hycool©
Solar Cooling Systems

Hybrid Heat Pump

MEASUREMENT PROTOCOL AND EXAMPLE OF RESULTS

This project has received funding from the H2020 programme under Grant Agreement No. 792073

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- Testing procedure and data reduction
- Examples of HYCOOL hybrid chiller measurement

Understanding the measurement: aim and background /1

The measurement procedures and protocol arise from the answer to two questions:

«Why are we doing the measurement?»

«What do we want to measure?»

Different answers lead to different outcomes. For instance, the need for certification leads to the necessity of following a certification manual, whereas if a lab assessment of a chiller's energy perfomance is needed, measurement in a controlled environment is chosen. If, on the contrary, measurement has to take place in operational environment and conditions, different procedures might be adopted.

Accordingly, also different parameters can be of importance. For lab assessment purposes, temperatures are generally set and the measurement focuses on the parameters related to the capacity and efficiency of the chiller, but in measurement in operational environment, the temperatures reached in all the circuits of the chiller are of the uttermost importance.

Understanding the measurement: aim and background /2

The evaluation of chiller performance is generally based on some standards. Currently, in the EU, the requirements for chillers are set by the **Ecodesign directive for heating and cooling products** (https://ec.europa.eu/growth/single-market/european-standards/harmonised-standards/ecodesign/energy-related-products_en).

According to this directive, the key parameter for air heating products is the seasonal space heating energy efficiency; for cooling products, the seasonal space cooling energy efficiency; and for high temperature process chillers, the seasonal energy performance ratio. However, also NOx requirements and information requirements might be needed.

Understanding the measurement: aim and background /3

The prescribed parameters are shown in the table below.

Water-cooled, having leaving chilled water temperature ≥ 2° C.

		Space heating or cooling energy efficiency	Emissions of nitrogen oxides	Information requirements
TIER I		01/01/2018	26/08/2018	1/1/2018
TIER II		01/01/2021	01/01/2021	-
Warm air heaters	**using fuel**	✓	✓	✓
	using electricity	✓	N.A.	✓
Comfort chillers	**combustion engine**	✓	✓	✓
	electric	✓	N.A.	✓
Air-to-air air conditioners	**combustion engine**	✓	✓	✓
	electric	✓	N.A.	✓
Water/brine-to-air air conditioners		N.A.	N.A.	✓
Fan coil units		N.A.	N.A.	✓
Heat pumps	**combustion engine**	✓	✓	✓
	electric	✓	N.A.	✓
High temperature process chillers		✓	N.A.	✓

Meant to provide cooling to a refrigerated appliance or system and not to provide cooling of a space for the thermal comfort of human beings.

Understanding the measurement: aim and background /4

The Ecodesign directive applies also to sorption chillers and heat pumps (even though its applicability will be the subject of a scheduled revision in 2022), but it does not apply to hybrid sorption/compression chillers.
Nonetheless, since the directive recommends to prefer measurements and calculations done by using harmonised standards, it is useful to make reference to that in the measurement of hybrid chillers.
The limits for the key parameters are given in:

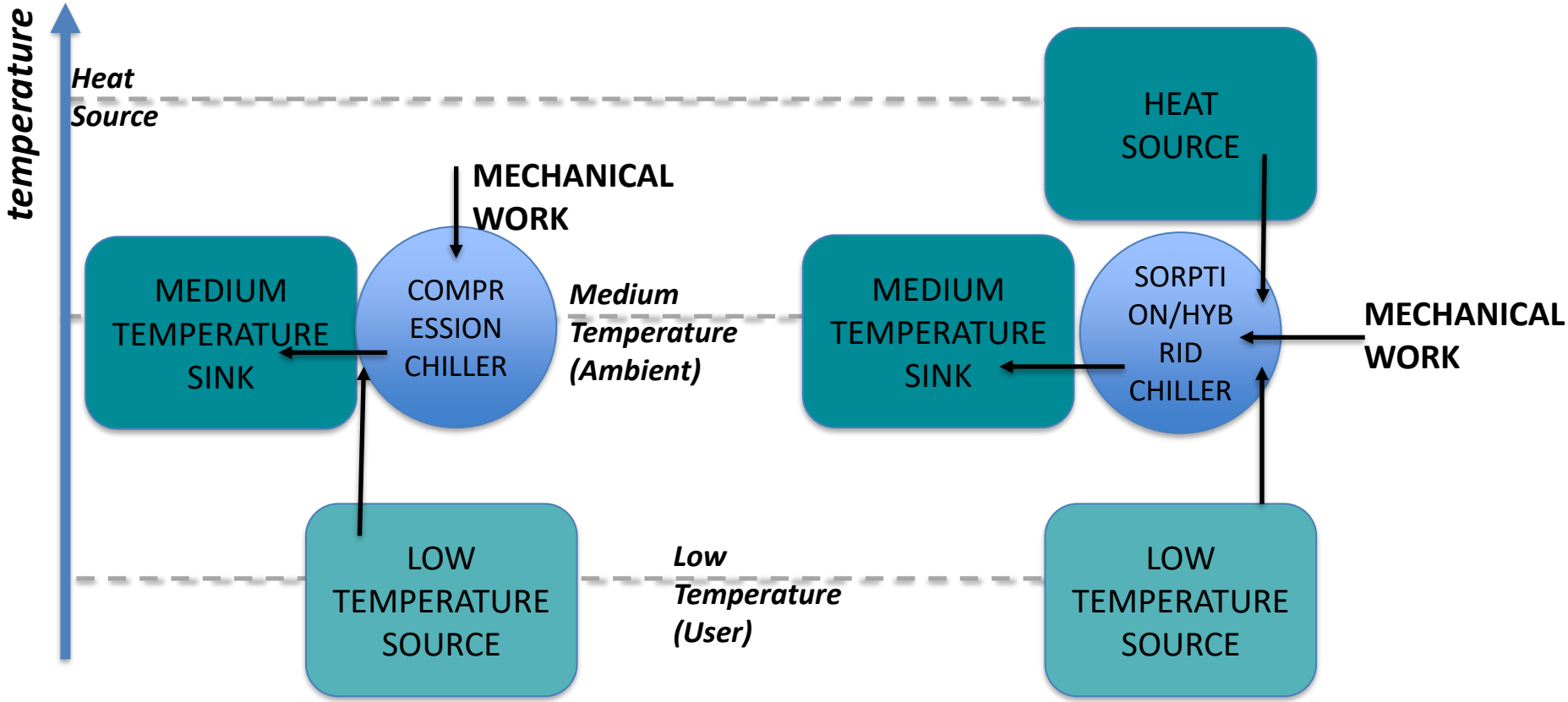
2015 LT & MT Regulations 2015/1095 :
http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32015R1095&from=EN
2016 HT & Comfort Regulations 2016/2281 :
http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32016R2281&from=EN

The parameters that should be calculated and that are explained in the following are:

- **Seasonal energy performance ratio**
- **Refrigeration capacity**
- **Energy efficiency ratio**
- **Thermal COP**

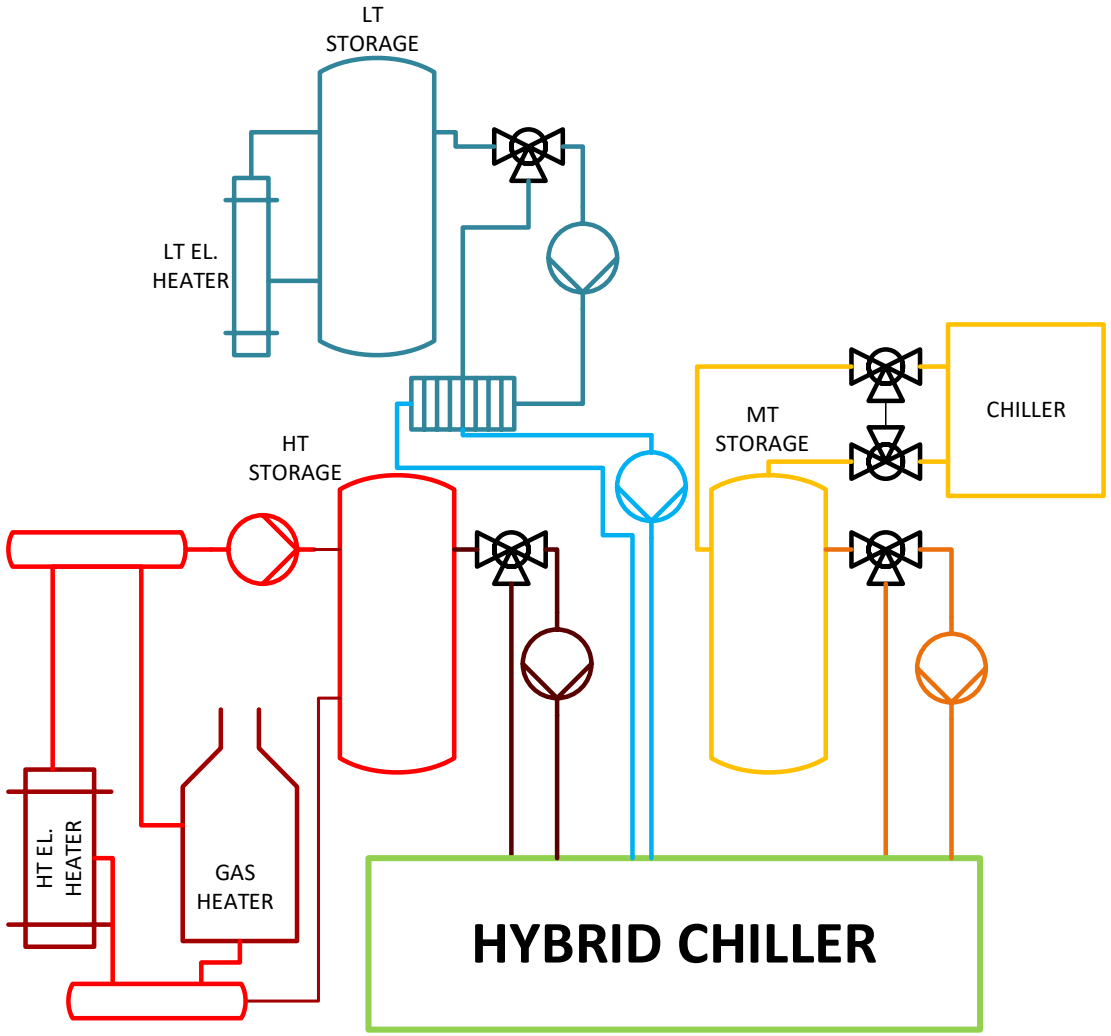
Testing procedure/1: Requirements of a testing rig

A compression chiller works between two thermal sources: the medium temperature side (condenser) and the low temperature side (evaporator). A sorption chiller and a hybrid chiller work between three different temperature levels: high temperature heat source (source for the regeneration of the sorbent), medium temperature (condenser) and low temperature (evaporator).



Testing procedure/2: Requirements of a testing rig

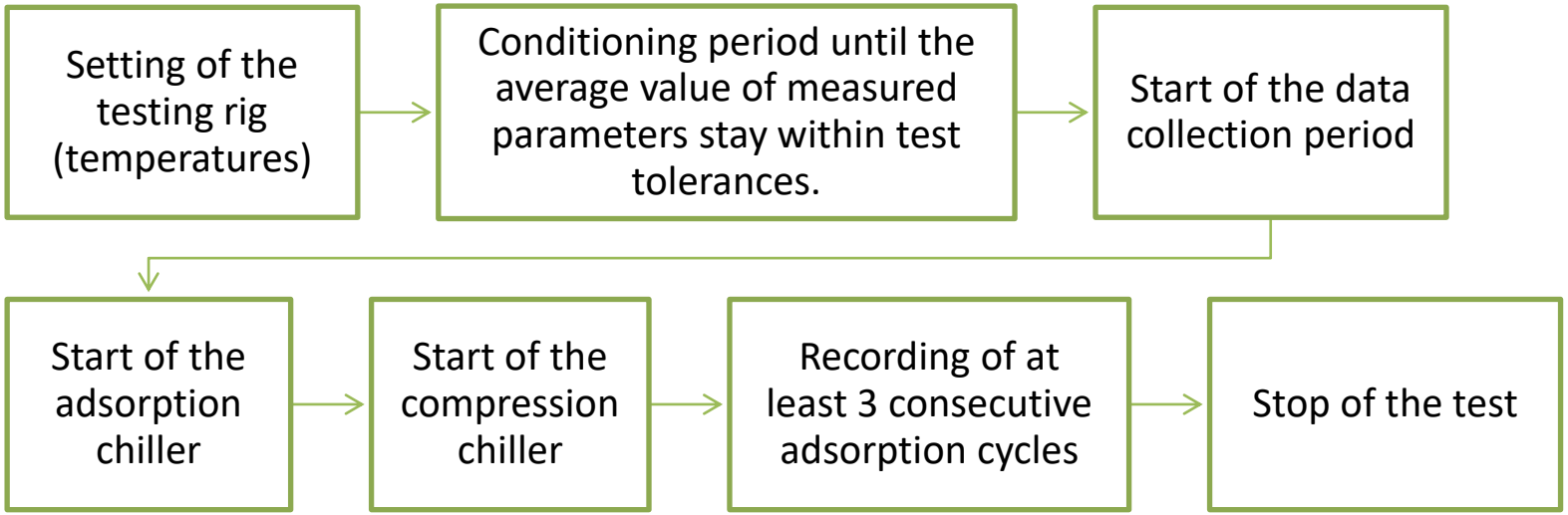
Consequently, the testing rig should include the elements to supply the required temperature levels and capacity. Therefore, it should contain heat sources for high and low temperature and the equipment to dissipate heat at medium temperature. In order to guarantee constant temperatures, usually storages are included in the installation.



Example of the testing rig at CNR ITAE.

Testing procedure/4: testing procedure followed for HYCOOL hybrid chiller

Since no standard exists for adsorption and hybrid chillers, the protocols described in the standards EN12309, (for gas-fired sorption appliances), EN14511 and EN14825 (for electrically driven appliances) have been adapted to meet the peculiarities of their (*discontinuous*) working operation (see Melograno et al., https://www.sciencedirect.com/science/article/pii/S1876610216303861).



Testing procedure/5: Data reduction

Calculation of thermal power at each circuit:

- If a heat meter is installed, it can be directly measured using the heat meter.
- Otherwise, thermal power can be derived from temperatures and flow rate:

$$\dot{Q} = \dot{m} c_p (T_{in} - T_{out})$$

Where Q is the instant power in kW, $\dot{m}$ is the mass flow rate in the circuit in kg/s, c_p is the specific power of the heat transfer fluid and T_{in} and T_{out} are the inlet and outlet temperatures of the circuit considered.

The refrigeration capacity of the chiller is the thermal power measured at the low temperature circuit.

Calculation of electric power:

- If an electricity meter is installed, it can be directly measured using the electricity meter.
- Otherwise, if a current meter is installed, the electric power can be derived from the current and the rated voltage:

$$P_{el} = VA$$

Testing procedure/5: Data reduction

Calculation of Energy Efficiency Ratio:

The Energy Efficiency Ratio is the ratio between the cooling capacity of the chiller at a certain temperature condition and the electricity consumption in the same conditions:

$$EER = \frac{\dot{Q}_{chill}}{P_{el}}$$

The EER will change as a function of operating conditions, i.e. temperature levels at the different components.

As such, a performance map can be derived. According to the standards, however, a single value of **Seasonal EER should be given**.

Testing procedure/7: THERMAL COP

Calculation of Thermal COP:

The thermal COP of the sorption chiller in the hybrid is the ratio between the heat supplied and the cooling powered delivered at the evaporator

$$COP = \frac{\dot{Q}_{low\ T\_sorption}}{\dot{Q}_{heat}}$$

Testing procedure/6: SEER

European Seasonal Energy Efficiency Ratio

According to the European standard, the seasonal energy efficiency ratio *SEER* shall be calculated as the ratio of the reference annual cooling demand Q_C and the reference annual energy consumption for cooling Q_{CE}, *where:*

- 'reference annual cooling demand' (Q_C) means the reference cooling demand to be used as basis for calculation of *SEER* and calculated as the product of the design cooling load ($P_{design,c}$) and the equivalent active mode hours for cooling (H_{CE}), expressed in kWh.
- annual energy consumption for cooling' (Q_{CE}) means the energy consumption required to meet the 'reference annual cooling demand' and is calculated as the 'reference annual cooling demand' divided by the 'active mode seasonal energy efficiency ratio' ($SEER_{on}$) and the electricity consumption of the unit for thermostat-off, standby, off and crankcase heater mode during the cooling season, expressed in kWh;
- 'equivalent active mode hours for cooling' (H_{CE}) means the assumed annual number of hours the unit must provide the 'design cooling load' ($P_{design,c}$) in order to satisfy the 'reference annual cooling demand', expressed in hours.

All the values needed are given in tables in the COMMISSION REGULATION (EU) 2016/2281.

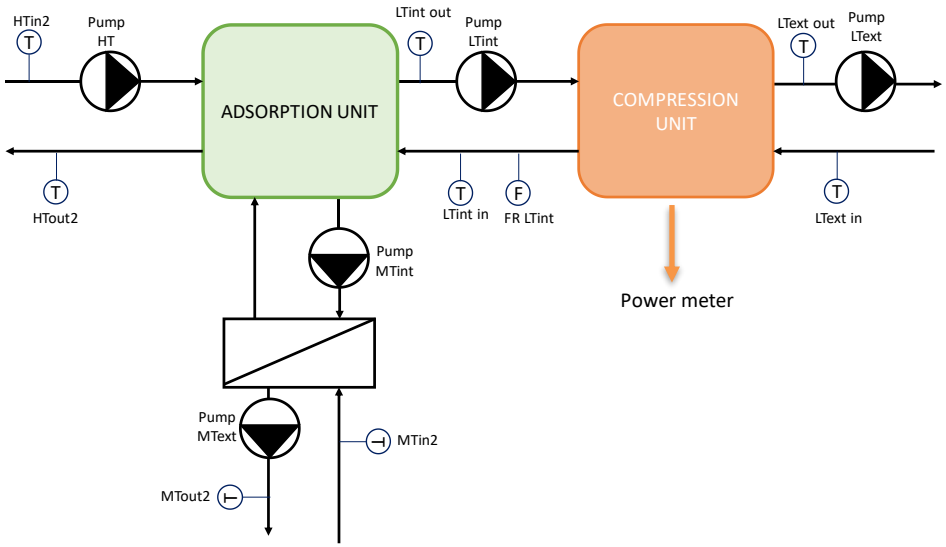
Operational hours per functional mode for comfort chillers, air conditioners and heat pumps

Season		Operational hours				
		On-mode	Thermostat Off mode	Standby mode	Off mode	Crankcase heater mode
		H_{CE} (cooling); H_{HE} (heating)	H_{TO}	H_{SB}	H_{OFF}	H_{CK}
Cooling (to calculate *SEER*)	Average	600	659	1 377	0	2 036
	Colder	300	436	828	0	1 264
	Warmer	900	767	1 647	0	2 414

Standard rating conditions for water/brine-to-water comfort chillers

		Outdoor side heat exchanger		Indoor side heat exchanger	
		inlet temperature °C	outlet temperature °C	inlet temperature °C	outlet temperature °C
Cooling mode	water-to-water (for low temperature heating applications) from cooling tower	30	35	12	7
	water-to-water (for medium temperature heating applications) from cooling tower	30	35	23	18

Examples of HYCOOL hybrid chiller measurement at ITAE

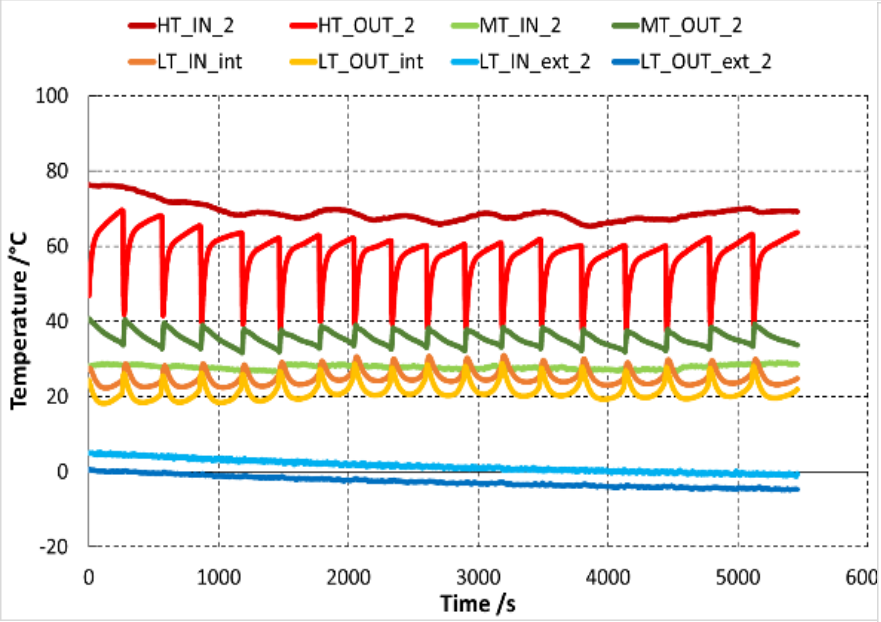


Schematic of the installation and sensors

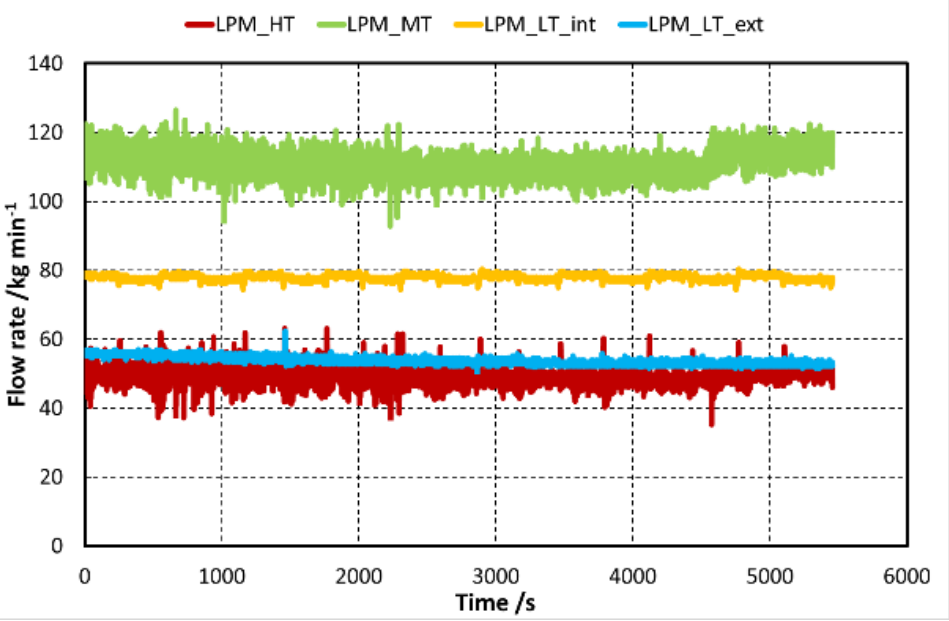
The hybrid system installed in the lab of CNR.

Examples of HYCOOL hybrid chiller measurement at ITAE

Parameters directly measured from installed sensors



Temperatures



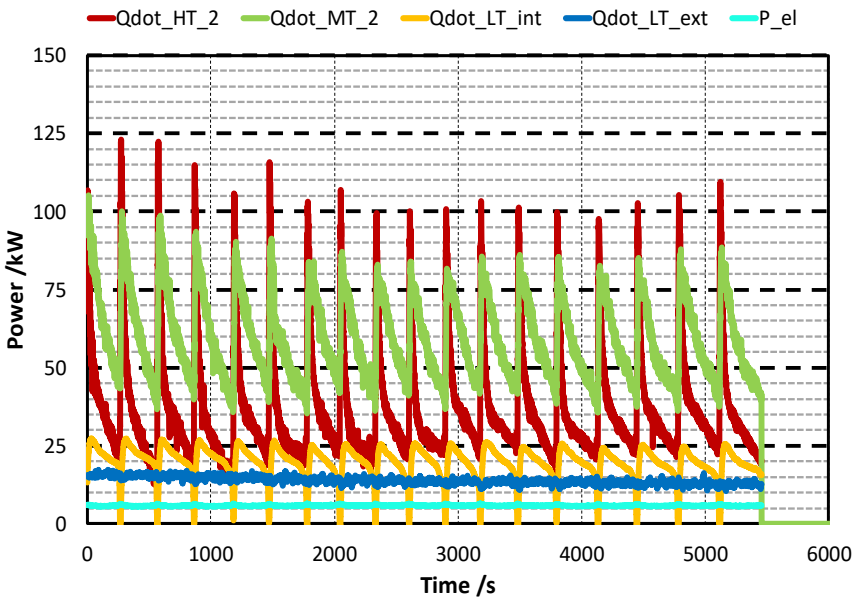
Flow rates

→ It is possible to clearly distinguish the different cycles of the adsorption chiller.

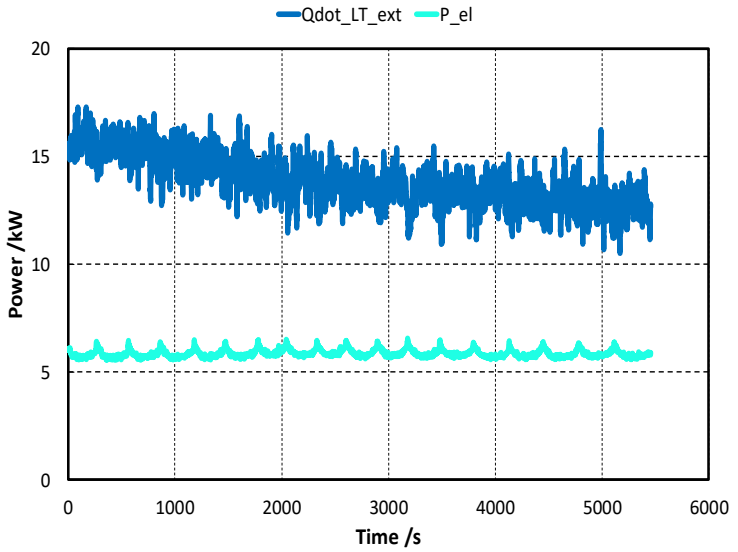
→ Peaks mark the switch between the phases.

Examples of HYCOOL hybrid chiller measurement at ITAE

Thermal and electric power



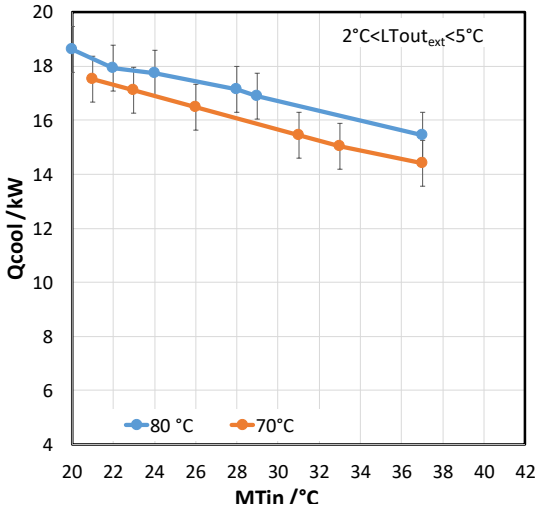
The thermal powers are consistent with cyclic operation.

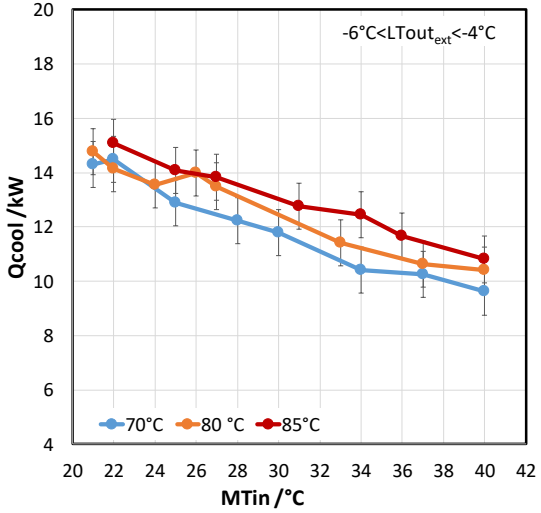


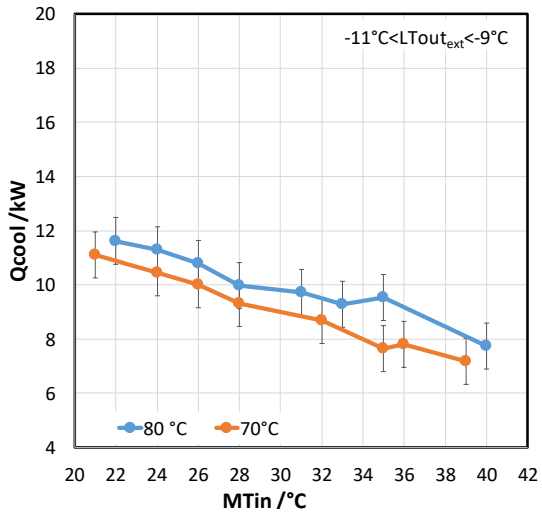
The electric power has a cycle trend as well, due to the variable temperature during the cycle.

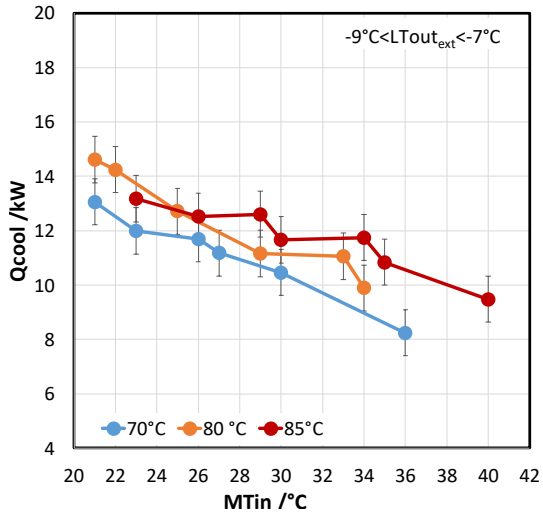
Examples of HYCOOL hybrid chiller measurement at ITAE

Aggregated results – cooling power as a function of operating temperatures



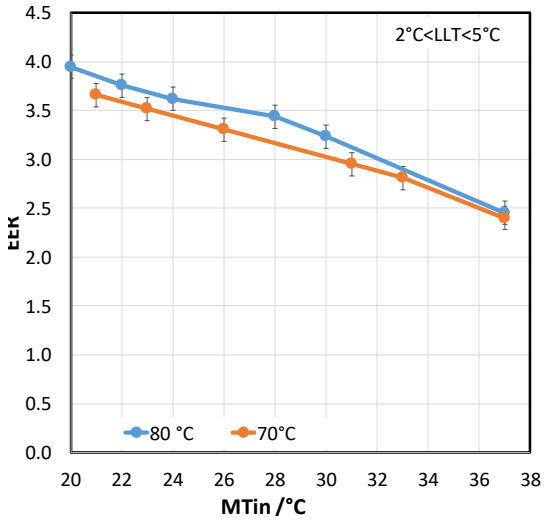


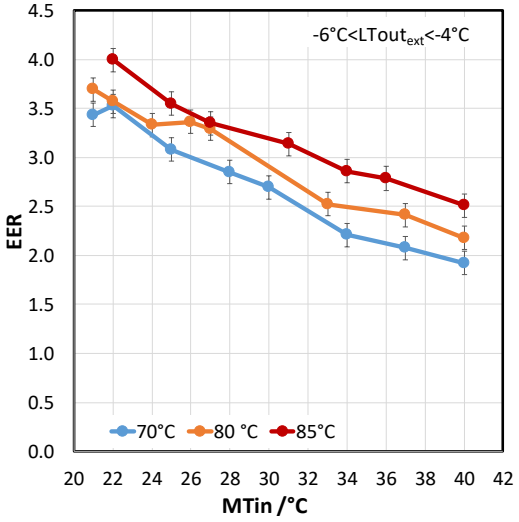


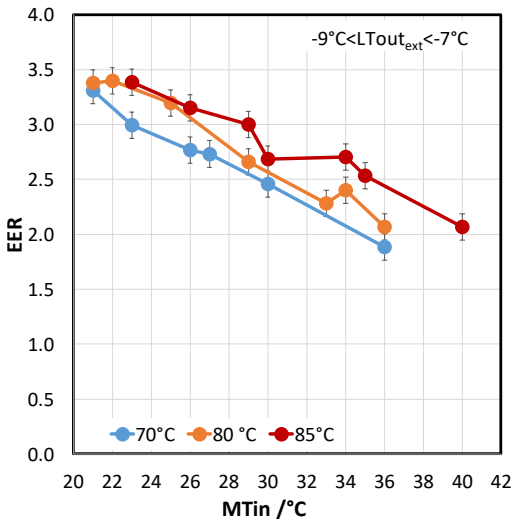


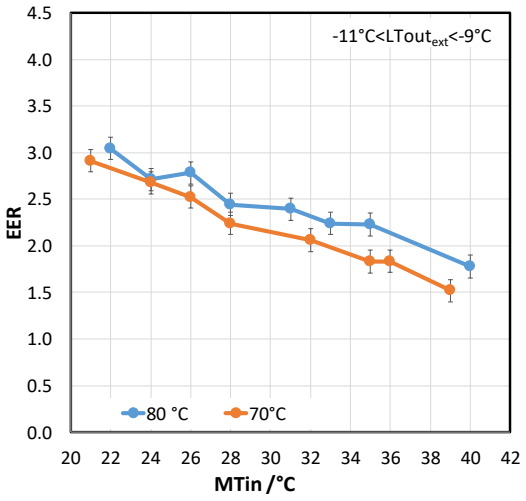
Examples of HYCOOL hybrid chiller measurement at ITAE

Aggregated results – EER as a function of operating temperatures



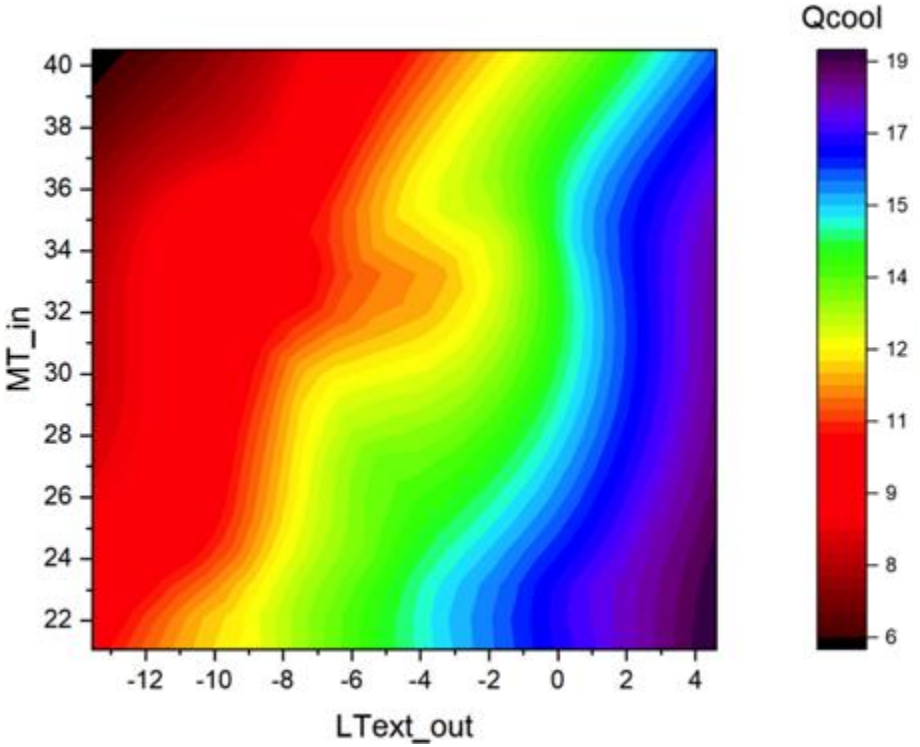




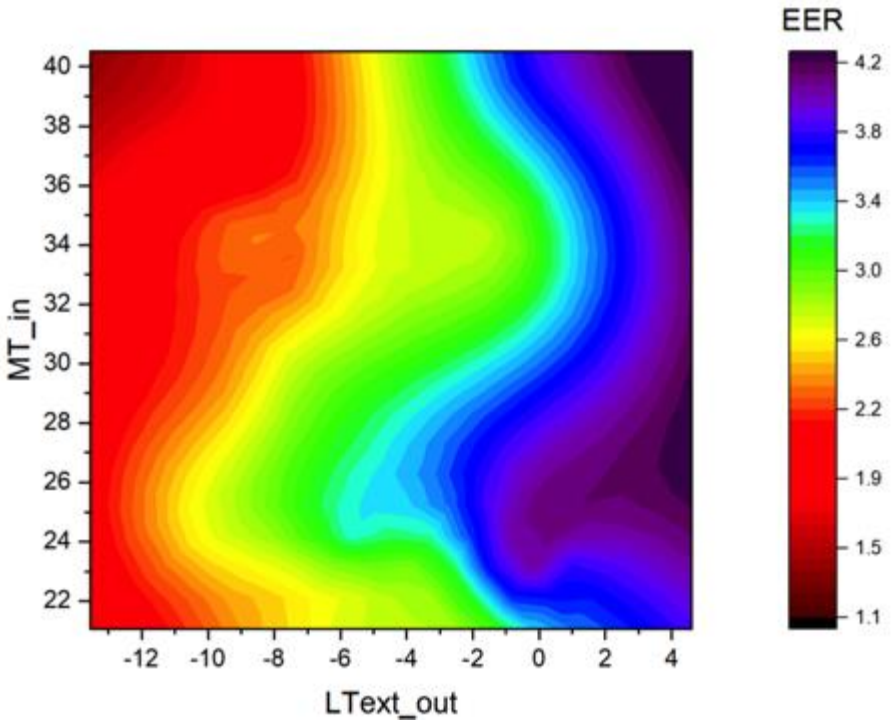


Examples of HYCOOL hybrid chiller measurement at ITAE

Aggregated results –performance maps



cooling power in different condensation and evaporation conditions for heat source temperature of 85-90° C.



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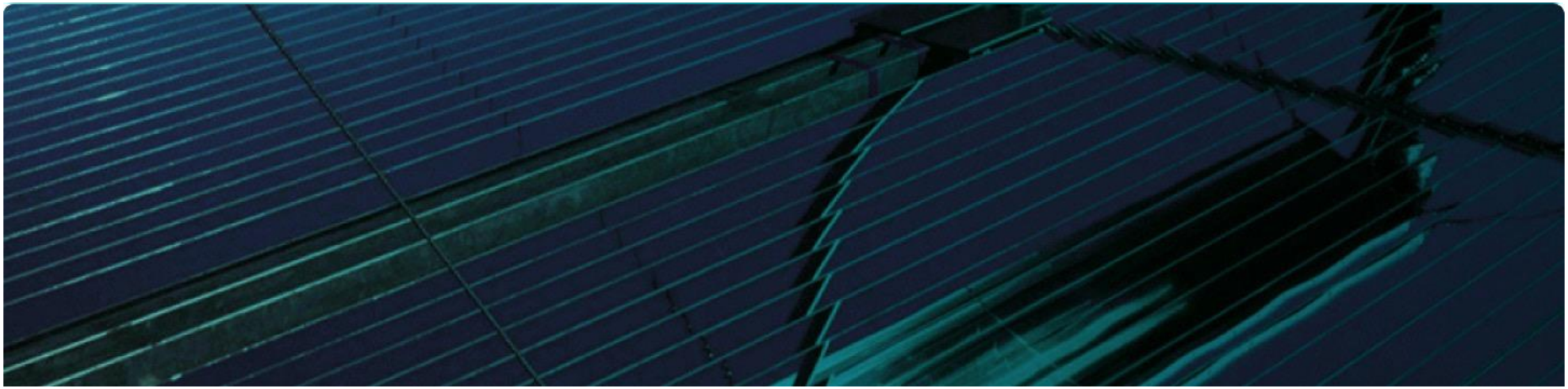

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