The Path to Carbon Neutral Laboratories

Jim Sharpe, PE, LEED AP BD+C
Principal
Affiliated Engineers, Inc.
jsharpe@aeieng.com
Learning Objectives

• Identify significant energy consumers in science and technology research facilities
• Understand the impact of local climate on energy consumption for laboratories
• Understand how Energy Efficiency + Heat Recovery can eliminate the dependency on local carbon emitting fuel sources
The Path to Carbon Neutrality

1. Reduce Energy Loads

2. Electrify Everything

3. Generate Site Electrical and/or Buy Green Power (then Carbon Offsets)
COMPARE 60% LAB/40% OFFICE BUILDING IN SAN FRANCISCO AND BOSTON

425,000 sq. ft building with 65% window to wall ratio
Mechanical Design
How can the EUI be driven down by implementing smart energy efficiency?
SOME MEASURES TO REDUCE THE MAJOR ENERGY DRIVERS

<table>
<thead>
<tr>
<th>Active Chilled Beams</th>
<th>Lighting and HVAC Controls Integration</th>
<th>Plug Load Management</th>
<th>Auto Sash Closers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating</td>
<td>Fan</td>
<td>Equipment</td>
<td>Heating</td>
</tr>
<tr>
<td>Cooling</td>
<td></td>
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<td>Fan</td>
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LOADS

ELECTRIFY

GREEN POWER
IMPLEMENT AUTO-SASH FUME HOOD CLOSERS – SAN FRANCISCO

- (38) 8 foot fume hoods at 100 FPM
- Auto sash closers – mandatory in CA from 2020
- Cost: $5,000/fume hood >~5 year payback
WHAT TO DO AFTER ENERGY EFFICIENCY? 100% ELECTRIC HEATING

- Heat Recovery Chiller
- Run Around Coil
- Exhaust Air Heat Recovery
- Air Source Heat Pump (ASHP)
- Electric Boiler
- Green Power or Carbon Offsets

LOADS
ELECTRIFY
GREEN POWER
HEAT RECOVERY CHILLER MAKES SENSE IN LAB BUILDINGS

Good idea for baseload in lab buildings due to reheat

A water to water heat pump = efficient

HW supply temp < 130°F
RUN AROUND COIL: ONLY USEFUL IN EXTREME CLIMATES

• Provides heating and cooling benefit

• Used for AHU preheat, not zone level reheat
EXHAUST AIR HEAT RECOVERY: EXTRACT WASTE HEAT IN WINTER

Heat Recovery Chiller generates hot water for preheat or zone level reheat.
HOW TO SERVE THE REMAINING HEATING LOAD

Air Source Heat Pump (ASHP)

- Heat from the air is absorbed by refrigerant in outdoor coil
- Refrigerant in indoor coil releases heat into house

© Collaborative Efficiency

Electric Boiler
BASE: 0% ELECTRIFIED HEATING

Daily Average Cooling and Heating Load in San Francisco

- Cooling Loads [kBtu]
- Heating Loads [kBtu]
HEAT RECOVERY CHILLERS: 48% ELECTRIFIED HEATING

Heat Recovery Chillers in San Francisco

- HRC to Cooling Load [kBtu]
- Low Lift Chiller to Cooling Load [kBtu]
- HRC to Heating Load [kBtu]
- Remaining Heating Load [kBtu]
RUN AROUND COIL: 57% ELECTRIFIED HEATING

Heat Recovery Chiller with Run Around Coil in San Francisco

<table>
<thead>
<tr>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>HRC to Cooling Load [kBtu]</td>
<td>HRC to Heating Load [kBtu]</td>
<td>Run Around Coil to Cooling Load [kBtu]</td>
<td>Low Lift Chiller to Cooling Load [kBtu]</td>
<td>Run Around Coil to Heating Load [kBtu]</td>
<td>Remaining Heating Load [kBtu]</td>
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</table>
EXHAUST AIR HEAT RECOVERY: 100% ELECTRIFIED HEATING

Heat recovery chiller does need to be significantly larger to support heat recovery: 700 to 1000 tons.
BASE: 0% ELECTRIFIED HEATING

Daily Average Cooling and Heating Load in Boston

- Cooling Load [kBtu]
- Heating Load [kBtu]
HEAT RECOVERY CHILLER: 22% ELECTRIFIED HEATING

Heat Recovery Chillers in Boston

ELECTRIFY GREEN POWER
RUN AROUND COIL: 54% ELECTRIFIED HEATING

Heat Recovery Chillers with Run Around Coil in Boston

- HRC to Cooling Load [kBtu]
- HRC to Heating Load [kBtu]
- Run Around Coil to Cooling Load [kBtu]
- Low Lift Chiller to Cooling Load [kBtu]
- Run Around Coil to Heating Load [kBtu]
- Remaining Heating Load [kBtu]
Heat recovery chiller does need to be significantly larger to support heat recovery: 700 to 1400 tons.
SENSITIVE VARIABLES CAN DRAMATICALLY CHANGE ENERGY & CARBON EMISSIONS COSTS

- **Equipment Efficiencies**
  - 0.5 kWh/ton chiller
  - 0.8 kWh/ton HRC

- **Natural Gas and Electricity Cost**
  - $0.60 / therm
  - 0.10 / kWh

- **Green Power & Carbon Offset Costs**
  - $20 / MTCDE
  - +$0.02 / kWh Green
ENERGY COST AND CARBON EMISSIONS COMPARISON IN SAN FRANCISCO

Run Around Coil:
No need in mild climate

Exhaust Coil Heat Recovery: cheapest and very low carbon footprint
Energy Cost and Carbon Emissions Comparison in Boston

- **Heat Recovery Chiller**: Adds carbon as grid is not as green.
- **Run Around Coil**: More effective than Exhaust Coil Heat Recovery.

### Graph Details:
- **Base**
  - Costs: $717
  - Load: 4,011
- **Heat Recovery Chiller**
  - Costs: $472
  - Load: 4,078
  - Cost Savings: $569
- **Run Around Coil**
  - Load: 2,700
  - Load: 2,374
- **Exhaust Coil Heat Recovery**
  - Costs: $666

### Rows:
- **$0**
- **$100**
- **$200**
- **$300**
- **$400**
- **$500**
- **$600**
- **$700**
- **$800**

### Columns:
- **Cost ($)**
- **Cooling**
- **Heating**
- **Fan**
- **Carbon Offsets**
- **Cost Savings ($)**
- **Total ($)**
- **Carbon Emissions [MTCDE]**
The Path to Carbon Neutrality

Questions

1. Reduce Energy Loads
2. Electrify Everything
3. Generate Site Electrical and/or Buy Green Power (then Carbon Offsets)

Jim Sharpe
jsharpe@aeieng.com
Appendix
GREEN POWER IN SAN FRANCISCO AT $0.11 AND $0.12/kWh

$0.11/kWh

Energy Cost and Carbon Emissions Comparison in San Francisco

$0.12/kWh

Energy Cost and Carbon Emissions Comparison in San Francisco
GREEN POWER IN BOSTON AT $0.11 AND $0.12/kWh

$0.11/kWh

Energy Cost and Carbon Emissions Comparison in Boston

- Cost [S]
- Cooling
- Heating
- Fan
- Cost Savings [S]
- Total [S]
- Carbon Emissions [MTCD]

$0.12/kWh

Energy Cost and Carbon Emissions Comparison in Boston

- Cost [S]
- Cooling
- Heating
- Fan
- Cost Savings [S]
- Total [S]
- Carbon Emissions [MTCD]
Sensitive Variables can dramatically change Operating Cost

- Natural Gas Cost [$/therm] 0.6
- Average Commercial Electricity Rate [$/kWh] 0.1

<table>
<thead>
<tr>
<th>Emission Type</th>
<th>Amount</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO$_2$ from Natural Gas Combustion [lb./MBH]</td>
<td>117</td>
<td>EIA</td>
</tr>
<tr>
<td>CO$_2$ from Grid MA [lb./kWh]</td>
<td>0.846</td>
<td>2017 EIA</td>
</tr>
<tr>
<td>CO$_2$ from Grid CA [lb./kWh]</td>
<td>0.485</td>
<td>2017 CARB</td>
</tr>
<tr>
<td>Cost of 2019 Carbon Offset [$/MTCDE]</td>
<td>20</td>
<td>Low estimate</td>
</tr>
</tbody>
</table>

Chiller Efficiency (Carrier 19DV)
- High Lift Chiller Efficiency [kW/ton] 0.8
- Low Lift Chiller Efficiency [kW/ton] 0.5

IESVE Energy Model for Loads and Building Level Airflows
Carbon Offsets [$/MTCDE] are volatile and hard to predict

Max Estimated Cost: $95
Approximate Social Cost of Carbon: $60
Yale University
Swarthmore College
Minimum Estimate: $20

Sources:
- Second Nature: Internal Carbon Pricing in Higher Education
- Higher education leadership on carbon pricing
EXHAUST AIR HEAT RECOVERY: EXTRACT WASTE HEAT IN WINTER

Heat Recovery Chiller generates hot water for preheat or zone level reheat.
Air Source Heat Pump can serve the remaining heating load

- Can electrify small remaining heating load by serving into the HRC CHW return (more efficient as the ASHP does not have to lift water temperature up to 120°F)
- Newer ASHPs work even in cold climates such as Boston, but are less efficient
- But off the shelf sizes are < 150 tons: Often too small
<table>
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<tr>
<th>Technology</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric/Electrode Boilers</td>
<td>Not efficient as a heating solution. 1 to 1 electricity to heat conversion</td>
</tr>
<tr>
<td>Ground Source Heat Pump/Geo-exchange</td>
<td>Needs a lot of physical infrastructure, extremely high capital cost, but good in temperate climates such as Boston. Site specific, deeper analysis needed</td>
</tr>
<tr>
<td>Geothermal Heat</td>
<td>Need deep pipes to get hot water directly from the ground</td>
</tr>
<tr>
<td>Solar Thermal Flat Plate</td>
<td>Low grade heat and low capacity factor. The sun shines less when the heat is needed most.</td>
</tr>
<tr>
<td>Solar Thermal Evacuated/Parabolic</td>
<td>High grade heat but low capacity factor. The sun shines less when the heat is needed most.</td>
</tr>
<tr>
<td>Biomass/Biogas + Boilers</td>
<td>Expensive fuel and must perform careful carbon accounting + Volatility of Market</td>
</tr>
<tr>
<td>Natural Gas Boilers + Offsets</td>
<td>While this may be an easy way out, the price of carbon offsets are volatile and expected to rise dramatically as various companies pledge to be carbon neutral</td>
</tr>
</tbody>
</table>
Heating Load in Boston
Heat Recovery Chiller

CHW Supply at 42°F

CHW Return at ~56°F

Exhaust Coil

Exhaust air at 70°F, 30% RH

Winter Case: Exhausted air at ~ 40°F

Cooling Load in AHU

Heat Recovery Chiller

Summer Case: Exhausted air at 70°F/50%RH

Low Lift Chiller

Cooling Towers

HW Supply at 120°F

Heating Load in AHU OR Zone

HW Return at 90°F