Task 65

Sunbelt Chiller – An Innovative Solar Cooling Adaption

Technical Features and Life-Cycle Cost-Benefit-Analyses in Comparison to Double Effect Absorption Chiller

In 2016, air conditioning accounted for nearly 20% of the total electricity demand in buildings worldwide and is growing faster than any other energy consumption in buildings. The main share of the projected growth in energy use for air conditioning comes from emerging economies. Recognizing this developing market, in July 2020, IEA SHC Task 65 on Solar Cooling for the Sunbelt Regions began its work on innovations for affordable, safe and reliable solar cooling systems for the Sunbelt region. The "innovation" is the adaptation of existing concepts/technologies to the Sunbelt regions using solar energy.

Solar thermal-driven cooling systems can play an important role in decarbonizing cooling demand worldwide. Especially if, besides cooling demand, there is a demand for heating. One of the most widely used solar thermal cooling systems are two-stage absorption chillers (Double-Effect) powered by concentrating solar collectors. However, in regions like the SunBelt, with high ambient temperatures regularly above 30°C, these systems require a wet cooling tower. Often, in these regions, the availability of water is limited; therefore, wet re-cooling systems cannot be used (for regulatory or economic reasons).

To solve this problem, the Sunbelt Chiller (SBC) was developed within the research project "Solar thermal energy system for cooling and process heating in the Sunbelt region – SunBeltChiller (SBC)" (for more details, refer to SHC Task 65 report, Climatic Conditions and Applications.

The SBC is a modified Double-Effect (DE) absorption chiller. During the daytime, it can be re-cooled in the first stage at high temperatures of up to 90°C with a COP of 0.35 when ambient temperatures are high. The waste heat produced is stored in a hot water energy storage. In the second step, this heat is reused to run the SunBelt Chiller with a COP of 0.75 when ambient temperatures are lower (especially during nighttime) so that a dry cooling tower can be used. Depending on the application, using a cold storage is suitable to cover the cooling demand as required. In summary, this results in the following advantages of the SunBelt Chiller:

- No wet cooling tower needed.
- Reliable operation even at high ambient temperatures.
- High efficiency with an overall COP of up to 1.35.
- High solar cooling coverage reachable.

	Fresnel Collector + DE Chiller	Fresnel Collector + SBC
	Energy demand	
Cooling demand	10.955 MWh/year	
Heating demand	16.433 MWh/year	
Electrical demand	2.191 MWh/year	
	Technical parameters	
Fresnel peak power	1.500 kW	
Nominal cooling power DE/SBC	3.000 kW	
Cold storage size	-	1.000 m^3
Hot storage size	-	1.800 m^3
	Results	
Solar heating energy provided	8.098 MWh/year	
Solar heating coverage	49%	
Solar cooling energy provided	1.701 MWh/year	4.522 MWh/year
Electrical energy demand savings	338 MWh/year	864 MWh/year
Solar cooling coverage	16%	**41%**
Reduction CO_2 emissions for cooling	142 tons/year	363 tons/year
Reduction electrical energy demand for cooling / Reduction CO_2 emissions for cooling	13%	**34%**

▲ Table 1. Energy demand of the considered industrial applications, technical parameters of the DE and SBC, and results of the comparative study.

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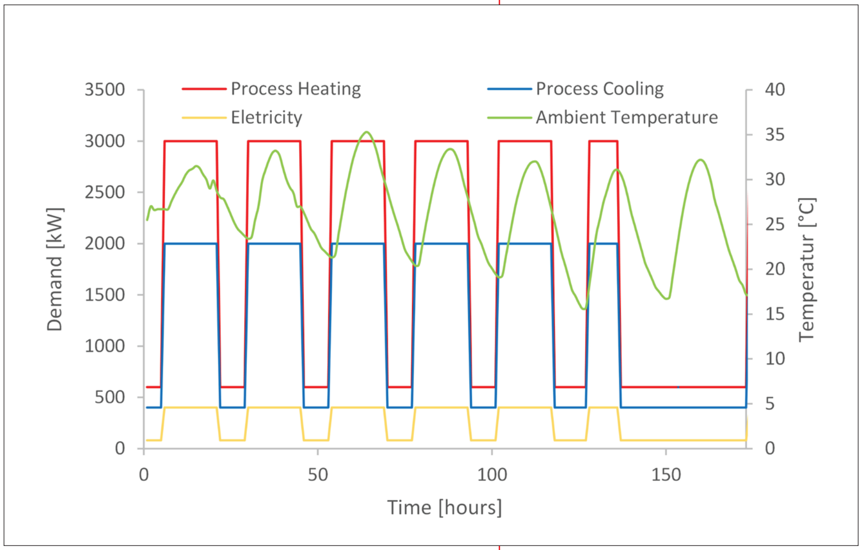
- Highly efficient heat supply at up to 90°C.
- Components are available on the market.

Within the research project, the SBC was evaluated using a comparative study between SBC and DE chiller (each equipped with a dry re-cooler) to assess the economic and ecological advantages. Both systems use concentrated solar collectors (Fresnel collectors) as a heat source to cover the heat requirements of the process and the chillers. To map the energy requirement, load curves for process heating (at 160°C), process cooling (at 6°C) and electricity, the example of an industrial process plant in Windhoek, Namibia, with a typical production cycle (two shifts during the week, rest day on Sunday) was used. The two solar cooling systems have the same installed collector peak power and nominal cooling capacity, but the SBC has hot and cold water storage. Key properties are summarized in Table 1.

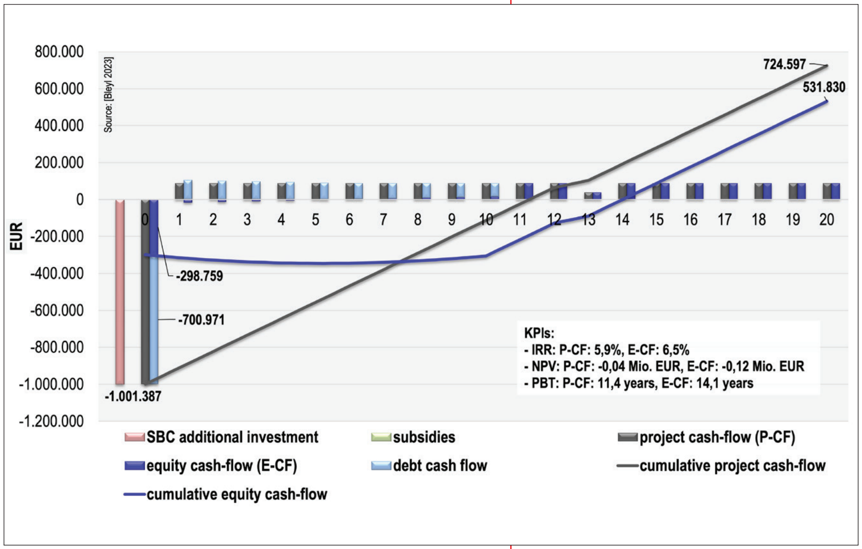


▲ **Figure 1. Plot of energy requirements of the industrial application and the ambient temperature over a week in Windhoek, Namibia.**

As shown in Table 1, both systems are reaching a high solar heating coverage of nearly 50%. However, the DE-Chiller can provide a solar cooling coverage of only 16% due to the limitation of the dry cooling tower operating at high ambient temperatures. SBC, on the other hand, achieves a solar cooling coverage of 41%, thus significantly reducing CO_2 emissions, 221 tons per year.

How does this translate into monetary terms? More precisely,

- What are the economic and financial implications of the additional investment for the SBC?
- How do the additional electricity savings calculated at 150 EUR/MWh impact the SBC business case?
- What would be the effect of an assumed carbon pricing at 90 EUR/ton CO_2?
- Does the project cash flow (CF) support debt service for a 70% loan at a 5% interest rate?



▲ **Figure 2. Investment project and equity cash flows (annual and cumulative), including carbon pricing at 90 EUR/ton CO_2.**

Life-cycle costs and benefits of the SBC business case are modeled over a 20-year project cycle, taking the standard Double-Effect solution as a reference case (baseline). The net CF accounts for revenues from electricity savings and all life-cycle costs (CAPEX, fixed and variable OPEX, as well as 5% re-investment budgets in year 13).

Based on the additional SBC investment cost of 1 million EUR, the project CF reveals a

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cumulative net surplus of 325,000 EUR after 20 years. Its internal rate of return (IRR) stands at 2.9% and has a dynamic payback period of 15.4 years, which would require very low expectations on the investor's side.

If carbon pricing at 90 EUR/ton CO_2 is included, the cumulative net surplus increases to 725,000 EUR with an IRR of 5.9% and a payback of 11.4 years, as depicted in Figure 2.

Regarding financing, the debt service for the 700,000 EUR loan can be covered from the net savings. After the 10-year loan repayment, the net surpluses accrue to the equity investor and amount to a surplus of 532,000 EUR with an IRR of the equity CF of 6.5%.

In conclusion, the SBC is one of only a few solar thermal cooling systems equipped with a dry re-cooling tower that can reach significant solar cooling coverage and CO_2 emissions savings despite high ambient temperatures. CO_2 savings are almost three times higher than a similar solar cooling system with a DE chiller.

Economically, the SBC investment still requires a long-term business case. Feasibility is greatly increased by a remuneration for avoided CO_2 emissions (and other 'Multiple Benefits' of reduced fossil fuel consumption).

It is also interesting to note that the SBC payback period is just 6 months longer than a standard DE solution (compared to a conventional compression chiller + natural gas heating solution). In any case, the availability of long-term and reasonably cheap (WACC (Weighted Average Cost of Capital) ≤ 6.5%) financing options is a key pre-requisite (as for many renewable, decarbonized supply options).

More technical design features and findings on the economic and financial life-cycle cost-benefit comparison of different electricity heating and cooling supply options will be published in an upcoming SHC Task 65 report (planned for January 2024). And, ZAE Bayern is currently setting up a laboratory system with a cooling capacity of approximately 50 kW to demonstrate the SBC. The next step will be a proof of concept at a larger scale (> 500 kW) under actual operating conditions.

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