Proposed system 1:

Adsorption Heat Pump driven by **Solar Thermal** energy

Design and sizing Guidelines

Heat4COOL project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 723925

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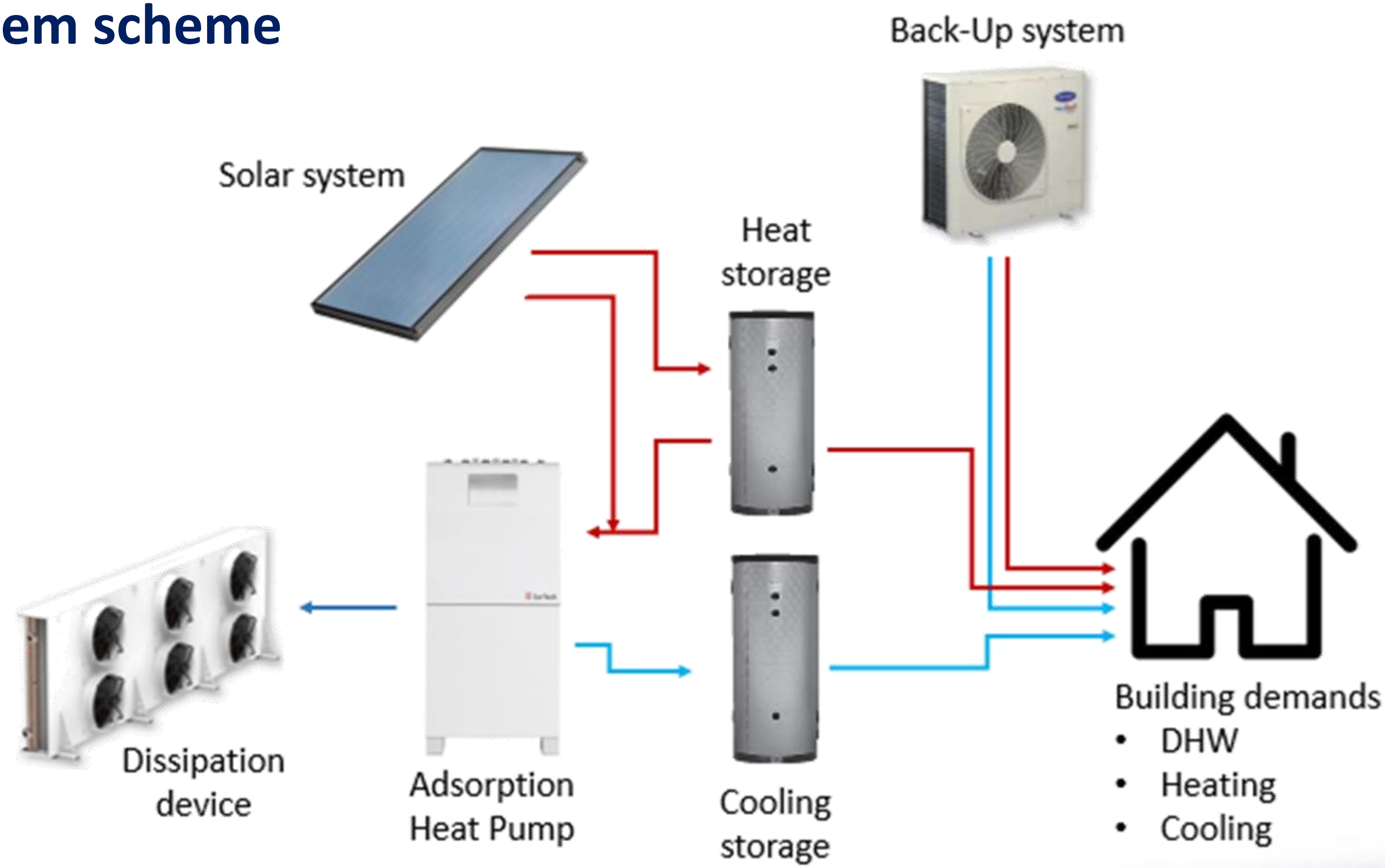
System design

System scheme



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System design

Solar system design

- Components: Solar collectors, circulating pump, balancing valves, expansion vessel, purge, controller.

- Dissipation device shared with the Adsorption Heat Pump

- Evacuated tubes and Flat Plate collectors technologies are suitable.
  - Evacuated tubes have greater efficiency and outlet temperature, but more expensive
  - Tip: select evacuated tubes if high temperatures are mandatory or surface availability is reduced

- Consider all related national and municipal regulations
  - Security regulations
  - Aesthetic regulations

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System design

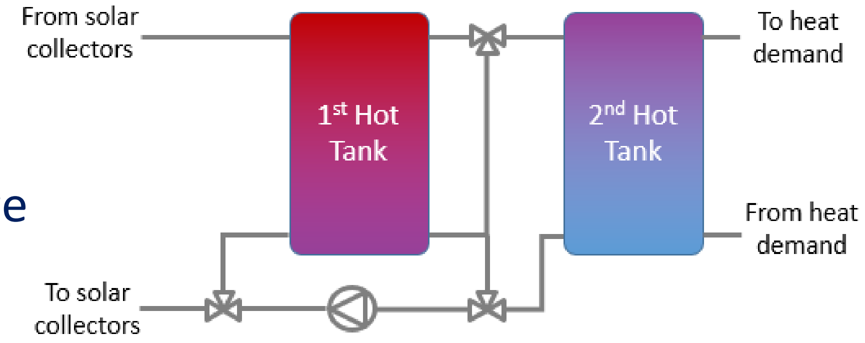
Thermal storage design

Solar storage:

- Enough to store all the daily solar production in the sunniest days
- Achieve useful temperatures in winter (not too great volume)

Option: double tank storage

- 1st tank for solar storage
- 2nd tank as heating storage/solar storage



Cooling storage:

Enables a constant cooling production of the Adsorption unit independently from cooling demand.

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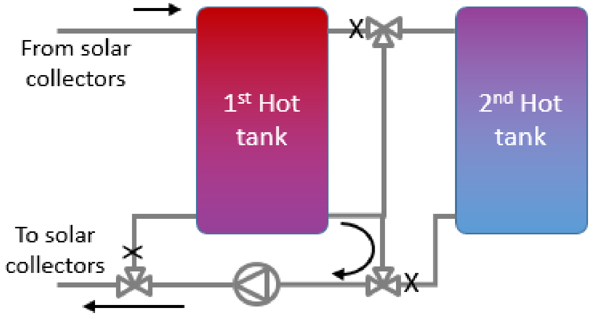
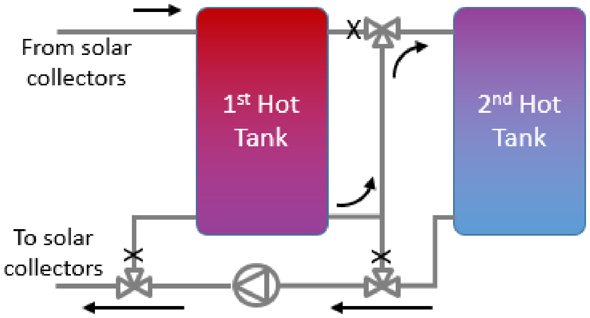
System design

Thermal storage design

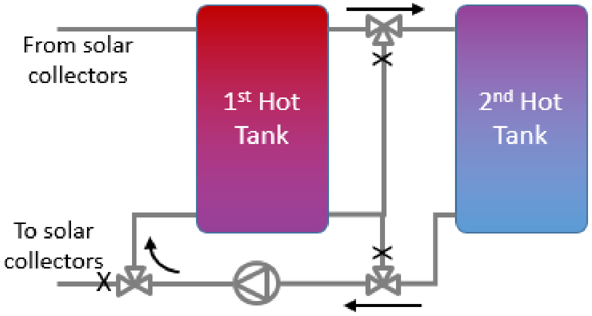
Connection cases:



Charge of only the first tank from the solar collectors



Charge of both tanks in series from the solar collectors



Charge of the second tank from the first one (when there is no solar production)

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System design

Adsorption Heat Pump design

Unit performance depends on Temperature conditions in the Temperature sources:

- Avoid if possible the introduction of heat exchangers between HP and temperature sources

- Use low temperature emission systems

- Carefully define the production temperature:
  - Covering all heat demand → low production temperature → lower efficiency
  - Cover partially the heat demand → higher efficiency / lower demand ratio covered

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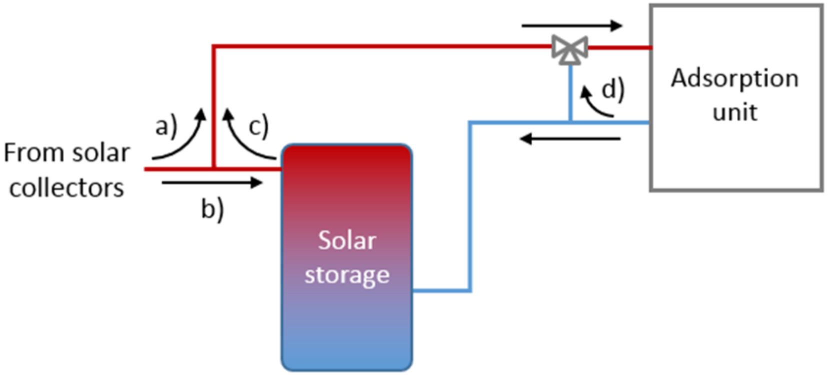
System design

Adsorption Heat Pump design

Driving circuit connection



2 scenarios:

- $\dot{V}_{Solar\_col} > \dot{V}_{AdHP}$: a) + b)
- $\dot{V}_{Solar\_col} < \dot{V}_{AdHP}$: a) + c)

If a defined temperature is desired at the Adsorption unit hot circuit, a 3-way valve used to mix the return (d).

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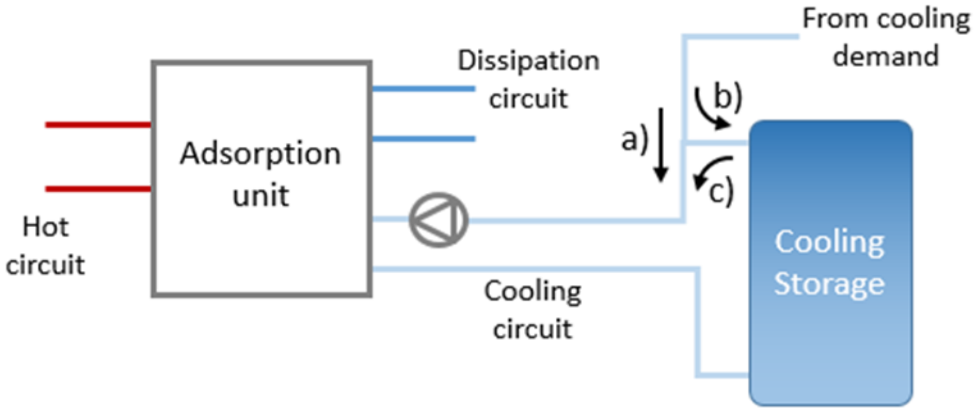
System design

Adsorption Heat Pump design

Cooling circuit connection



2 scenarios:

- $\dot{V}_{Demand} > \dot{V}_{AdHP}$: a) + b)
- $\dot{V}_{Demand} < \dot{V}_{AdHP}$: a) + c)

In series with auxiliary system: 1st Adsorption unit - 2nd auxiliary system.

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System design

Adsorption Heat Pump design

Dissipation circuit connection: to dissipation device (no insulation in pipes)

Heating mode operation:

- Medium temperature circuit as heat source for the demand
- Low temperature circuit as heat pump (to dissipation device to obtain heat from external source)

Unit placement:

Placed indoor or in a protected ambient (5 – 45 ^{o}C), avoid mainly freezing risk

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System design

Dissipation device design

Dissipation focus: ambient air

Device: dry cooler

Could be replaced by other focus or dissipation device if available/allowed.

Device also used for dissipating the solar system surplus (with better performance since DT between the primary side and dissipation source is greater).

Consider:

- Space limitations
- Municipality and national regulations

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System design

Back-up system design

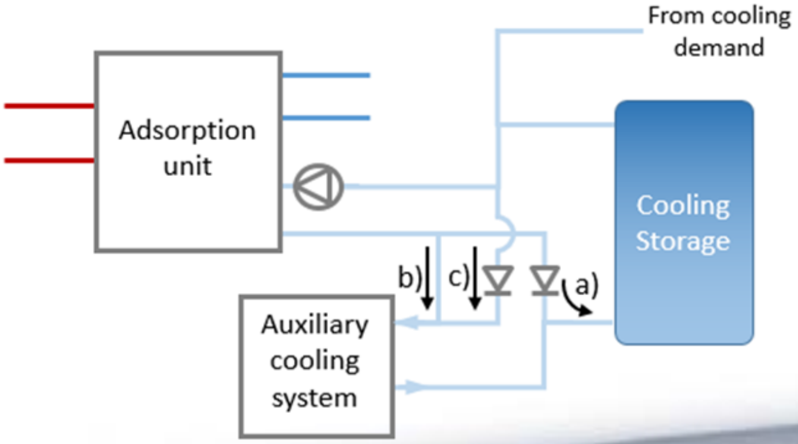
Design possibilities:

- Back-up system: support when the innovative system is not able to work. Sporadic exploitation.
- Auxiliary system: complementing the base production of the innovative system. Quite often exploited.

In series to the innovative system.

Operation options:

- Only Adsorption unit: a)
- The 2 systems in series: b)
- Only auxiliary cooling system c)



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System sizing

Considerations

Renewable energy systems **main costs**: investment (great investment costs per capacity unit)

Renewable energy systems **savings**: depend on the amount of energy produced (number of hours of exploitation of the installed capacity).

To be economically competitive:

- minimize the installed capacity
- maximize the energy produced

} Maximize the exploitation time

Benefited by:

- Use of storage systems
- Combination with conventional systems to cover the peak loads

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System sizing

Considerations

Adsorption unit exploitation depends on:

- The cooling demand
- The available solar energy

Adsorption unit sized so that:

- It is highly exploited
- Exploitation is not often limited (in time and power) by:
    - A low demand
    - Solar energy lack

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System sizing

Solar Thermal system sizing

Objective: produce the daily required solar energy for driving the Adsorption Heat Pump during the required hours of exploitation.

Collectors orientation and slope optimized as usually done:

- Consider shading elements
- Consider national and municipality regulations
- Available solar surface

General rule:

- Optimal orientation is facing the equator
- Optimal slope is similar to the location latitude (lower slopes maximize production in summer, greater slopes maximize production in winter)

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System sizing

Solar Thermal system sizing

Number of collectors in series determined by:

- The recommended flow rate by the collectors producer
- The desired outlet temperature
- The radiation on the location

Variable circulating pump flow rate to get as possible the desired outlet temperature.

Prevention mechanism for the solar surplus must be considered (Adsorption unit dissipation device).

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System sizing

Solar Thermal system sizing

Controller special features:

- 2 set-points:
  - Winter set-point: required temperature for satisfying the DHW and heating demand
  - Summer set-point: required temperature for the adsorption unit activation

- If dealing with a double tank storage system: the operation rules depend on the monitored temperature in both tanks.

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System sizing

Solar Thermal system sizing

Solar storage:

- Enough to store the daily solar production in the sunniest days
- Achieve useful temperatures in winter

Limited by space availability and maximal slab admissible load

System with 2 tanks:

Less limitations due to the slab admissible load

Each tank ~1/2 of total storage (or 1st tank slightly greater than the 2nd one)

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System sizing

Adsorption Heat Pump sizing

Objective: maximize the exploitation of the installed capacity

No restrictions for solar system → Adsorption unit designed for maximizing the cooling production

- Operation seeking the maximal capacity
- Unit capacity defined from the daily cooling energy demanded and the daily exploitation hours.

Solar system restricted → Adsorption unit sized in relation to the solar energy in summer days

- Operation seeking maximal thermal efficiency performance
- Unit capacity defined from the daily available solar energy in summer and the daily exploitation hours

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System sizing

Adsorption Heat Pump sizing

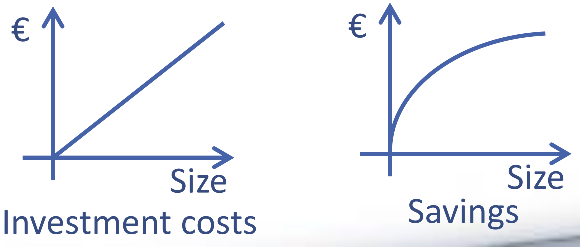
If heat exchangers required for circuits separation:

- Additional electrical consumption of circulating pumps
- Temperature level loses (worse temperature conditions for the unit performance). Critical at dissipation and cooling circuits.

Aim: great heat exchange between the fluids with small DT and DP

Solution: cross flow plate heat exchanger

Balance: Investment costs vs savings (optimize Payback-period)



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System sizing

Dissipation device sizing

Dry cooler

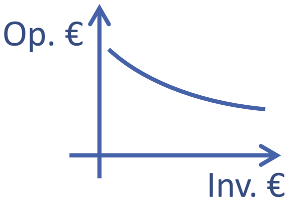
- Maximize heat exchange

↓

- Minimize DT introduced between fluids
- Minimize pumping introduced

} Minimize operation costs

- Imply investment costs
- Balance: Investment costs vs Operation costs



Recommended solution: DT 2~3 K between $Tout_{HTF}$ and T_{source}

Consider dissipation of solar over production

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System sizing

Cooling storage sizing

Amount of energy to be stored:

- Adsorption unit capacity
- Hours of exploitation (depending on solar energy stored)
- Cooling demand during charging hours
- Temperature variation of the storage mass

Evaluated for the most storage demanding day (beginning of summer):

- High solar production
- Many hours of low cooling demand

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System sizing

Back-up system sizing

Capacity dimensioned to satisfy the potential maximal power of the indispensable cooling demand.

Use cases:

- Back-up system: support when the innovative system is not able to work. Sporadic exploitation.
- Auxiliary system: complementing the base production of the innovative system. Quite often exploited.

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Operation optimization

Optimal operation depends on either the limitation is the available solar energy or the cooling demand.

Adsorption unit performance (capacity, $COP_{Thermal}$ & $COP_{electrical}$) depends on:

- $\downarrow T_{dissip} \rightarrow \uparrow$Capacity + $\uparrow COP_{Thermal}$ + $\uparrow COP_{electrical}$
- $\uparrow T_{cooling} \rightarrow \uparrow$Capacity + $\uparrow COP_{Thermal}$ + $\uparrow COP_{electrical}$
- $\uparrow T_{driving} \rightarrow \uparrow$Capacity but $\downarrow COP_{Thermal}$ + $\downarrow COP_{electrical}$

Always desired to operate:

- The lowest dissipation circuit temperature
- The highest cooling circuit temperature
- Hot circuit temperature depends on the case (capacity vs efficiency)

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Operation optimization

Lowest dissipation temperature

- Maximize the heat exchange at dissipation device
- Dissipation device at 100% → Greater operation costs

Balance: dissipate the required energy with admissible operation costs

Reference: Tout$_{HTF}$ - Tambient = 2~3 K

High cooling temperature

- Deliver the cooling energy at the highest admissible temperature
- Depends on the emission system and the given DT between $T_{\text{space air}}$ and T_{HTF}

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Operation optimization

Driving (hot temperature) circuit temperature optimization

- No limitations for solar production → Operated maximizing the unit capacity: maximal hot circuit inlet temperature
- Limitation for solar system → Operated maximizing thermal efficiency: hot circuit inlet temperature for maximal efficiency

If solar surplus operation is changed:

- 1. Lower cooling production T (deeper cooling storage charge)
- 2. Increase hot circuit temperature (greater capacity)
- Dissipation at dissipation device

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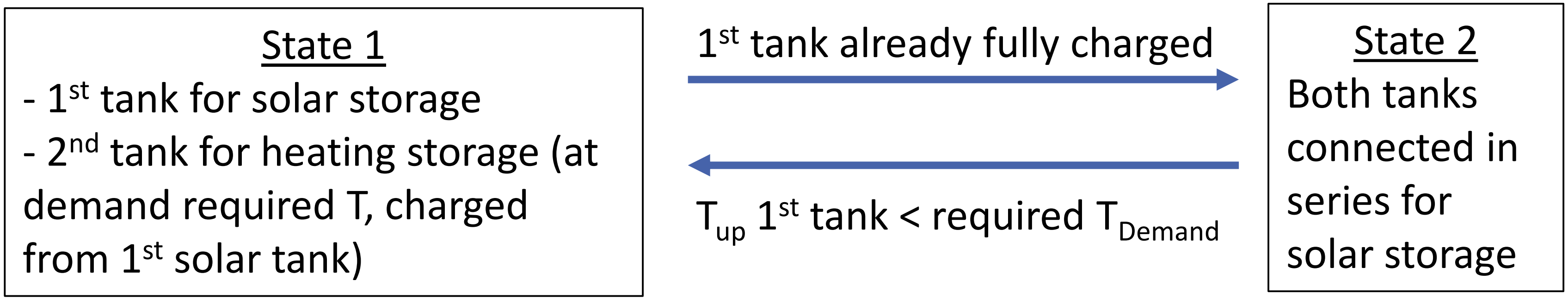
Operation optimization

Solar system operation: variable circulating flow rate maintaining desired outlet temperature (in winter for heating, in summer for adsorption unit)

Double tank system operation:



State 1
- 1st tank for solar storage
- 2nd tank for heating storage (at demand required T, charged from 1st solar tank)

1st tank already fully charged

T_{up} 1st tank < required T_{Demand}

State 2
Both tanks connected in series for solar storage

Required temperatures at each storage tank:

- DHW and heating demand supplied from 2nd tank
- Adsorption unit supplied from 1st tank (only in cooling season)

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For a more detailed explanation refer to:

Heat4Cool_D6.3_Trainings and Guidelines. Adsorption Heat Pump driven by Solar Thermal Energy. Design and sizing Guidelines.

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heat4cool.eu

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