Thank You!

• NEEP Technical Committee
  – Elizabeth Titus
  – Danielle Wilson
  – Dave Jacobson
  – Steve Waite

• Sponsors
Agenda

- Study Objectives
- Technology Review
- Methods
- Results (Unit, Loadshapes, Aggregate)
- Key Lessons/Recommendations
Study Objectives

- Produce 8,760 savings loadshapes
- Determine annual kWh and kW savings
- Suggest TRM updates

Evaporator Fan Motor Retrofit
Evaporator Fan Motor Control
Door Heater Control
Evaporator Fan Motor Retrofit
Evaporator Fan Motor Retrofit

SP motor

EC motor

Fan Watts

8/9  8/29  9/18  10/8  10/28  11/17
Evaporator Fan Motor Controls

Motor controller
Evaporator Fan Motor Controls

Variable/Multi-Speed

On/Off

Fan Watts

High speed

Low speed

0 50 100 150 200
12:00 12:15 12:30 12:45 13:00

Fans ON

Fans OFF

0 50 100 150 200
12:00 12:15 12:30 12:45 13:00
Door Heater Controls

Heater control

Door moisture sensor
Door Heater Controls

Micropulsing

On/Off
Primary Data Collection

<table>
<thead>
<tr>
<th>State</th>
<th>Pre-retrofit August</th>
<th>Pre-retrofit September</th>
<th>Pre-retrofit October</th>
<th>Pre-retrofit November</th>
<th>Post-retrofit October</th>
<th>Post-retrofit November</th>
</tr>
</thead>
<tbody>
<tr>
<td>Massachusetts (11)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maryland (12)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>New York (13)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rhode Island (4)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Subcontractor Count

<table>
<thead>
<tr>
<th>Subcontractor</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>NRM</td>
<td>18</td>
</tr>
<tr>
<td>GEE</td>
<td>11</td>
</tr>
<tr>
<td>Anthony International</td>
<td>2</td>
</tr>
<tr>
<td>Johnson Controls</td>
<td>6</td>
</tr>
<tr>
<td>Unknown</td>
<td>1</td>
</tr>
<tr>
<td>Willdan</td>
<td>2</td>
</tr>
</tbody>
</table>

Building Type Count

<table>
<thead>
<tr>
<th>Building Type</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small Retail</td>
<td>35</td>
</tr>
<tr>
<td>Restaurant</td>
<td>3</td>
</tr>
<tr>
<td>Other</td>
<td>1</td>
</tr>
<tr>
<td>Large Retail</td>
<td>1</td>
</tr>
</tbody>
</table>
Final Sample – Evaporator Fan Motors

**EC Motor Retrofit Power Measurements**

- Number of Sites: 48
- Unique Measurements: 92
  - SP Measurements: 23
  - PSC Measurements: 2
  - ECM Measurements: 67

**Motor Controller Runtime Measurements**

- Number of Sites: 35
- Unique Measurements: 57
  - Pre Runtime Measurements: 25
  - Post Runtime Measurements: 32
    - On/Off Controller Measurements: 17
    - Variable Speed Measurements: 15

On/Off Controllers: MA, RI, MD
Variable Speed Controllers: NY, MD
Final Sample – Door Heater Controls

ASDH Runtime Measurements

Number of Sites: 22
Unique Measurements: 29

Pre Runtime Measurements: 10
Post Runtime Measurements: 19

On/Off Controllers: NY, MD
Micropulse Controllers: MA, RI, MD
Unknown Controllers: 7
Method

1. Data Collection
   - Unit Data (Primary)
   - Unit Data (Secondary)

2. Data Analysis
   - Unit Parameters and Profiles

3. Average Parameters & Profiles
4. Equipment Savings Loadshapes
5. Interactive Refrigeration Impacts
6. Total Savings Loadshapes

- TRM inputs
- Equipment savings metrics
- Total savings metrics
Aggregation

3. Combine unit data to calculate average parameters and profiles (all units are evenly weighted)

4. Combine average parameters and profiles to calculate hourly savings loadshapes
Any questions before we jump into results?
Results

• Sumary
• For each technology:
  – Unit Level Results
    • Performance
    • Key findings
  – Aggregate Results
    • Compare to current TRM estimates
    • Final savings estimates
  – Discussion
Summary of Results

- All three measures provide reliable energy and demand savings
- Easy to install and unobtrusive
- Appropriate for large and small commercial refrigeration
Evaporator Fan Motor Retrofit
Evaporator Fan Motor Retrofit

Formula

$$\Delta W_{ECM} = \left( \frac{W_{PRE} - W_{POST}}{W_{POST}} \right) \times \left( \frac{W}{hp} \right)_{ECM} \times hp_{ECM}$$

Constant = 1,192 W/hp

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Source</th>
<th>Meter Sample (Circuits)</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\frac{W_{PRE} - W_{POST}}{W_{POST}}$</td>
<td>% change in power relative to post wattage</td>
<td>Pre/post metering only</td>
<td>9 primary 0 secondary</td>
<td>1.57</td>
</tr>
<tr>
<td>$(\frac{W}{hp})_{ECM}$</td>
<td>Post power normalized by horsepower</td>
<td>Pre/post and post-only metering</td>
<td>42 primary 24 secondary</td>
<td>759 W/hp</td>
</tr>
</tbody>
</table>
Evaporator Fan Motor Motor Power Retrofit

Number of Motors Metered

- 1/62
- 1/50
- 1/20
- 1/15
- 1/12
- 1/5
- 1/4

Measured Motor Power

- Average Motor hp = 1/12

* Motors rated below 1/50-hp are reported in Watts; value is equivalent hp.
Evaporator Fan Motor Retrofit
Power Reduction

Site #. Measure ID: Building Type

- Pre
- Post
- Percent Reduction
Evaporator Fan Motor Retrofit

Motor Power – TRM Comparison

<table>
<thead>
<tr>
<th>EC Motor Wattage (Watts/motor)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
<tr>
<td>NEEP CRL: based on average ECM size</td>
</tr>
<tr>
<td>VT TRM: average, walk-in</td>
</tr>
<tr>
<td>VT TRM: average, case</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Baseline Motor Wattage (Watts/motor)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
<tr>
<td>NEEP CRL: avg pre kW from pre/post</td>
</tr>
<tr>
<td>NEEP CRL: avg metered SP</td>
</tr>
<tr>
<td>VT TRM: average SP, walk-in</td>
</tr>
<tr>
<td>VT TRM: average SP, case</td>
</tr>
<tr>
<td>VT TRM: average SP</td>
</tr>
<tr>
<td>VT TRM: average PSC</td>
</tr>
<tr>
<td>VT TRM: weighted average SP, PSC</td>
</tr>
</tbody>
</table>

Note: Not all TRMs use each parameter; in some cases, we use TRM information to calculate parameters for comparison
## Evaporator Fan Motor Retrofit

### Power Reduction – TRM Comparison

<table>
<thead>
<tr>
<th>Parameter Description</th>
<th>Load Reduction Factor (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NEEP CRL: baseline SP (equivalent LRF)</td>
<td>61%</td>
</tr>
<tr>
<td>MA, RI, NY: walk-in</td>
<td>65%</td>
</tr>
<tr>
<td>MA, RI, NY: case, baseline SP</td>
<td>53%</td>
</tr>
<tr>
<td>CT: baseline SP</td>
<td>65%</td>
</tr>
<tr>
<td>VT: walk-in, baseline SP</td>
<td>70%</td>
</tr>
<tr>
<td>VT: case, baseline SP</td>
<td>73%</td>
</tr>
<tr>
<td>MA, RI, NY: case, baseline PSC</td>
<td>29%</td>
</tr>
<tr>
<td>CT: baseline PSC</td>
<td>40%</td>
</tr>
</tbody>
</table>

Note: Not all TRMs use each parameter; in some cases, we use TRM information to calculate parameters for comparison.
Evaporator Fan Motor Retrofit Aggregation Decisions

• One site where retrofit took place, but not part of utility program
  – Included in analysis

• Two sites where PSC as baseline
  – Removed from analysis
Evaporator Fan Motor Retrofit
Equipment Savings Loadshape

SP to EC Motor Retrofit Savings
Evaporator Fan Motor Motor Retrofit

Equipment Savings Metrics

Annual Energy Savings

Peak Demand Savings
(at hp = 1/12)

*Error bars indicate relative precision at 90% confidence interval

<table>
<thead>
<tr>
<th>Measure</th>
<th>Annual Total Energy Savings</th>
<th>ISO-NE Peak Demand Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RP @ 90%</td>
<td>RP @ 80%</td>
</tr>
<tr>
<td>EC Motor Retrofit</td>
<td>5.3%</td>
<td>4.1%</td>
</tr>
</tbody>
</table>

Savings at average motor hp (1/12): 857 kWh/motor

Savings at most frequent motor hp (1/15): 685 kWh/motor

[CADMUS]
Evaporator Fan Motor Control
Evaporator Fan Motor Control

Formula

\[
\Delta W_{motor\ ECM} = \left( \frac{W}{hp} \right)_{ECM} \times (\%ON\ PRE - \%ON\ POST) \times hp_{ECM}
\]

\[
\Delta W_{motor\ SP} = \left( \frac{W}{hp} \right)_{SP} \times (\%ON\ PRE - \%ON\ POST) \times hp_{SP}
\]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Source</th>
<th>Meter Sample (Circuits)</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \left( \frac{W}{hp} \right)_{ECM} )</td>
<td>Post-retrofit power normalized by hp</td>
<td>Post and Pre/Post</td>
<td>42 primary 24 secondary</td>
<td>759 W/hp</td>
</tr>
<tr>
<td>( \left( \frac{W}{hp} \right)_{SP} )</td>
<td>Pre-retrofit power normalized by hp</td>
<td>Pre and Pre/Post</td>
<td>13 primary 5 secondary</td>
<td>2,088 W/hp</td>
</tr>
</tbody>
</table>
Evaporator Fan Motor Control

%Runtime

On/Off

Site #: Measure ID: Building Type

Variable Speed

Average = 66%

Controlled Runtime

Average
## Evaporator Fan Motor Control
### %Runtime – TRM Comparison

<table>
<thead>
<tr>
<th>TRM Type</th>
<th>%Runtime w/Controls (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NEEP CRL: average</td>
<td>66%</td>
</tr>
<tr>
<td>MA, RI: walk-in</td>
<td>46%</td>
</tr>
<tr>
<td>NY: walk-in</td>
<td>64%</td>
</tr>
<tr>
<td>CT: general</td>
<td>65%</td>
</tr>
<tr>
<td>CT: on/off controls</td>
<td>66%</td>
</tr>
<tr>
<td>CT: 2-speed controls</td>
<td>57%</td>
</tr>
<tr>
<td>VT: cooler</td>
<td>50%</td>
</tr>
<tr>
<td>VT: freezer</td>
<td>50%</td>
</tr>
</tbody>
</table>

**Note:** Not all TRMs use each parameter; in some cases, we use TRM information to calculate parameters for comparison.
Evaporator Fan Motor Control

Aggregation Decisions

• One site had SP motor with controls as baseline
  – Used wattage on uncontrolled motor as baseline
• One site installed controls on SP motor as part of program
  – Used runtime as post-retrofit condition
• Two sites where controls were disconnected
  – Included in analysis
• One site where technician advised against installing controls – were never installed
  – Used pre data only
Evaporator Fan Motor Control

Equipment Savings Loadshape

SP Motor On/Off Controls

EC Motor On/Off Controls

Savings (W/hp)

Day

Sunday Monday Tuesday Wednesday Thursday Friday Saturday

SP All SP Variable Speed SP On/Off EC All EC Variable Speed EC On/Off
Evaporator Fan Motor Control

Equipment Savings Metrics

Annual Energy Savings
(at hp = 1/12)

<table>
<thead>
<tr>
<th>Control Type</th>
<th>Annual Total Energy Savings</th>
<th>ISO-NE Peak Demand Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Annual Total Energy Savings</td>
<td>ISO-NE Peak Demand Savings</td>
</tr>
<tr>
<td></td>
<td>RP @ 90%</td>
<td>RP @ 80%</td>
</tr>
<tr>
<td>All SP</td>
<td>5.6%</td>
<td>4.4%</td>
</tr>
</tbody>
</table>

*Error bars indicate relative precision at 90% confidence interval

Peak Demand Savings
(at hp = 1/12)

<table>
<thead>
<tr>
<th>Control Type</th>
<th>ISO-NE Peak Summer Demand Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RP @ 90%</td>
</tr>
<tr>
<td>All SP</td>
<td>6.4%</td>
</tr>
</tbody>
</table>

*Error bars indicate relative precision at 90% confidence interval
Door Heater Control
Door Heater Controls

Formula

\[ \Delta W = \frac{\text{Watt}}{\text{door}_{\text{BASE}}} \times (\%ON_{\text{PRE}} - \%ON_{\text{POST}}) \times N_{\text{doors}} \]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Source</th>
<th>Meter Sample (Circuits)</th>
<th>Average Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>\frac{\text{Watt}}{\text{door}_{\text{BASE}}}</td>
<td>Operating power per door</td>
<td>Pre, Post, and Pre/Post</td>
<td>21 primary 6 secondary</td>
<td>130 Watts/door</td>
</tr>
</tbody>
</table>
Door Heater Controls

Door Heater Power (W/door)

Average Full Operating Power of All Control Types
130 W/door

*Indicates secondary data
Door Heater Controls

Door Heater Power – TRM Comparison

<table>
<thead>
<tr>
<th></th>
<th>Door Heater Power (W/door)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NEEP CRL: average</td>
<td>130</td>
</tr>
<tr>
<td>VT: cooler</td>
<td>131</td>
</tr>
<tr>
<td>VT: freezer</td>
<td>245</td>
</tr>
</tbody>
</table>

Note: Not all TRMs use each parameter; in some cases, we use TRM information to calculate parameters for comparison.
Door Heater Controls

%Runtime

- Power (W)
- Percent Reduction (%)
- Micropulse
- On/Off
- Unknown

*Indicates secondary data
Door Heater Controls

%Runtime – TRM Comparison

Note: Not all TRMs use each parameter; in some cases, we use TRM information to calculate parameters for comparison.
Door Heater Controls

Aggregation Decisions

• One site did not use a door heater in the baseline case.
  – Used data from post-installation case only

• At one site, store manager manually turned off heaters at night in pre and post case.
  – Included in analysis

• Three sites showed no savings
  – Dropped from the loadshape calculations
Door Heater Controls

Equipment Savings Loadshapes

![Graph showing power savings by control type over a week.]

- **Unknown Controls**
- **Micropulse Controls**
- **All Controls**
- **On/Off Controls**

Day:
- Sunday
- Monday
- Tuesday
- Wednesday
- Thursday
- Friday
- Saturday

Power Savings (W)
Door Heater Control

Equipment Savings Metrics

### Annual Energy Savings

<table>
<thead>
<tr>
<th>Control Type</th>
<th>Annual Energy Savings (kWh/door)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>515</td>
</tr>
<tr>
<td>Micropulse</td>
<td>547</td>
</tr>
<tr>
<td>On/Off</td>
<td>364</td>
</tr>
<tr>
<td>Unknown</td>
<td>617</td>
</tr>
</tbody>
</table>

*Error bars indicate relative precision at 90% confidence interval*

### Peak Demand Savings

<table>
<thead>
<tr>
<th>Control Type</th>
<th>Peak Demand Savings (W/door)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISO-NE Summer</td>
<td>57</td>
</tr>
<tr>
<td>ISO-NE Winter</td>
<td>58</td>
</tr>
<tr>
<td>PJM Summer</td>
<td>70</td>
</tr>
</tbody>
</table>

*Error bars indicate relative precision at 90% confidence interval*

### Table: Annual Total Energy Savings

<table>
<thead>
<tr>
<th>Control Type</th>
<th>Annual Total Energy Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RP @ 90%</td>
</tr>
<tr>
<td>All</td>
<td>6%</td>
</tr>
</tbody>
</table>

*Error bars indicate relative precision at 90% confidence interval*
Interactive Refrigeration Impacts
Interactive Refrigeration Savings Method

- $\Delta kW \times 3,412 \text{ Btu/h per kW} \times \% \text{ heat in case}$
  - 100% for EF Motors/Controls
  - 66% for Door Heaters

- $\Delta \text{ Refrig. Load} \times \text{ Refrig. Performance}$
  - 30°F cooler evap. temp.
  - -10°F freezer evap. temp.

*Performance data based on average of representative units*
Interactive Refrigeration Savings

TRM Comparison

Note: Not all TRMs use each parameter; in some cases, we use TRM information to calculate parameters for comparison
Evaporator Fan Motor Retrofit
Total Savings Loadshape (1 week)

*Results shown incorporate weather data from Boston, MA*
Evaporator Fan Motor Retrofit
Total Savings Loadshape (1 year)

*Results shown incorporate weather data from Boston, MA*
Evaporator Fan Motor Retrofit

Total Savings Metrics

Annual Energy Savings

Peak Demand Savings
(at hp = 1/12 hp)

Note: This example is based on SP motor baseline and Boston, MA weather data.
Summary of Findings

• All three measures provide reliable energy and demand savings
• Easy to install and unobtrusive
• Appropriate for large and small commercial refrigeration
Summary of Findings

• Evaporator Fan Motor Retrofits
  – Almost all baseline motors observed were shaded pole. PAs that use a blended SP/PSC baseline should consider using SP only.
  – These measures operate continuously and are good for peak kW savings

• Evaporator Fan Controls
  – Almost all baseline motors observed were shaded pole. PAs that use a blended SP/PSC baseline should consider using SP only.
  – At two sites, controls were disconnected by the customer
  – When it works, these measures operate continuously and are good for peak kW savings

• Door Heater Controls
  – Large variation and small sample sizes makes it difficult to draw conclusions, HOWEVER...
  – Two types of door heater controls perform differently
  – Three sites exhibited no savings despite installed controls
  – When it works, this measure operates continuously and is good for peak kW savings
# Summary of Savings

<table>
<thead>
<tr>
<th>Parameter</th>
<th>EF Motor Retrofit</th>
<th>EF Motor Controls</th>
<th>Door Heater Controls</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduction Factor</td>
<td>61% (power)</td>
<td>34% (runtime)</td>
<td>55% (runtime)</td>
</tr>
<tr>
<td>Annual Energy Savings (no RIE)</td>
<td>857 kWh/motor(^1)</td>
<td>147 kWh/motor(^2)</td>
<td>515 kWh/door(^3)</td>
</tr>
<tr>
<td>Annual Energy Savings (w/RIE)(^4)</td>
<td>1,186 kWh/motor(^1)</td>
<td>204 kWh/motor(^2)</td>
<td>713 kWh/door(^3)</td>
</tr>
<tr>
<td>Peak Demand Savings (no RIE)(^5)</td>
<td>98 W/motor(^1)</td>
<td>14 W/motor(^2)</td>
<td>57 W/door(^3)</td>
</tr>
<tr>
<td>Peak Demand Savings (w/RIE)(^4,5)</td>
<td>136 W/motor(^1)</td>
<td>19 W/motor(^2)</td>
<td>80 W/door(^3)</td>
</tr>
</tbody>
</table>

\(^1\)For average motor hp (1/12)  
\(^2\)EC savings for average EC motor hp (1/12), for all control types  
\(^3\)Average for all control types  
\(^4\)For a Cooler  
\(^5\)ISO-NE Summer
Next Steps

• Currently drafting report, complete by end of June
• Final report, data transfer, and loadshape tool to follow
Questions
## Contacts

<table>
<thead>
<tr>
<th>Name</th>
<th>Email</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elizabeth Titus</td>
<td><a href="mailto:etitus@neep.org">etitus@neep.org</a></td>
</tr>
<tr>
<td>Carlyn Aarish</td>
<td><a href="mailto:Carlyn.Aarish@cadmusgroup.com">Carlyn.Aarish@cadmusgroup.com</a></td>
</tr>
<tr>
<td>Tim Murray</td>
<td><a href="mailto:Tim.Murray@cadmusgroup.com">Tim.Murray@cadmusgroup.com</a></td>
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