Unified Energy System: What’s the Point?

Jon Bisila, Kiya Govek, Jack Lightbody, Zephyr Lucas, Dustin Michels, Carolyn Ryan
problem
data
database
api
dashboard
analysis
conclusion
1. What is energy analytics?
2. Why do we care?
3. Current System
4. Our Task
What is “energy analytics?”

1. What is energy analytics?
2. Why do we care?
3. Current System
4. Our Task
Ideally, equipment is...

- Functioning properly
- Active only when necessary
- Coordinating with others / taking relevant information into account
Ideally, equipment is...

- Functioning properly
- Active only when necessary
- Coordinating with others / taking relevant information into account
Ideally, equipment is...

Air side economizer
Ideally, equipment is...

Air side economizer
Ideally, equipment is...

Air side economizer
Un-ideally, equipment is...

- Malfunctioning / broken
- “Over-cycling” in search of target
- Fighting other equipment
Un-ideally, equipment is...

- Malfunctioning / broken
- “Over-cycling” in search of target
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Un-ideally, equipment is...

- Malfunctioning / broken
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http://blog.virtjoule.com/2011/10/hvac-sensor-reporting-intervals/
Un-ideally, equipment is...

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- Fighting other equipment

“Simultaneous heating and cooling”
Un-ideally, equipment is...

- Malfunctioning / broken
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“Simultaneous heating and cooling”
Un-ideally, equipment is...

- Malfunctioning / broken
- “Over-cycling” in search of target
- Fighting other equipment

“Simultaneous heating and cooling”
Energy Analytics Tools

- Benchmarking and Monthly Utility Bill Analysis
- Fault Detection and Diagnostics
- Building Automation System (BAS)
- Energy Information Systems

Energy Analytics Tools

Energy Analytics Tools

 ”Managing”

Why do we care?

1. What is energy analytics?
2. Why do we care?
3. Current System
4. Our Task
What’s the point?
What’s the point?

1. Climate Change
What’s the point?

1. Climate Change
What’s the point?

1. Climate Change
2. Finance
What’s the point?

1. Climate Change
2. Finance

$3,383,000

Spending 2017
What’s the point?

1. Climate Change
2. Finance
3. Knowledge for its own sake
What’s the point?

1. Climate Change
2. Finance
3. Knowledge for its own sake

“The unexamined building is not worth living in”
-Socrates
Carleton Already Engaged

Maintenance Staff

Sustainability Assistants (STAs)

Martha Larson
Manager of Campus Energy and Sustainability,
Carleton will remain on or ahead of a straight-line path to climate neutrality by 2050 through implementation of strategies that result in a net savings to the College over the life of the plan such as the second wind turbine, a portfolio of energy conservation strategies.
Climate Action Plan
May 2011
Climate Action Plan
May 2011

FIGURE VI.3: CARBON REDUCTION WEDGE DIAGRAM

- MTCDE
- 2010
- 2020
- 2025
- 2030
- 2040
- 2045
- 2050

- projected business as usual emissions growth
- grid footprint change
- space utilization
- green building standards
- green IT
- behavior change initiatives
- backpressure turbine
- wind turbine #2
- energy conservation
- wind turbine #1 replace + direct tie
- biogas supply for boilers
- geothermal at Rec Center
- straight-line path to climate neutrality

interim net GHG emissions targets:
17,000 MTCDE by 2020; 14,000 MTCDE by 2025; 11,000 MTCDE by 2030
Current System

1. What is energy analytics?
2. Why do we care?
3. Current System
4. Our Task
Current System

“Points”

SIEMENS

Automated Logic

United Technologies
Siemens / ALC
Siemens / ALC

✓ Offer detailed information
✓ Configurable
✓ Interface with hardware
Siemens / ALC

✓ Offer detailed information

✓ Configurable

✓ Interface with hardware
Siemens / ALC

- ✔ Offer detailed information
- ✔ Configurable
- ✔ Interface with hardware
- ✗ Difficult to use
- ✗ Limited data visualization capabilities
- ✗ Don’t offer automated analysis
Current System

“Points”

SIEMENS

AUTOMATEDLOGIC

United Technologies

lucid

Mountain View campus exceeded peak demand threshold by 10%

Night time base load electricity has increased by 55%
Current System

“Points”

SIEMENS

AUTOMATEDLOGIC
United Technologies

lucid™

Xcel ENERGY

Mountain View campus exceeded peak demand threshold by 10%

Night time base load electricity has increased by 55%
Lucid

✓ Modern user interface
✓ Slick data visualizations
✓ Scrape PDFs for utility $
Lucid

✓ Modern user interface
✓ Slick data visualizations
✓ Scrape PDFs for utility $

✗ “High-level” overview
✗ Not easy to customize
✗ Also doesn’t offer automated analysis
Current System

“Points”
Current System
Current System
Current System
Current System
Current System
Current System
Current System
Current System
Current System
Current System
Current System

Martha’s Desktop

Remote Desktop

Microsoft Visual Basic

SIEMENS

Automated Logic

Upload Server

Lucid

Xcel Energy

Web dashboard Server

API Server

Insight Server

Xcel Energy

SIEMENS

Windows 95

Microsoft

https://
Our Task

1. What is energy analytics?
2. Why do we care?
3. Current System
4. **Our Task**
Our Task

1. Unify data into integrated system
Our Task

1. Unify data into integrated system
2. Enable new forms of analysis
Our System

Data Sources
- Wind Data
- Meter Data

Importers → DB

Storing / Serving Data

API

Using Data
- Energy App
- Dashboard
- Analysis
1. The Task
2. Within Industry
3. Examples
4. Tagging
Our System

Data Sources
- Wind Data
- Meter Data

Importers

DB

API

Using Data
- Energy App
- Dashboard
- Analysis

Storing / Serving Data
Point Naming:

The Task

Within Industry

Examples

Tagging

NOURSE.FIRE

CH.FLH.E110.STP

LIV54.ORGSTPT

HU.R215.RSET

FACCLUB.ELEC

LIA3WA

WCC-AHU14.MAT
Inconsistent naming conventions are inevitable when using legacy systems and multiple BAS platforms, but this presents serious challenges and time required to integrate BAS points into any third-party platform (fault detection, scheduling, energy management, etc.)
Point Naming:

The Task
Within Industry
Examples
Tagging

ACDIN.EF4
Point Naming:

The Task
Within Industry
Examples
Tagging

ACDIN.EF4
Exhaust Fan 4
Point Naming:

The Task
Within Industry
Examples
Tagging

LDC
ACDIN.EF4
Exhaust Fan 4
Point Naming:

The Task
Within Industry
Examples
Tagging

MC02ZT
Point Naming:

The Task
Within Industry
Examples
Tagging

CMC
MC02ZT
Point Naming:

The Task
Within Industry
Examples
Tagging

CMC

MC02ZT

Calculus Room 2
Point Naming:

The Task
Within Industry
Examples
Tagging

MC02ZT

CMC

Calculus Room 2
Room Temp
Point Naming:
The Task
Within Industry
Examples
Tagging

CMC

MC02ZT

Calculus Room 2

Room Temp

???
Point Naming:

The Task
Within Industry
Examples
Tagging

EV.RM102.RT

ACDIN.CHW.RT
Point Naming:
The Task
Within Industry
Examples
Tagging

EVANS
EV.RM102.RT

ACDIN.CHW.RT
Point Naming:
The Task
Within Industry
Examples
Tagging

EVANS

EV.RM102.RT

Room 102

ACDIN.CHW.RT
Point Naming:

The Task
Within Industry
Examples
Tagging

EVANS
Room Temp

EV.RM102.RT
Room 102

ACDIN.CHW.RT
Point Naming:

The Task
Within Industry
Examples
Tagging

EVANS
Room Temp

EV.RM102.RT
Room 102
LDC

ACDIN.CHW.RT
Point Naming:
The Task
Within Industry
Examples
Tagging

EVANS
Room Temp
EV.RM102.RT
Room 102
LDC
ACDIN.CHW.RT
Chilled Water Unit
Point Naming:

The Task
Within Industry
Examples
Tagging

EVANS
Room Temp

EV.RM102.RT
Room 102

LDC
Return Temp

ACDIN.CHW.RT
Chilled Water Unit
Point Naming:

The Task
Within Industry
Examples
Tagging
Point Naming:

The Task
Within Industry
Examples
Tagging

TAG
Unique Identifier
Point Naming:

The Task
Within Industry
Examples
Tagging

TAG
Unique Identifier
ROOMTEMP
Point Naming:

The Task
Within Industry
Examples
Tagging

<table>
<thead>
<tr>
<th>TAG</th>
<th>Unique Identifier</th>
<th>Parsing Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROOMTEMP</td>
<td></td>
<td></td>
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</table>
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<td>...</td>
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<tr>
<td>Type</td>
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</tbody>
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Point Naming:

The Task
Within Industry
Examples
Tagging

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<tbody>
<tr>
<td>Unique Identifier</td>
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</tr>
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</tr>
<tr>
<td>Type</td>
<td>Measurement</td>
</tr>
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### Point Naming:

#### The Task

- Within Industry

#### Examples

#### Tagging

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</tr>
</thead>
<tbody>
<tr>
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<td>ROOMTEMP</td>
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<tr>
<td>Parsing Information</td>
<td>...</td>
</tr>
<tr>
<td>Type</td>
<td>Measurement</td>
</tr>
<tr>
<td>Is Indexed?</td>
<td></td>
</tr>
</tbody>
</table>
### Point Naming:

#### The Task
Within Industry

#### Examples
Tagging

<table>
<thead>
<tr>
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<th>Type</th>
<th>Is Indexed?</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROOMTEMP</td>
<td></td>
<td>...</td>
<td>Measurement</td>
<td>False</td>
</tr>
</tbody>
</table>
## Point Naming:

**The Task**

**Within Industry**

**Examples**

**Tagging**

<table>
<thead>
<tr>
<th>TAG</th>
<th>Unique Identifier</th>
<th>Parsing Information</th>
<th>Type</th>
<th>Is Indexed?</th>
<th>Human Readable Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ROOMTEMP</td>
<td>...</td>
<td>Measurement</td>
<td>False</td>
<td></td>
</tr>
</tbody>
</table>
**Point Naming:**

- **The Task**
- **Within Industry**
- **Examples**
- **Tagging**

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<th>Parsing Information</th>
<th>Type</th>
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<th>Human Readable Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ROOMTEMP</td>
<td>...</td>
<td>Measurement</td>
<td>False</td>
<td><strong>Measurement of the temperature of the room this point is located in.</strong></td>
</tr>
</tbody>
</table>
Point Naming:
The Task Within Industry Examples Tagging

<table>
<thead>
<tr>
<th>TAG</th>
<th></th>
</tr>
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<tr>
<td>Parsing Information</td>
<td>...</td>
</tr>
<tr>
<td>Type</td>
<td>Measurement</td>
</tr>
<tr>
<td>Is Indexed?</td>
<td>False</td>
</tr>
<tr>
<td>Human Readable Description</td>
<td>Measurement of the temperature of the room this point is located in.</td>
</tr>
<tr>
<td>Units Information</td>
<td></td>
</tr>
</tbody>
</table>
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**The Task**

**Within Industry**

**Examples**

**Tagging**

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<td>ROOMTEMP</td>
<td></td>
<td>...</td>
<td>Measurement</td>
<td>False</td>
<td>Measurement of the temperature of the room this point is located in.</td>
<td>Degrees F</td>
</tr>
<tr>
<td>Point Naming:</td>
<td>Types of Tags:</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>The Task</td>
<td></td>
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</tr>
<tr>
<td>Within Industry</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Examples</td>
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<td>Tagging</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>
Point Naming:  Types of Tags:

The Task  Building
Within Industry
Examples
Tagging
## Point Naming:

### The Task

### Within Industry

### Examples

### Tagging

## Types of Tags:

| Building | Library |
## Point Naming:

- The Task
- Within Industry
- Examples
- Tagging

## Types of Tags:

<table>
<thead>
<tr>
<th>Building</th>
<th>Library</th>
<th>LIV25.ORGSTPT</th>
</tr>
</thead>
</table>

### Point Naming:

#### The Task
Within Industry
Examples
Tagging

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<thead>
<tr>
<th>Building</th>
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<tbody>
<tr>
<td>Room</td>
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<tr>
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<th>Within Industry</th>
<th>Examples</th>
<th>Tagging</th>
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</table>

### Types of Tags:

<table>
<thead>
<tr>
<th>Type</th>
<th>Example Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building</td>
<td>Library</td>
</tr>
<tr>
<td>Room</td>
<td>Room, 300</td>
</tr>
<tr>
<td>LIV25.ORGSTPT</td>
<td></td>
</tr>
</tbody>
</table>
**Point Naming:**

- The Task
- Within Industry
- Examples
- Tagging

**Types of Tags:**

<table>
<thead>
<tr>
<th>Building</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Room</td>
<td>Room, 300</td>
<td>HU.R300.RM</td>
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## Point Naming:

The Task Within Industry Examples Tagging

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<tbody>
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<tr>
<td>Equipment</td>
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### Point Naming:

- **The Task Within Industry Examples**
- **Tagging**

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</tr>
<tr>
<td>Equipment</td>
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<td></td>
</tr>
</tbody>
</table>
### Point Naming:

**The Task Within Industry Examples Tagging**

### Types of Tags:

<table>
<thead>
<tr>
<th>Building</th>
<th>Library</th>
<th>Tag</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>LIV25.ORGSTPT</td>
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<td>WCC-AHU13.MAT</td>
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### Point Naming:

- **The Task**
- **Within Industry**
- **Examples**
- **Tagging**

### Types of Tags:

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<td>Equipment</td>
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<tr>
<td>Set Point</td>
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**The Task Within Industry Examples Tagging**

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<td></td>
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</tbody>
</table>

Note: The task of point naming involves assigning unique identifiers to various elements in a building's infrastructure, such as buildings, rooms, equipment, and set points. This ensures that each component is easily identifiable and manageable in an industry setting.
Point Naming:

The Task
Within Industry
Examples
Tagging

Types of Tags:

<table>
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<td></td>
</tr>
<tr>
<td>Set Point</td>
<td>Room Temp</td>
<td>HU.R2AA.RSET</td>
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</tr>
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# Point Naming:

## The Task Within Industry Examples Tagging

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<table>
<thead>
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<td>Room Temp</td>
<td>HU.R2AA.RSET</td>
</tr>
<tr>
<td>Measurement</td>
<td>Radiation Valve %</td>
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### Point Naming:

**The Task**

Within Industry

**Examples**

**Tagging**

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<tr>
<td>Measurement</td>
<td>Radiation Valve %</td>
<td>EV.RM211.V</td>
</tr>
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</table>
1. How we get data
2. Importers
3. Overview of structure
Our System

Data Sources
- Wind Data
- Meter Data

Importers → DB → API

Storing / Serving Data

Using Data
- Energy App
- Dashboard
- Analysis
Where We Get Data
Where We Get Data

- Siemens
- ALC
- Carleton’s Energy Server
- Martha’s Computer
- LUCID
- API Server
### Database: Importers

- CSV Dumps
- Name parsing
- Separate importers for Lucid and Siemens

<table>
<thead>
<tr>
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Database: Importers

- CSV Dumps
- Name parsing
- Separate importers for Lucid and Siemens

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### Database: Importers

- **CSV Dumps**
- **Name parsing**
- **Separate importers for Lucid and Siemens**

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- **Hulings CSV**

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Building: Evans

Room: 102

Equipment Box: Air Handling Unit

Point Type: Valve

Source: Siemens
# Database Schema

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**Database Schema**

EV.RM102.AH.V
## Database Schema

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# Database Schema

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**07/20/17 11:00:00**

75
Database Schema

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- PointID: 75

PointSources
- ID
- Name: EV.RM102.AH.V

Points
- ID
- Name: EV.RM102.AH.V
- Description
- PointSourceID
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**Database Schema**

- **PointSources**
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  - Name: Siemens

- **Points**
  - ID
  - Name: EV.RM102.AH.V
  - Description
  - PointSourceID
Database Schema

PointValues
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- PointID
- Value: 75

Points
- ID
- Name: EV.RM102.AH.V
- Description
- PointSourceID
- RoomID

Rooms
- ID
- Name
- BuildingID

PointSources
- ID
- Name: Siemens
### Database Schema

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- **Value**: 75

#### Points
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- **Name**: EV.RM102.AH.V
- **Description**
- **PointSourceID**
- **RoomID**

#### Rooms
- **ID**
- **Name**: 102
- **BuildingID**

#### PointSources
- **ID**
- **Name**: Siemens
**Database Schema**

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- **PointSources**
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- **Rooms**
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  - BuildingID

- **Buildings**
  - ID
  - Name
Database Schema

Evans
Database Schema

PointValues
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- Time: 11:00:00
- Value: 75

Points
- ID
- Name: EV.RM102.AH.V
- Description
- PointSourceID
- RoomID
- EquipmentBoxID

PointSources
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- Name: Siemens

Rooms
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- BuildingID

Buildings
- ID
- Name: Evans

EquipmentBoxes
- ID
- Name
- Description
Database Schema

Air Handling Unit
Database Schema
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- PointSourceID
- RoomID
- EquipmentBoxID
- PointTypeID

**PointSources**
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- Name: Siemens

**Rooms**
- ID
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- BuildingID

**Buildings**
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**EquipmentBoxes**
- ID
- Name: Air Handling Unit

**PointTypes**
- ID
- Name: Valve
- Description
- Units: % Open
- ReturnType: Float

**Database Schema**
- Valve
- % Open
- Float
1. Why?
2. What do we want?
3. How do we get it?
Our System

Data Sources
- Wind Data
- Meter Data

Importers → DB → API

Storing / Serving Data

Using Data
- Energy App
- Dashboard
- Analysis
Use Cases

- What are all the buildings on campus?
- What are the names of all the points in Hulings?
- What were the temperatures in Evans 204 last week?
What do we want to return?

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<td>21</td>
<td>float</td>
<td>0</td>
<td>21</td>
</tr>
<tr>
<td>2015-08-10 00:00:00</td>
<td>416</td>
<td>1</td>
<td>bool</td>
<td>416</td>
<td>True</td>
</tr>
</tbody>
</table>
1. Background
2. Comparison
3. Heatmap
4. Alerts
5. Room Explorer
Our System

Data Sources
- Wind Data
- Meter Data

Importers

DB

API

Using Data
- Energy App
- Dashboard
- Analysis

Storing / Serving Data
What is the current solution?

- Lucid does not allow for side-by-side comparisons, nor custom date selections.
What is the current solution?

- Lucid does not allow for side-by-side comparisons, nor custom date selections.
- ALC and Siemens do not have any effective built-in options for data visualization or analysis.
What is the current solution?

- Lucid does not allow for side-by-side comparisons, nor custom date selections.
- ALC and Siemens do not have any effective built-in options for data visualization or analysis.
- No easy solution exists for comparing data from different sources. Facilities instead has to collate the data manually.
How can we improve this?

Provide proof-of-concept solutions for the common problems:

- Side-by-side comparisons
How can we improve this?

Provide proof-of-concept solutions for the common problems:

- Side-by-side comparisons
- Improvements on the heatmap tool
How can we improve this?

Provide proof-of-concept solutions for the common problems:

- Side-by-side comparisons
- Improvements on the heatmap tool
- Rudimentary anomaly detection
Dashboard: Comparisons

- Custom point selectors
Dashboard: Comparisons

- Custom point selectors
- Custom time ranges
Dashboard: Comparisons

- Custom point selectors
- Custom time ranges
- Side-by-side comparisons
Side-by-side comparison: Hulings Room Temperature

Building: Hulings

Point name: HLJ.R213B.RMT- 213B TEMP

From: 2016-08-18 To: 2017-08-30

Building: Hulings

Point name: HLJ.R212.RMT- 212 TEMP

From: 2016-08-18 To: 2017-08-30
Dashboard: Heatmap

Features we wanted:

- Custom date and point selection
- Different presets for the colors
- Ability to hover over text and see values for a given point
Lucid Heatmap

Cell color represents usage intensity, each row represents one day.

37 kW
4pm, Tue Aug 29
4 HDD / 2 CDD
Our Heatmap

Weekend!
Our Heatmap

Start of work day (6 am)

End of work day (5 pm)
Dashboard: Alerts

Very basic metric for anomalies: flag points that are three standard deviations away from the mean of all values over the selected time frame.

Useful as a "proof-of-concept" in case we didn't get to other, fancier analysis for the dashboard.
Alerts Page: Nourse Electricity Consumption

Building: Nourse Hall
Point name: Nourse Hall - Electricity

From: 08/18/2017   To: 08/30/2017

Point Name: Nourse Hall – Electricity
Average: 44.28
Standard Deviation: 7.91

<table>
<thead>
<tr>
<th>Date/Time</th>
<th>Value (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2017-08-24 21:00:00</td>
<td>72.50</td>
</tr>
<tr>
<td>2017-08-29 15:00:00</td>
<td>17.75</td>
</tr>
</tbody>
</table>
Alerts Page: Nourse Electricity Consumption

Building: Nourse Hall
Point name:
Nourse Hall - Electricity - Electricity (kWh)
From: 08/18/2017 To: 08/30/2017

Point Name: Nourse Hall - Electricity
Average: 44.28
Standard Deviation: 7.91

<table>
<thead>
<tr>
<th>Date/Time</th>
<th>Value (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2017-08-24 21:00:00</td>
<td>72.50</td>
</tr>
<tr>
<td>2017-08-29 15:00:00</td>
<td>17.75</td>
</tr>
</tbody>
</table>
Dashboard: Room Inspection

Facilities' Experiment: How far can we push our current radiators?
Dashboard: Room Inspection

Facilities' Experiment: How far can we push our current radiators?

Our Solution: Build a tool that can display the room temperature and the radiator valve percentage for each room in a building and detect "anomalous points".
Proof-of-Concept: Room Inspection

- Displays the room temperature and radiator valve percentage
Proof-of-Concept: Room Inspection

- Displays the room temperature and radiator valve percentage
- permits viewing a "snapshot" of room temperature and valve percentage points for a building.
Proof-of-Concept: Room Inspection

- Displays the room temperature and radiator valve percentage
- Permits viewing a "snapshot" of room temperature and valve percentage points for a building.
- Optional Detect Anomalies feature
Proof-of-Concept: Room Inspection

- Performs k-means clustering to detect points that appear anomalous
Proof-of-Concept: Room Inspection

- Performs k-means clustering to detect points that appear anomalous
- Colors the cells to provide an indicator of which points appear as anomalous for that day
### Dashboard: Room Inspection

#### Evans Hall, Room: 003

<table>
<thead>
<tr>
<th>Room</th>
<th>Room Temp (deg F)</th>
<th>Valve Percent (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>003</td>
<td>67.85</td>
<td>0.0</td>
</tr>
<tr>
<td>102</td>
<td>68.1</td>
<td>100.0</td>
</tr>
<tr>
<td>106</td>
<td>61.58</td>
<td>19.86</td>
</tr>
<tr>
<td>107</td>
<td>70.58</td>
<td>40.01</td>
</tr>
<tr>
<td>108</td>
<td>66.05</td>
<td>100.0</td>
</tr>
<tr>
<td>109</td>
<td>69.18</td>
<td>40.43</td>
</tr>
</tbody>
</table>
1. Our data
2. Decision Trees
3. Association Rules
4. Anomaly Detection
Our System

Data Sources
- Wind Data
- Meter Data

Importers → DB → API

Storing / Serving Data

Using Data
- Energy App
- Dashboard
- Analysis
### What data do we have to work with?

<table>
<thead>
<tr>
<th>Date/Time</th>
<th>EV.RM203.RT</th>
<th>ACDIN.EF1</th>
<th>Evans Hall - Electricity</th>
<th>BI1DSP</th>
</tr>
</thead>
<tbody>
<tr>
<td>2017-12-20 00:00:00</td>
<td>67.2</td>
<td>ON</td>
<td>71.41</td>
<td>1.5</td>
</tr>
<tr>
<td>2017-12-20 01:00:00</td>
<td>67.4</td>
<td>OFF</td>
<td>50.92</td>
<td>1.49</td>
</tr>
<tr>
<td>2017-12-20 02:00:00</td>
<td>68.1</td>
<td>OFF</td>
<td>&lt;null&gt;</td>
<td>1.5</td>
</tr>
</tbody>
</table>
What data do we have to work with?

<table>
<thead>
<tr>
<th>Date/Time</th>
<th>EV.RM203.RT</th>
<th>ACDIN.EF1</th>
<th>Evans Hall - Electricity</th>
<th>BI1DSP</th>
</tr>
</thead>
<tbody>
<tr>
<td>2017-12-20 00:00:00</td>
<td>67.2</td>
<td>ON</td>
<td>71.41</td>
<td>1.5</td>
</tr>
<tr>
<td>2017-12-20 01:00:00</td>
<td>67.4</td>
<td>OFF</td>
<td>50.92</td>
<td>1.49</td>
</tr>
<tr>
<td>2017-12-20 02:00:00</td>
<td>68.1</td>
<td>OFF</td>
<td>&lt;null&gt;</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Most points are continuous, some points are categorical, and some points are missing data. We have no idea what this point means.
What could we use to analyze this data?

- Unsupervised
- Data-driven
- Not too complex
Decision Trees

Goal: Identify points of interest based on their placement in a decision tree
How do we have to change the data?

<table>
<thead>
<tr>
<th>Date/Time</th>
<th>EV.RM203.RT</th>
<th>ACDIN.EF1</th>
<th>Evans Hall - Electricity</th>
<th>BI1DSP</th>
</tr>
</thead>
<tbody>
<tr>
<td>2017-12-20 00:00:00</td>
<td>67.2</td>
<td>ON</td>
<td>≥ 60 (high)</td>
<td>1.5</td>
</tr>
<tr>
<td>2017-12-20 01:00:00</td>
<td>67.4</td>
<td>OFF</td>
<td>&lt; 60 (low)</td>
<td>1.49</td>
</tr>
<tr>
<td>2017-12-20 02:00:00</td>
<td>68.1</td>
<td>OFF</td>
<td>&lt;null&gt;</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Bin our class variable

Remove rows with null values

Ignore categorical variables
Decision Tree

**Node 1:**
- **Decision:** $\text{BI1HRT} \leq 70.93$
- **Entropy:** 0.992
- **Samples:** 94
- **Value:** [42, 52]
- **Class:** (35, 50)

**Branches:**
- **True Branch:**
  - **Decision:** $\text{HU.R1AG.SCFM} \leq 404.635$
  - **Entropy:** 0.592
  - **Samples:** 42
  - **Value:** [36, 6]
  - **Class:** (0, 35)

- **False Branch:**
  - **Decision:** $\text{HU.R112.RMT} \leq 69.81$
  - **Entropy:** 0.516
  - **Samples:** 52
  - **Value:** [6, 46]
  - **Class:** (35, 50)

**Outcomes:**
- **Low Energy**
- **High Energy**
“Hulings typically uses more energy when this temperature is higher than 70 °F”*
“Hulings typically uses more energy when this temperature is higher than 70 °F”*

*On a specific day in August
“Hulings typically uses more energy when this temperature is higher than 70 °F”*

*On a specific day in August

*Which probably just means it’s hot outside
Cool problem: Boliou

Load Profile Analysis

- Night using more energy
- Day using less energy
<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>BO.1.COMM</th>
<th>BO.1.COMM</th>
<th>BO.1.COMM</th>
<th>BO.1.COMM</th>
<th>BO.1.COMM</th>
<th>BO.1.COMM</th>
<th>BO.1.COMM</th>
<th>BO.1.COMM</th>
<th>BO.1.COMM</th>
</tr>
</thead>
<tbody>
<tr>
<td>6/1/16</td>
<td>0:00:00</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
</tr>
<tr>
<td>6/1/16</td>
<td>0:15:00</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
</tr>
<tr>
<td>6/1/16</td>
<td>0:30:00</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
</tr>
<tr>
<td>6/1/16</td>
<td>0:45:00</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
</tr>
<tr>
<td>6/1/16</td>
<td>1:00:00</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
</tr>
<tr>
<td>6/1/16</td>
<td>1:15:00</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
</tr>
<tr>
<td>6/1/16</td>
<td>1:30:00</td>
<td>No Data</td>
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<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
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<td>No Data</td>
</tr>
<tr>
<td>6/1/16</td>
<td>1:45:00</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
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<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
</tr>
<tr>
<td>6/1/16</td>
<td>2:00:00</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
</tr>
<tr>
<td>6/1/16</td>
<td>2:15:00</td>
<td>No Data</td>
<td>No Data</td>
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<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
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</tr>
<tr>
<td>6/1/16</td>
<td>2:30:00</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
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<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
</tr>
<tr>
<td>6/1/16</td>
<td>2:45:00</td>
<td>No Data</td>
<td>No Data</td>
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<td>No Data</td>
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<td>No Data</td>
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</tr>
<tr>
<td>6/1/16</td>
<td>3:00:00</td>
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<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
</tr>
<tr>
<td>6/1/16</td>
<td>3:15:00</td>
<td>No Data</td>
<td>No Data</td>
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<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
</tr>
<tr>
<td>6/1/16</td>
<td>3:30:00</td>
<td>No Data</td>
<td>No Data</td>
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<td>6/1/16</td>
<td>3:45:00</td>
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<td>No Data</td>
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</tr>
<tr>
<td>6/1/16</td>
<td>4:00:00</td>
<td>No Data</td>
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<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
</tr>
<tr>
<td>6/1/16</td>
<td>4:15:00</td>
<td>No Data</td>
<td>No Data</td>
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<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
</tr>
<tr>
<td>6/1/16</td>
<td>4:30:00</td>
<td>No Data</td>
<td>No Data</td>
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<td>No Data</td>
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<td>No Data</td>
</tr>
<tr>
<td>6/1/16</td>
<td>4:45:00</td>
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<td>No Data</td>
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<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
</tr>
</tbody>
</table>
Association Rules

**Goal:** Identify links between points and points of interest

**Data requirements:** Boolean if data value is present or not
Association Rules

Goal: Identify links between points and points of interest

Data requirements: Boolean if data value is present or not
How do we have to change the data?

One hot encoding:

<table>
<thead>
<tr>
<th></th>
<th>EV.RM203.RT</th>
<th>ACDIN.EF1</th>
<th>Evans Hall - Electricity</th>
</tr>
</thead>
<tbody>
<tr>
<td>2017-12-20 00:00:00</td>
<td>71</td>
<td>ON</td>
<td>65</td>
</tr>
<tr>
<td>2017-12-20 01:00:00</td>
<td>68</td>
<td>OFF</td>
<td>55</td>
</tr>
</tbody>
</table>
How do we have to change the data?

One hot encoding:

<table>
<thead>
<tr>
<th>Date</th>
<th>EV.RM203.RT</th>
<th>ACDIN.EF1</th>
<th>Evans Hall - Electricity</th>
</tr>
</thead>
<tbody>
<tr>
<td>2017-12-20 00:00:00</td>
<td>&gt;= 70</td>
<td>ON</td>
<td>65</td>
</tr>
<tr>
<td>2017-12-20 01:00:00</td>
<td>&lt;70</td>
<td>OFF</td>
<td>55</td>
</tr>
</tbody>
</table>
How do we have to change the data?

<table>
<thead>
<tr>
<th>Date</th>
<th>EV.RM203.RT &lt; 70</th>
<th>EV.RM203.RT &gt;= 70</th>
<th>ACDIN.EF1</th>
<th>Evans Hall - Electricity</th>
</tr>
</thead>
<tbody>
<tr>
<td>2017-12-20 00:00:00</td>
<td>FALSE</td>
<td>TRUE</td>
<td>ON</td>
<td>65</td>
</tr>
<tr>
<td>2017-12-20 01:00:00</td>
<td>TRUE</td>
<td>FALSE</td>
<td>OFF</td>
<td>55</td>
</tr>
</tbody>
</table>
How do we have to change the data?

<table>
<thead>
<tr>
<th>Date/Time</th>
<th>EV.RM203.RT &lt; 70</th>
<th>EV.RM203.RT &gt;= 70</th>
<th>ACDIN.EF1</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>2017-12-20 00:00:00</td>
<td>FALSE</td>
<td>TRUE</td>
<td>ON</td>
<td>Evans Hall - Electricity</td>
</tr>
<tr>
<td>2017-12-20 01:00:00</td>
<td>TRUE</td>
<td>FALSE</td>
<td>OFF</td>
<td>55</td>
</tr>
</tbody>
</table>
How do we have to change the data?

<table>
<thead>
<tr>
<th>Date</th>
<th>EV.RM203.RT &lt; 70</th>
<th>EV.RM203.RT &gt;= 70</th>
<th>ACDIN.EF1 = ON</th>
<th>ACDIN.EF1 = OFF</th>
<th>Evans Hall - Electricity</th>
</tr>
</thead>
<tbody>
<tr>
<td>2017-12-20 00:00:00</td>
<td>FALSE</td>
<td>TRUE</td>
<td>TRUE</td>
<td>FALSE</td>
<td>65</td>
</tr>
<tr>
<td>2017-12-20 01:00:00</td>
<td>TRUE</td>
<td>FALSE</td>
<td>FALSE</td>
<td>TRUE</td>
<td>55</td>
</tr>
</tbody>
</table>
How do we have to change the data?

<table>
<thead>
<tr>
<th>Date</th>
<th>EV.RM203. RT &lt; 70</th>
<th>EV.RM203. RT &gt;= 70</th>
<th>ACDIN.EF 1 = ON</th>
<th>ACDIN.EF 1 = OFF</th>
<th>Evans Hall - Electricity ≥ 50</th>
<th>Evans Hall - Electricity &lt; 50</th>
</tr>
</thead>
<tbody>
<tr>
<td>2017-12-20</td>
<td>FALSE</td>
<td>TRUE</td>
<td>TRUE</td>
<td>FALSE</td>
<td>TRUE</td>
<td>FALSE</td>
</tr>
<tr>
<td>00:00:00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2017-12-20</td>
<td>TRUE</td>
<td>FALSE</td>
<td>FALSE</td>
<td>TRUE</td>
<td>TRUE</td>
<td>FALSE</td>
</tr>
<tr>
<td>01:00:00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Association Rules

Evans Unit 4
Heat Coil Valve
< 49.26

Evans Unit 5
Heat Coil Valve
< 49.26
Association Rules Software

Number of rules: 100,000
Filtered rules: 40,000
Selected rules: 0
Selected examples: 0

Find association rules
Minimal support: 3%
Minimal confidence: 4%
Max. number of rules: 100,000
Induce classification (itemset → class) rules

Filter rules
Antecedent
Contains:
Min. items: 1 Max. items: 999

Consequent
Contains:
Min. items: 1 Max. items: 999

Find Rules
Association Rules Software

Number of rules: 10000
Selected rules: 1
Covered examples: 27

Rules:

<table>
<thead>
<tr>
<th>Supp</th>
<th>Conf</th>
<th>Covr</th>
<th>Stgr</th>
<th>Lift</th>
<th>Leve</th>
<th>Antecedent</th>
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<td>1.167</td>
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<td>0.766</td>
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+ 502 more
Association Rules Software

Number of rules: 10000
Selected rules: 1
Covered examples: 27

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<th>Stug</th>
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HU.R1AH.OSUP=0.0 → BIE25C=2.0, HU.R1AG.OSUP=
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H.U.R1AH.OSUP=0.0 → BIE25C=2.0, H.U.R1AG.OSUP=
BIE25C=2.0, H.U.R1AH.OSUP=0.0 → H.U.R112.SACFM=
BIE25C=2.0, H.U.R1AH.OSUP=0.0 → H.U.R112.SACFM=
BIE25C=2.0, H.U.R1AH.OSUP=0.0 → H.U.R112.SACFM=0.0

+ 502 more
Association Rules Software
Decision Trees
Association Rules
Anomaly Detection
Anomaly Detection via Clustering

**Goal:** Identify points that aren’t behaving as expected

<table>
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<tr>
<th>Time</th>
<th>EV.RM101.RT</th>
<th>EV.RM102.RT</th>
<th>EV.RM103.RT</th>
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<td>68.5</td>
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<td>32.4</td>
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</table>
Anomaly Detection via Clustering

**Goal:** Identify points that aren’t behaving as expected

**Data Requirements:** Continuous data for multiple similar points, or multiple days for the same point

<table>
<thead>
<tr>
<th></th>
<th>EV.RM101.RT</th>
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<tr>
<td><strong>2017-12-20 01:00:00</strong></td>
<td>68.4</td>
<td>70.0</td>
<td>32.4</td>
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</tbody>
</table>

Too cold? Too hot?
Anomaly Detection via Clustering

**Goal:** Identify points that aren’t behaving as expected

**Data Requirements:** Continuous data for multiple similar points, or multiple days for the same point

**Method:**
1. Perform k-means clustering
2. Pick out anomalies as points that are far from their cluster center
Anomaly Detection

Room Temp in Evans on 1/5: Cluster 3

Time of day

Room temperature
Anomaly Detection

Room Temp in Evans on 1/5: Cluster 1

- Time of day
- Room temperature

Graph shows temperature trends over the day with a notable anomaly.
Anomaly Detection

Room Temp in Evans on 1/5: Cluster 2

- Time of day
- Room temperature
<table>
<thead>
<tr>
<th>Room</th>
<th>Room Temp (deg F)</th>
<th>Valve Percent (%)</th>
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1. Challenges
2. Future
3. THX
Overall challenges

- Difficulty with data
- Inexperience with field
- Design challenges
Future possibilities

- Parsing more points
- More tools for the dashboard
- Try more analysis algorithms
Live data?
Thank you to:

- Jeff Ondich
- Martha Larson, Mitch Miller, Jeff Mason
- Mike Tie, Dave Flynn
- CS Faculty and peers
- Our friends and family
Questions?