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**Building Integration of Solar Thermal Systems – TU1205 – BISTS**

# Solar Heating and Cooling Systems

Presented by: Dr. Georgios Florides

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## Solar Space–heating and Cooling

- A solar space –heating and Cooling system can consist of a passive system, an active system, or a combination of both
- Passive Solar Systems use the advantages of the sun in a building and are of Low-technology
- Active Solar Systems use the sun to create hot water, hot air or electricity and are of High-technology

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The diagram shows three passive heating strategies:

- Direct Gain:** A house with a large window facing the sun. Red arrows indicate heat entering through the window and being distributed throughout the room.
- Thermal Storage Wall:** A house with a window and a thick wall. Red arrows show heat entering through the window and being stored in the thick wall.
- Sunspace Wall:** A house with a window and a glass-enclosed sunspace. Red arrows show heat entering through the window and being stored in the sunspace, which then heats the main living space.

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The diagram shows three passive cooling strategies:

- Shading:** A house with a large window and a horizontal overhang. Red arrows show how the overhang shades the window, preventing direct sunlight from entering.
- Ventilation:** A house with a window. Red arrows show air entering through the window and moving through the room, providing cooling.
- Earth Contact:** A house with a window and a ground connection. Red arrows show heat from the house being transferred to the earth, providing cooling.

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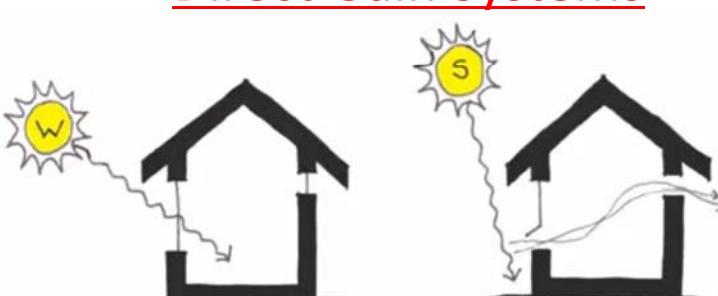
### Systems and Parameters of Passive Solar Air-conditioning

- Direct Gain Systems
- Indirect and Isolated Gain systems
- Building Orientation
- Solar Shading
- Thermal Mass
- Glass Type
- Ventilation
- Room Arrangement
- Daylight

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### Direct Gain Systems



Heating  
In winter the sun is low

Cooling  
In summer the sun moves higher

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## Design features

<b>Area of Glass on South per Floor Area</b>				
Average Winter Temp.	36° N	40° N	44° N	48° N
20° F, -7° C	<b>0.24</b>	<b>0.25</b>	<b>0.29</b>	<b>0.31 w/ night insulation</b>
25° F, -4° C	<b>0.22</b>	<b>0.23</b>	<b>0.25</b>	<b>0.28 w/ night insulation</b>
30° F, -1° C	<b>0.19</b>	<b>0.20</b>	<b>0.22</b>	<b>0.24</b>
35° F, 2° C	<b>0.16</b>	<b>0.17</b>	<b>0.19</b>	<b>0.21</b>
40° F, 4° C	<b>0.13</b>	<b>0.14</b>	<b>0.16</b>	<b>0.17</b>
45° F, 7° C	<b>0.10</b>	<b>0.11</b>	<b>0.12</b>	<b>0.13</b>
50° F, 10° C				

\*clear days in December and January. This can be found online.  
From "The Passive Solar Design and Construction Handbook" by Steven Winter Associates

Table applies when the house has the proper thermal mass, in which case the heating savings can be as much as 80%

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## Indirect Gain Systems

- Absorb heat during the day and transfer it slowly into the space during the whole day
- Obstruct daylight and view

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**Design features**

<b>Area of Thermal Storage Wall per Floor Area</b>				
Average Winter Temp.*	36° N	40° N	44° N	48° N
20° F, -7° C	0.71	0.75	0.85	0.98 Insul.
25° F, -4° C	0.59	0.63	0.75	0.84 Insul.
30° F, -1° C	0.50	0.53	0.60	0.70
35° F, 2° C	0.40	0.43	0.50	0.55
40° F, 4° C	0.32	0.35	0.40	0.44
45° F, 7° C	0.25	0.26	0.30	0.33
50° F, 10° C				

\* clear days in December and January. This can be found online.  
Insul. = with insulation covering glass at night. Recommended for other locations too.  
From "The Passive Solar Design and Construction Handbook" by Steven Winter Associates

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**Isolated Gain Systems**

**THERMOSIPHON**

- The system uses convection
- Most efficient but expensive system

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## Building Orientation

The diagram illustrates the sun's path across the sky for two extreme seasonal conditions: Winter Solstice and Summer Solstice.

- WINTER SOLSTICE:** The sun is low in the sky. At solar noon, the sun is at an angle of 27° above the horizon. At sunset, it is at 30°. At sunrise, it is at 30°. The building is oriented North (N) and South (S).
- SUMMER SOLSTICE:** The sun is high in the sky. At solar noon, the sun is at 74° above the horizon. At sunset, it is at 72°. At sunrise, it is at 27°. The building is oriented North (N) and South (S).

To avoid heating in summer:

- Minimize glass on east and west
- Plant trees on east and west

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## Solar Shading

- Block the high summer sun externally,  $X = \text{latitude} + 20^\circ$
- Allow the low winter sun in,  $Y > \text{sun angle at solstice}$
- Use roof overhangs, external shutters louvers etc

**SOLAR SHADE SIZING**

The diagram shows a cross-section of a building facade with a window. A horizontal line labeled 'A' indicates the height of the window. A vertical line labeled 'B' indicates the width of the window. A diagonal line labeled 'X' represents the high summer sun angle. A dashed line labeled 'Y' represents the low winter sun angle. The diagram illustrates how a solar shade must be angled to block the high summer sun while allowing the lower winter sun to reach the window.

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## Thermal Mass

- Any dense material used inside a building to store heat energy
- Most effective when spread out in walls , located in direct sunlight
- At least 0.3-1 m<sup>2</sup> of 10cm thick thermal mass per 0.3m<sup>2</sup> of south glass



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## Glass Type

- Use multi-pane glass with U-factor<0.35 and low-E
- Tune glass to solar orientation. Use low SHGC glass on east and west
- Avoid skylights since the roof is the area of the biggest heat gain in summer

 <b>World's Best Window Co.</b> Millennium 2000+ Vinyl-Clad Wood Frame Double Glazing - Argon Fill - Low E Product Type: Vertical Slider  <b>ENERGY PERFORMANCE RATINGS</b> U-Factor (U.S./I-P) <b>0.30</b> Solar Heat Gain Coefficient <b>0.30</b>  <b>ADDITIONAL PERFORMANCE RATINGS</b> Visible Transmittance <b>0.51</b> Air Leakage (U.S./I-P) <b>0.2</b>	
<small>Manufacturer indicates that these ratings conform to applicable NFRC procedures for determining whole window performance. Ratings are based on specific window size and configuration. Actual performance may vary due to specific product size. NFRC does not recommend any product and does not warrant the suitability of any product for any specific use. Consult manufacturer's literature for other product performance information. <a href="http://www.nfrc.org">www.nfrc.org</a></small>	

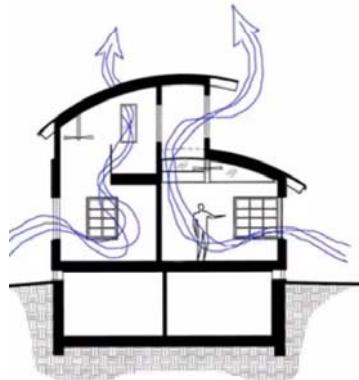
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## Ventilation

- In summer use convection to bring in cool night air
- Induce cross ventilation for better mixing
- Use ceiling fans to avoid stratification



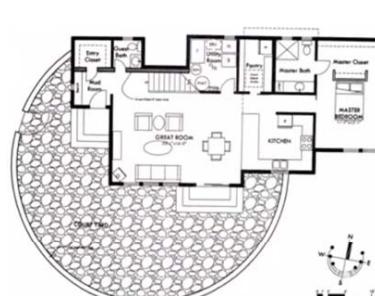
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## Room Arrangement

- Frequently used rooms must be located on the south and rooms with low use on the north side
- Use an open floor plan for ventilation and heat comfort and increased day-lighting



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## Day Lighting

- Sunlighting promotes health and saves energy
- Bring in light with clearstory windows
- Balance light
- Design circulation areas of rooms next to southern glass
- Avoid skylights



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## Other important strategies

- Use insulation especially on the roof
- Air-seal the building
- Prefer light-coloured roof
- Use high-efficiency appliances and lighting
- Use local and green materials if possible.



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## Active solar space heating systems

- Active solar space heating systems consist of collectors that collect and absorb solar radiation combined with electric fans or pumps to transfer and distribute the heat
- Active systems also may have an energy storage system to provide heat when the sun is not shining.

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## Basic techniques to provide space heating in cold climates using solar thermal collectors

- Direct Solar Heating
- Water Storage Solar Heating
- High Mass Solar Heating

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## Direct Solar Heating

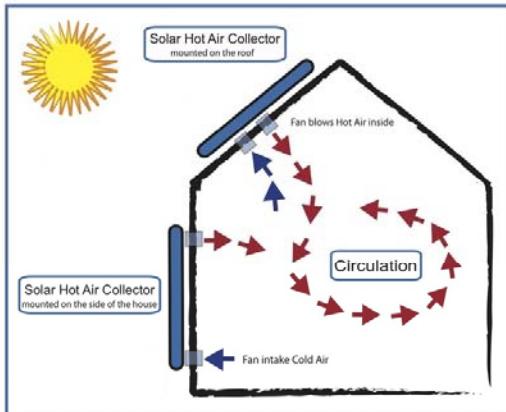
- Direct solar heating systems are the simplest and least expensive solar space heating systems. There is no storage medium for the collected solar energy other than the thermal mass that already exists in the house. On sunny days during the heating season, the heat is simply transferred into the house as it is collected.

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## Space heating-Solar Hot Air Collector

Solar Hot Air Collectors use the power of the sun to generate heat. A powered fan is used to distribute the hot air into the desired area.



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## Air collectors - SolarDuct®



SolarDuct is a solar heating system that heats ventilation air before it enters the air handling units. The system uses an all-metal collector panel (transpired solar collector). Perforations in the panels allow the heat that normally collects on a dark surface to be uniformly drawn through the SolarDuct panel and then ducted into the conventional HVAC system.

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## Water Storage Solar Heating

- A water storage solar heating system stores the collected heat in a water tank. After the heat has been delivered to the storage tank, it can be distributed to the building.

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## Active solar space heating systems

The diagram illustrates an active solar space heating system. A solar collector is mounted on a building's roof, receiving direct sunlight. The collected heat is transferred through a fluid loop consisting of a pump, a controller, and a tank. The tank contains a coil that heats the fluid. This heated fluid can either be directed to a heating system or returned to the collector for further heating. Additionally, a separate boiler provides heat to the tank via a cold water feed line.

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## Solar Collector types

		Collector Type	Concentration Ratio, $C_1$ for Direct Insolation	Indicative Temperature Obtained T (K)
		Name	Schematic Diagram	
<b>Motion</b>	<b>Stationary</b>	Non-convecting Solar Pond		$C \leq 1$ $300 < T < 360$
		Flat-plate Absorber		$C \leq 1$ $300 < T < 350$
<b>Motion</b>	<b>Single Axis</b>	Evacuated Envelope		$C \leq 1$ $320 < T < 460$
		Compound Parabolic Reflector		$1 \leq C \leq 5$ $340 < T < 510$ $5 \leq C \leq 15$ $340 < T < 560$
<b>Motion</b>	<b>Solar Tracking</b>	Parabolic Reflector		$15 < C < 40$ $340 < T < 560$
		Fresnel Refractor		$10 < C < 40$ $340 < T < 540$
<b>Motion</b>	<b>Two Axis</b>	Cylindrical Refractor		$10 < C < 50$ $340 < T < 540$
		Parabolic Dish Reflector		$100 < C < 1000$ $340 < T < 1200$
		Spherical Bowl Reflector		$100 < C < 300$ $340 < T < 1000$
		Heliostat Field		$100 < C < 1500$ $400 < T < 3000$

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**Solar Collector Efficiency**

Difference between collector and ambient temperature (°C)	Evacuated tube collector (%)	Flat plate collector (%)	Unglazed collector (%)
0	80	80	80
20	75	70	60
40	70	60	40
60	65	50	30
80	60	40	20
100	55	30	15
120	50	20	10
140	45	15	5

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**High Mass Solar Heating**

- In this type of system, the solar energy is stored in an insulated, compacted sand bed that is usually 1 m deep and is located directly under the building. Collected heat is delivered to and stored in the sand bed using a grid of tubes. The storing of solar heat begins in late summer. When the sand bed becomes warm, and outside temperatures drop, the stored heat will slowly rise up into the building, warming the floors and the whole building, though provisions for air movement.

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## High Mass Solar Heating

The diagram illustrates a high mass solar heating system integrated into a building. A yellow arrow labeled "Cold water in" enters a vertical pipe on the left side of the building's wall. This pipe leads to a yellow rectangular component labeled "Collector". From the collector, the pipe continues upwards and to the right, passing through a red rectangular component labeled "Storage tank". A purple arrow labeled "Hot water out" exits from the top of the storage tank. The building's roof is pink, and the interior is yellow.

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## Active solar space cooling systems

- Night cooling
- Adsorption cooling
- Absorption cooling

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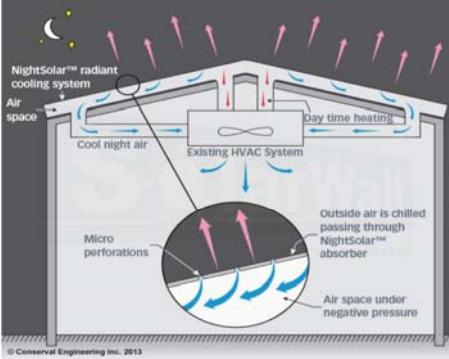
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## Active Solar Cooling Systems

### The NightSolar® system



This technology is partly based on nocturnal sky radiation, which can cool a roof by as much as 10° C below ambient temperature on a clear night. The warm night air touches the cooler surface of the system and it cools. The chilled air is then drawn in through perforations in the collector and enters the HVAC unit via an economizer cycle. This cooling reduces the use of conventional air conditioning. During the daytime, the system reduces daytime heat gains normally received through the roof.

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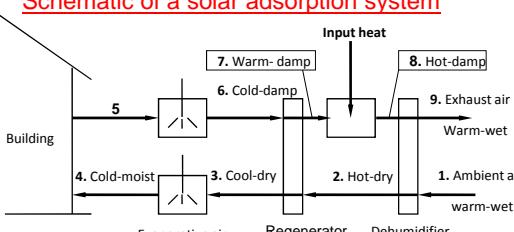
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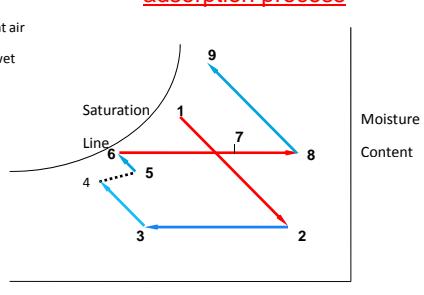
## Adsorption cooling

### Schematic of a solar adsorption system



Solid adsorbents: silica gels, zeolites, activated aluminas, carbons and synthetic polymers. Liquid adsorbents: triethylene glycol solutions of lithium chloride and lithium bromide solutions.

### Psychrometric diagram of a solar adsorption process



Adsorption cooling is a group of sorption air conditioners that utilises an agent to adsorb the moisture from the air and then uses the evaporative cooling effect to produce cooling. Solar energy can be used to regenerate the drying agent.

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## Adsorption cooling

### Rotary solid desiccant systems

• Most common systems for continuous removal of moisture from the air.  
 • The desiccant wheel rotates through two separate air streams.  
 • In the first stream the process air is dehumidified by adsorption, which does not change the physical characteristics of the desiccant.  
 • In the second stream the reactivation or regeneration air, which is first heated, dries the desiccant

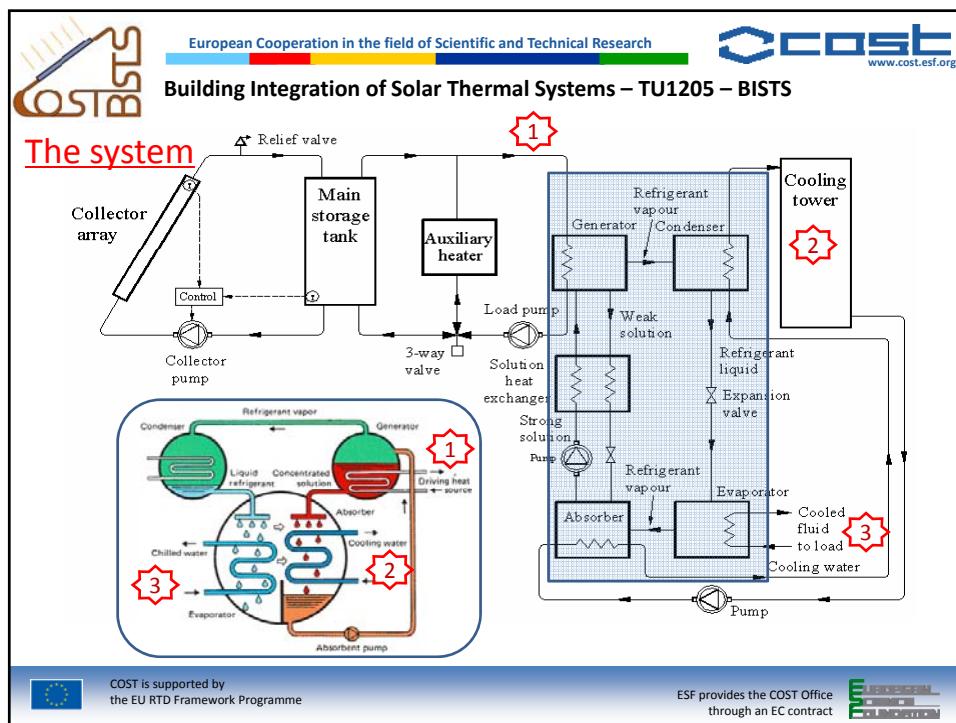
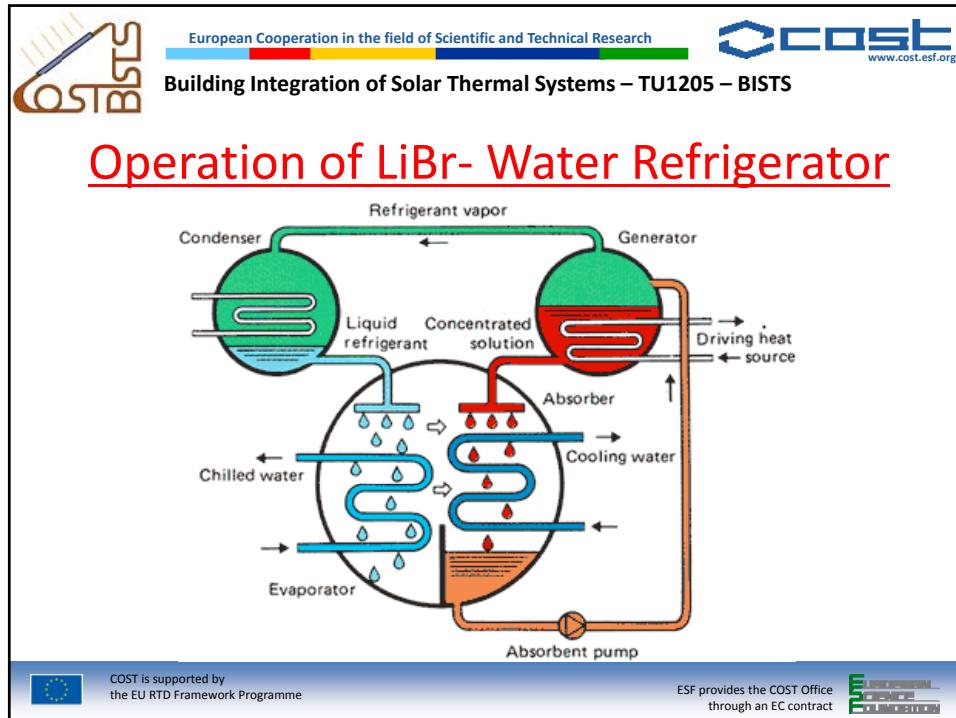
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## Absorption machines

- Absorption machines are thermally activated and for this reason, high input (shaft) power is not required. In this way, where power is unavailable or expensive then gas, geothermal or solar heat can be used. Absorption machines provide reliable and quiet cooling
- In absorption systems an absorbent, on the low-pressure side, absorbs an evaporating refrigerant. The most usual combinations of fluids include lithium bromide-water (**LiBr-H<sub>2</sub>O**) where **water** vapor is the refrigerant and ammonia-water (**NH<sub>3</sub>-H<sub>2</sub>O**) systems where **ammonia** is the refrigerant
- Lithium bromide-water chillers are available in two types, the single and the double effect. The single effect absorption chiller is mainly used for building cooling loads, where **chilled water** is required at **6-7° C**. Their coefficient of performance (**COP**) is about **0.7**. They *operate with a hot water temperature ranging from about 80° C to 120° C* when water is pressurized, whereas for the double effect much higher temperatures are required.

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Solar collectors



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LiBr Absorption cooler



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**Auxiliary system**

**BMS showing the condition of the Solar panels**

**SOLAR PANELS**

Panel	Temperature (°C)	Flow Rate (m³/h)
1	88.0	11.6
2	89.5	11.6
3	87.1	11.6
4	88.3	11.6
5	85.5	11.6
6	87.7	11.6
7	88.4	11.6
8	87.1	11.6
9	88.3	11.6
10	87.0	11.6
11	88.0	11.6
12	87.0	11.6

**PLANT SWITCH**  
Auto

**ENERGY**  
207.3 kW

**FROM CYLINDERS**  
2.7 l/s  
4.9 l/s  
87.0 °C  
88.0 °C

**TO CYLINDERS**  
100%  
100%  
87.0 °C  
88.0 °C

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BMS showing the condition of the Solar cylinders

**SOLAR CYLINDERS**

FROM BOILERS → 39.8 °C 0.0 mbar  
TO ABSORPTION CHILLERS OR AHU/FCU  
ENERGY 103.1 kWh  
SOLAR → 88.8 °C 67.8 °C 4.0 bar 3.7 bar  
TO CHILLERS  
TO BOILERS

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