Distributed High Capacity Cold Storage in District Cooling Systems

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300 MW
380 GWh/year

Central Stockholm
Introduction

• Comfort cooling demand is increasing around the world resulting in:
  High peak demand in electrical power
  Increased environmental impact (GHG emissions)
• Cold storage will play an important role in developing energy efficient and environmentally sound cooling systems.
• District cooling system in Stockholm will in near future need to expand capacity to take on new customers and service the existing:
  1. Expanding cooling production capacity and/or network capacity.
  2. Coupling present production to centrally placed cold water storages.
  3. Smaller scale cold storages to be placed at the district cooling customer.
Integration of cold storage

- load
- chiller on
- storage is charged by chiller
- chiller handles the load
- storage handles the load

load (kW)

time of day
# Cold Storage Options

<table>
<thead>
<tr>
<th>Technology</th>
<th>Energy density (kWh\textsubscript{cooling}/m\textsuperscript{3})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stratified cold water storage, $\Delta T=10^\circ$C</td>
<td>12</td>
</tr>
<tr>
<td>PCM salt (Commercial salt with latent heat of phase change 162 kJ/kg.)</td>
<td>63 (IPF=1)</td>
</tr>
<tr>
<td>Paraffin (Commercial paraffin with latent heat of phase change $\approx$156 kJ/kg)</td>
<td>37 (IPF=1)</td>
</tr>
<tr>
<td>Ice (latent heat of phase change 333 kJ/kg)</td>
<td>92 (IPF=1)</td>
</tr>
</tbody>
</table>
Important design aspects

- How much energy [J] should be stored?
- With what power [J/s] does the storage need to be charged/discharged?
- In case of advanced storage concepts using phase change materials, what IPF is obtainable?
- And, the shape of the load curve – how much energy needs to be stored per unit reduced power? The ENERGY-TO-POWER ratio:

\[
EPR = \frac{\Delta Q_{\text{cooling}} \, [\text{kWh}]}{\Delta P_{\text{cooling}} \, [\text{kW}]}
\]
Peak-shaving is likely only feasible to a certain percentage after which the storage becomes too large.
Integration of Storage with DC network

District Cooling Side

Heat Exchanger

Cooling Demand Side

+8ºC to dehum.

8ºC to regular load

14ºC to regular load

Return fr load

8ºC

18ºC

16ºC return

6ºC supply
# Loads Considered and Summarized Results

<table>
<thead>
<tr>
<th>Customer</th>
<th>Peak Cooling Load [kW]</th>
<th>Feasible Peak Shaving [kW] / [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shopping center</td>
<td>3400</td>
<td>PCM: 500/15 SCWS: 200/6</td>
</tr>
<tr>
<td>Office building</td>
<td>270</td>
<td>PCM: 30/11 SCWS: not feasible</td>
</tr>
<tr>
<td>Industry (process cooling)</td>
<td>1200</td>
<td>PCM: 124/10 SCWS: not feasible</td>
</tr>
</tbody>
</table>
Results – Office Building

Office Building
Original Peak Power: 270 kW_{cooling}

<table>
<thead>
<tr>
<th>Peak Power Reduction (%)</th>
<th>Investment Cost (Euro)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>10000</td>
</tr>
<tr>
<td>2%</td>
<td>20000</td>
</tr>
<tr>
<td>4%</td>
<td>30000</td>
</tr>
<tr>
<td>6%</td>
<td>40000</td>
</tr>
<tr>
<td>8%</td>
<td>50000</td>
</tr>
<tr>
<td>10%</td>
<td>60000</td>
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<tr>
<td>12%</td>
<td>70000</td>
</tr>
<tr>
<td>14%</td>
<td>80000</td>
</tr>
<tr>
<td>16%</td>
<td>90000</td>
</tr>
</tbody>
</table>

- Alternative cost 300 Euro/kW
- SCWS
- PCM storage
Cost Break-Down – Office Building

- Tank: 16%
- PCM: 15%
- Controls: 15%
- Other: 15%
- Space: 10%
Results – Energy-to-Power Ratio

![Graph showing the relationship between ice packing factor and energy-to-power ratio.]
Conclusions

- It is economically feasible with small-scale PCM cold storage for peak-shaving in the Stockholm District Cooling System.
- Cold water storage not as feasible.
- The so-called Ice Packing Factor greatly influences the investment cost for peak-shaving with storage – the greater the IPF, the lower the cost per unit power (kW) shaved.
- The feasibility is greatly influenced by the customer’s load profile, with feasibility being the greatest for loads where sharp peaks occur.
- To obtain cost-effective cold storage systems, effective system design with integration of components is needed.
- More demonstration projects!
Acknowledgments

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Thank you!