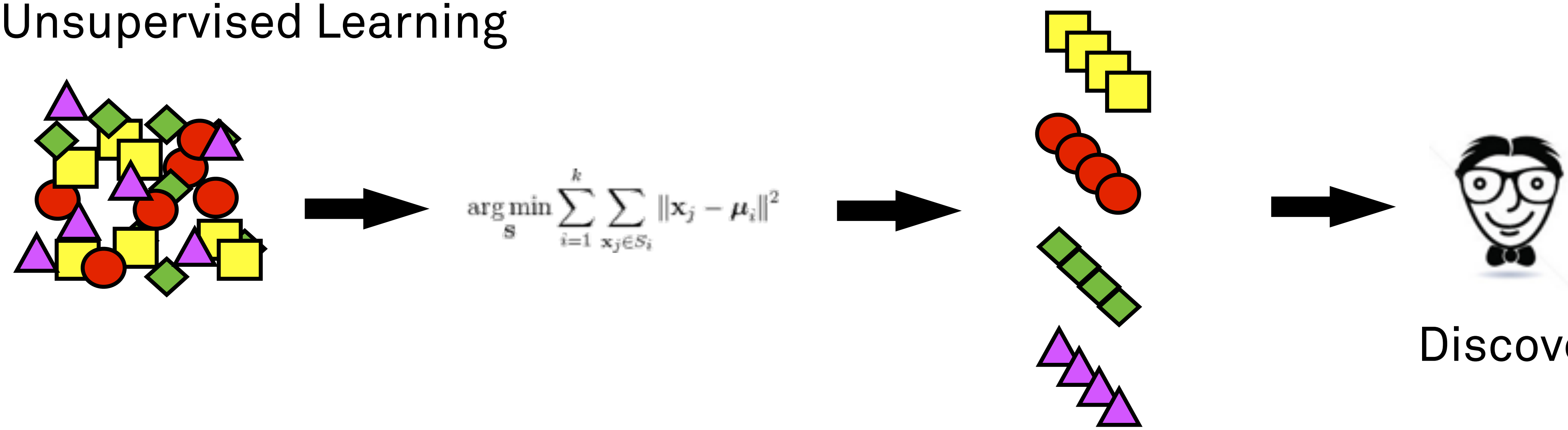
Detailed Model Calibration
(Reddy et al. 2007)

Requires intimate knowledge of detailed data

Machine Learning Techniques

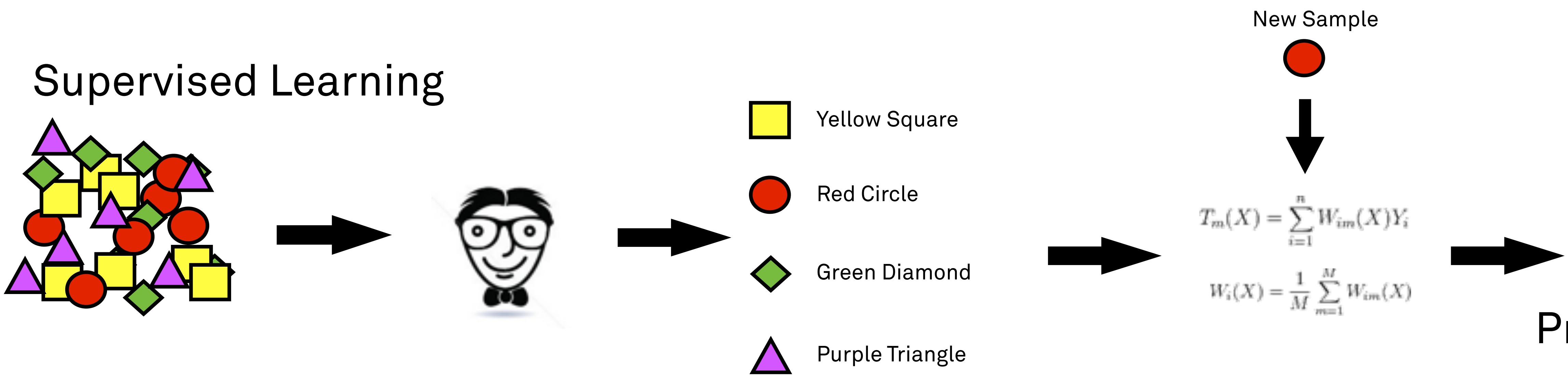
"Field of study that gives computers the ability to learn without being explicitly programmed"

Unsupervised Learning



Discovery

Supervised Learning



Prediction

Revolutionized information gain for large, raw data in:
Biology, Finance, Marketing, Advertising, Sales, Genetics and many more

1. **Investigate machine learning techniques** in the building data context

2. Develop and test a **process of analysis** on new/recently renovated high performance projects

3. Create a **web-based prototype** of a visualization and analysis interface

Preliminary investigation of machine learning techniques in building industry

Use of neural networks to detect general building problems (Dodier & Kreider 1999)

Pattern recognition and clustering to detect abnormal days (Seem 2005; Seem 2007)

Identifying causal variables in building energy fault detection (Yoshida et al. 2008)

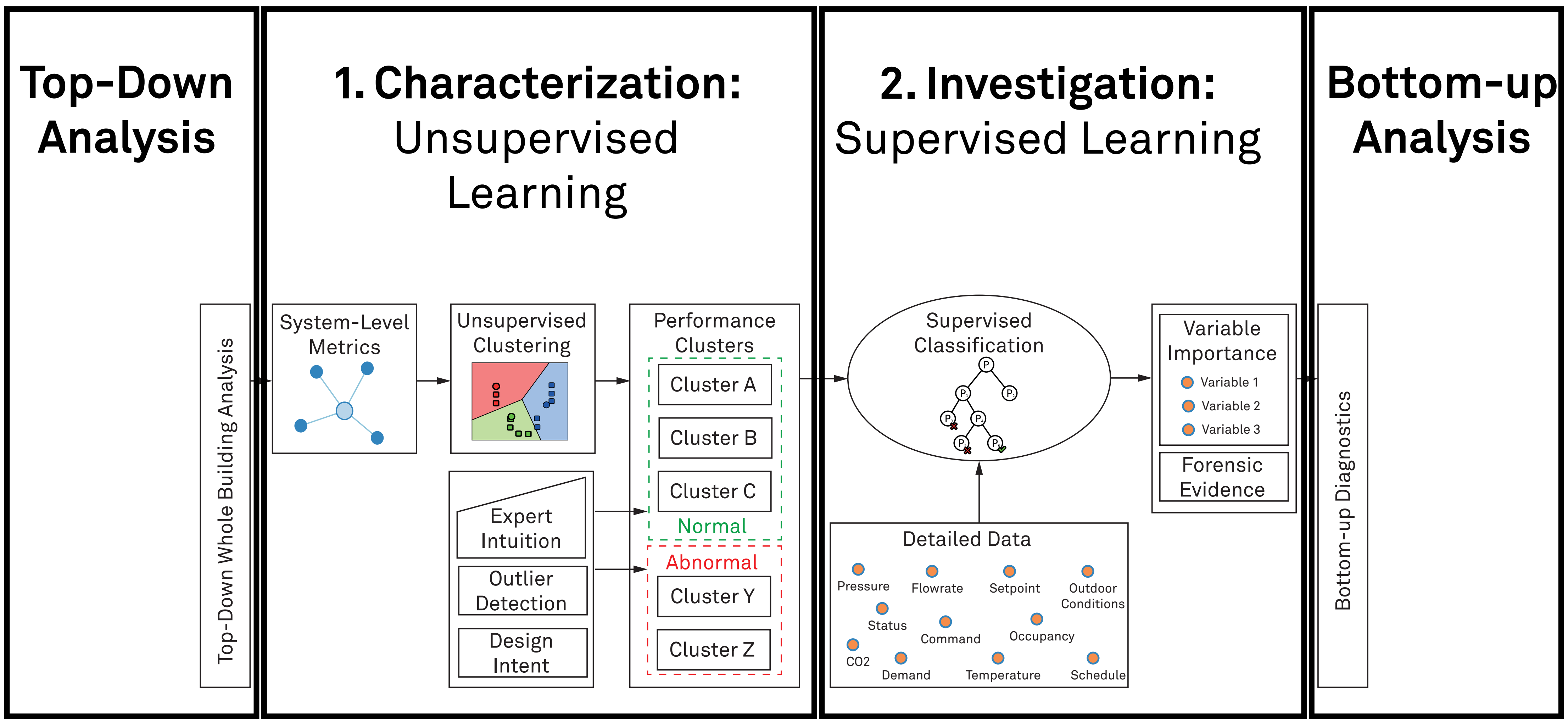
Classification tree for whole building abnormal behavior (Liu et al. 2010)

Various data mining procedures for pattern detection (Yu et al. 2012; Yu 2012)

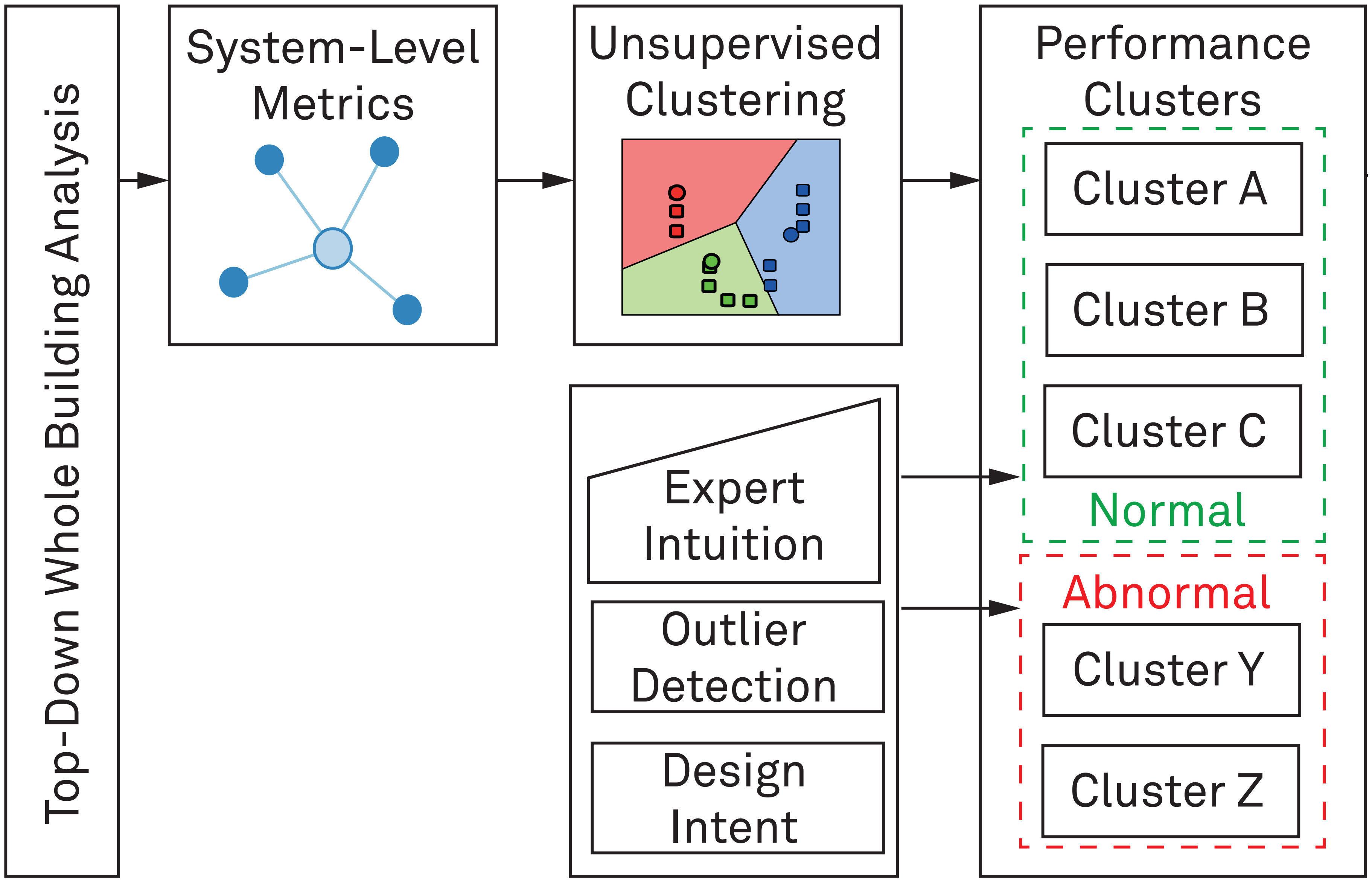
Feature selection of modeling (H.-X. Zhao & Magoulès 2012; H. Zhao 2011)

"Strip, Bind, and Search Method" correlation model for devices (Fontugne et al. 2013)

Proposed Process of Analysis



Step 1: Characterization



Characteristic Clustering Methodology

Demonstration of the standard algorithm

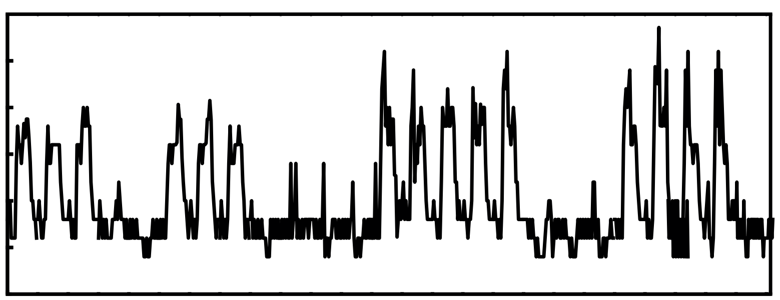
1) *k* initial "means" (in this case *k*=3) are randomly generated within the data domain (shown in color).

2) *k* clusters are created by associating every observation with the nearest mean. The partitions here represent the Voronoi diagram generated by the means.

3) The centroid of each of the *k* clusters becomes the new mean.

4) Steps 2 and 3 are repeated until convergence has been reached.

System-Level Metrics



Coefficients of Performance
Submeters
Heating and Cooling Energy

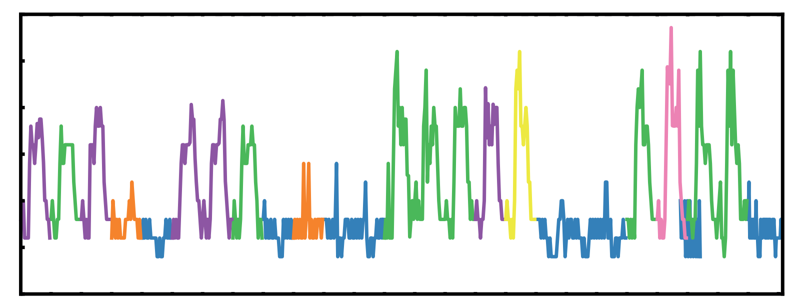
→

Tests:

1. Techniques: k-means/ PAM clustering
2. Number of Clusters
3. Visualization of Output

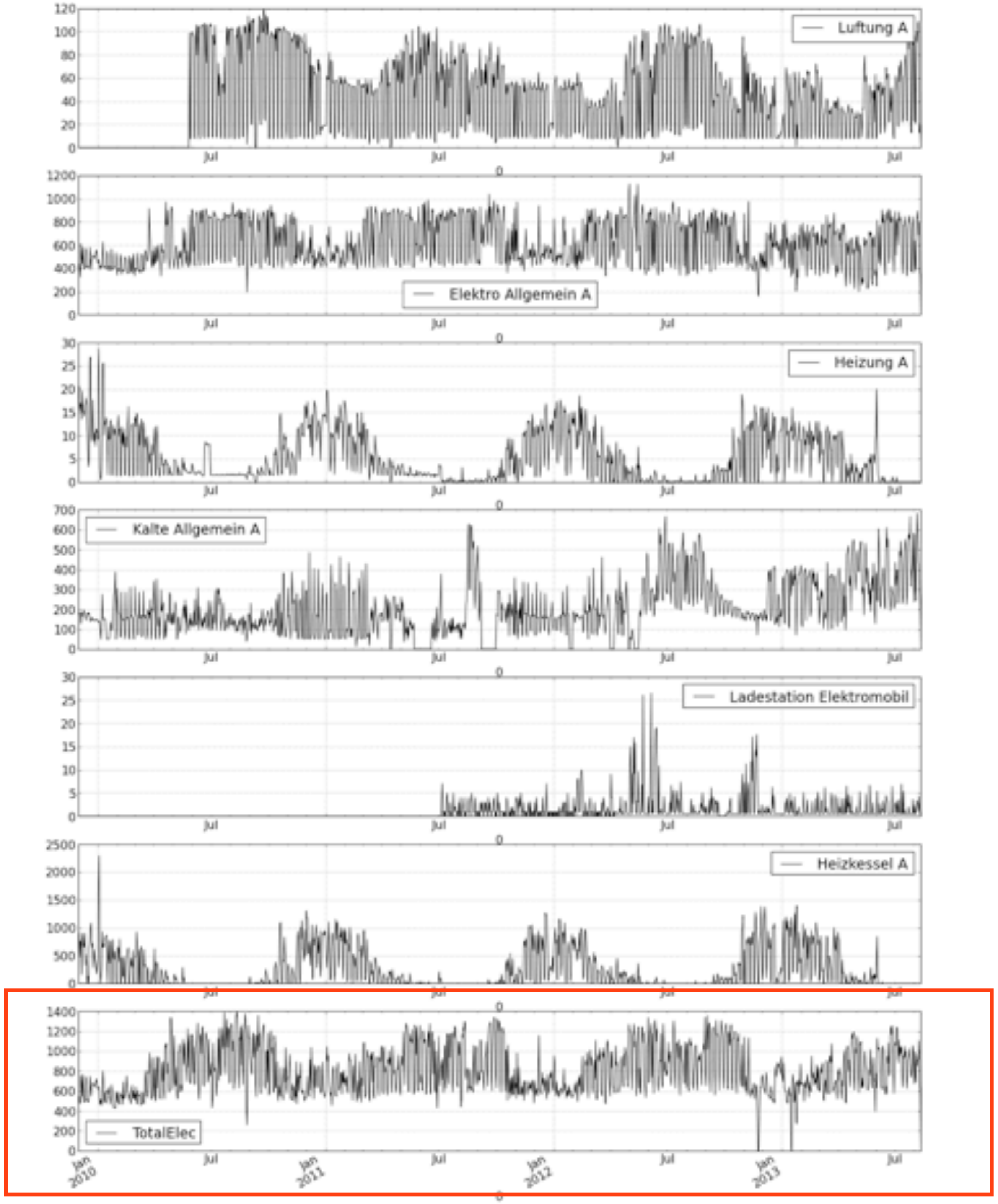
→

Clustered Output



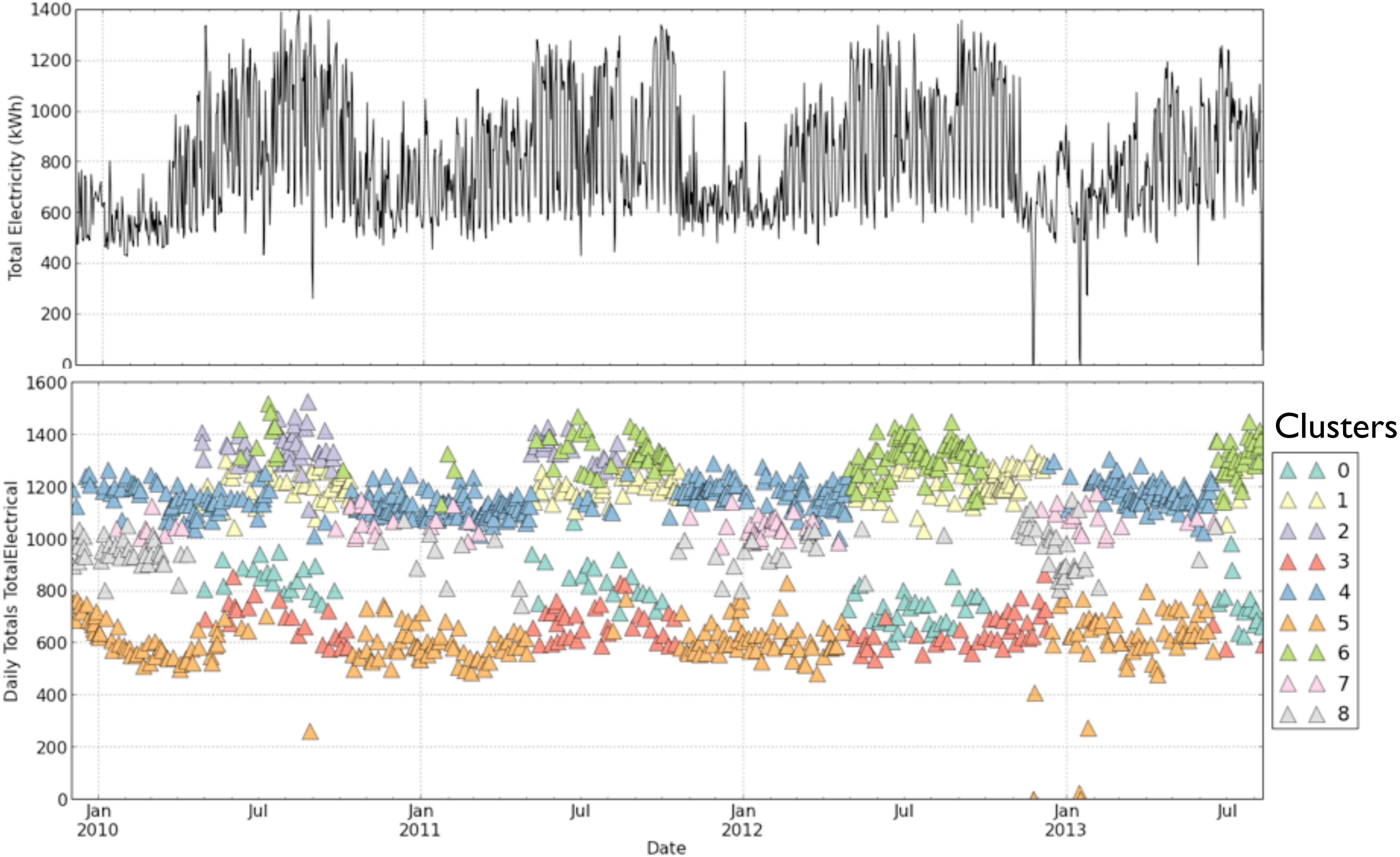
Interpretation:
Normal vs. Abnormal
Outlier Detection

Performance Metrics to Analyze

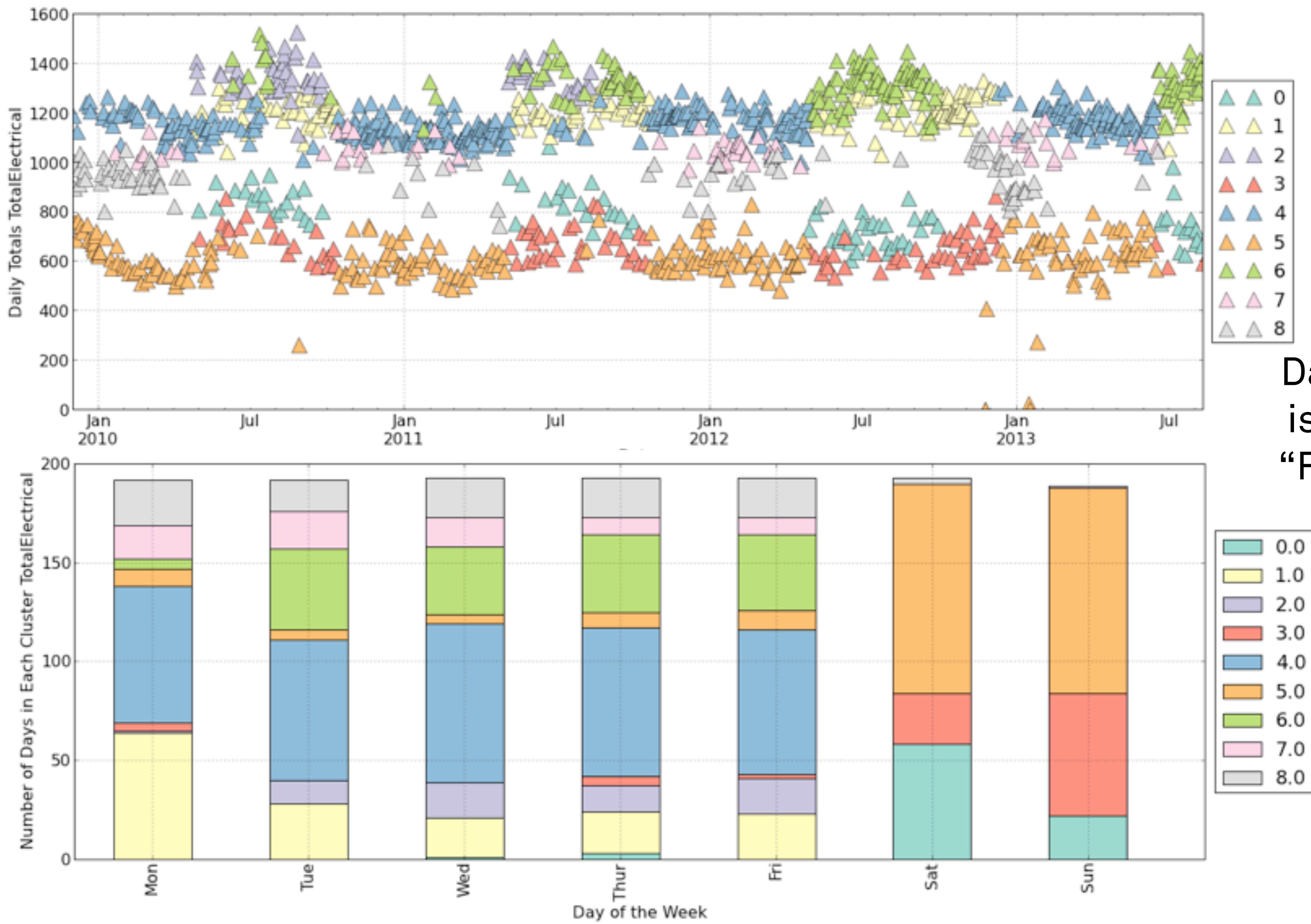


Whole
Building Electricity

Step 1: Characterization - Whole Building Electricity

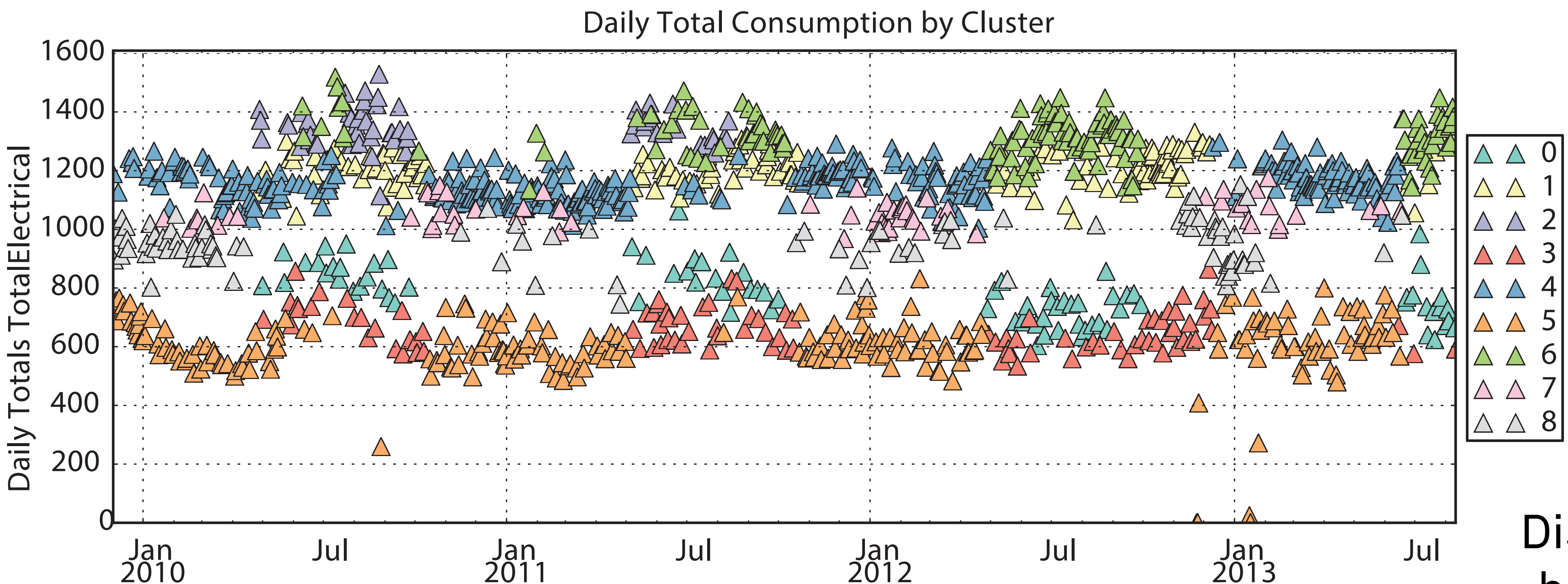


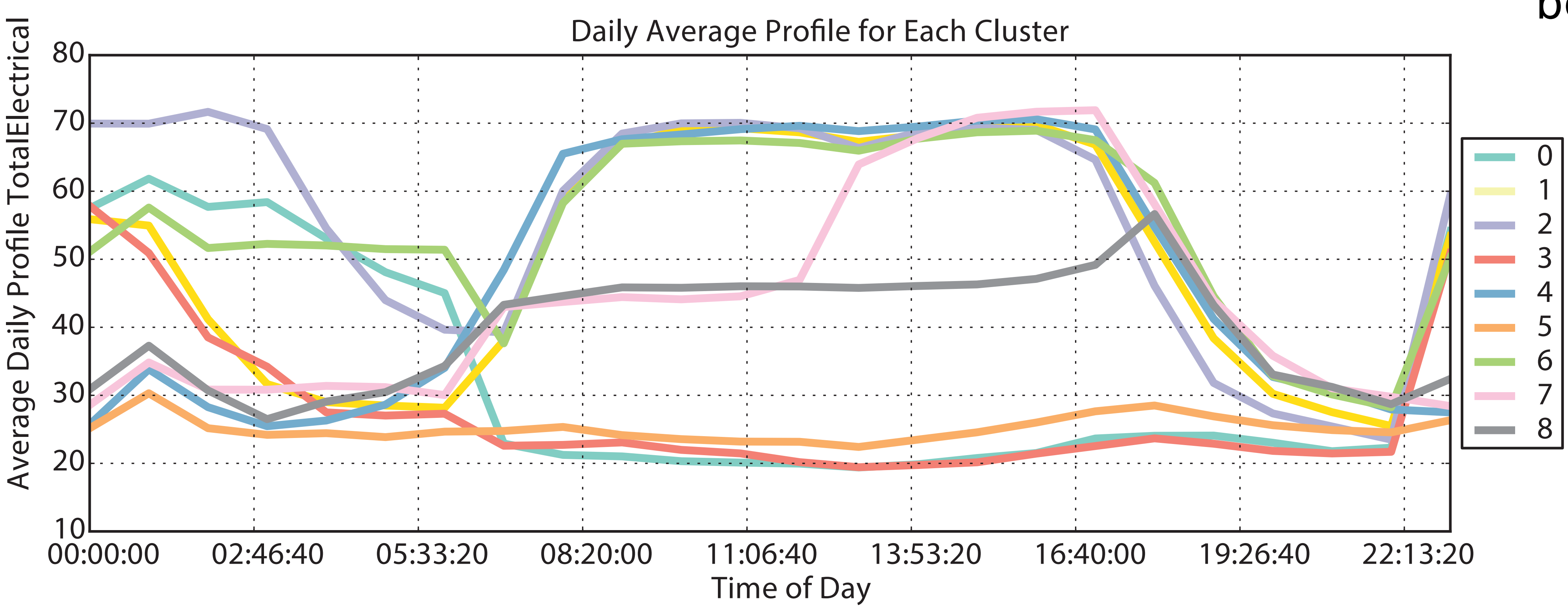
Whole Building Electricity Clusters by Day of the Week



Day of the Week is an important "Feature" in this data

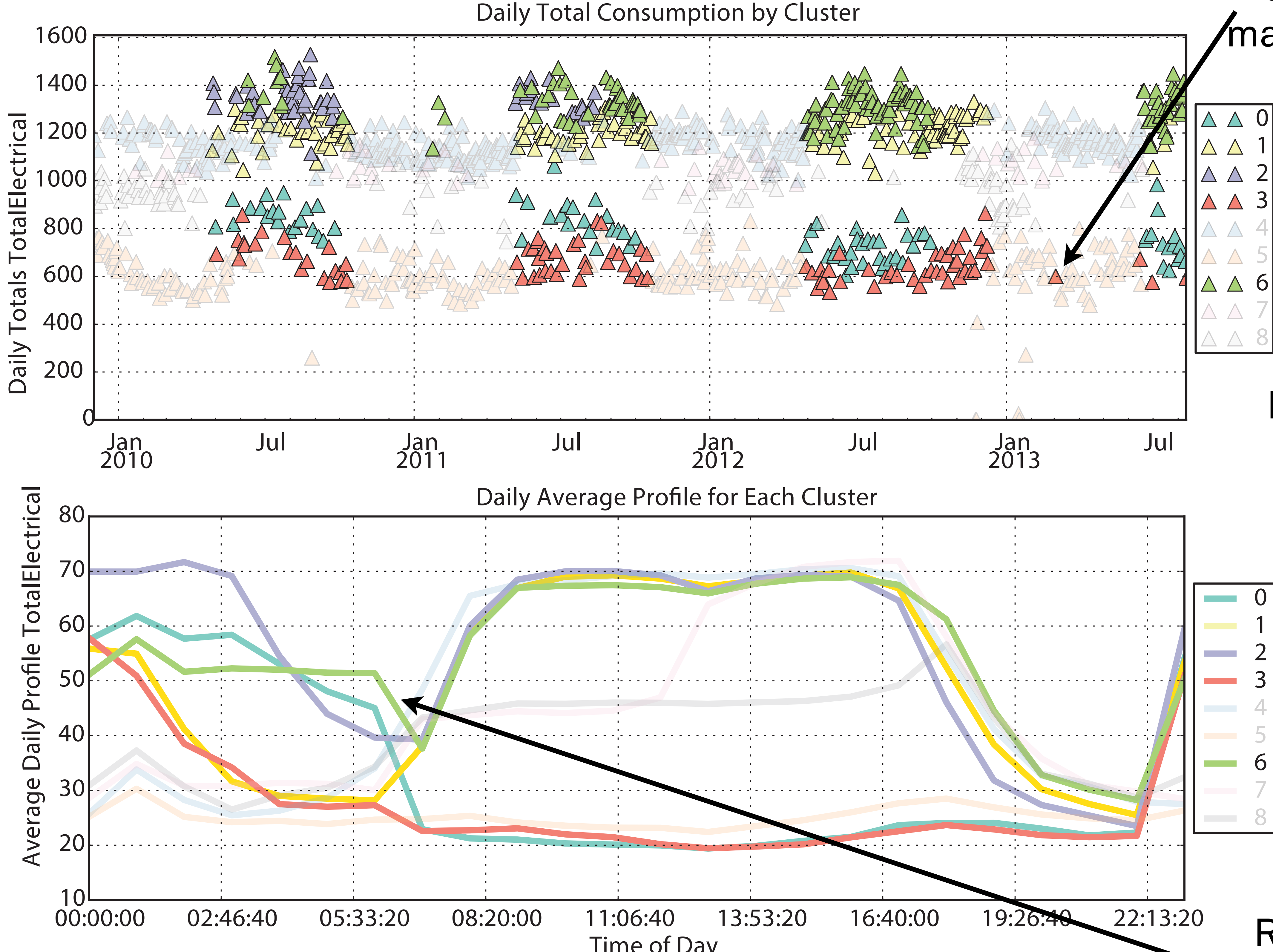
Load Profiles of Clusters





Distinct differences between seasonal load profiles

Summer Cluster Profiles

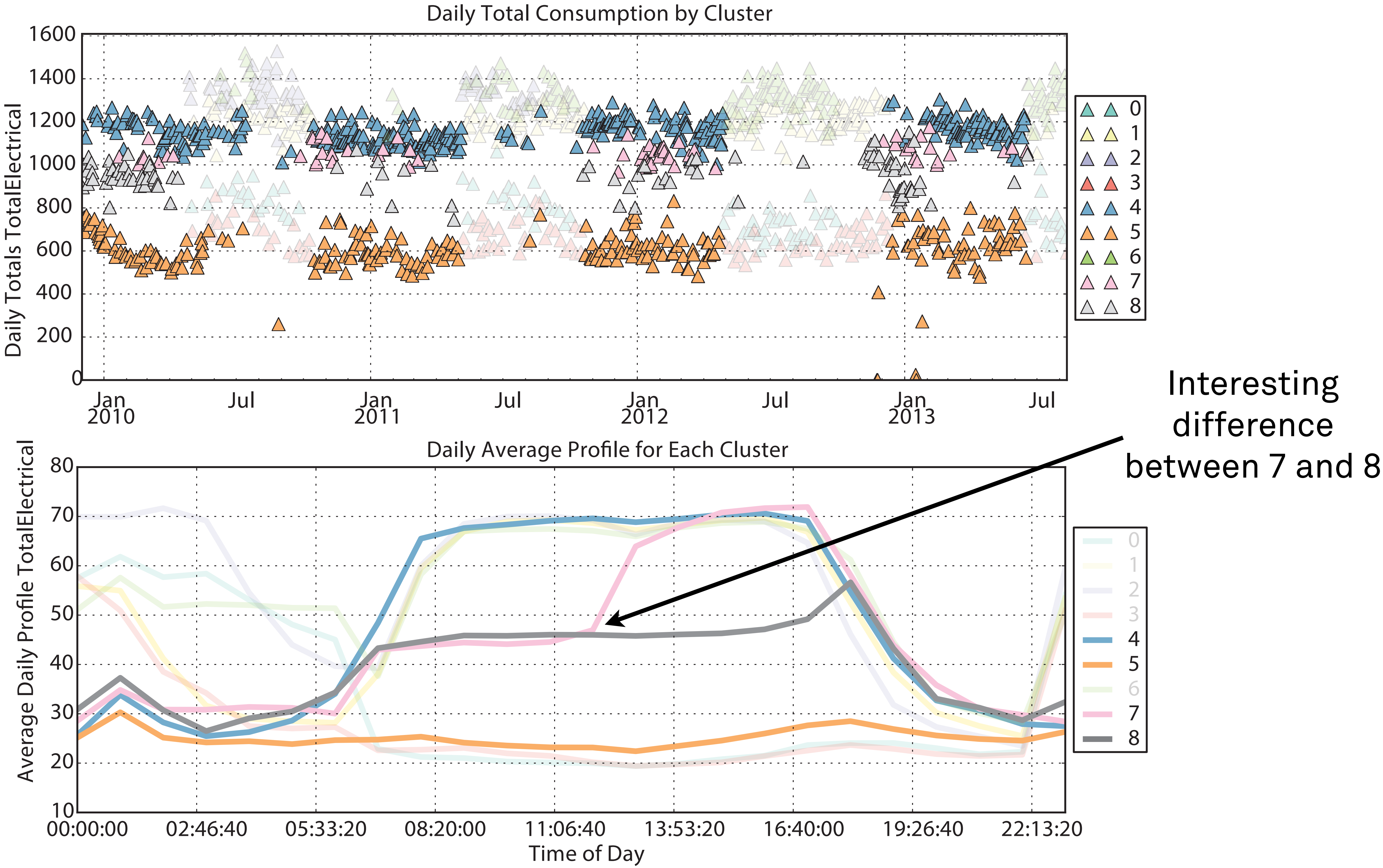


Outliers can be manually observed

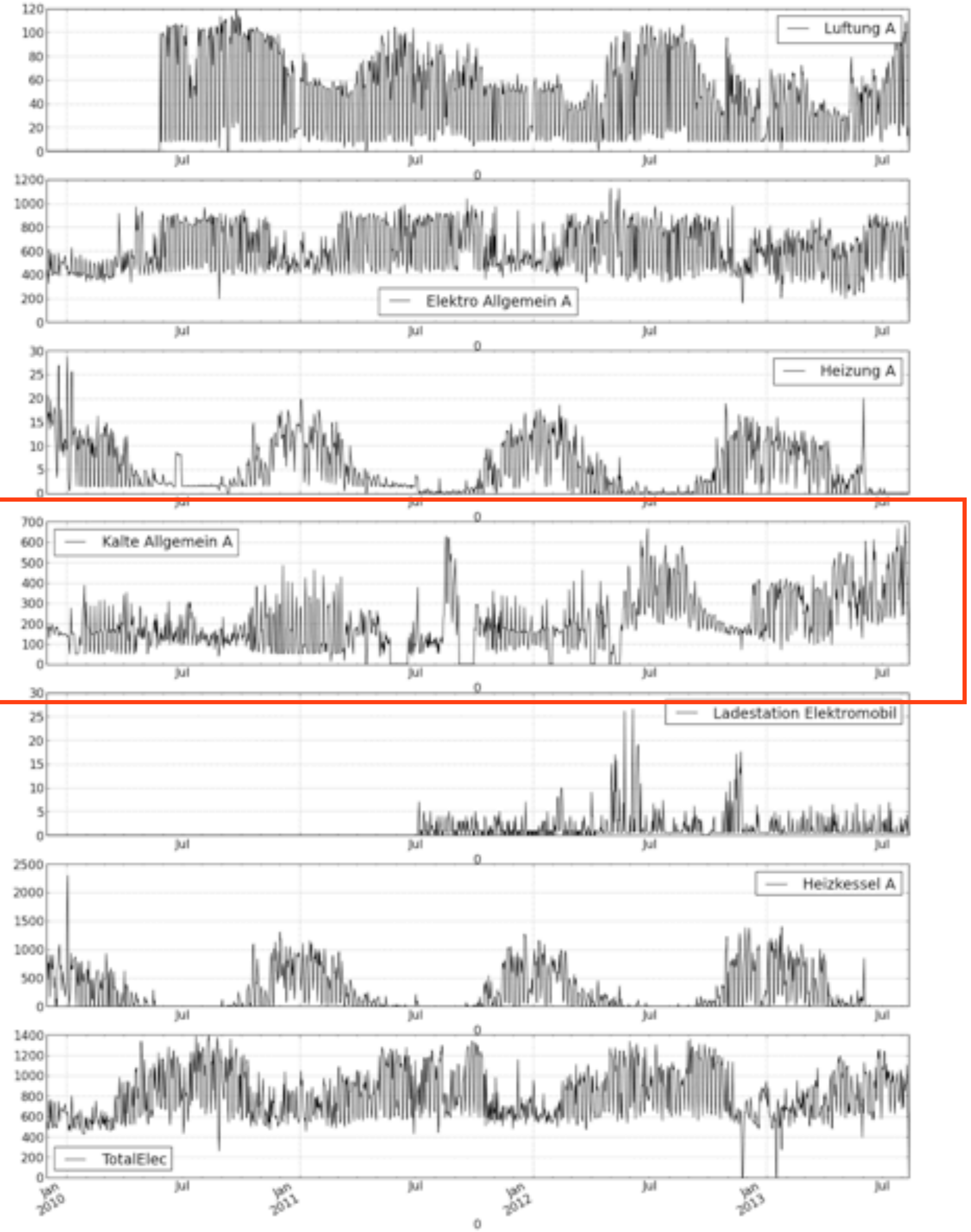
Demand Control Strategies are apparent in summer

Reason for multiple “types” of strategies?

Winter Cluster Profiles

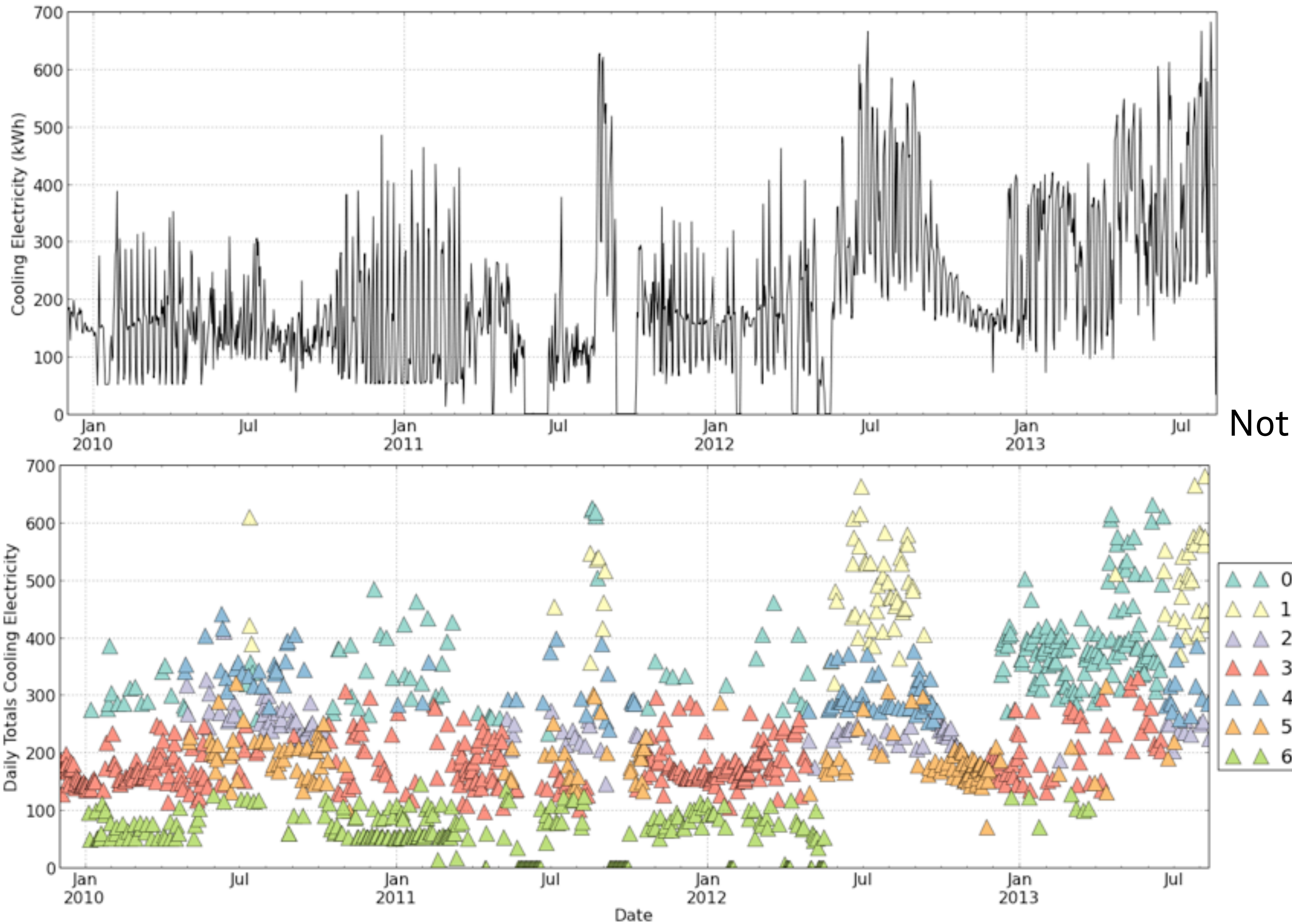


Performance Metrics to Analyze



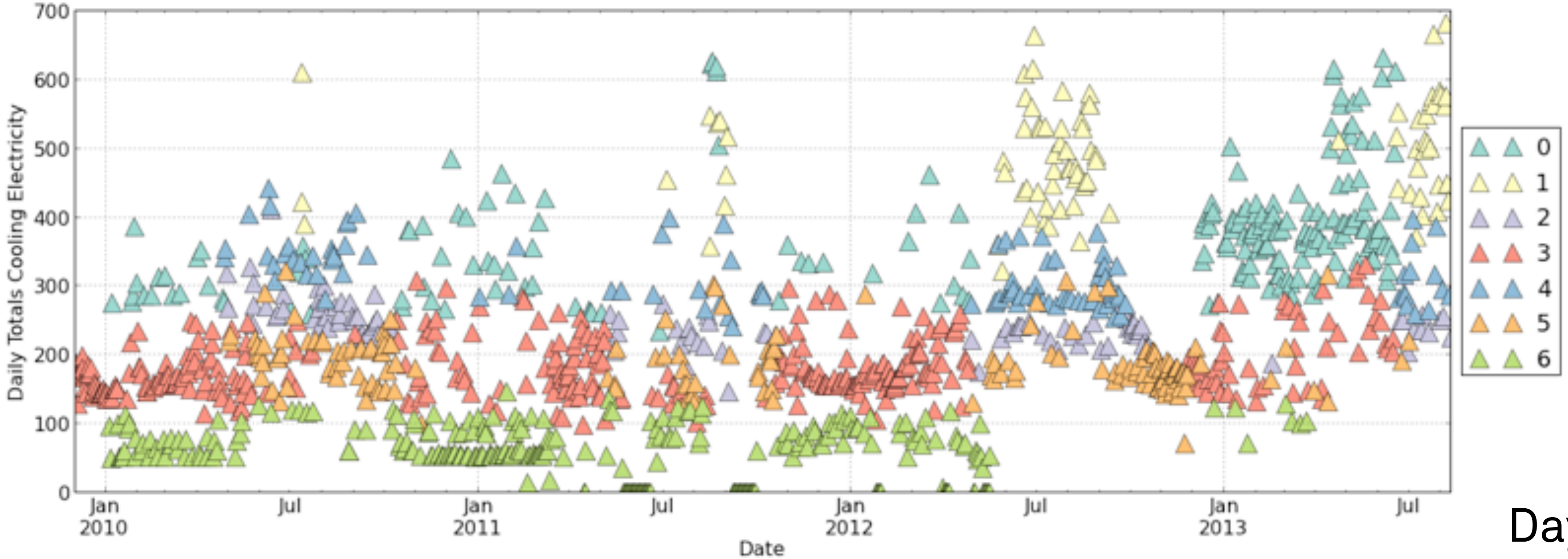
Cooling Electricity

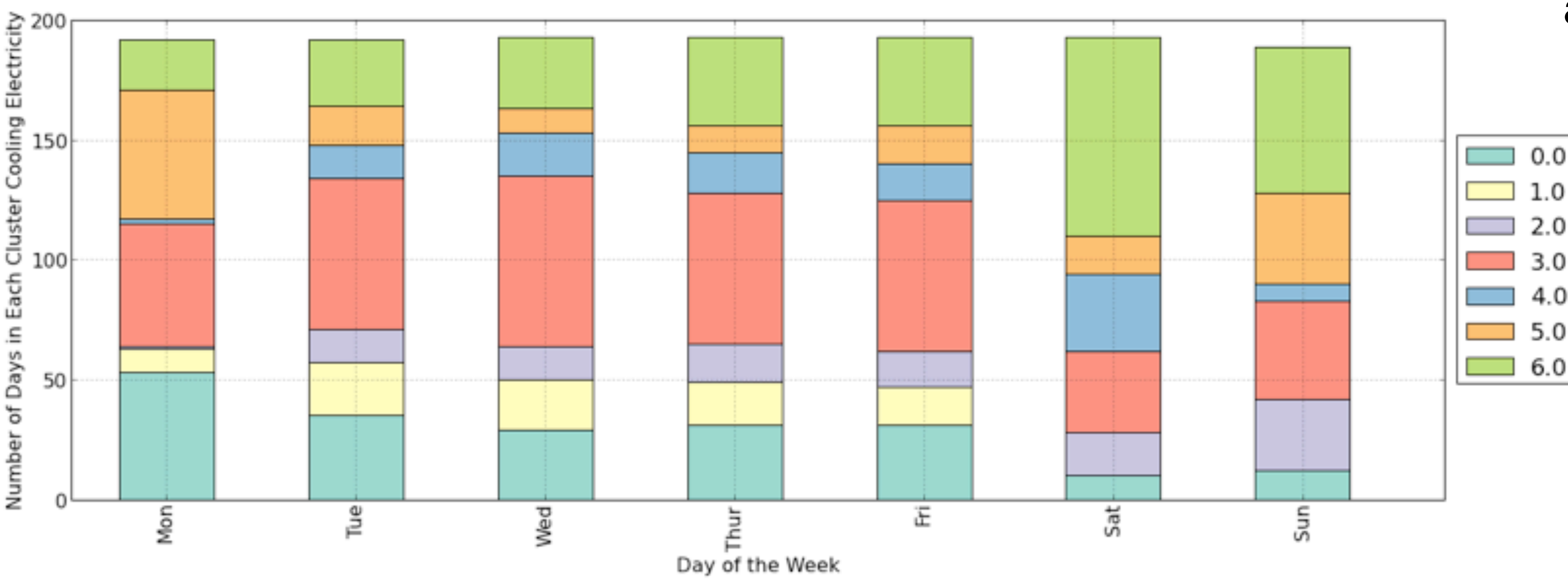
Cooling Characterization



Not as consistent over time

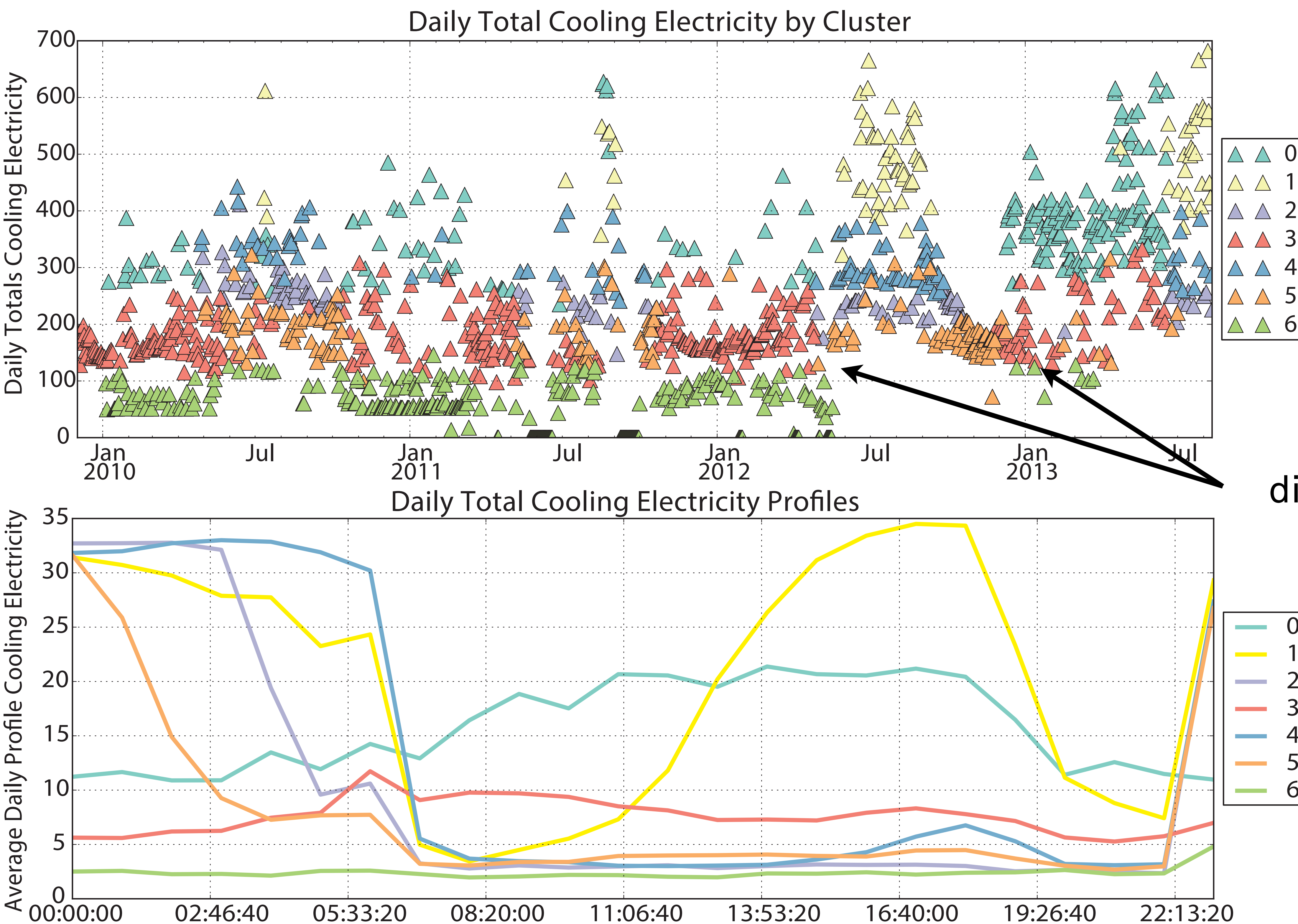
Cooling Electricity Clusters by Day of the Week





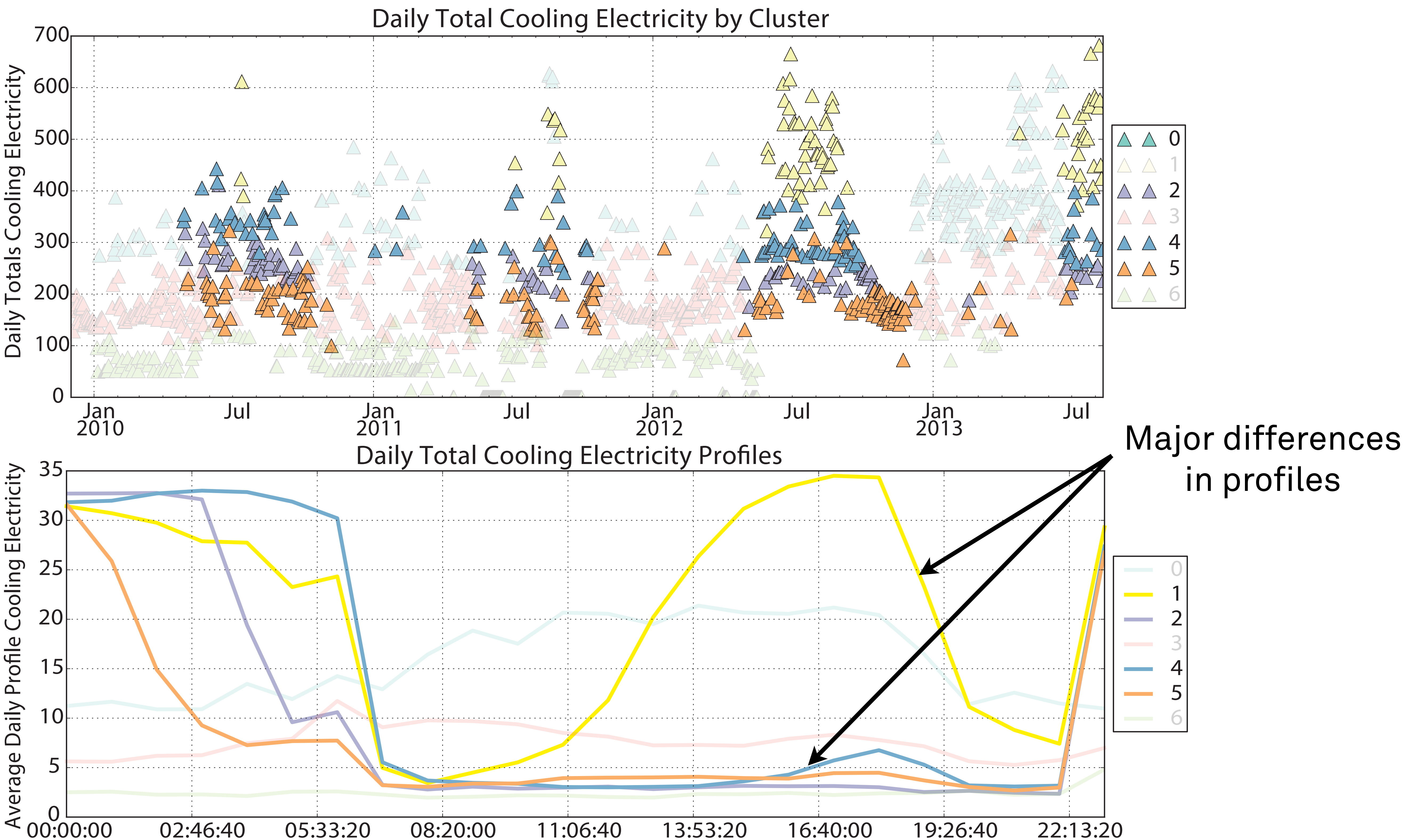
Day of the week not as important

Cooling Cluster Profiles

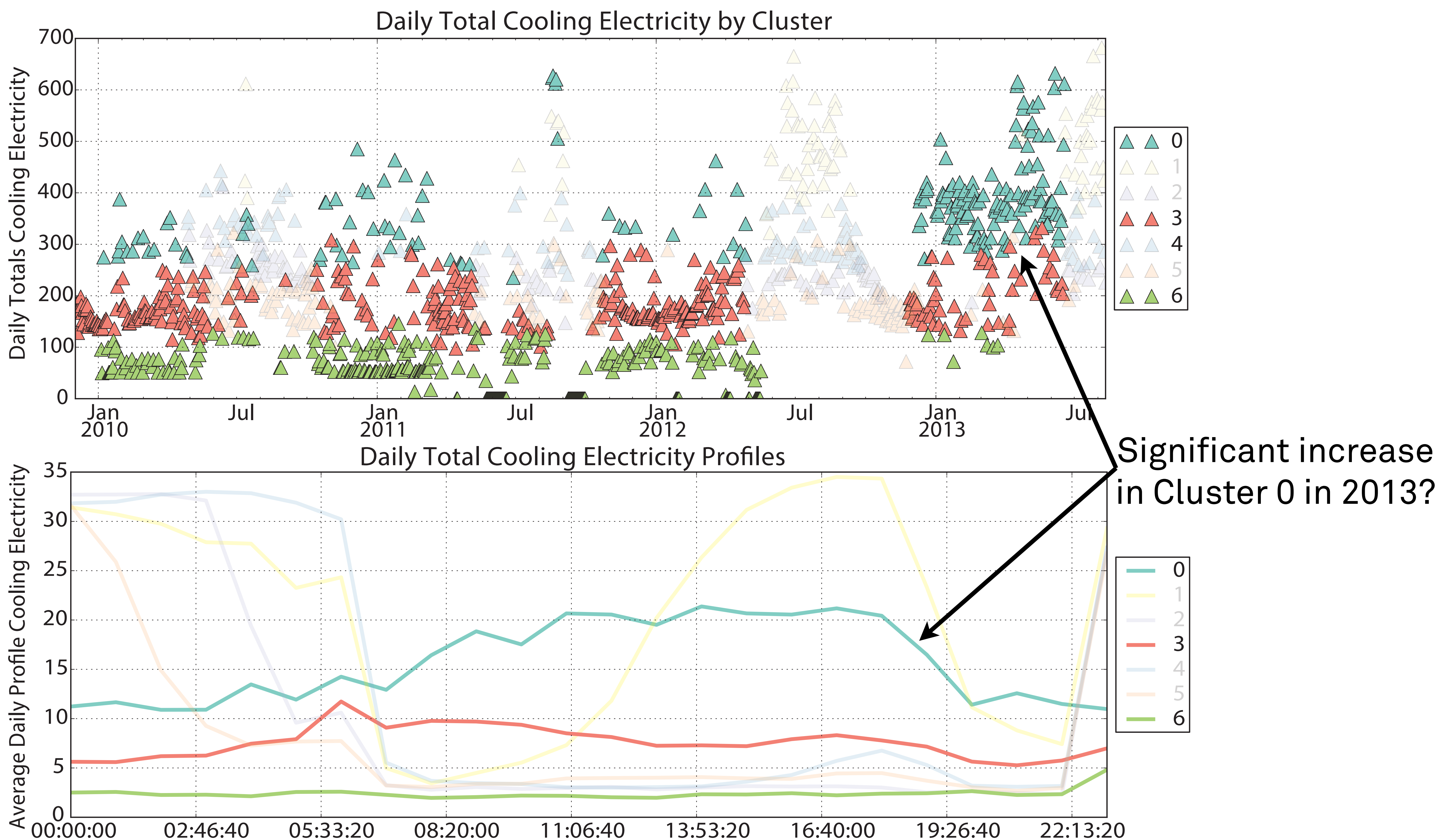


Obvious disruptions or changes

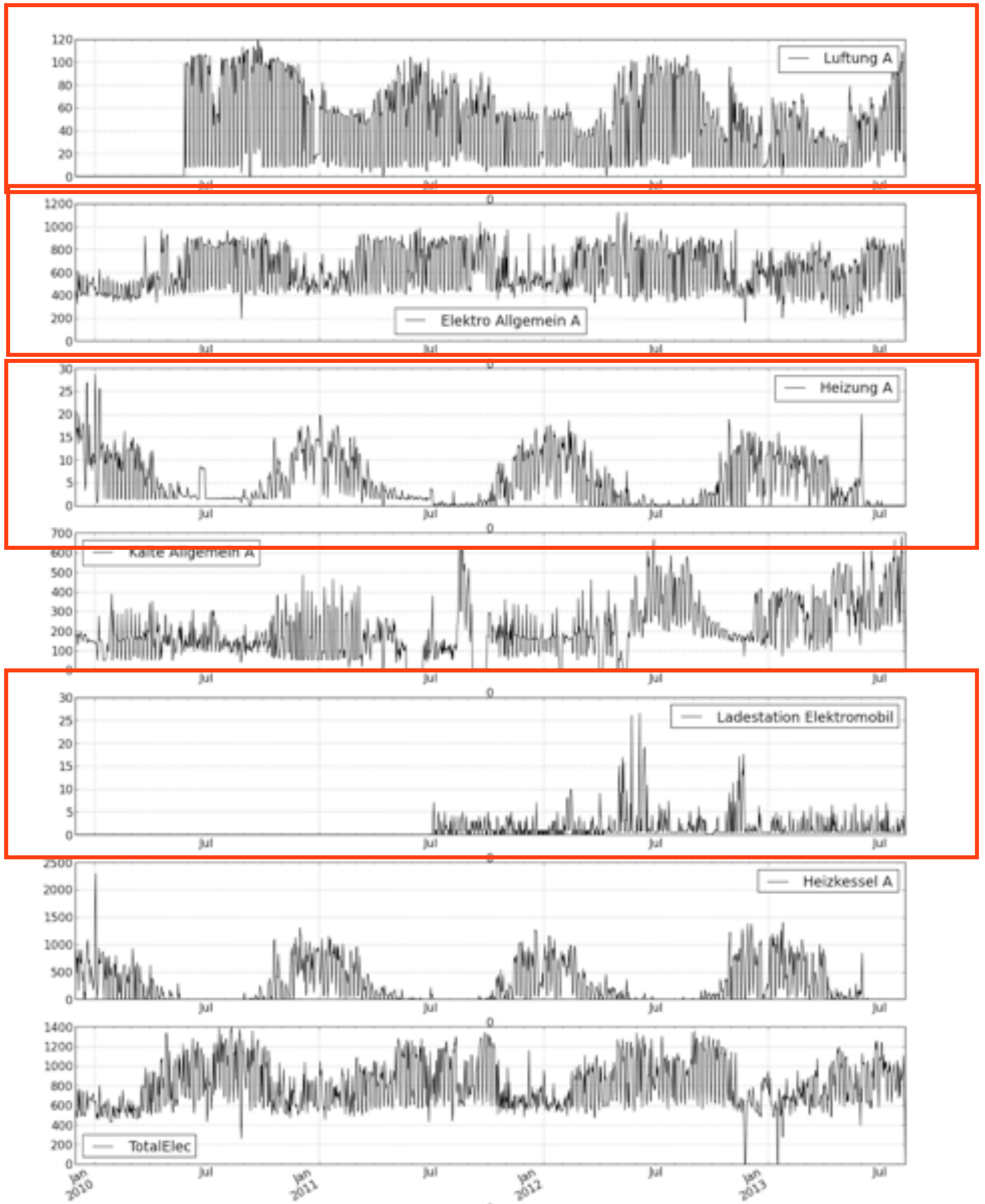
Summer Cooling Cluster Profiles



Winter Cooling Cluster Profiles



Performance Metrics to Analyze



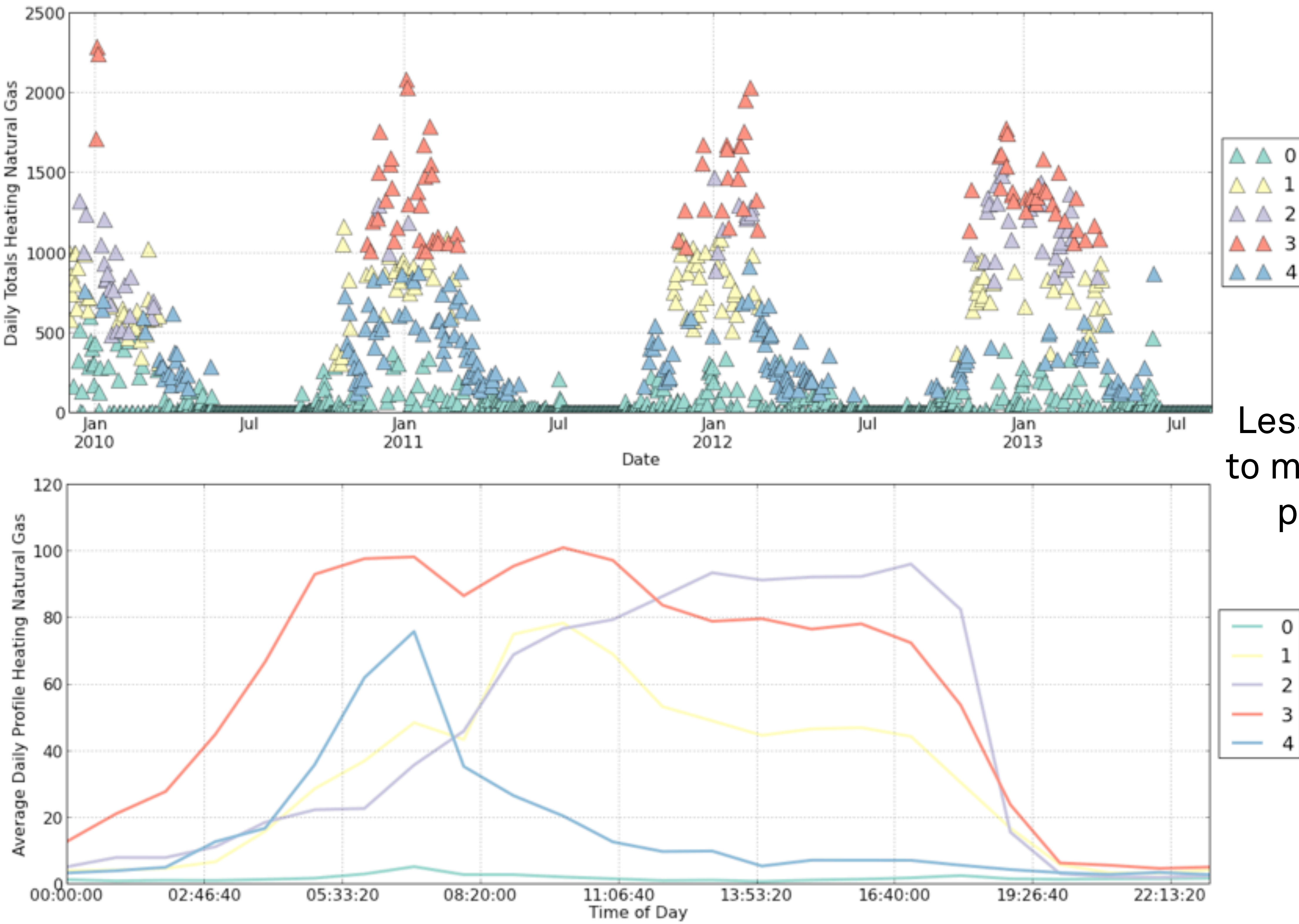
Ventilation

Miscellaneous

Heating Meter

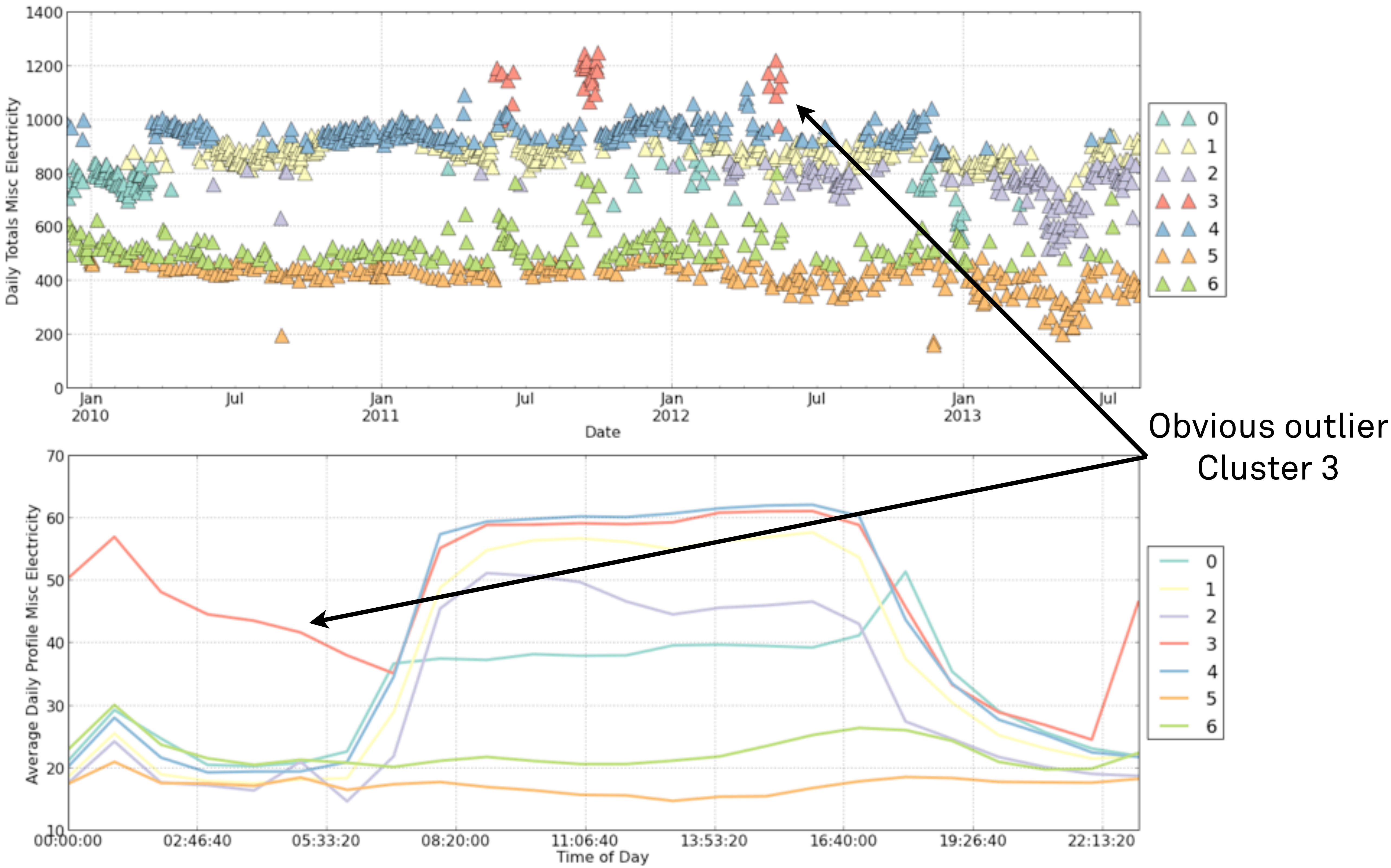
Electric Car Station

Heating Meter

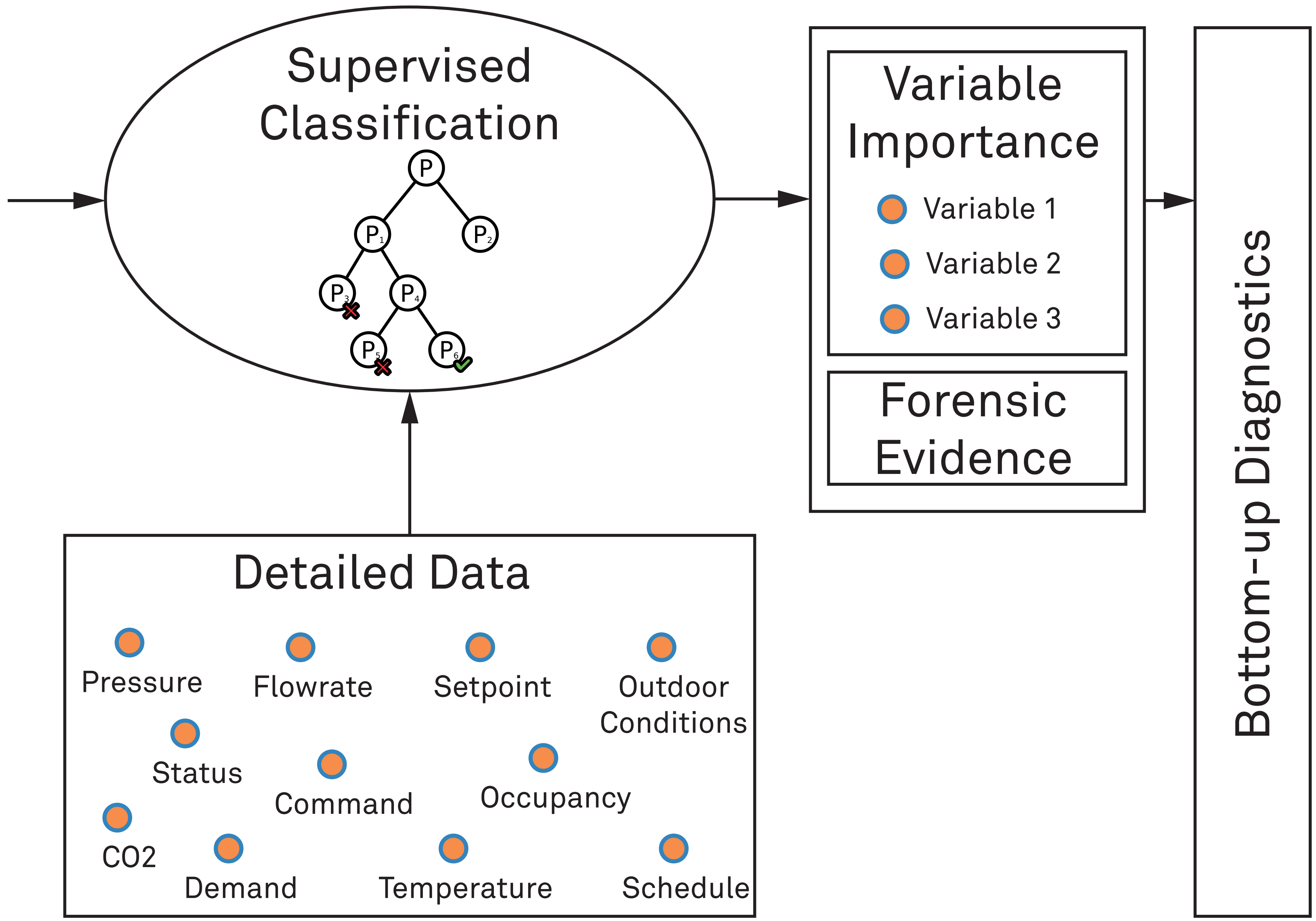


Less clusters due to more consistent performance

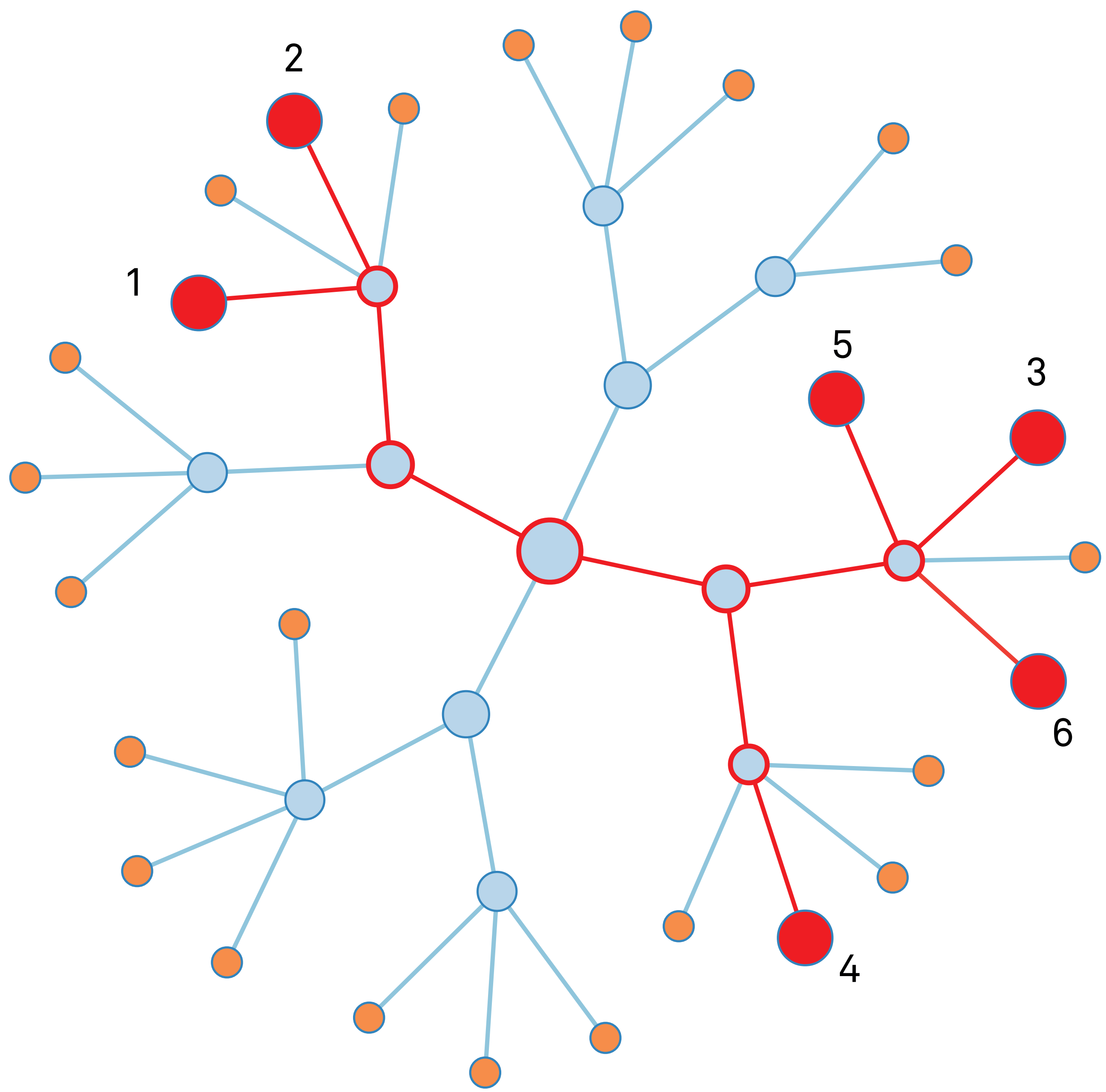
Miscellaneous Electricity Consumption

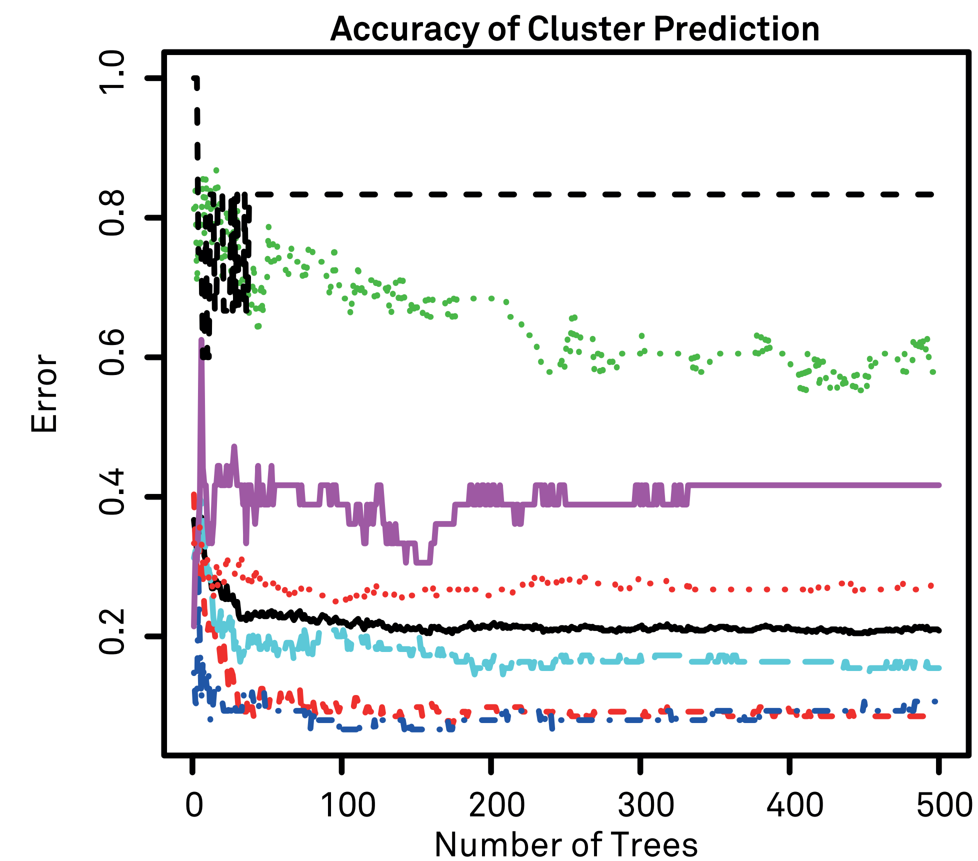


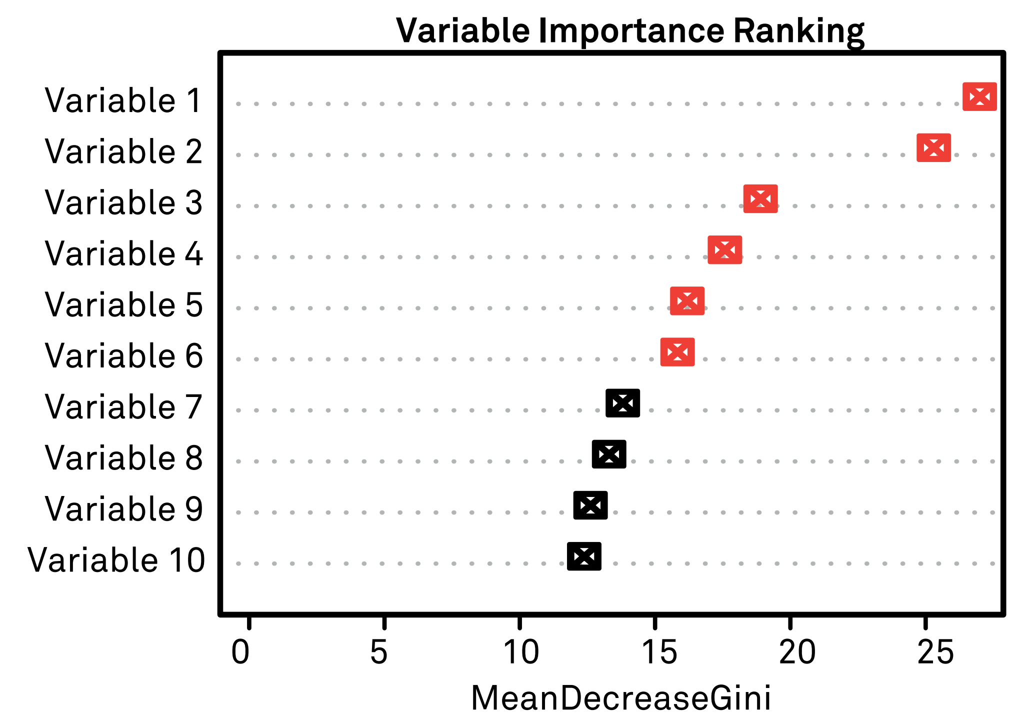
Step 2: Investigation



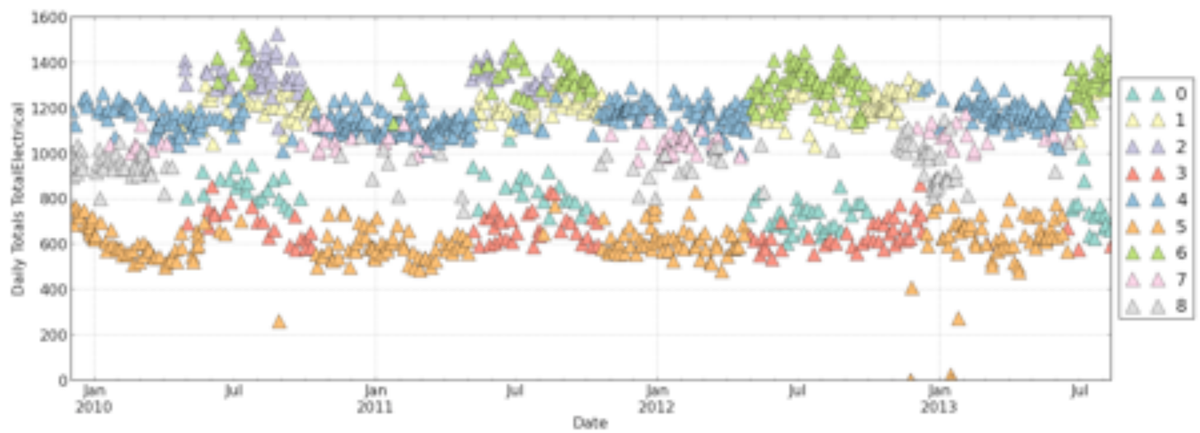
Variable Importance Estimation

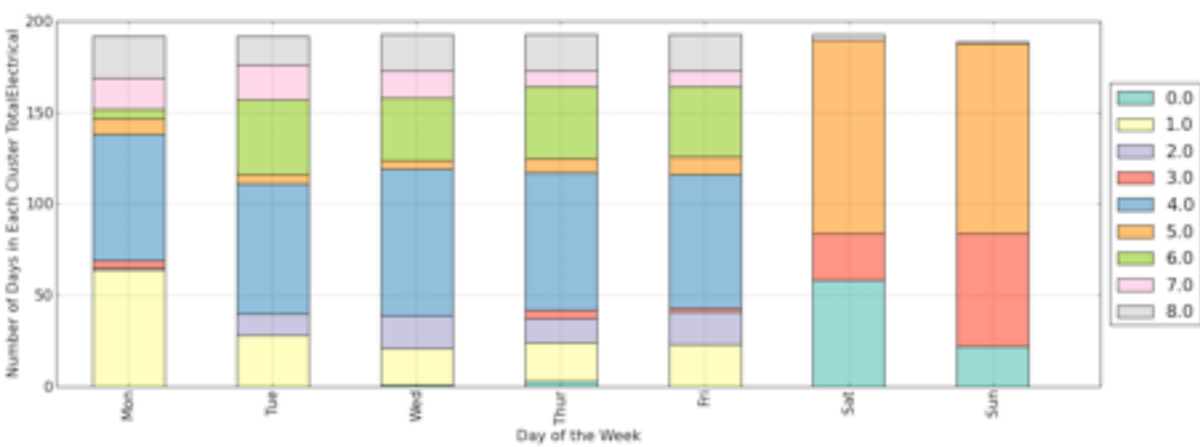


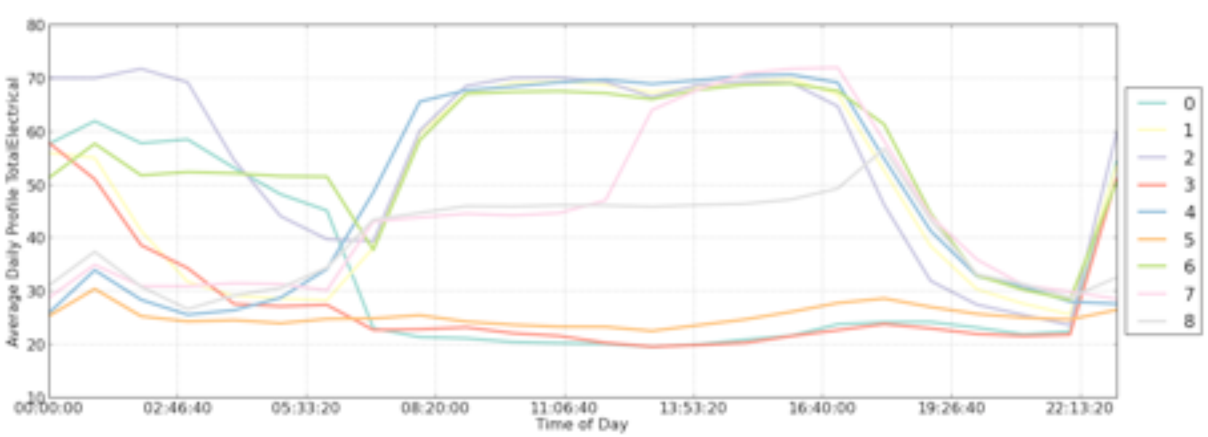


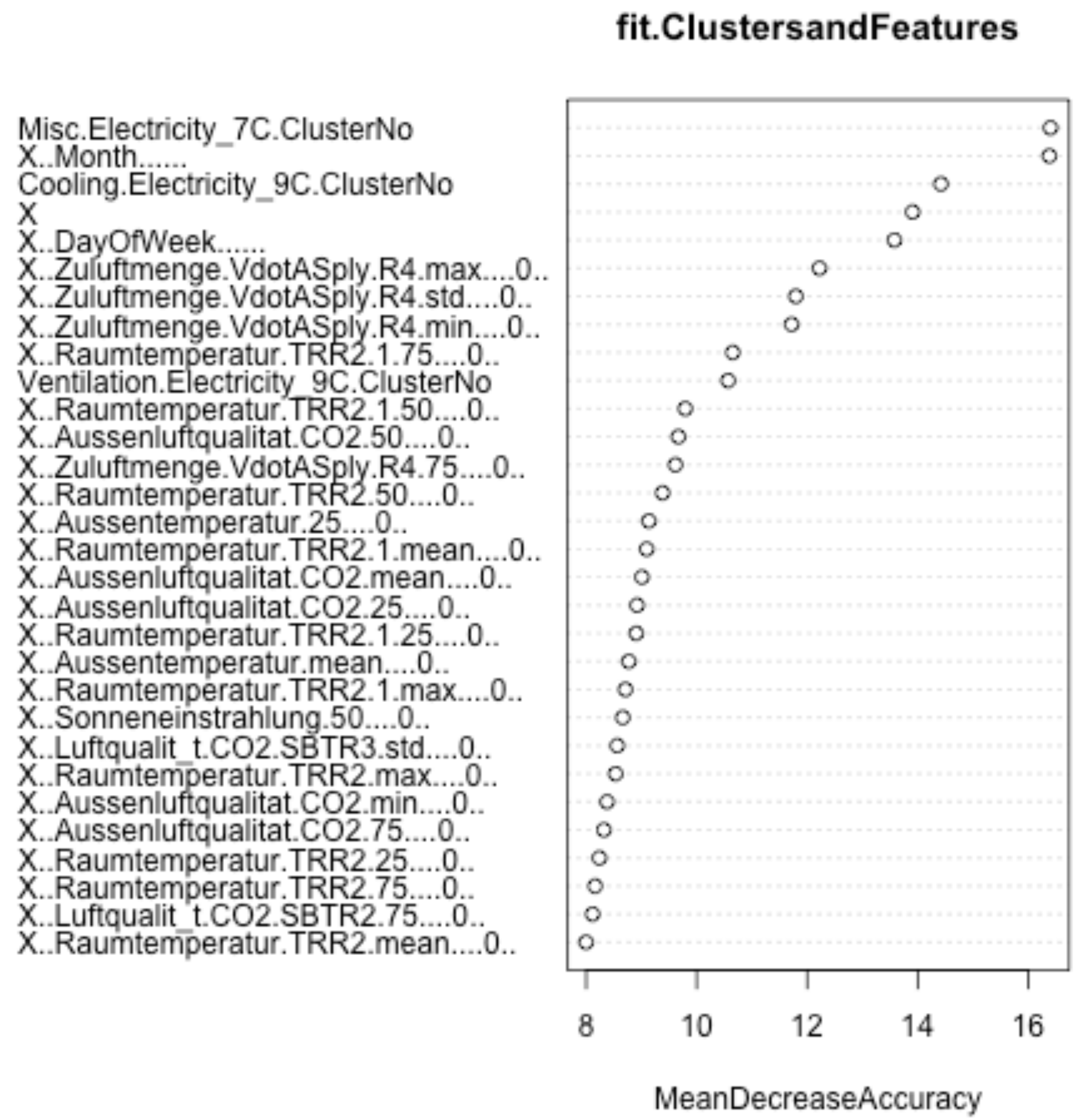


Feature Importance Estimation - Total Electricity

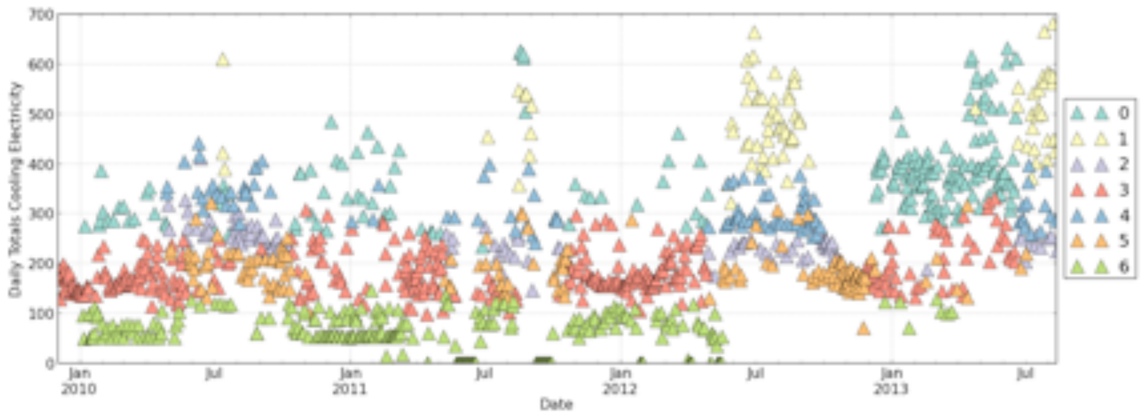


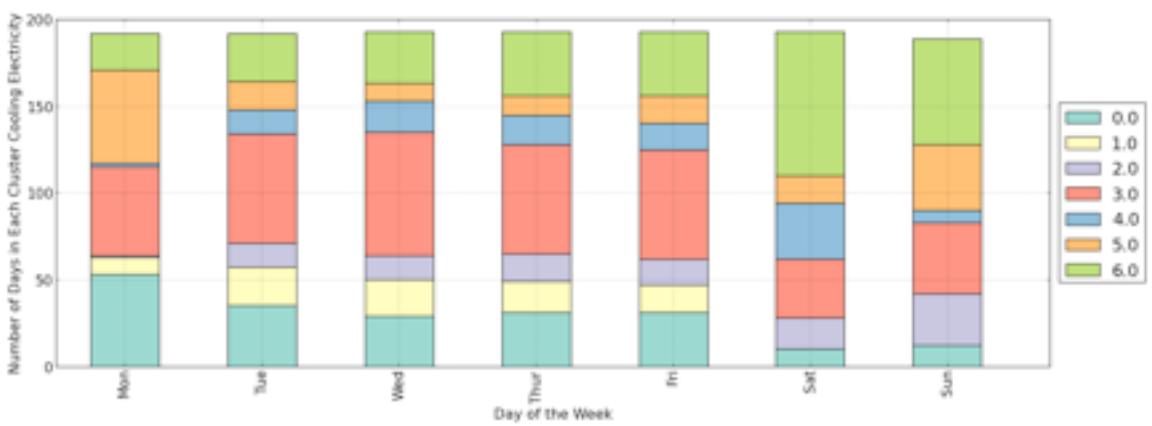


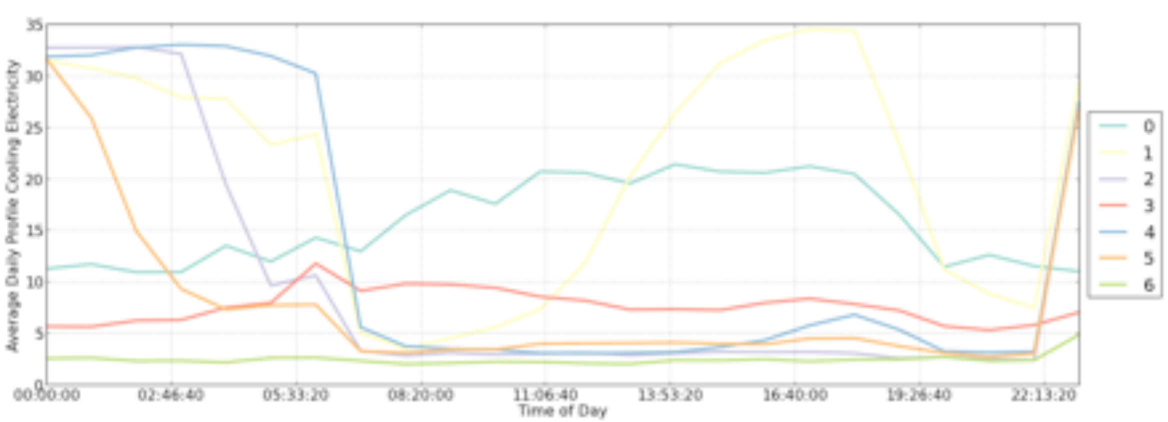


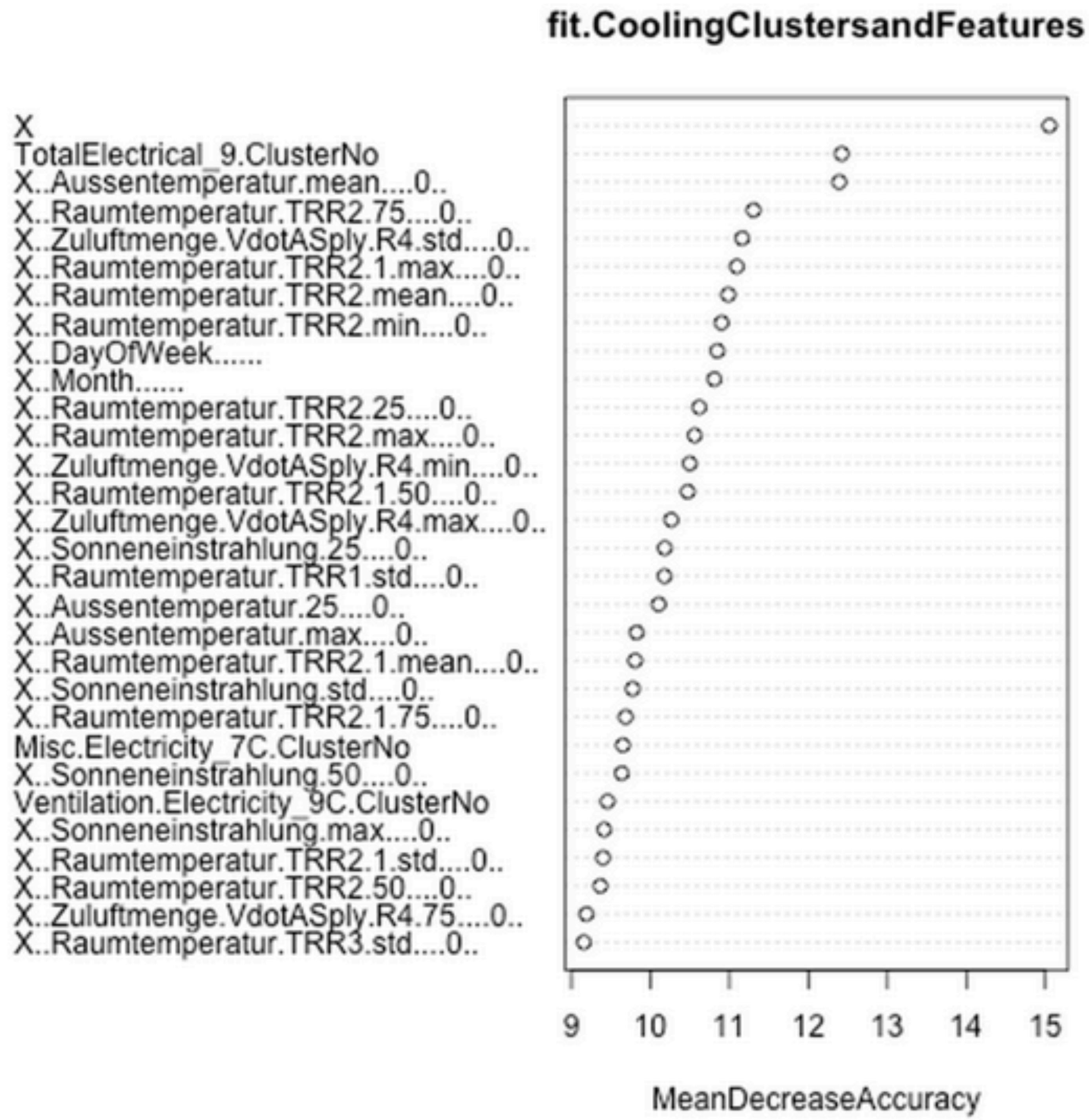


Feature Importance Estimation - Cooling Electricity

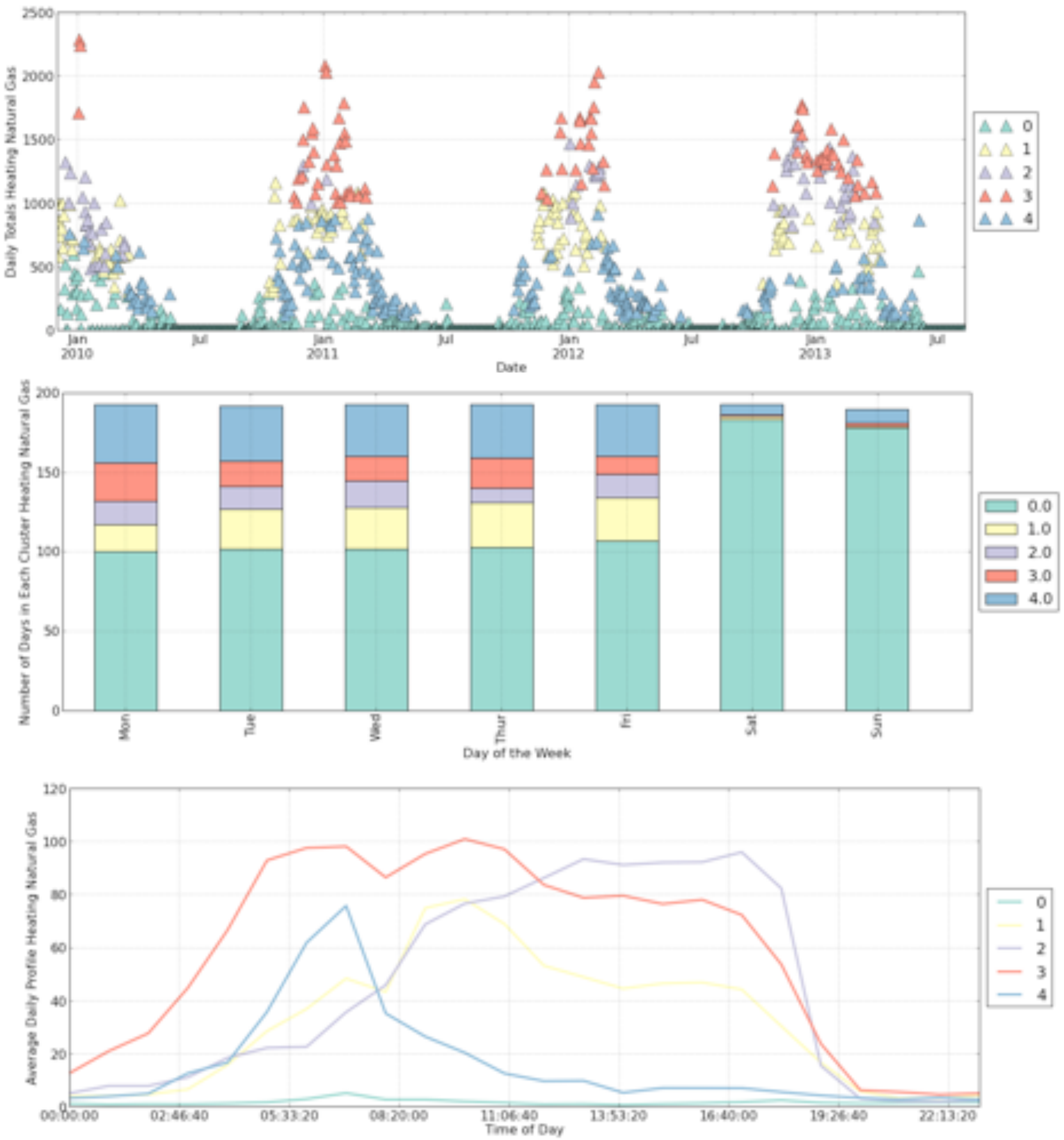


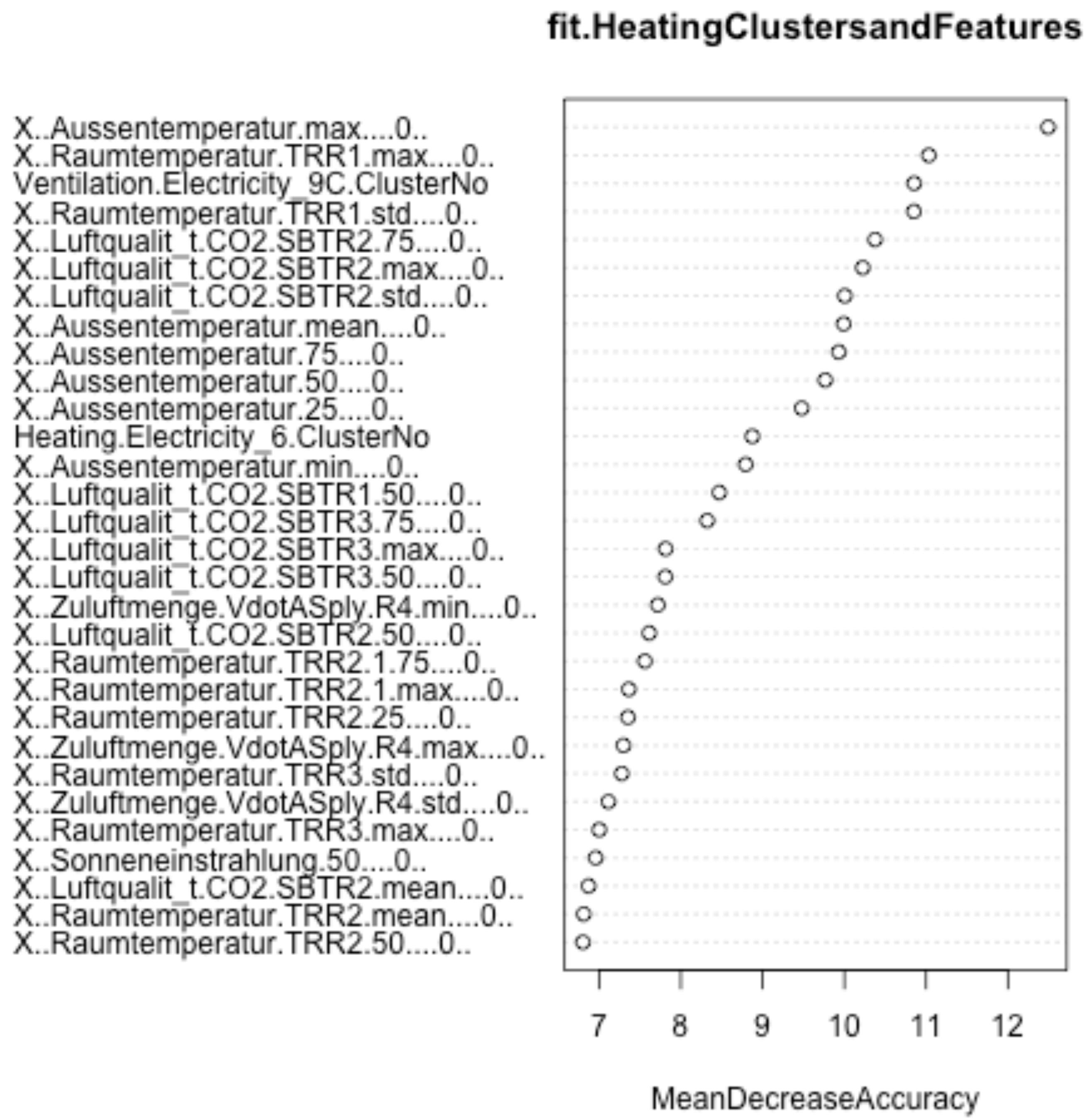






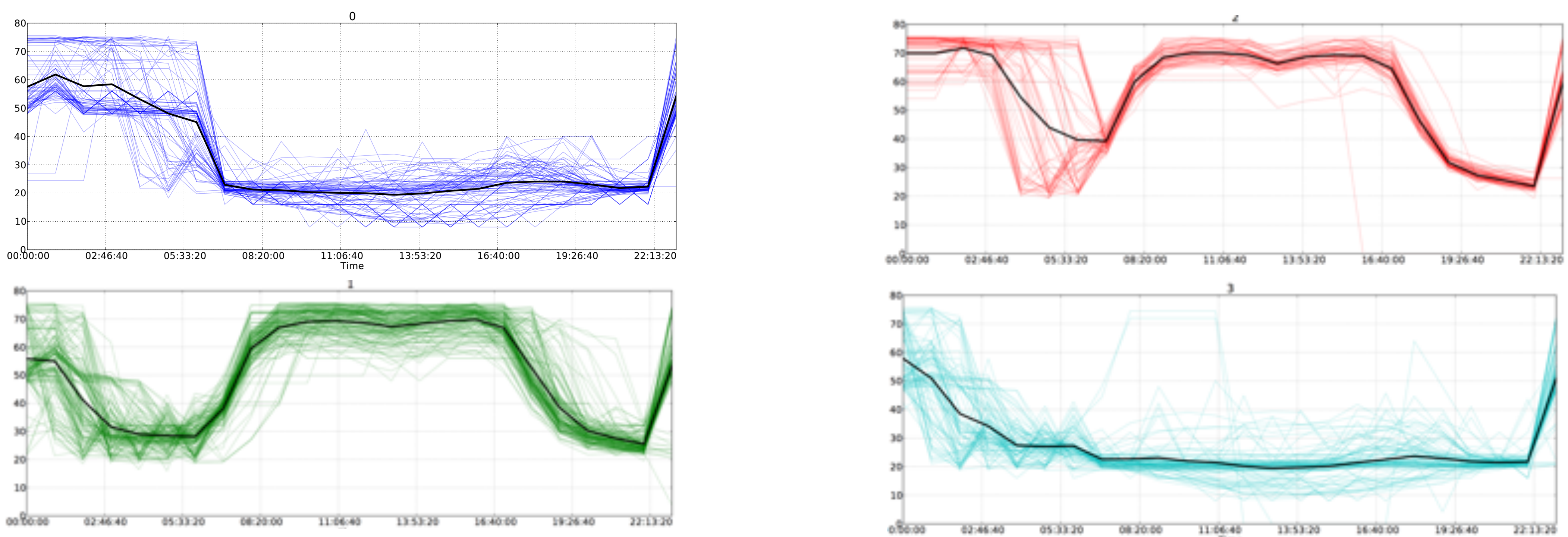
Feature Importance Estimation - Heating Meter





Characterization:

- **Automation of Outliers Detection and Abnormalities** within each cluster
- Cluster effectiveness metrics
- Visualization techniques to present clustered data



Investigation:

- Validate the variable importance estimations
- Use the results to develop rules to **detect energy issues in real-time**
- Use results to build models to predict future trends

ENERGY SAVINGS

A tested set of techniques to leverage detailed building measurement data in a **robust way**

Information dissemination in the form of research publications and a website (www.datadrivenbuilding.org)

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Questions?

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