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ADVANCED MODEL-BASED-CONTROL FOR SOLAR THERMAL COOLING

Summary

Solar thermal cooling systems offer a promising solution for sustainable cooling due to the temporal alignment between solar irradiation and cooling demand. However, their operation is characterized by complex interactions between system components and varying boundary conditions, often leading to suboptimal performance under conventional control strategies. This work presents a model-based control approach for solar thermal cooling systems with absorption chillers, combining simplified component models with an optimization-based operating strategy. The method determines optimal set points by jointly adjusting key variables such as hot and cooling water temperatures. The approach is evaluated in a simulation study based on real plant data. The results show that electrical energy consumption can be reduced by up to 30%, highlighting the potential of model-based control for efficient system operation.

Keywords: *absorption cooling, solar-thermal, model-based control,*

Field of application for the findings: *Solar Air Conditioning and Refrigeration*

Addressed audience: *Researcher, Control-Engineers, Industry and Planners*

1. Introduction

Cooling demand in buildings is strongly correlated with solar radiation: During hot summer periods, when cooling demand is highest, solar energy is also abundant. Solar cooling technologies exploit this temporal correlation by utilizing solar energy to provide cooling, thereby aligning energy supply with demand. This is particularly relevant as global space cooling demand continues to rise rapidly, while the decarbonization of the cooling sector requires an increased deployment of renewable-based solutions (REN21, 2025).

Among the available technologies, solar thermal cooling systems use solar heat to drive thermally activated chillers, such as absorption systems (see e.g. Figure 1). However, their operation is characterized by a complex interaction of system components (i.e. cooling tower, solar collectors and chiller) and time-varying boundary conditions such as ambient temperature and cooling demand. As a result, conventional control strategies often lead to suboptimal system operation. To address these challenges, this work proposes a model-based, modular control approach that determines optimal set points via an optimization problem using simplified component models. By jointly adjusting hot and cooling water temperatures, the controller aims at minimizing operating costs while maintaining the required cooling performance.

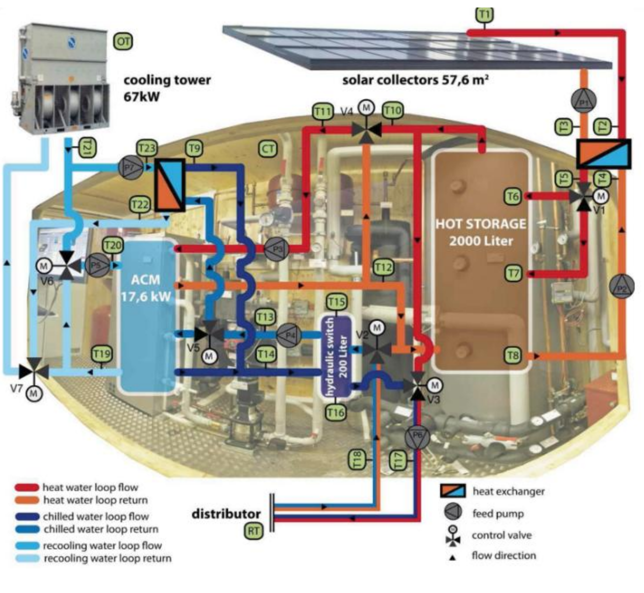

Figure 1: Schematic of "Energy Cabin" plant at SOLID headquarters showing Absorption Cooling Machine, hot water storage, cold water storage, cooling tower and solar collectors

2. Methodology

The proposed control approach is evaluated by means of a simulation study based on real operating data from a solar thermal cooling plant, assessing performance under realistic, time-varying boundary conditions. The investigated system is based on the "Energy Cabin" demonstrator located at the SOLID headquarters in Graz, Austria (see Figure 1), comprising a solar thermal collector field (58 m², 40.6 kW), a hot water storage tank (2,000 L), an absorption chiller with a nominal cooling capacity of 16 kW, and a chilled water storage tank (200 L), supplying solar-driven heating and cooling to an office building. The system allows control of the chiller's hot and cooling water inlet temperatures $T_{hot,in}$ and $T_{cool,in}$ via a mixing valve in the hot water circuit and by adjusting the cooling tower fan speed, respectively.

For the simulation study, measurement data from June 21 to August 31, 2024 (70 days), including ambient temperature, humidity, and global irradiation, are used as boundary conditions. The solar thermal system and storage are modeled in a simulation environment, and the proposed model-based control is compared to a conventional strategy under identical conditions, allowing for a direct evaluation of system performance.

3. Model-Based-Control Algorithm

An absorption chiller's cooling capacity strongly varies with both the hot and cooling water temperatures, $T_{hot,in}$ and $T_{cool,in}$, making these variables effective control inputs. While many conventional control strategies adjust only $T_{hot,in}$ and keep $T_{cool,in}$ constant, the proposed model-based approach exploits this additional degree of freedom by varying both temperatures simultaneously to not only regulate cooling capacity but also minimize operating costs. The proposed approach builds upon the model-based control strategy introduced by Albers (2014), extending it to solar-driven systems by explicitly incorporating the solar collector's temperature-dependent efficiency. Consequently, the proposed control algorithm is based on the following simplified component models of the absorption chiller, cooling tower and solar collector:

The chiller is represented by linear correlations that describe hot and chilled water heat flow rates $\dot{Q}_{hot}$ and $\dot{Q}_{ch}$ as functions of the corresponding water inlet temperatures $T_{hot,in}$, $T_{cool,in}$ and $T_{ch,in}$:

$$\dot{Q}_{hot} = K_{hot,0} + K_{hot,1}T_{hot,in} + K_{hot,2}T_{cool,in} + K_{hot,3}T_{ch,in} \quad \text{(eq. 1)}$$

$$\dot{Q}_{ch} = K_{ch,0} + K_{ch,1}T_{hot,in} + K_{ch,2}T_{cool,in} + K_{ch,3}T_{ch,in} \quad \text{(eq. 2)}$$

With all K_i being constant parameters.

Similarly, the wet cooling tower model is based on a simplified correlation relating the heat rejection rate $\dot{Q}_{CT}$ and electricity consumption $P_{el,CT}$ to the ambient wet bulb temperature $T_{amb,WB}$, water inlet temperature $T_{cool,out}$ as well as the air and cooling water flow rate $\dot{m}_{air}$ and $\dot{m}_{water}$:

$$\begin{aligned}\dot{Q}_{CT} = \sqrt{\frac{\dot{m}_{air}}{\dot{m}_{air,max}}}\sqrt[3]{\frac{\dot{m}_{water}}{\dot{m}_{water,max}}}\big(K_{CT,1}\left(T_{cool,out} - T_{amb,WB}\right) + K_{CT,2}T_{cool,out}^2 \\ + K_{CT,3}T_{amb,WB}^2 + K_{CT,4}T_{cool,out}T_{amb,WB}\big) = \dot{Q}_{cool} = \dot{Q}_{hot} + \dot{Q}_{ch}\end{aligned} \quad \text{(eq. 3)}$$

$$P_{el,CT} = P_{el,CT,max}\left(\frac{\dot{m}_{air}}{\dot{m}_{air,max}}\right)^3 \quad \text{(eq. 4)}$$

For the solar collector, temperature-dependent heat losses are considered using a linear model:

$$\dot{Q}_{loss} = A_{col}a_1\left(T_{hot,in} - T_{amb}\right) \quad \text{(eq. 5)}$$

The chiller and cooling tower models are parameterized using measurement data, while standard Solar Keymark parameters are used for the solar collector losses. The proposed control framework is inherently modular, allowing individual component models to be replaced or reparametrized.

These models are embedded in an optimization framework that continuously determines the optimal set point $T_{hot,in}^*$ and $T_{cool,in}^*$ which meet the required cooling demand while minimizing operating costs, considering current operating conditions. This is achieved by solving an optimization problem with the cost function

$$cost_{total} = P_{el,CT}\, price_{el} + (\dot{Q}_{hot} + \dot{Q}_{loss})\, price_{th} + |T^*_{hot,in,last} - T^*_{hot,in}|\, price_{\Delta sp} \qquad \text{(eq. 6)}$$

which accounts for electrical energy consumption (of the cooling tower fan), thermal energy consumption from the solar collectors, and penalties for set point variations to ensure stable operation.

Figure 2 shows an exemplary cost function and the optimal $T^*_{cool,in}$ as functions of $T^*_{hot,in}$ for a given cooling demand, chilled water inlet temperature, and ambient humidity at different ambient temperatures. The figure shows that the optimal operating point shifts with ambient temperature. At low $T^*_{hot,in}$, costs increase due to the need for low $T^*_{cool,in}$ and high cooling tower fan speeds, while at high $T^*_{hot,in}$, increased solar collector losses lead to higher costs.

In addition to the optimization-based control of $T^*_{hot,in}$ and $T^*_{cool,in}$, the pump speeds in the hot and cooling water circuits are continuously adjusted based on the current cooling demand, significantly reducing pumping costs under partial load conditions.

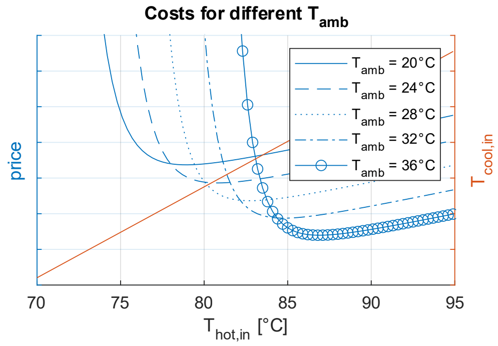

Figure 2: Exemplary cost function and cooling water temperature for different hot water inlet temperature and ambient temperatures (as example of one of the influencing factors)

4. Results

The simulation results demonstrate a clear performance improvement of the proposed model-based control compared to a conventional strategy with fixed cooling water setpoints and constant pump speeds. By dynamically adjusting $T^*_{hot,in}$ and $T^*_{cool,in}$ to changing operating conditions, the approach avoids inefficient operation, such as unnecessarily high cooling tower fan and pump speeds as well as elevated hot water temperatures under partial-load conditions. Electrical energy consumption is reduced by up to 30% through improved coordination of system components (see Table 1), while maintaining closer tracking of the chilled water temperature set point. It should be noted that the cooling water pump in the investigated system is slightly oversized. Therefore, lower savings related to pump operation can be expected in other systems, without affecting the overall benefit of the control approach.

Table 1: Simulation results comparing proposed model (new) to the conventional control strategy (old).

	el. energy cooling tower	**el. energy cooling water pump**	**el. energy hot water pump**	**el. energy total**	**cooling energy**	**solar yield**	**mean error chilled water outlet temp.**
Unit	[kWh]el	[kWh]el	[kWh]el	[kWh]el	[kWh]th	[kWh]th	[K]
old	862	352	45	1,258	4,394	8.017	-1.50
new	688	157	33	879	4,473	8.049	-1.23
old-new	174 (20%)	195 (55%)	11 (25%)	380 (30%)	-79 (-2%)	-32 (0%)	0.26

The control has also been implemented on the real system at the end of the 2025 cooling season and is currently in operation, enabling first experimental results from practical application to be presented at the conference.

The results demonstrate that the proposed model-based control effectively captures system interactions and enables optimized operation, while remaining suitable for implementation in standard PLC environments. A significant reduction in operating costs highlights its practical relevance, indicating that model-based control is a viable and scalable solution to improve the performance and competitiveness of solar cooling systems.

References

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