Exergy analysis of cooling systems and strategies

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Relevance

• The demand for ventilation and cooling of buildings is an increasing share of Europe’s total energy use in buildings

• The performance of HVAC systems is usually evaluated based on the first law of thermodynamics. Exergy-optimized systems make use of low temperature differences, which makes it possible to put to use renewable sources.

• Aim of this paper is to show the potential for optimization of three hybrid cooling systems

• This potential is addressed performing an exergy analysis of the cooling demand of a generic office building and of three supply systems, which use chillers in conjunction with evaporative cooling
Building model

Office building

Floor area: 1200 m$^2$
Walls area: 500 m$^2$, U-value of 0.15 W/(m$^2$ K)
Windows area: 250 m$^2$, U-value 1 W/(m$^2$ K)
Internal loads: 10 W/m$^2$
External loads: 15 W/m$^2$
Set-point temperature, indoor environment: 26 °C
Outdoor temperature: 30°C

Reference conditions

Environment temperature: 30 °C
Environment pressure: 110 kPa.
Humidity ratio: 0.01 kg$\text{w}$/kg$a$, RH= 40%.

Calculation of the cooling load, steady-state

\[ Q_{\text{cooling}} = U_{\text{windows}} A_{\text{windows}} (T_{\text{in}} - T_{\text{out}}) + U_{\text{walls}} A_{\text{walls}} (T_{\text{in}} - T_{\text{out}}) + Q_{\text{int}} + Q_{\text{ext}} \]

The obtained cooling load has been in all the three cases 31,500 W, delivered cooling power: 26 W/m$^2$
Cooling systems description

System 1

System 2

System 3
Software tool: SEPE
Components

- **Input Parameters Field**:
  - IN par
  - Temperature [°C]
  - Pressure [bar]
  - Ex par [J/kg]
  - Ex th [J/kg]

- **User-Dependent and System-Defining Parameters Field**:
  - Boiler
  - Env pressure
  - Enthalpy
  - Mass flow [kg/s]
  - Ex heat flow
  - Trise
  - Ex_ptr
  - Eta thermal
  - Epsilon
  - Ex increase,flow [W]
  - Ex loss [W]

- **Output Parameters Field**:
  - Oil
  - OUT par
  - Pressure
  - Temperature [°C]
  - Ex erg [J/kg]
  - Ex pl [J/kg]
  - Ex th [J/kg]
  - Primary energy
  - 72192,7

Values:
- 100000,5
- 0,0
- 26132,7
- 0,0
- 248.3
- 10520
- 2887,7
- 6586
Nodes description

<table>
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<tr>
<th>Chiller</th>
<th>IN par</th>
<th></th>
<th>OUT par</th>
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</thead>
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<td>Pressure [Pa]</td>
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<td>Pressure [Pa]</td>
<td>99350.0</td>
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<td>Temp [°C]</td>
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<td>Mass flow [kg/s]</td>
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<td>Mass flow [kg/s]</td>
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<tr>
<td>Heat discharged [W]</td>
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<td>Heat discharged [W]</td>
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<td>Electric power [W]</td>
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<td>Exergy loss [J]</td>
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<td>Exergy loss [J]</td>
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<table>
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<tr>
<th>Pipe</th>
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<td>Temp [°C]</td>
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<td>Exergy loss [J]</td>
<td>2874.3</td>
<td>Exergy loss [J]</td>
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</tbody>
</table>
Exergy calculations

\[ Ex_{spec} = f(T, T_0, P, P_0, \omega, \omega_0) \]

\[ Ex_{spec} = Ex_{th} + Ex_{pr} + Ex_{ch} \]

\[ Ex_{th} = c_p \left[ (T - T_0) - T \ln \frac{T}{T_0} \right] \]

\[ Ex_{pr} = T_0 R \ln \frac{P}{P_0} \]

\[ Ex_{ch} = R T_0 \left( 1 + 1.608 \omega \ln \frac{1 + 1.608 \omega}{1 + 1.608 \omega_0} \right) + 1.608 \omega \ln \left( \frac{\omega}{\omega_0} \right) \]
### Exergy supply and demand of the analyzed systems

<table>
<thead>
<tr>
<th>Component</th>
<th>System 1</th>
<th>System 2</th>
<th>System 3</th>
<th>Building demand</th>
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<td>460</td>
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<tr>
<td>Distribution pumps/fans</td>
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<td>200</td>
<td>400</td>
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<tr>
<td>Chiller</td>
<td>7600</td>
<td>3900</td>
<td>10500</td>
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<tr>
<td>Generation pumps</td>
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<td>Hybrid cooling tower</td>
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<td>1100</td>
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<tr>
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<td>150</td>
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</table>
Exergy losses in the cooling systems
Conclusions

• All three systems have a low exergy efficiency. The exergy demand for the building is low.
• The main losses occur in the generation systems, chillers and hybrid cooling tower, and in the heat exchangers.
• The system with the highest exergy efficiency in the analysis is the System 2.
  – Water: lower temperature difference
  – No heat exchanger
• Direct distribution of the chiller output to the emission system doubles the exergy efficiency in comparison with a system where an intermediate heat exchanger is necessary.
• Exergy potential in the outdoor air at mid European humidity conditions: for System 2, the exergy gained from the outdoor air is in the level of the losses from the chiller.
References


• Molinari, M. 2009. A pressure and thermal exergy analysis of a waterborne and an airborne system, Proceedings of the 15th „Building Services, Mechanical and Building Industry Days” International Conference, Debrecen.
Aknowledgements

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http://www.annex49.com/background.html
Thank you for your attention!