CHP, Waste Heat & District Energy

Module 8: CHP System Thermal Design

Module 5 Topics

• CHP System Design
• Thermally Activated Technologies
• System Optimization
**CHP Design Goals**

- Integrate natural gas engine, electric generator, heat recovery equipment and thermally driven HVAC equipment with the building systems
- Maximize economic advantage
- Minimize project cost

**CHP System Design**

- Maximize Economic Advantage
- Match the CHP system Thermal/Electric Ratio with the facility requirements and Baseload the CHP system electric and thermal output
  
  *Maximizing load factor is the way to maximize profit.*

- Minimize Project Cost
- Understand the electric, heating and cooling loads and select equipment for maximum load factor – Not necessarily maximum efficiency.
**CHP System Design**

**Thermal Form Varies – Electric Form is Constant**

Conventional Wisdom:
- Select Generator on Electric Load Basis
- Select Thermal Technology on Generator Basis
- Fit Thermal Output to Building

CHP Wisdom:
- Select Thermal Technology on Thermal Load Basis
- Select Generator on Thermal Basis
- Fit Electric Output to Building

‘Thermal First’ design is the way to maximize load factor

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**CHP System Design**

The heating and cooling **Thermal/Electric Ratios** are the key load characteristics required to ensure high CHP Load Factor.

**Heating T/E Ratio** = Heating Load in MBH / Electric Load in kW

**Cooling T/E Ratio** = Cooling Load in Tons / Electric Load in kW

(The T/E Ratio is the inverse of the Power/Thermal Ratio)

**Rule #3**

The Load T/E Ratios define the CHP Configuration
**CHP System Design**

**Economics**

Essentially the thermal revenue represents the annual cost savings.

Without thermal revenue, the cost savings are significantly reduced and the payback is greatly increased.

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**Know your Loads:**

Electric utilities usually provide 15 min interval data from which can be derived load duration curves.

Thermal information should be measured and tabulated through summer, winter and shoulder season.

Thermal characteristics (flow, pressure, temp) need to be identified.
### Averaged Cooling Load T/E Ratio

![Graph showing Electricity Consumption & Cooling T/E Ratio](source: 1995 EIA Buildings Survey)

### Typical CHP System Cooling T/E Ratio

<table>
<thead>
<tr>
<th>Generator</th>
<th>Range</th>
<th>Cooling TAT</th>
<th>T/E Ratio (Ton/kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass</td>
<td>&gt; .25 MW</td>
<td>2E Absorber</td>
<td>0.9 - 1.0</td>
</tr>
<tr>
<td>Gas Turbine</td>
<td>&gt; 1 MW</td>
<td>Steam Turbine 2E Absorber</td>
<td>0.6 - 0.7</td>
</tr>
<tr>
<td>Microturbine</td>
<td>&lt; 1 MW</td>
<td>2E Absorber Desiccant</td>
<td>0.4 - 0.5</td>
</tr>
<tr>
<td>IC Engine</td>
<td>.1 to 3 MW</td>
<td>1E Absorber 2E Absorber</td>
<td>0.2 - 0.4</td>
</tr>
</tbody>
</table>
CHP System Design

Aim for the highest thermal and electric load factor through all seasons – incorporate as many cooling and heating loads as possible.

Dom HW + cooling in summer ⇒ simultaneous heating and cooling.

Output has to be distributed so CHP system location is an important factor.

Building HVAC integration is a vital ingredient for new and retrofit CHP installations.

CHP System Design

Remember CHP cooling can reduce peak electric loads substantially

Series flow recommended on all thermal loops with the CHP system on the return line

Don’t forget O&M
Thermally Activated Technologies

Technologies:
- Hot Water HEX
- Boilers/Steam Generators
- Organic Rankin Cycle
- Backpressure Turbines
- Absorbers
- Steam Turbines
- Desiccants
- Adsorbers

Applications:
- Process Heat
- Space Heat
- Domestic Hot Water
- Cooling
- Freezing
- Dehumidification
- Power Generation

Cooling Technologies

- Cooling Technologies for CHP are HVAC devices that produce cooling from waste heat and include:
  - Steam Turbine Chillers
  - Double Effect Absorbers
  - Single Effect Absorbers
  - Desiccants
  - Adsorbers

- Cooling and Dehumidification Systems are available across a wide range of CHP configurations and sizes, from 50 kW to multi-MW applications.
**Steam Turbine Chillers**

- High Temperature Activation
- Moderate Cost at Large Tonnage
- High Pressure Steam System
- High Efficiency

700 to 5,000 Tons
High FL Efficiency – 1.2 COP, 10 lbs/ton, compact footprint
High IPLV Efficiency – 2 COP
High CHP Efficiency – FL at varying ambient
Condenser Water 3 to 4.5 GPM

**Absorption Chillers**

**Single Effect:**
- Low Temperature Activation, 200 F
- Low Cost
- Simple
- Good Efficiency – 0.7 COP

**Double Effect:**
- High Temperature Activation, 350 F
- Moderate Cost
- Complex
- High Efficiency – 1.2 COP

Wide range of models from <100 tons to >1,000 tons
Activated by Steam (15 psi - 125 psi), Hot Water and/or Exhaust
4 to 5 GPM Condenser Water, Large & Heavy, Slower Response
Desiccants

- Liquid or Solid Desiccant
- Low Temperature Activation - Bottoming Cycle
- Low Cost
- Low Efficiency – 0.5 COP
- Low Size

Adsorption

- Low Temperature Activation
- Low Efficiency – 0.5 COP
- Refrigeration Capable
- Large & High Cost
- Requires Surge Tanks & Cooling Tower
System Optimization

Electric refrigeration chiller cost can be reduced and its efficiency doubled by using a heat recovery absorber.

**System Optimization**

**System Integration for High Efficiency & Thermal Output**

- **Performance**
  - **Existing Chillers**
    - **Existing Refrigeration Chillers**
      - Chiller Output: 500 Tons
      - Chiller Efficiency: 2 kW/TR
      - Chiller input: 1,000 kW
      - CT Fan Input: 0 kW
      - Total Parasitics: 0 kW
    - **CHP System**
      - Power Generator
        - Electric Output: 2,388 kW
        - Total Efficiency: 39.1%
        - Fuel In: 22,936 MBH
        - Total HR: 6,500 MBH
      - 1E Absorber Output: 496 Tons
      - Abs/Cond Heat Rejection: 7,450 MBH
  - **Replacement Chillers**
    - **New Refrigeration Chillers**
      - Chiller Screw Output: 500 Tons
      - Chiller Efficiency: 1.533 kW/TR
      - Chiller input: 766.5 kW
      - CT Fan: 30 HP
      - Total Parasitics: 56 kW
    - **CHP Refrigeration Chiller**
      - Electric Chiller: 500 Tons
      - Electric Chiller Efficiency: 0.694 kW/TR
      - YK CD Output: 7,185 MBH
      - Chiller Input: 347 kW
    - **CHP System Parasitics**
      - Electric Chiller Fan: 30 HP
      - Absorber CT Fan: 50 HP
      - Total Parasitics: 101 kW

**Notes:**
1. Parasitics include cooling tower, container pump and absorber
2. Design wet bulb temperature = 73°F
3. Includes Jacket + Exhaust, excludes 2nd Stage Intercooler
4. CT not required when Abs. operating or use Abs. CT

- **Steam Turbine Efficiency**
  - Steam: 150 psig
  - Output: 2,000 Tons
  - Chilled W: 44°F
  - Steam Turbine Efficiency

- **Steam Pressure (psig)** vs. **Steam Flow (lbs/hr)**

- **Condenser Water Temp (F)** vs. **COP**

- **Steam Heat Supply/Return**
  - Chilled Water Supply/Return
  - Steam Heat Supply/Return

- **Biomass Boiler**

**U.S. DEPARTMENT OF ENERGY**
Mid-Atlantic Clean Energy Application Center
Promoting CHP, Electric Energy, and Water Heat Recovery

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**System Optimization**

**HR Surface Area/Size**

**CT & Pump Parasitics**

![Graph showing condenser water parasitic load, pump HP, CT HP, and total HP.](image)

**Wet Bulb Temperature**

**CT Size**

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**Load Optimization**

Some load profiles vary dramatically from peak to off-peak hours.

In order to maximize return on investment the CHP system should operate 24 hours per day.

![Graph showing mall summer electric load profile.](image)
Load Optimization

Thermal Storage and Electric Chillers can be used to level CHP electric and thermal load profiles for high 24 hour Load Factor

Load Factor vs Efficiency

• “No matter which basis is used to choose the prime mover, the degree of use of the available heat determines the overall system efficiency; this is the critical factor in economic feasibility. Therefore, the thermal/electric ratio of the prime mover and load must be analyzed as a first step towards making the best choice. Maximizing efficiency is generally not as important as thermal and electric utilization.”

• .......... ASHRAE Design Guide, Chapter 7 – CHP Systems