

Model-based Control for Solar Cooling Systems

Online setpoint optimization – from simulation-based design to real-plant operation

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SUBAREA 2.2
Automation and Control

1 Solar Cooling Systems

Solar cooling systems use **heat from solar thermal collectors** to drive an absorption **chiller**, thereby **reducing electrical energy demand** compared to compression chillers. Solar thermal energy is particularly suitable for this purpose, as its **availability** generally **coincides** well with cooling demand.

As illustrated in Fig. 1, the chiller provides chilled water at $T_{\mathrm{ch,out}}$ to meet the cooling demand $\dot{Q}_{\mathrm{ch}}$, using heat supplied at a high temperature level T_{hot} and rejecting heat at an intermediate temperature level T_{cool} through **a cooling tower**.

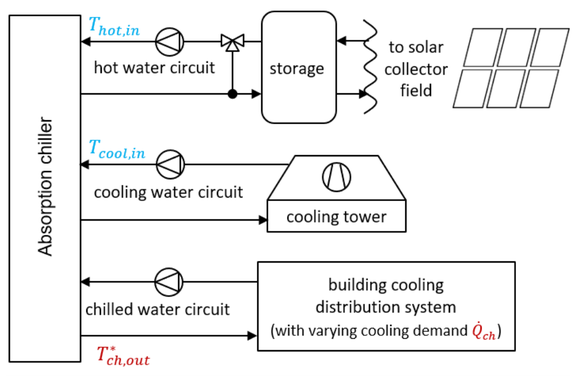


Fig 1: Scheme of a solar cooling system

2 Control Challenge

Efficient system operation requires balancing the different effects of the chiller operating temperatures:

- **High $T_{\mathrm{hot,in}}$** increases the chiller's capacity and efficiency but increases **thermal losses** in the solar collectors.
- **Low $T_{\mathrm{cool,in}}$** increases the chiller's capacity and efficiency but requires **increased cooling-tower** operation.
- The optimal combination of $T_{\mathrm{hot,in}}$ and $T_{\mathrm{cool,in}}$ depends on the current **operating conditions** (cooling demand $\dot{Q}_{\mathrm{ch}}$, available storage temperatures) and **weather conditions** (ambient temperature and humidity).

Conventional control strategies typically **do not account** for this system-wide **optimum** but use predefined operating conditions, such as keeping $T_{\mathrm{cool,in}}$ constant while varying $T_{\mathrm{hot,in}}$ to control the chilled water outlet temperature $T_{\mathrm{ch,out}}$.

3 Model-based Control

The proposed **model-based control** (MBC) **combines** simplified **models** of the absorption chiller, cooling tower and solar collector with an **online optimization**, considering current operating and weather conditions. The optimization continuously determines set points for $T_{\mathrm{hot,in}}$ and $T_{\mathrm{cool,in}}$ by **minimizing** the following **cost function** accounting for electrical energy consumption P_{el} and thermal energy demand $\dot{Q}_{\mathrm{sol}}$, while ensuring stable operation by penalizing sudden setpoint changes with $cost_{\Delta sp}$:

$$cost = P_{\mathrm{el}}\, price_{\mathrm{el}} + \dot{Q}_{\mathrm{sol}} price_{\mathrm{th}} + cost_{\Delta sp}$$

Fig. 2 shows an exemplary cost function, highlighting the **trade-off** between increased **cooling-tower operation** at low $T_{\mathrm{cool,in}}$ and higher **thermal losses** at high $T_{\mathrm{hot,in}}$. The resulting optimum shifts with changing weather conditions, as illustrated for different ambient temperatures T_{amb}.

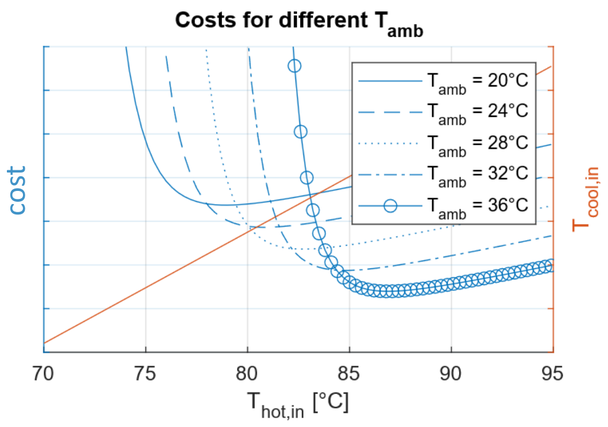


Fig. 2: Exemplary cost function for different ambient temperatures

4 Simulation-Based Validation

Conventional control and MBC were **compared** in a simulation study under **identical boundary conditions** using measured weather data from 70 summer days (21 June – 31 August 2024). The case study is based on the solar cooling demonstration plant *Cool Cabin* of SOLID Solar Energy Systems GmbH in Graz, Austria.

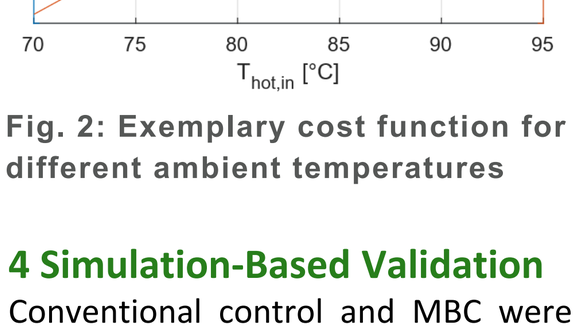


Fig. 3: Cool Cabin (demonstration plant used for validation)

The validation showed a significant **reduction in electrical energy demand** with the MBC:

-30 % electrical energy demand		
-20 % cooling tower	-55 % cooling water pump	-25 % hot water pump

5 Real-plant implementation

Following the simulation-based validation, the MBC was **implemented** on the real *Cool Cabin* in September 2025 and has been in operation since. The control runs on a **standard PLC** and was integrated into the existing control software.

Tools for parameterizing the component models from measurement data were developed to **facilitate adaptation** to different systems.

Fig. 4 shows exemplary operating data with the MBC in action. The optimized **$T_{\mathrm{hot,in}}$ and $T_{\mathrm{cool,in}}$ continuously adapt** to changing ambient conditions and cooling demand. For example, between 12:30 and 15:30, when high $T_{\mathrm{hot,in}}$ is available, the cooling-tower fan speed $n_{\mathrm{fan,CT}}$ is substantially lowered to **reduce operating costs**.

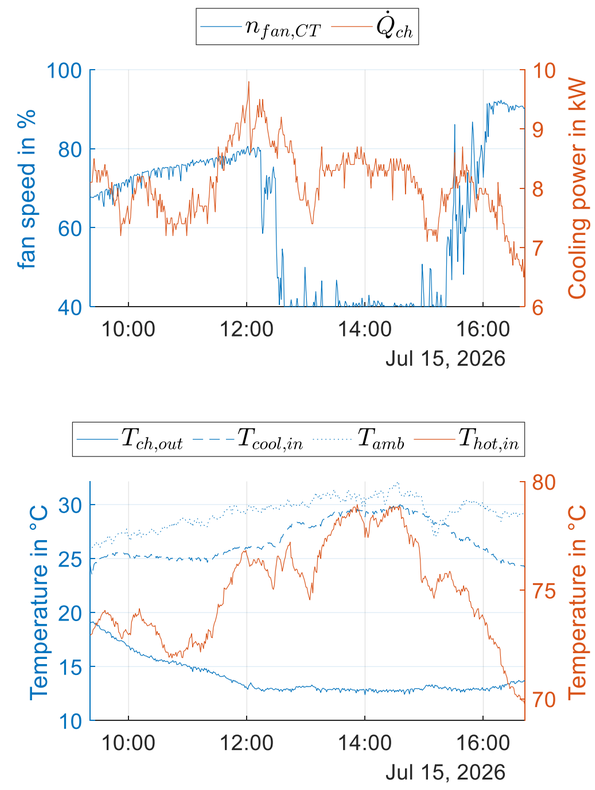


Fig. 4: Exemplary operation of the MBC on the real plant

6 Conclusion & Outlook

- **Model-based control** successfully **coordinates** absorption chiller, cooling tower and solar collector by continuously optimizing $T_{\mathrm{hot,in}}$ and $T_{\mathrm{cool,in}}$ to reduce operating costs.
- **30% lower el. energy demand** compared to conventional control
- **Real-plant implementation** on a standard PLC demonstrates **practical applicability**

Outlook: Systematic evaluation of field performance and transfer of the modular control approach to further solar cooling systems.

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