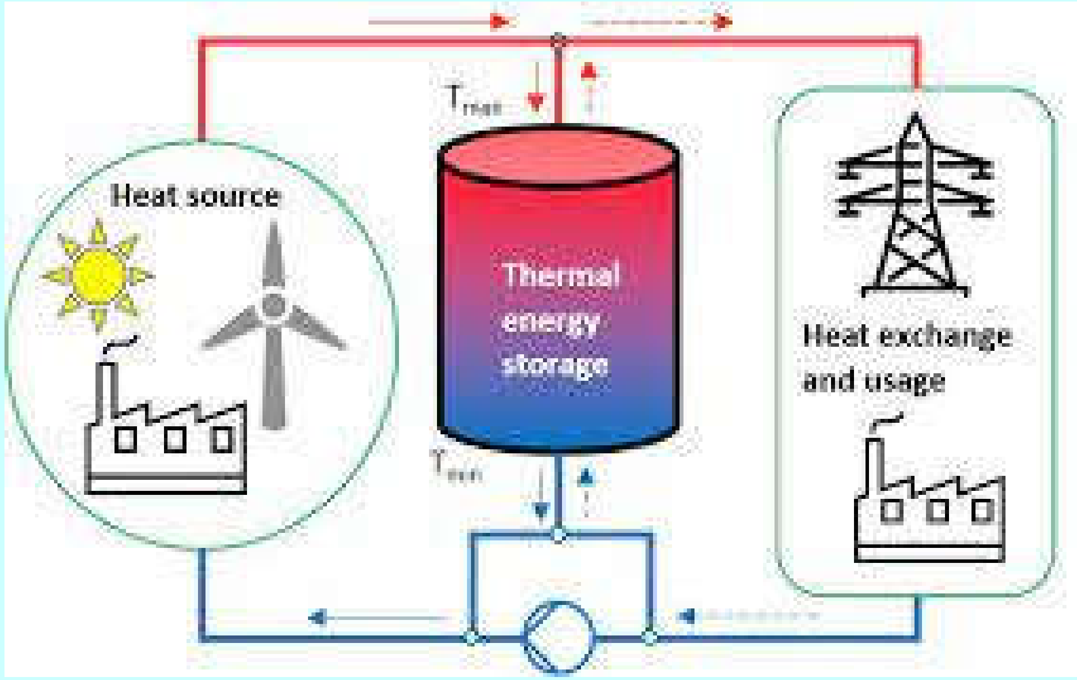
MEBS7014 Advanced HVAC applications

http://ibse.hk/MEBS7014/



Thermal Storage Systems I

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Contents

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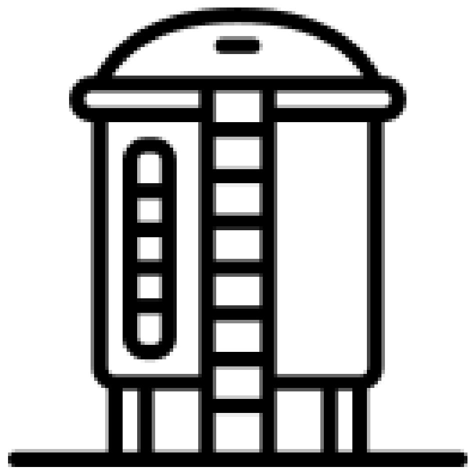
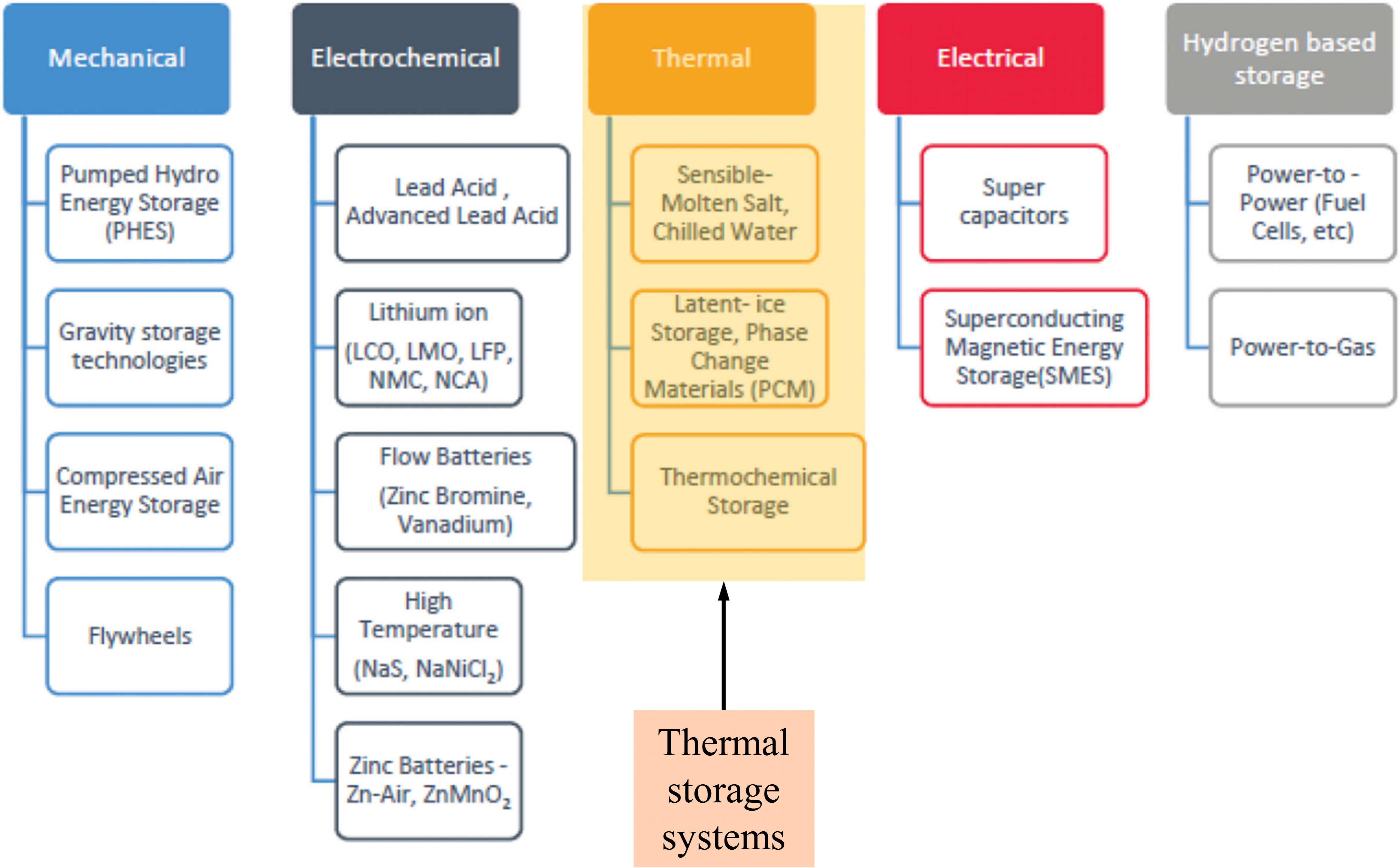
Basic concepts

- Energy storage
  - Capture of energy produced at one time for use at a later time to reduce imbalances between energy demand & energy production
- Energy storage methods:
  - Chemical (e.g. hydrated salts)
  - Electrical (e.g. capacitor)
  - Electrochemical (e.g. battery)
  - Mechanical (e.g. compressed air, flywheel)
  - Thermal energy storage (TES)

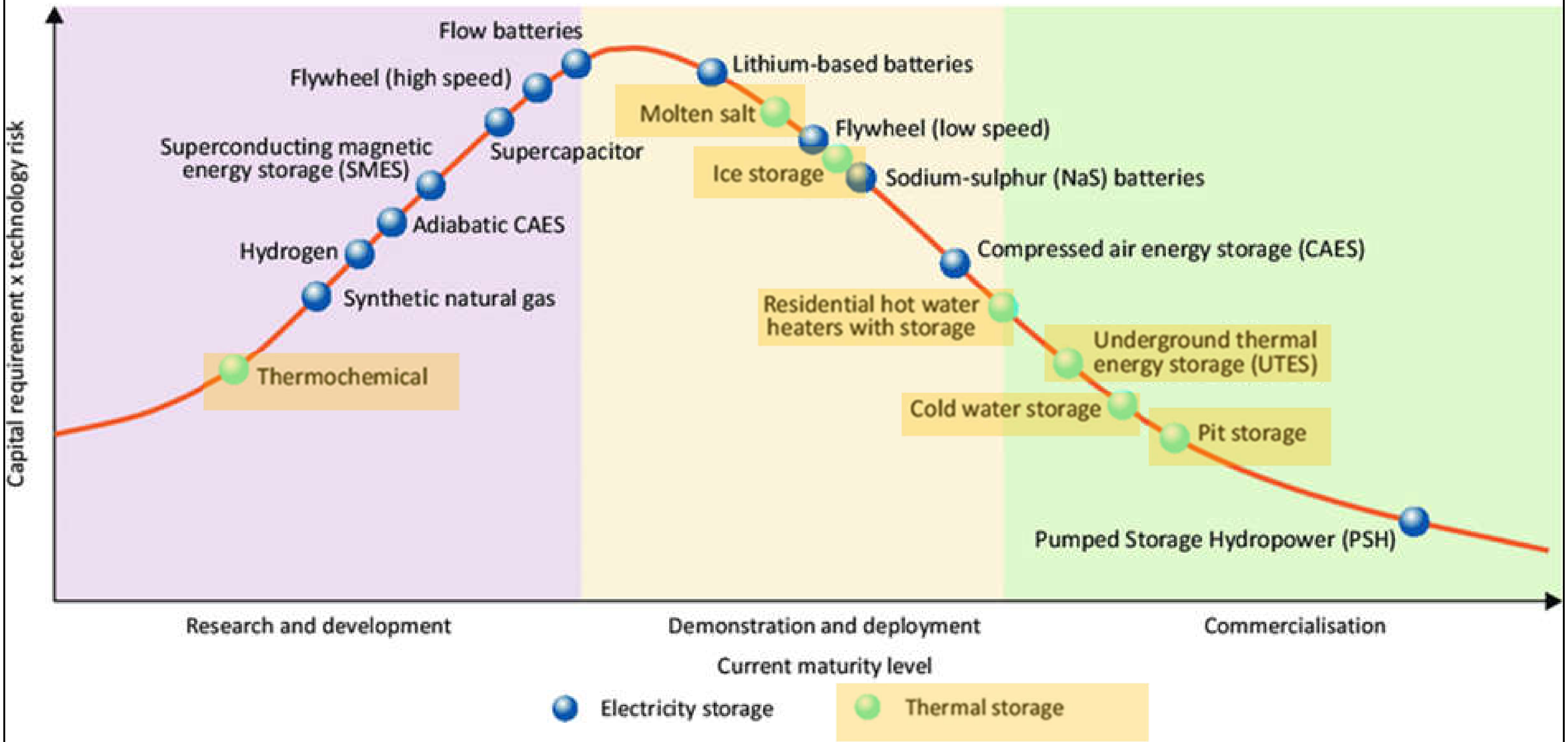


Classification of energy storage technologies



(Source: https://etn.news/energy-storage/classification-of-energy-storage-technologies-an-overview)

Maturity of energy storage technologies

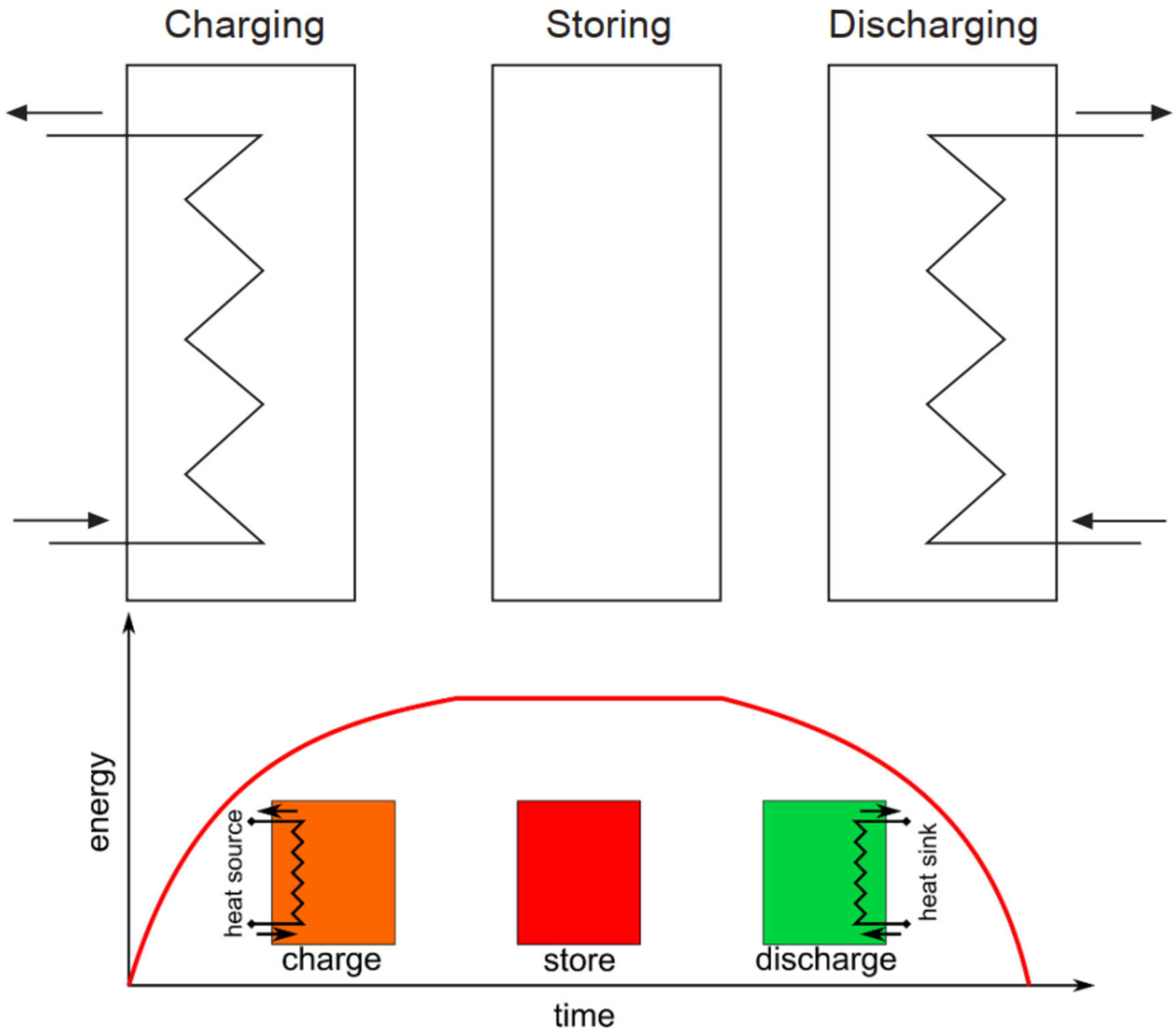


(Source: https://celsiuscity.eu/thermal-energy-storage/)

Basic concepts

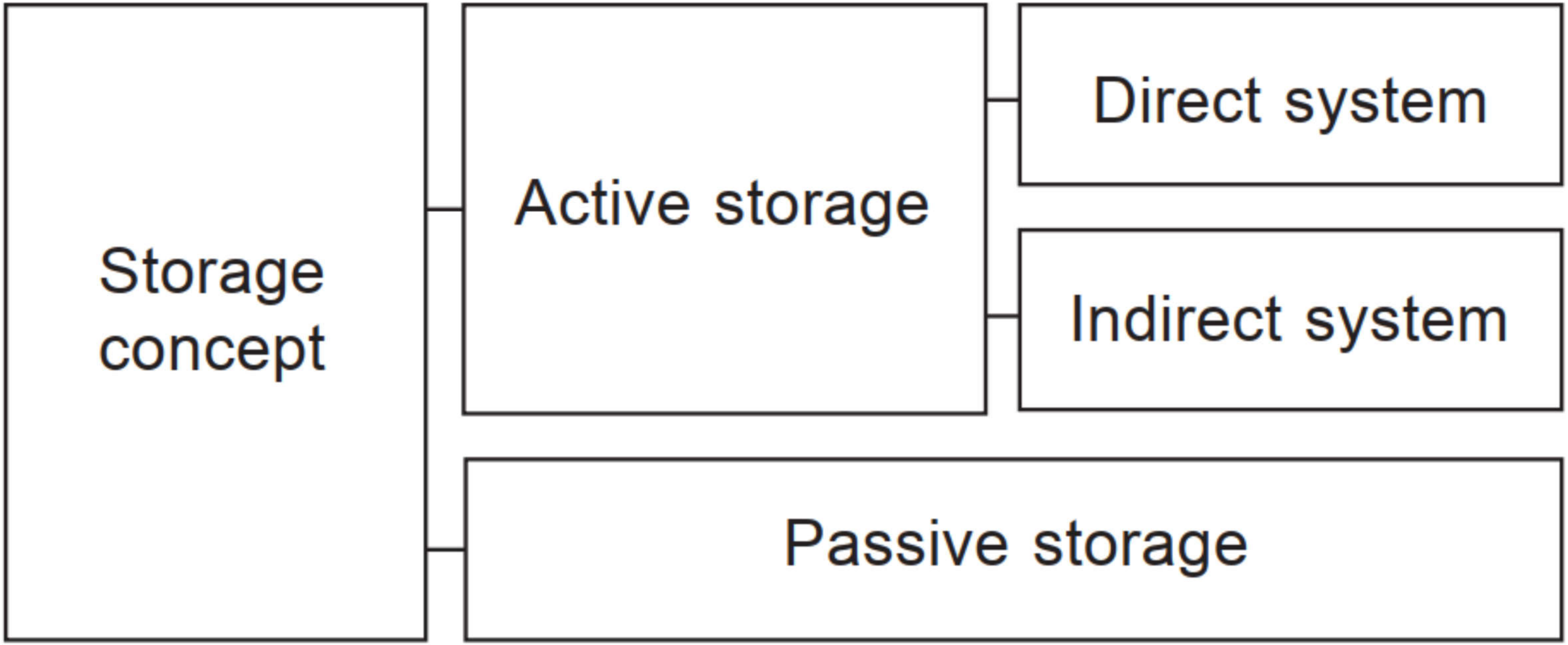
- Thermal energy storage (TES)
  - Can store heat or cold to be used under varying conditions for a later use for either heating or cooling applications and power generation
  - The main use of TES is to overcome the mismatch between energy generation and energy use
  - Energy is supplied to a storage system to be used at a later time, involving three steps: 1. charge, 2. storage and 3. discharge (a complete storage cycle)
  - Storage concepts: active or passive systems

Thermal energy storage (TES) complete storage cycle



(Source: Cabeza L. F. (ed.), 2015. *Advances in Thermal Energy Storage Systems: Methods and Applications*, Woodhead Publishing. https://doi.org/10.1016/C2013-0-16453-7)

Classification of different storage systems



<u>Active storage</u>: by forced convection heat transfer into the storage material; the storage material circulates through a heat exchanger, a solar receiver or a steam generator

(a) Direct systems: the heat transfer fluid (HTF) serving also as storage medium

(b) Indirect systems: a second medium is used for storing the heat

<u>Passive storage</u>: generally dual-medium storage systems, where the HTF passes through the storage only for charging and discharging a solid material

(Source: Cabeza L. F. (ed.), 2015. *Advances in Thermal Energy Storage Systems: Methods and Applications*, Woodhead Publishing. https://doi.org/10.1016/C2013-0-16453-7)

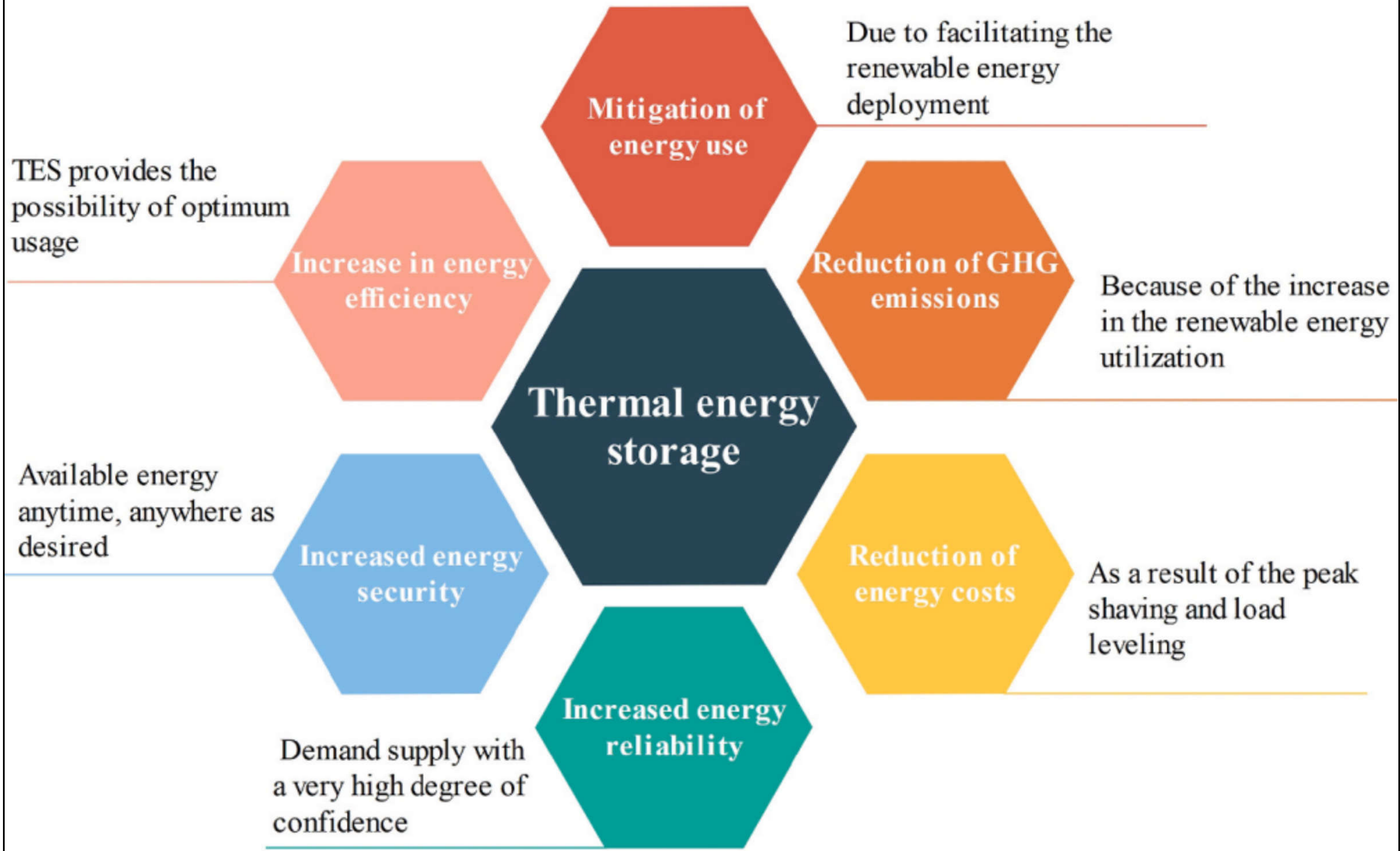
Basic concepts

- Main requirements for TES design
  - High energy density in the storage material
  - Good heat transfer between the heat transfer fluid and the storage material
  - Mechanical/chemical stability of storage material
  - Compatibility between the storage material and the container material
  - Complete reversibility of a number of cycles
  - Low thermal losses during the storage period
  - Easy control

Basic concepts

- Important design criteria of TES:
  - Operation strategy, maximum load needed, nominal temperature and enthalpy drop, and the integration into the whole application system
- Benefits of TES in energy systems:
  - Economics: reducing capital and operational costs
  - Efficiency: achieving a more efficient energy use
  - Less pollution of the environment and less CO_2 emissions
  - Better system performance & reliability

Benefits of thermal energy storage (TES) in energy systems

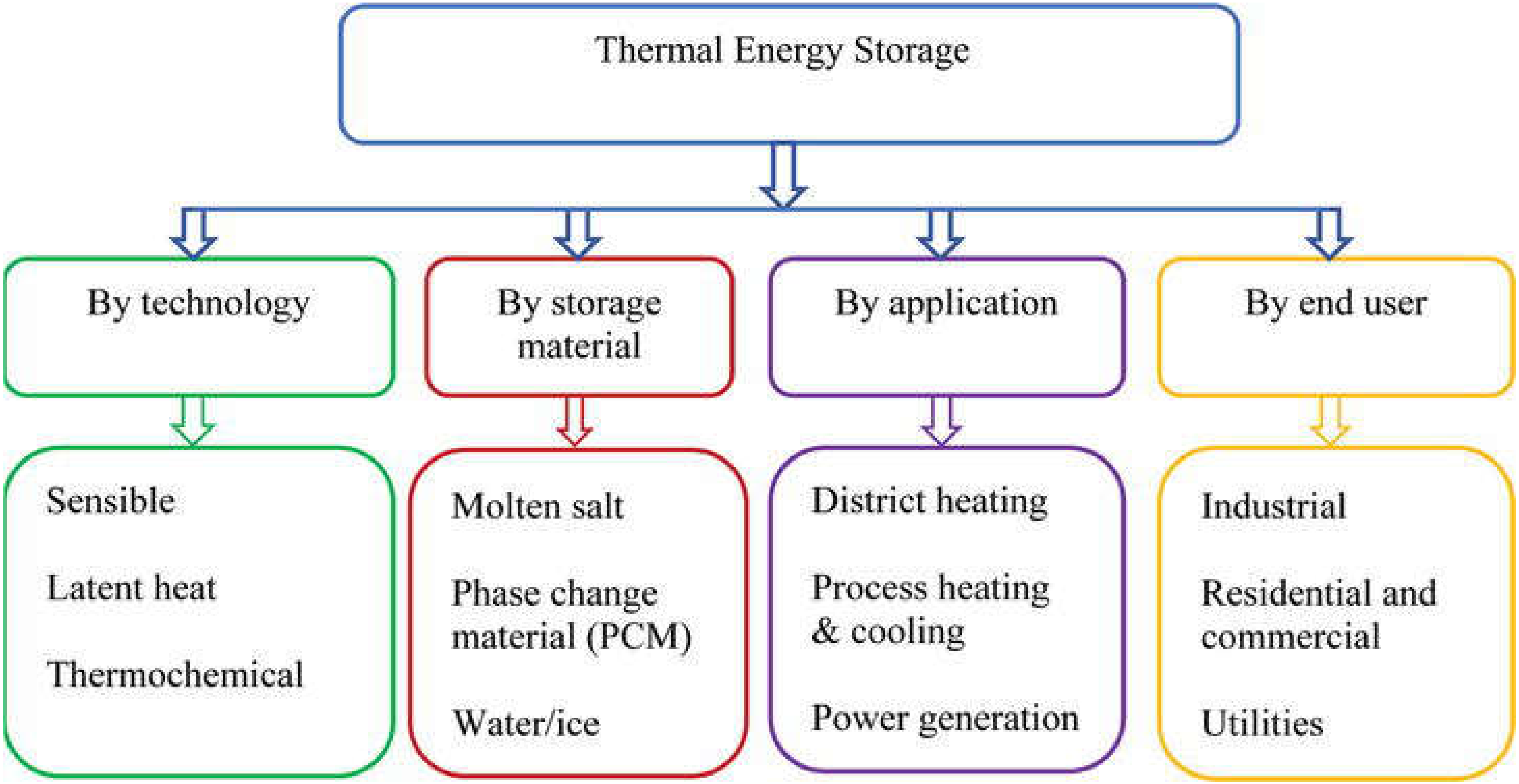


(Source: Behzadi A., *et al.*, 2022. Smart design and control of thermal energy storage in low-temperature heating and high-temperature cooling systems: A comprehensive review, *Renewable & Sustainable Energy Reviews*, 166: 112625. https://doi.org/10.1016/j.rser.2022.112625)

Basic concepts

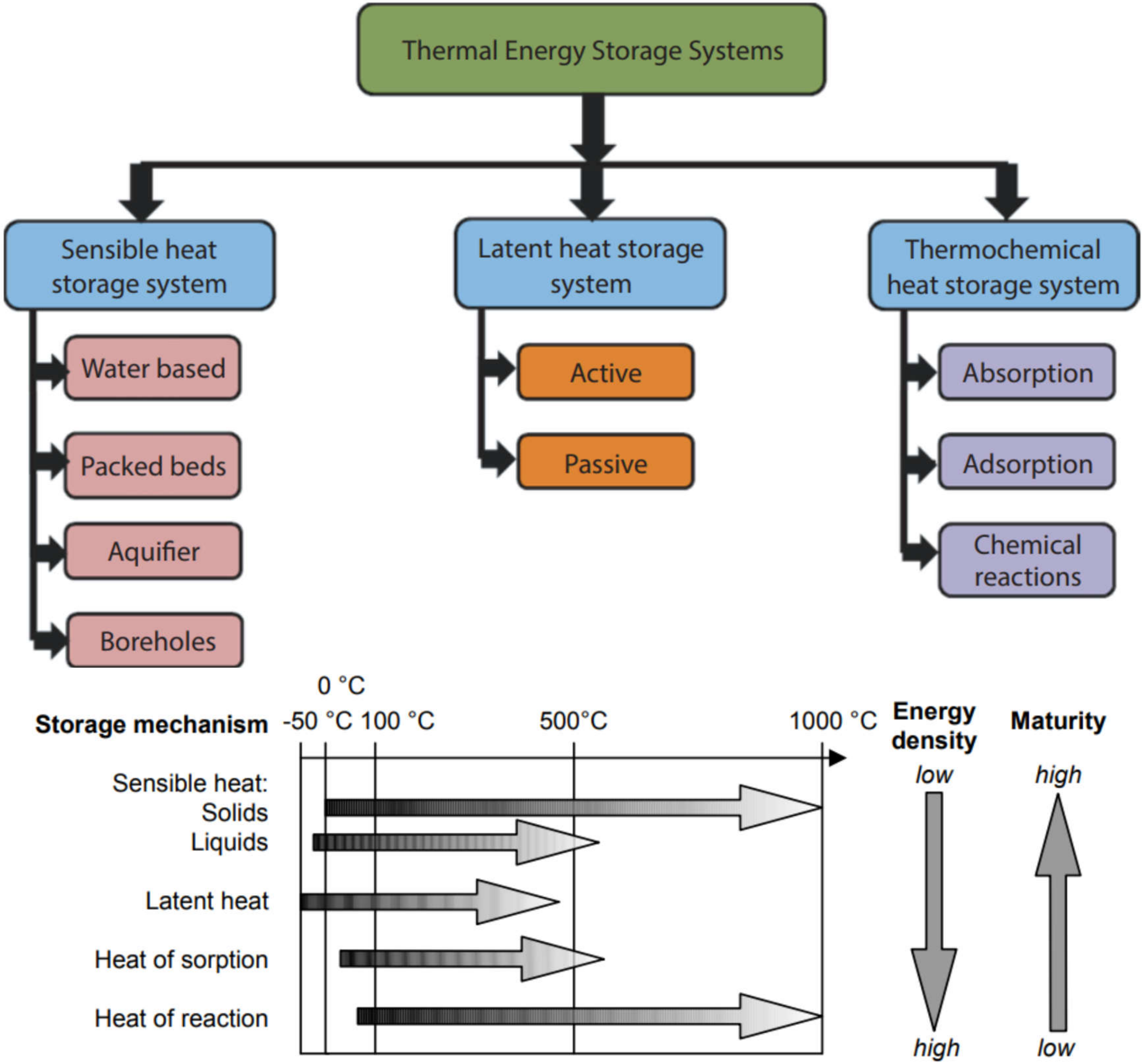
- Major sectors for thermal energy storage (TES)
  - Power (and renewable energy integration)
  - Industry (for heat use & industrial processes)
  - Cold chain (supply chain logistics of cold products)
  - District heating and cooling (storage capacity)
  - Buildings (for HVAC & energy management)
- Important driving factors nowadays
  - Decarbonisation
  - Energy efficiency & demand side management
  - Renewable energy & variable supply integration

Classification of thermal energy storage systems



(Source: https://www.intechopen.com/chapters/63027)

Different types of thermal energy storage systems



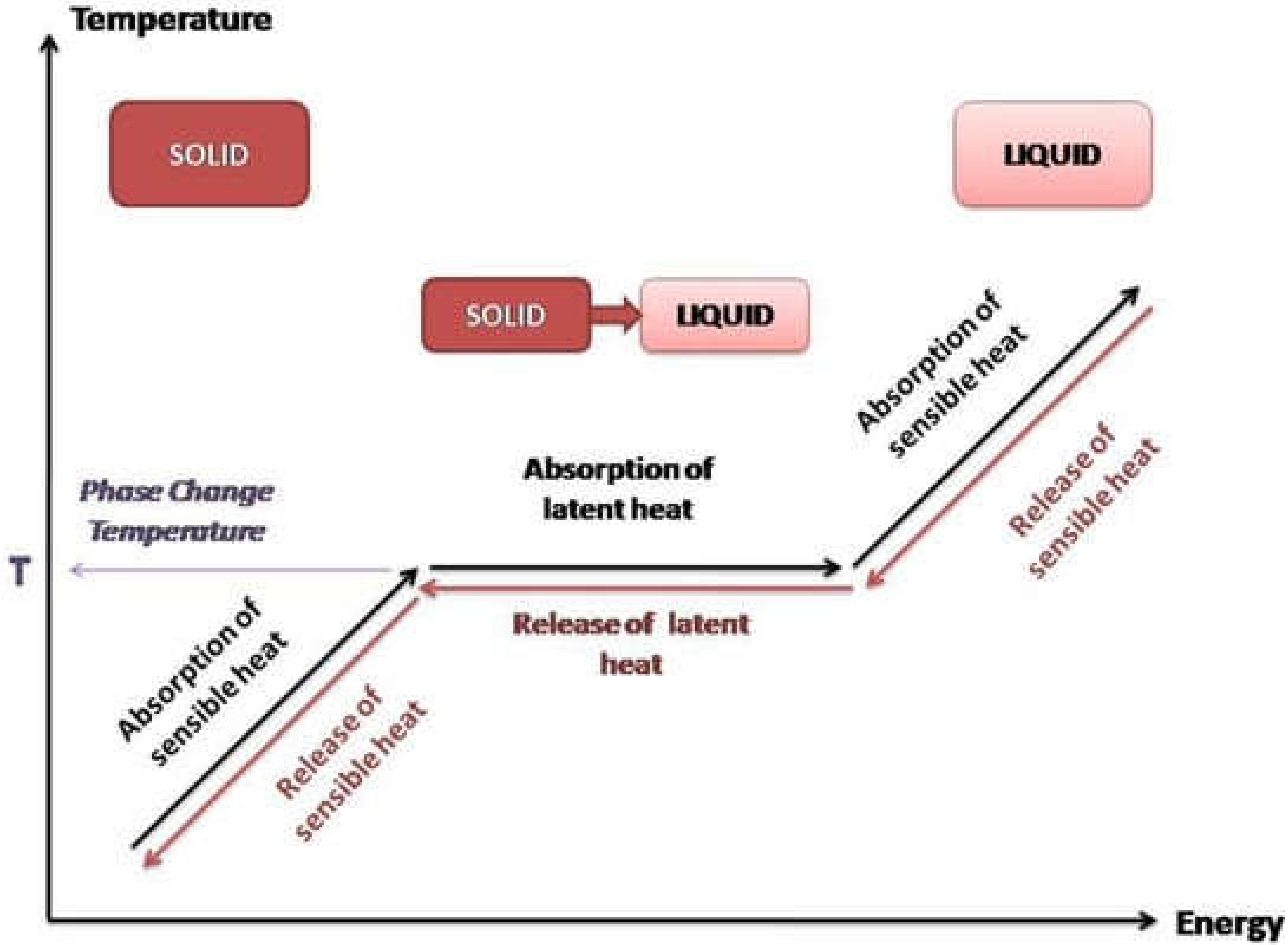
(Source: Sahoo U., 2021. *Energy Storage*, Scrivener Publishing, Beverly, MA. https://doi.org/10.1002/9781119555599)

Comparison of the storage density of different thermal storage methods

Type of storage technology	Material	Energy stored (MJ/m^3)	Energy stored (kJ/kg)	Comments
Sensible heat	Granite	50	17	$\Delta T = 20°C$
	Water	84	84	$\Delta T = 20°C$
Latent heat	Water	306	330	$T_{melting} = 0°C$
	Paraffins	180	200	$T_{melting} = 5–130°C$
	Salt hydrates	300	200	$T_{melting} = 5–130°C$
	Salt	600–1,500	300–700	$T_{melting} = 300–800°C$
Chemical reactions	H_2 gas (oxidation)	11	120,000	300 K, 1 bar
	H_2 gas (oxidation)	2,160	120,000	300 K, 200 bar
	H_2 liquid (oxidation)	8,400	120,000	20 K, 1 bar
	Fossil gas	32	–	300 K, 1 bar
	Gasoline	33,000	43,200	–
Electrical storage	Zn/Mn oxide battery	–	180	–
	Pb battery	–	70–180	–

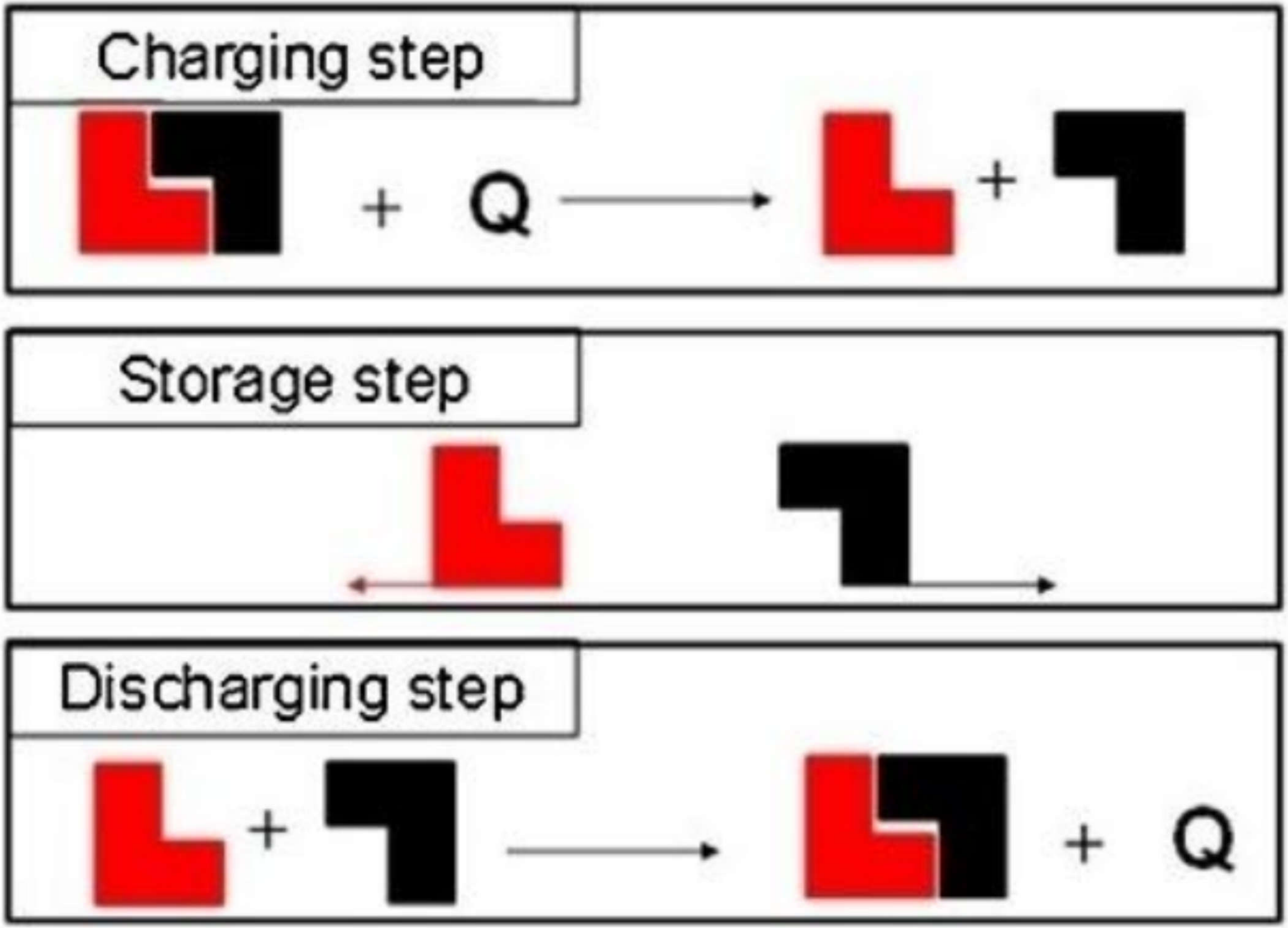
(Source: Cabeza L. F. (ed.), 2015. *Advances in Thermal Energy Storage Systems: Methods and Applications*, Woodhead Publishing. https://doi.org/10.1016/C2013-0-16453-7)

Thermal energy can be stored either as sensible heat or as latent heat



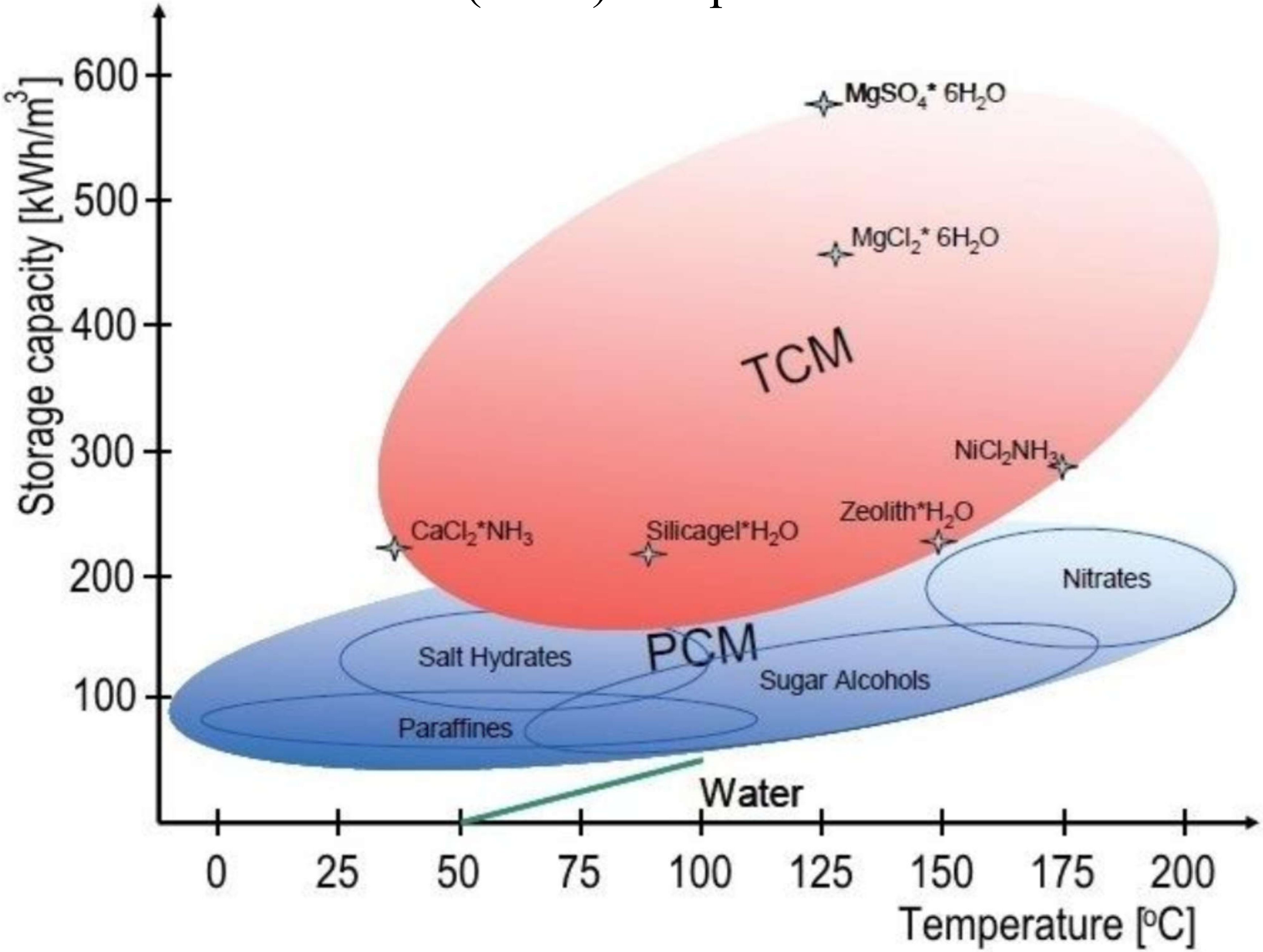
(Source: https://www.mdpi.com/2076-3417/11/4/1490)

Basic concept of thermo-chemical reactions for thermal storage system



(Source: Sarbu I. & Sebarchievici C., 2018. A comprehensive review of thermal energy storage, *Sustainability*, 10 (1) 191. https://doi.org/10.3390/su10010191)

Storage capacities of phase change materials (PCM) and thermochemical materials (TCM) compared to water



(Source: Cabeza L. F. (ed.), 2015. *Advances in Thermal Energy Storage Systems: Methods and Applications*, Woodhead Publishing. https://doi.org/10.1016/C2013-0-16453-7)

HVAC thermal storage

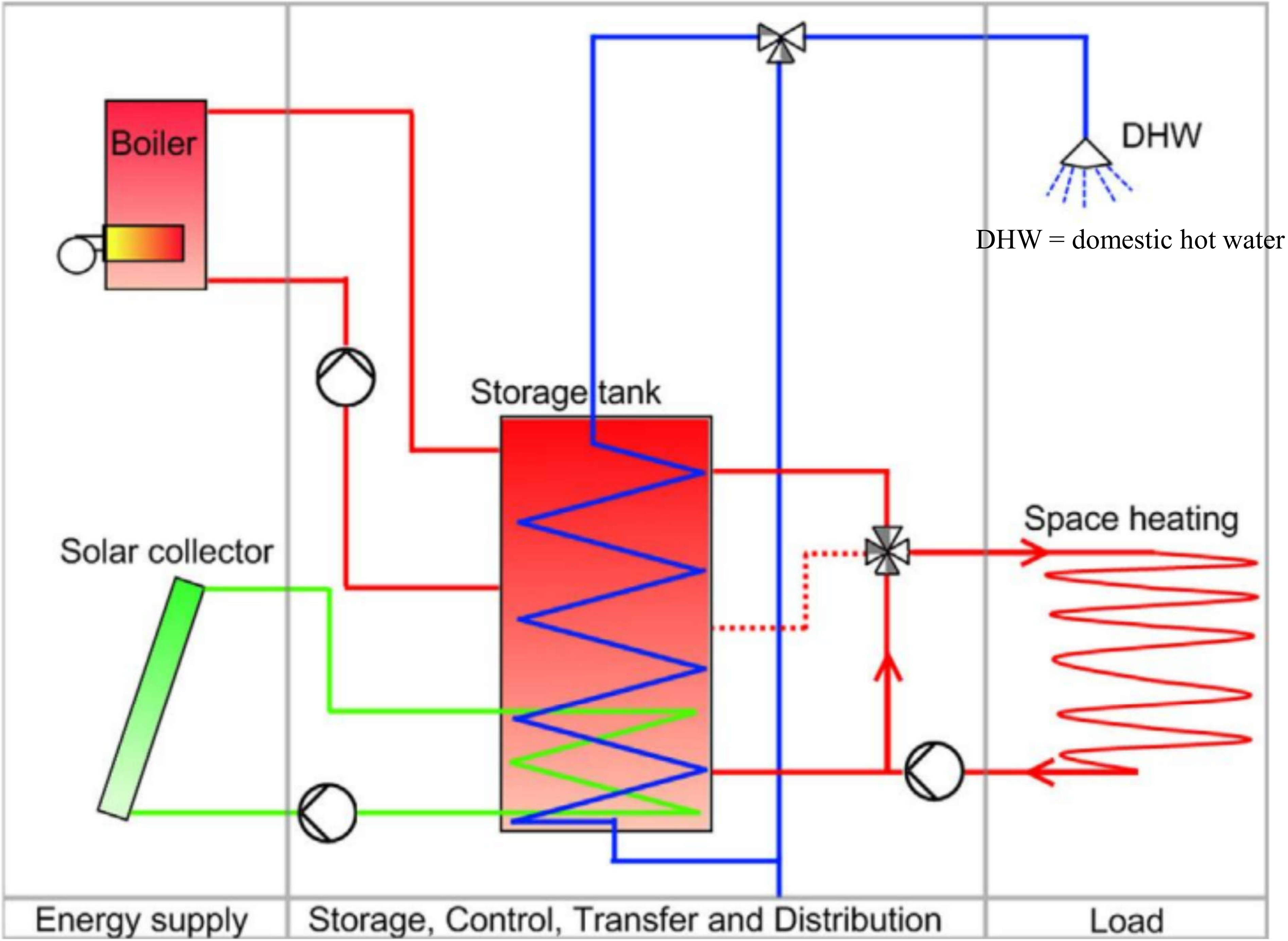
- History of thermal energy storage for cooling
  - Can be traced to ancient time where snow/ice was transported from distant mountains to cool drinks and for bathing water for the wealthy
  - Block ice was cut from frozen lakes and shipped in insulated rail cars for food preservation and health-care facilities
- Electric utility impacts
  - Demand-side management (DSM) was embraced to address peak electric demand; to reduce peak demand using thermal energy storage

Block ice farming and harvesting (for cooling thermal storage)

HVAC thermal storage

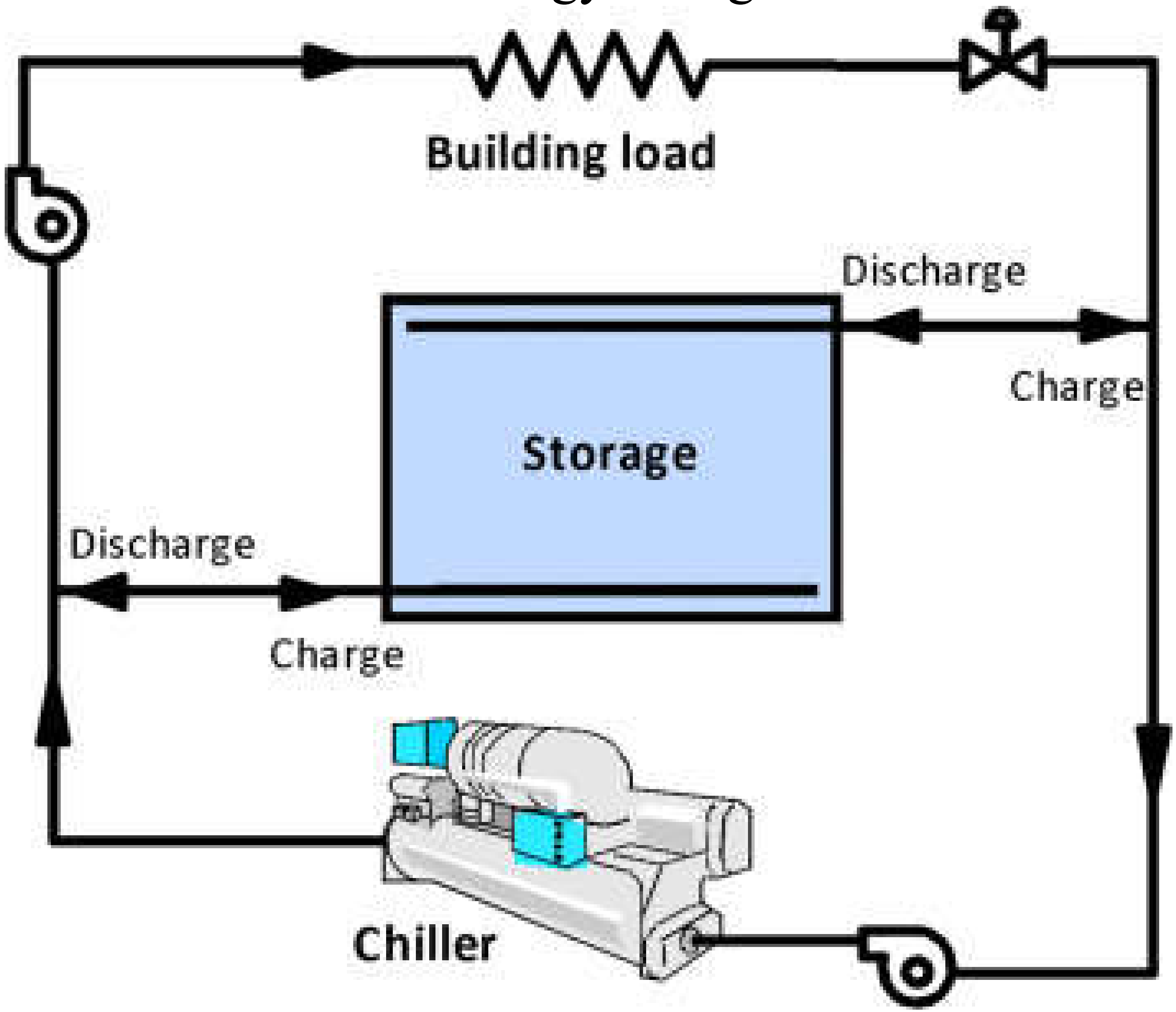
- Types of HVAC thermal storage systems
  - High-temperature storage: with solar energy or high-temperature heating
  - Cool storage: with air-conditioning, refrigeration, or cryogenic-temperature processes
  - Energy may be charged, stored, and discharged daily, weekly, annually, or in seasonal or rapid batch process cycles
  - Can provide balancing services and other critical needs of the electric grid, e.g. frequency control and renewable energy integration (e.g. solar, wind)

A hot water storage system with solar collectors and a boiler



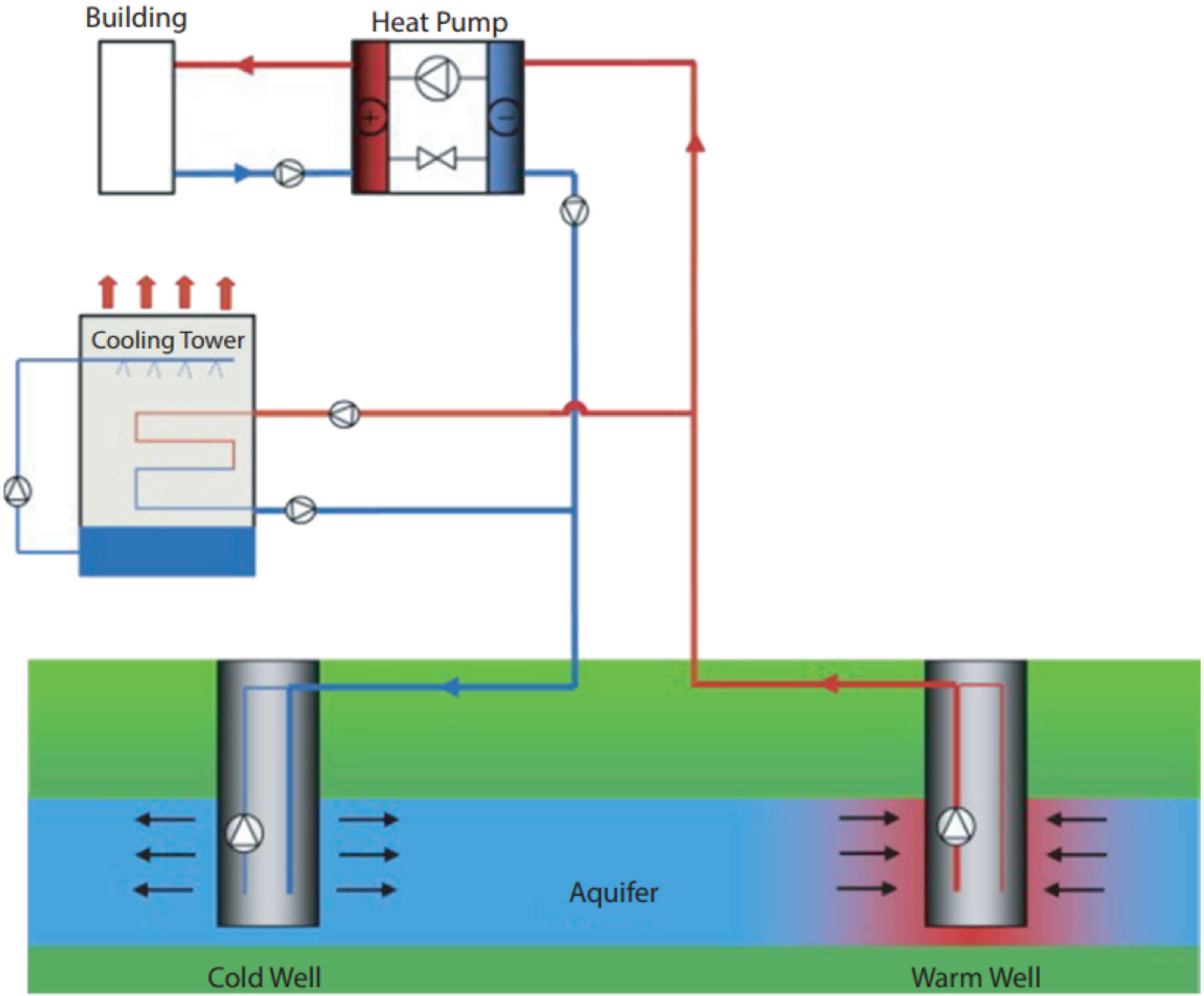
(Source: Sarbu I. & Sebarchievici C., 2018. A comprehensive review of thermal energy storage, *Sustainability*, 10 (1) 191. https://doi.org/10.3390/su10010191)

Space conditioning system providing cooling to a building with thermal energy storage



(Source: Brun K., Allison T. & Dennis R. (eds.), 2021. *Thermal, Mechanical, and Hybrid Chemical Energy Storage Systems*, Academic Press, London. https://doi.org/10.1016/C2019-0-00430-X)

Integration of aquifer thermal energy storage (ATES) system with solar pump for space heating/cooling

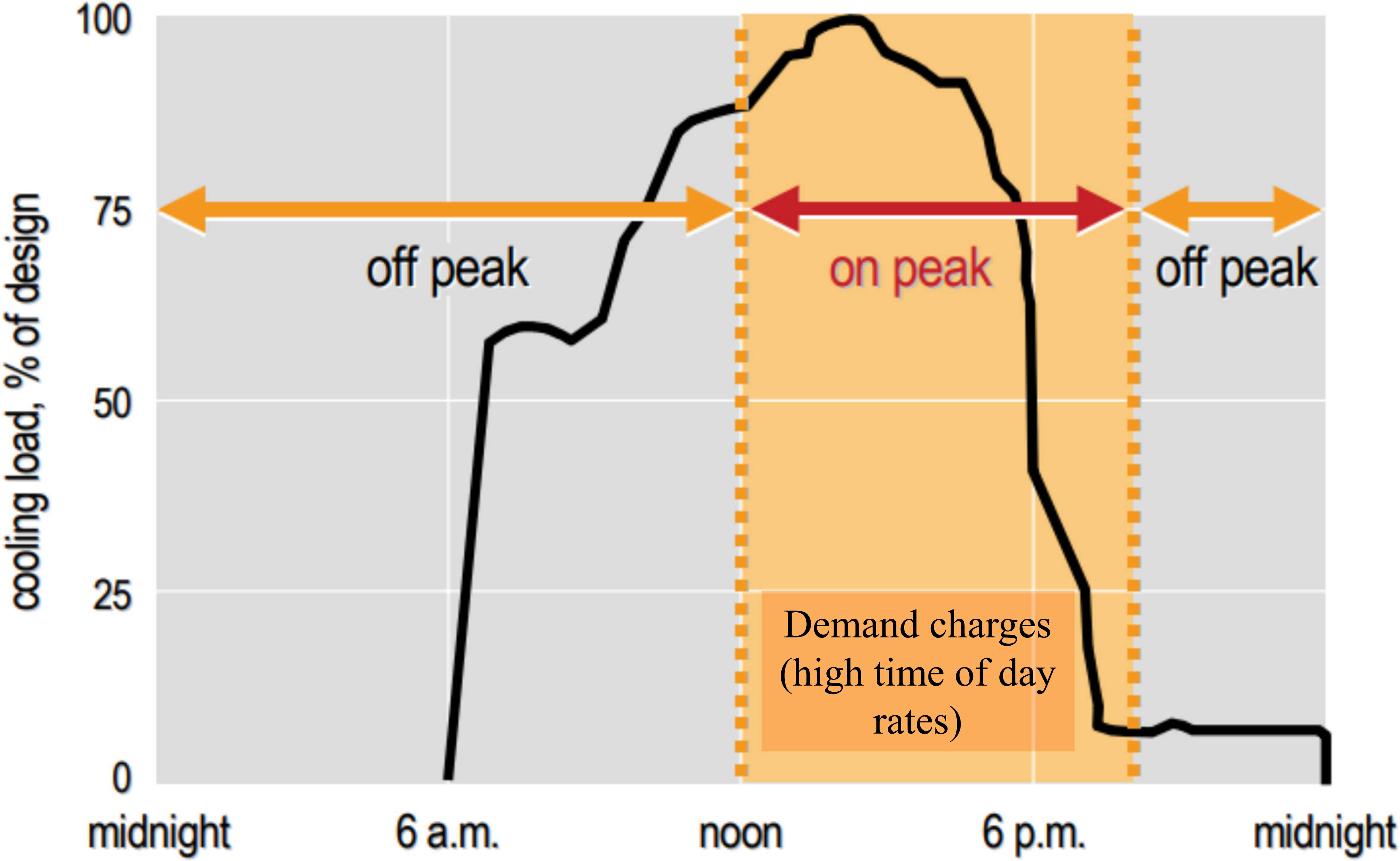


(Source: Sahoo U. (ed.), 2021. *Energy Storage*, Scrivener Publishing, Beverly, MA. https://doi.org/10.1002/9781119555599)

HVAC thermal storage

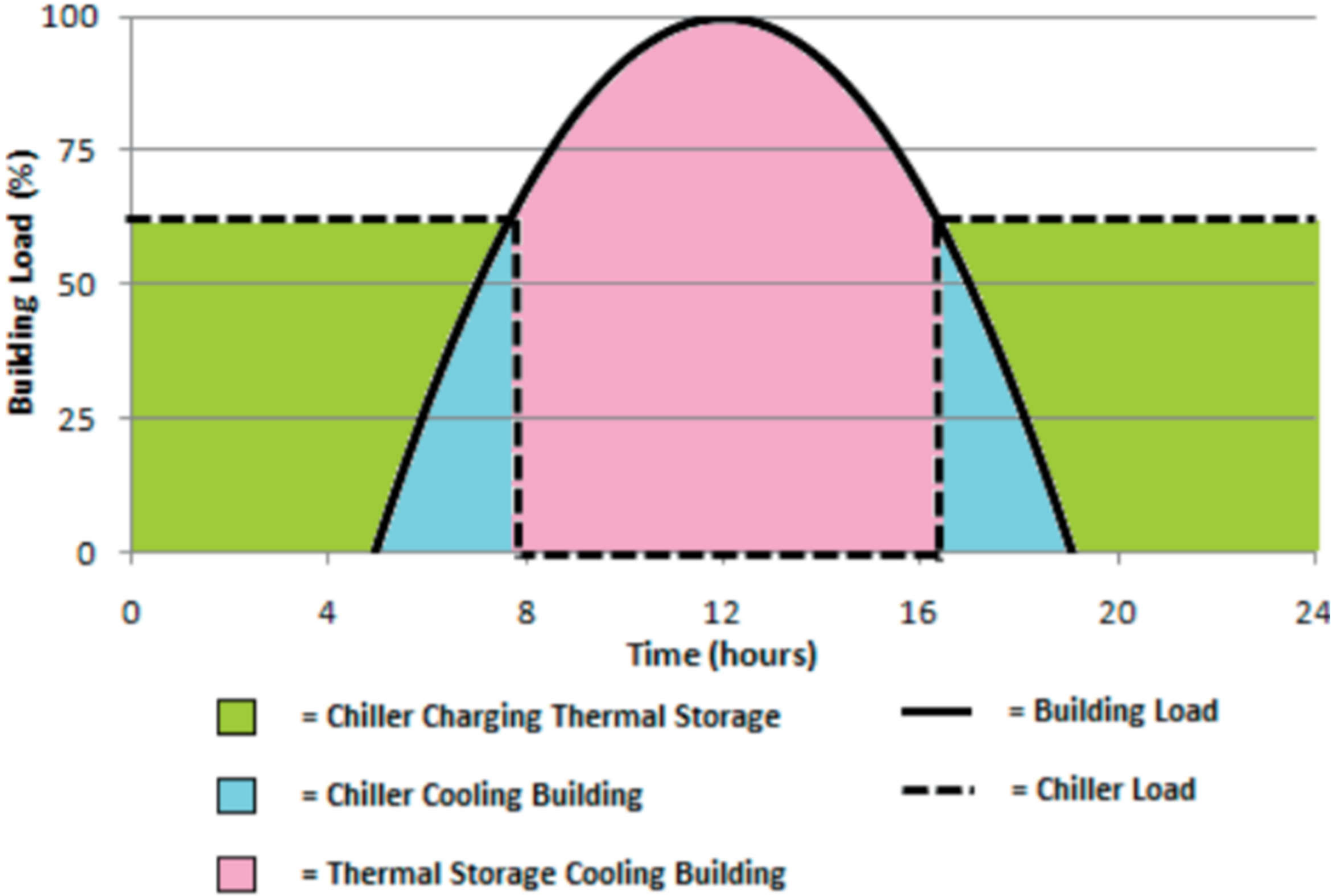
- A properly designed and installed thermal storage system can:
  - Shift loads from peak to nonpeak times
  - Reduce operating or initial costs
  - Reduce size of electric service and cooling or heating equipment
  - Increase operating flexibility
  - Provide back-up capacity
  - Extend the capacity of an existing system
  - Support balancing & renewable energy integration

On-peak and off-peak periods



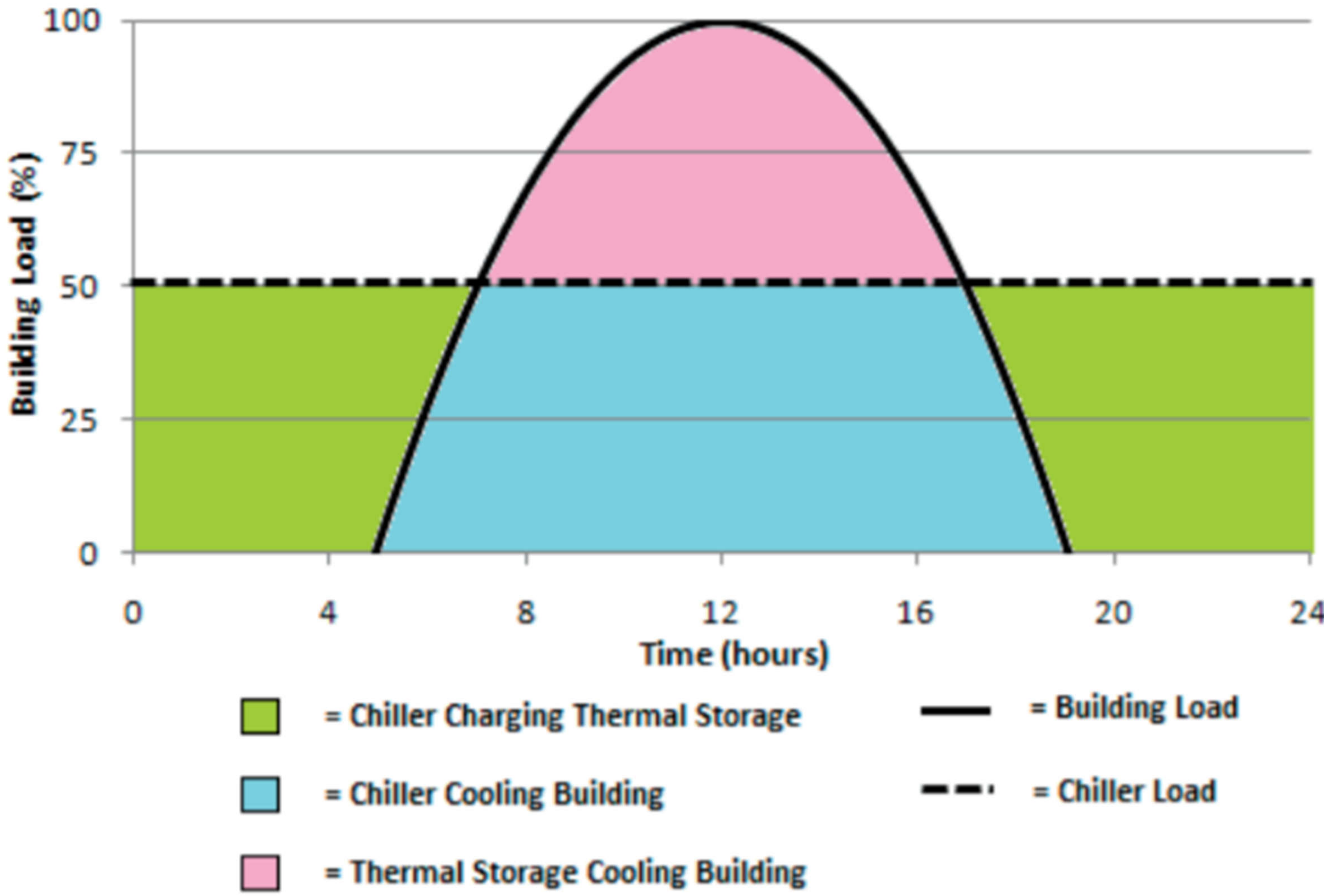
(Source: Trane)

Load shifting strategy (full storage)



(Source: https://hvac-eng.com/thermal-storage-hvac/)

Load levelling strategy (partial storage)



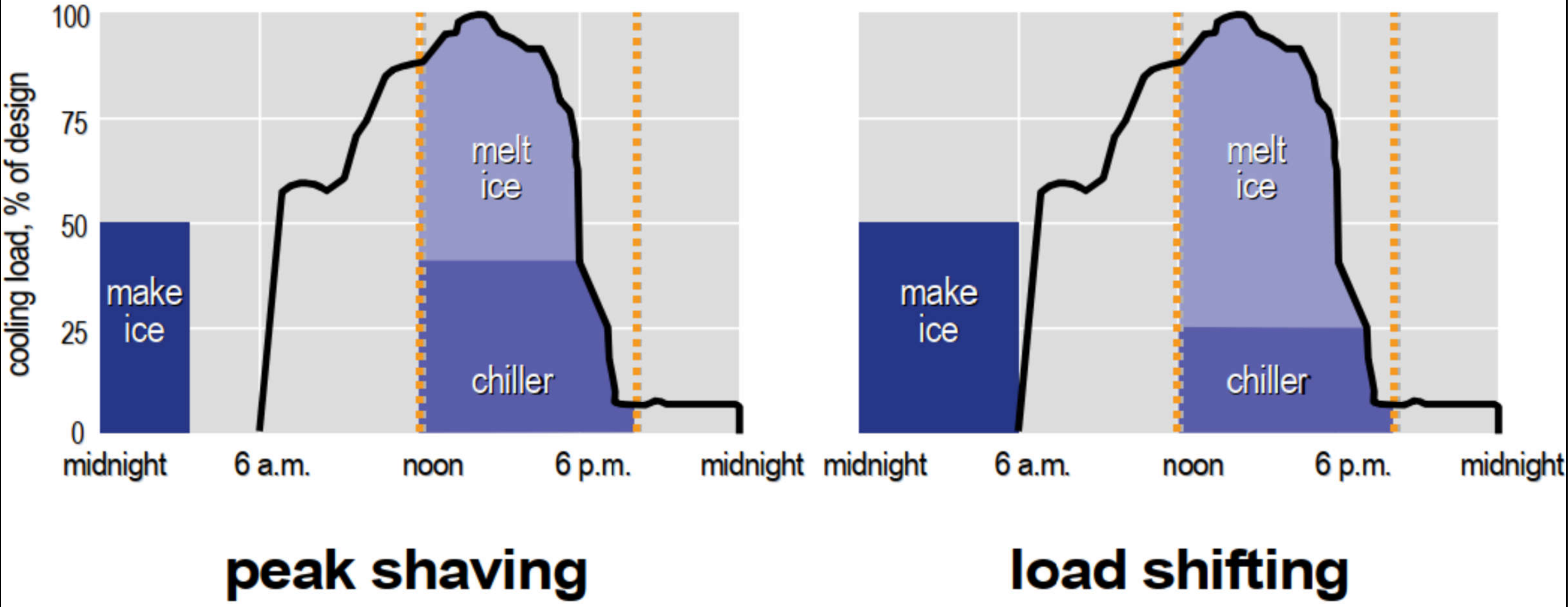
(Source: https://hvac-eng.com/thermal-storage-hvac/)

Benefits of thermal storage in HVAC systems

- Energy cost savings (e.g. reduce peak demand charge)
- Ancillary services benefit (e.g. balancing & frequency control)
- Reduced equipment size (meet the average load only)
- Capital cost savings (from downsizing equipment)
- Energy savings (e.g. lower condensing temperature at off-peak)
- Improved HVAC operation (by decoupling the thermal load)
- Back-up capacity (from the storage reservoir)
- Extending existing systems' capacity
- Distributed energy resource for utilities (demand side management)
- Renewable energy integration
- Storage may be used for fire fighting at emergency or disaster
- Other benefits (e.g. integrated with cold-air distribution)

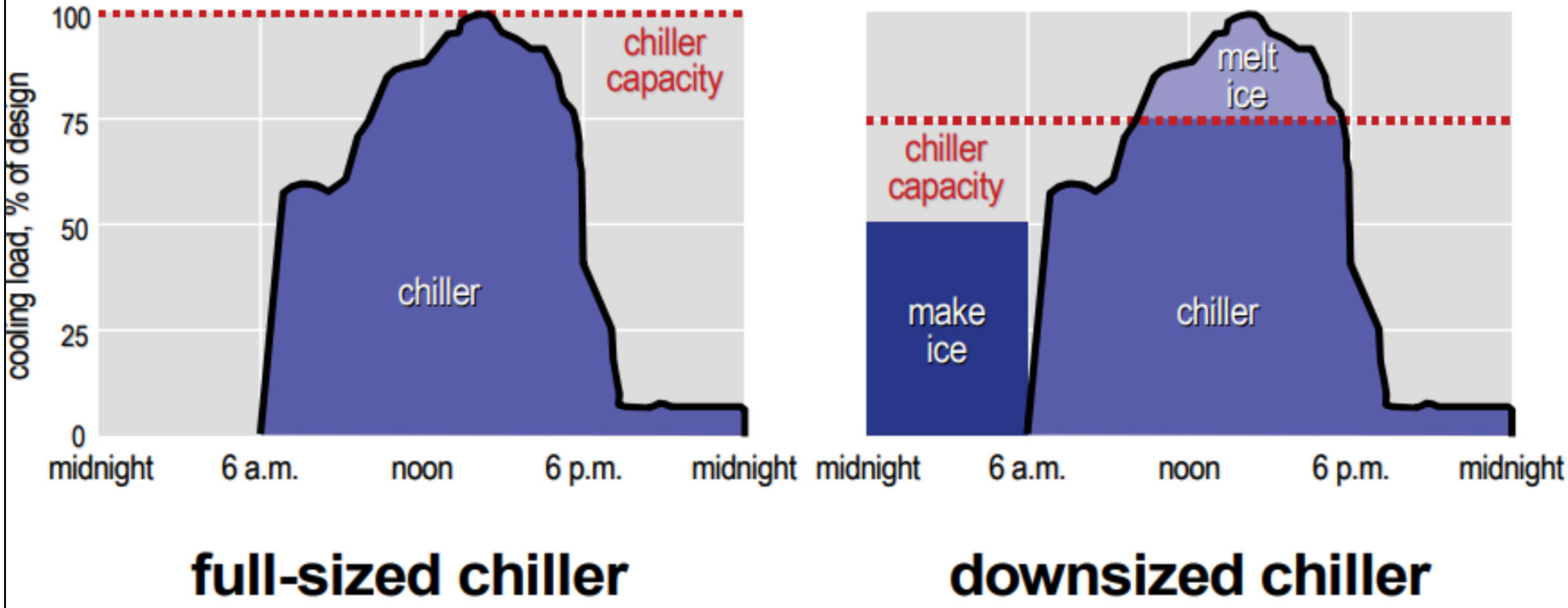
(Source: *ASHRAE HVAC Systems and Equipment Handbook 2020*, SI edition, Chp. 50 Thermal Storage)

Peak shaving and load shifting by thermal storage system



(Source: Trane)

Using thermal storage system to downsize the chiller



(Source: Trane)

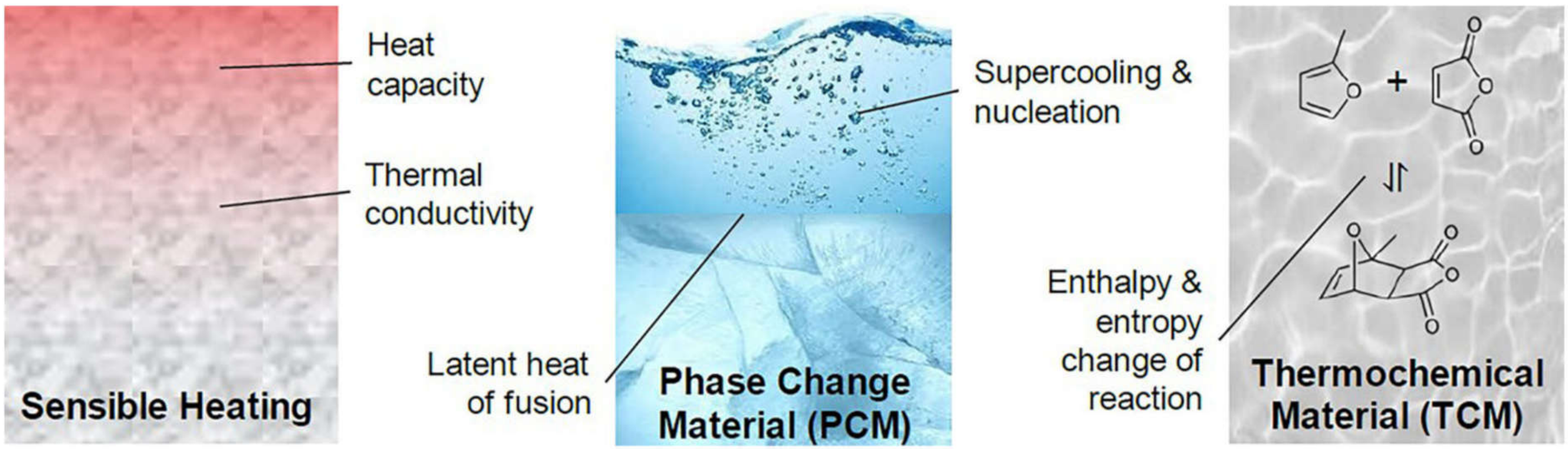
Conditions making thermal storage attractive in HVAC systems

- Loads are of short duration
- Loads occur infrequently
- Loads are cyclical
- Loads are not coincident with energy source availability
- Energy costs are time-dependent (e.g. time-of-use energy rates)
- Charges for peak power demand are high
- Utility rebates, tax credits, or other economic incentives are provided for using load-shifting equipment
- Energy supply is limited, thus limiting or preventing the use of full-size non-storage systems
- Facility expansion is planned, and the existing heating or cooling equipment is insufficient to meet the new peak load but has spare non-peak capacity
- A mission-critical operation requires uninterrupted heating and/or cooling

(Source: *ASHRAE HVAC Systems and Equipment Handbook 2020*, SI edition, Chp. 50 Thermal Storage)

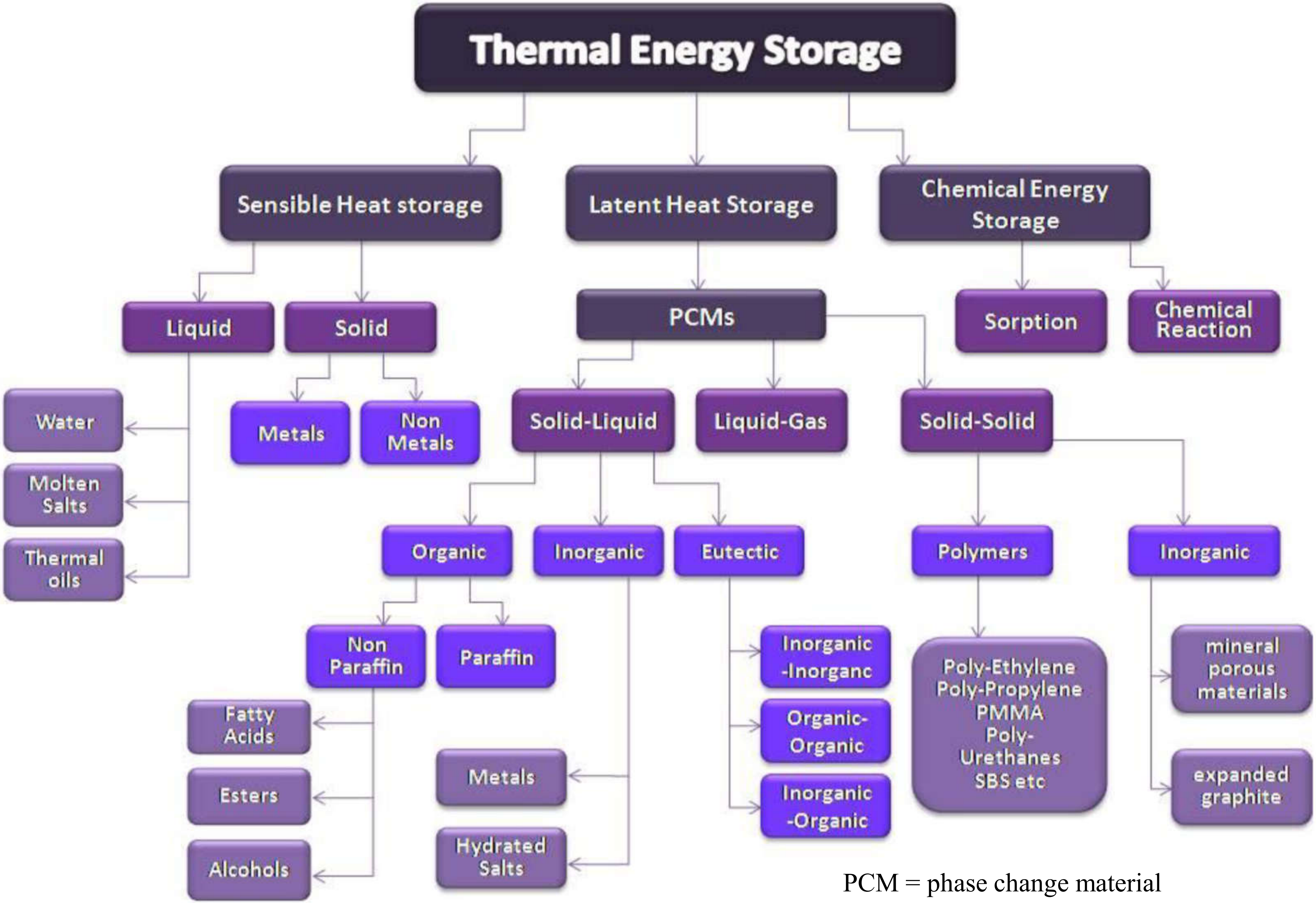
Comparing media of thermal storage

Storage medium	Volume (L/ton-hour)	Storage temperature (°C)	Discharge temperature (°C)	Strengths
Chilled water	303-595	4-7	5-8	Can use existing chillers; water in storage tank can do double duty for fire protection
Ice	68-93	0	1-2	High discharge rates; potential for low temperature air system
Eutectic salts	170	8	9-10	Can use existing chillers



(Image source: https://phys.org/news/2021-12-phase-materials-thermal-energy-storage.html)

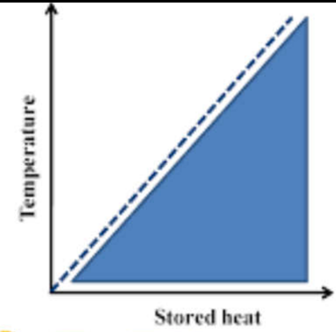
Classification of thermal energy storage types and materials



PCM = phase change material

(Source: https://www.mdpi.com/2076-3417/11/4/1490)

Sensible thermal storage



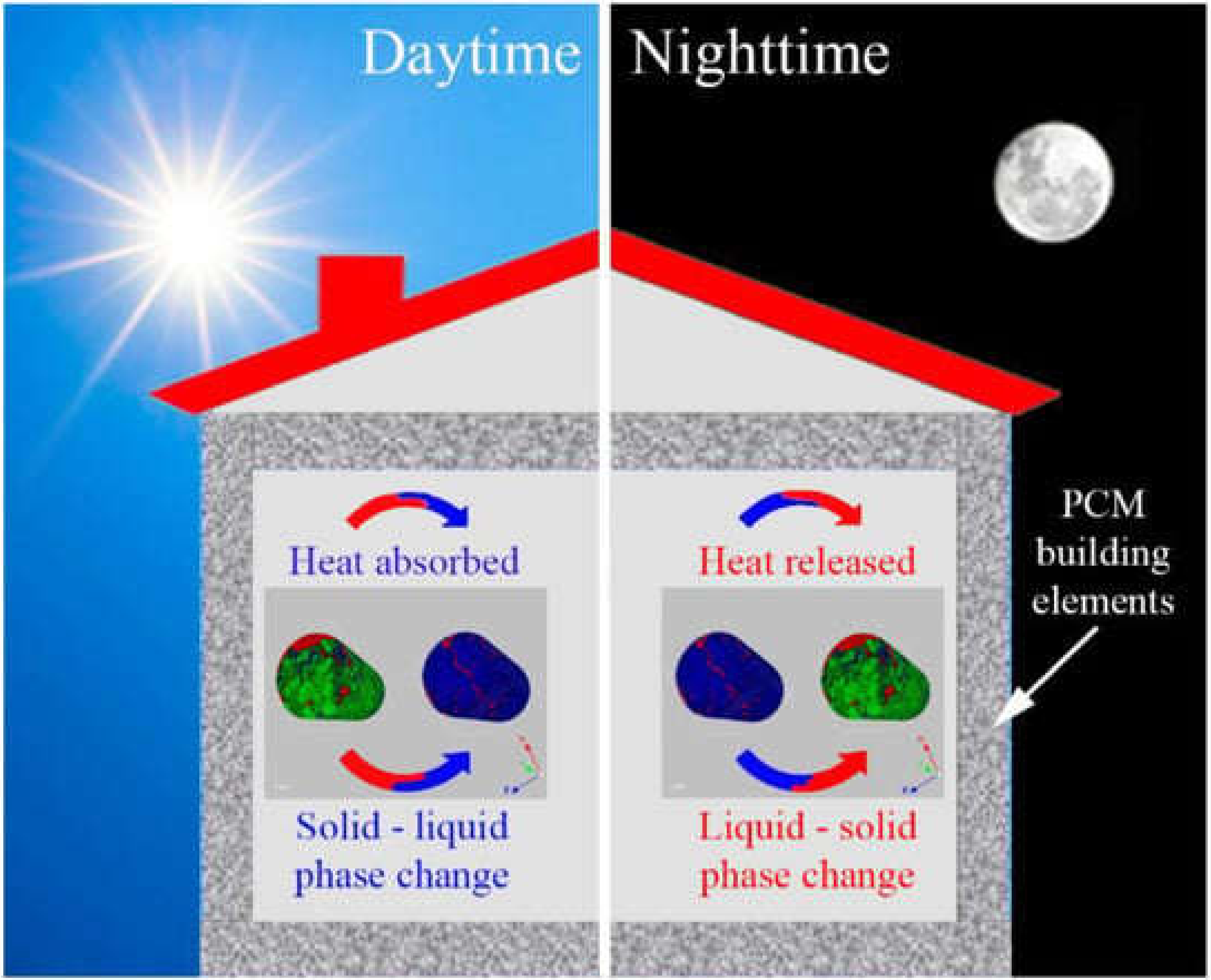
- It refers to the heat storage within a medium that does not result in a change of state, e.g.
  - Using building mass (like a Trombe wall) or high thermal-mass materials (passive technologies)
  - Using water storage
- Water is well suited for both hot and cold sensible energy storage applications and is the most common sensible storage medium
  - Specific heat capacity of water = 4.18 kJ/(kg·K)

List of selected solid-liquid materials for sensible heat storage

Medium	Fluid Type	Temperature Range (°C)	Density (kg/m^3)	Specific Heat (J/(kg·K))
Sand	-	20	1555	800
Rock	-	20	2560	879
Brick	-	20	1600	840
Concrete	-	20	2240	880
Granite	-	20	2640	820
Aluminium	-	20	2707	896
Cast iron	-	20	7900	837
Water	-	0–100	1000	4190
Calorie HT43	Oil	12–260	867	2200
Engine oil	Oil	≤160	888	1880
Ethanol	Organic liquid	≤78	790	2400
Propane	Organic liquid	≤97	800	2500
Butane	Organic liquid	≤118	809	2400
Isotunaol	Organic liquid	≤100	808	3000
Isopentanol	Organic liquid	≤148	831	2200
Octane	Organic liquid	≤126	704	2400

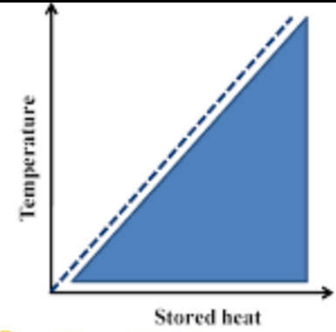
(Source: Sarbu I. & Sebarchievici C., 2018. A comprehensive review of thermal energy storage, *Sustainability*, 10 (1) 191. https://doi.org/10.3390/su10010191)

Charging process (working of PCM during daytime) and discharging process (working of PCM during nighttime)



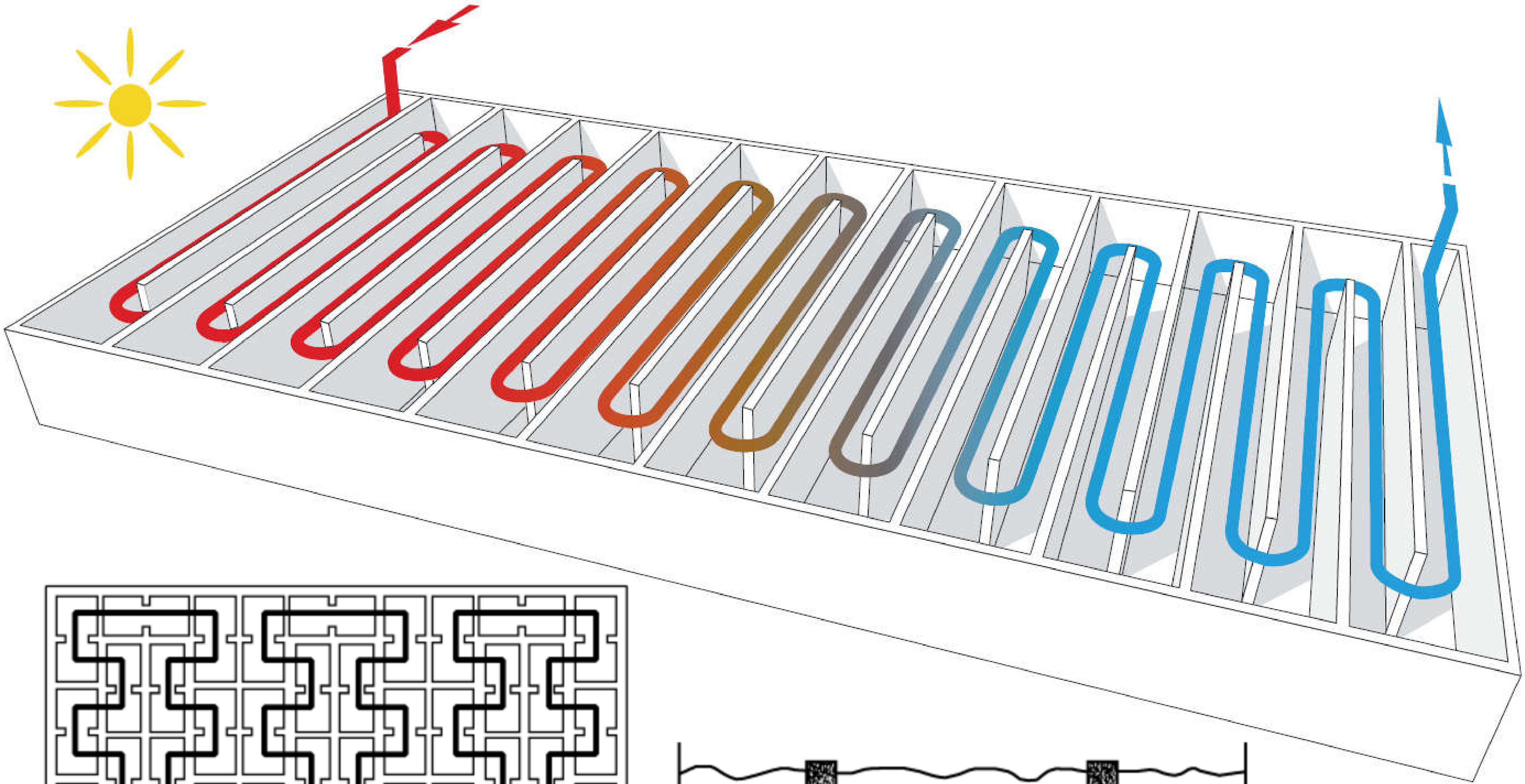
(Source: https://www.mdpi.com/2076-3417/11/4/1490)

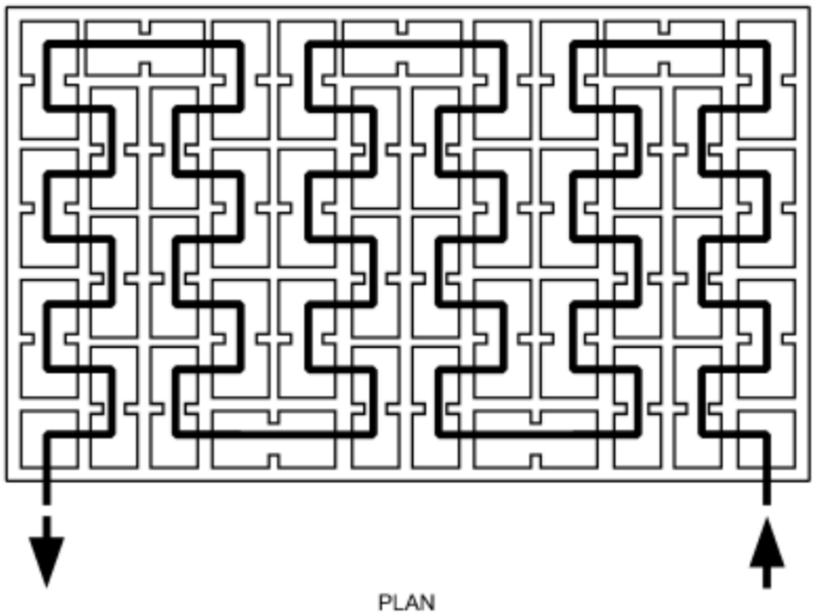
Sensible thermal storage

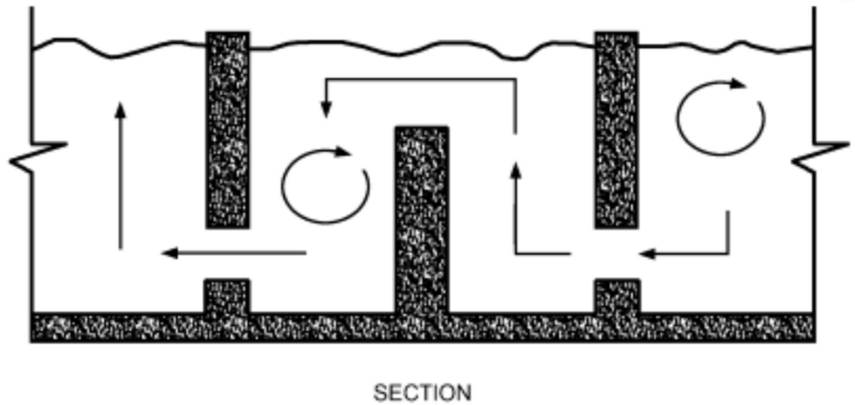


- Examples of sensible thermal storage systems:
  - Empty tank method (one tank for cool supply water + one tank for warm return water)
  - Labyrinth tank (multitude of compartments)
  - Baffle-and-weir (internal walls separated compartments within a tank)
  - Membrane or diaphragm separation
  - Thermally stratified
  - Aqueous sodium nitrite/nitrate

Examples of Labyrinth tank (with multitude of compartments)

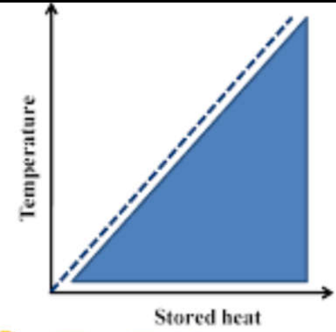






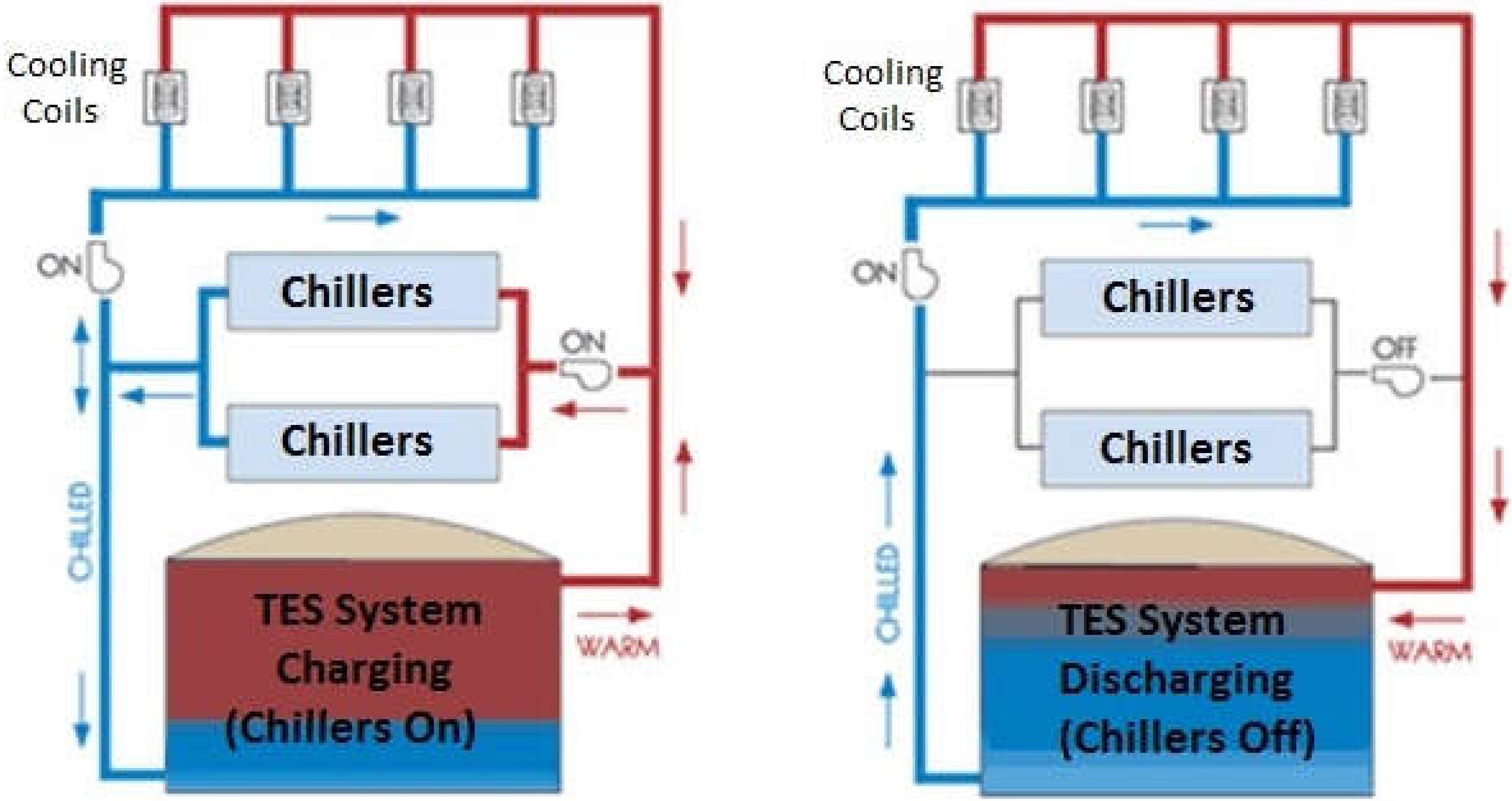
(Source: https://www.designingbuildings.co.uk/wiki/Thermal_labyrinths)

Sensible thermal storage



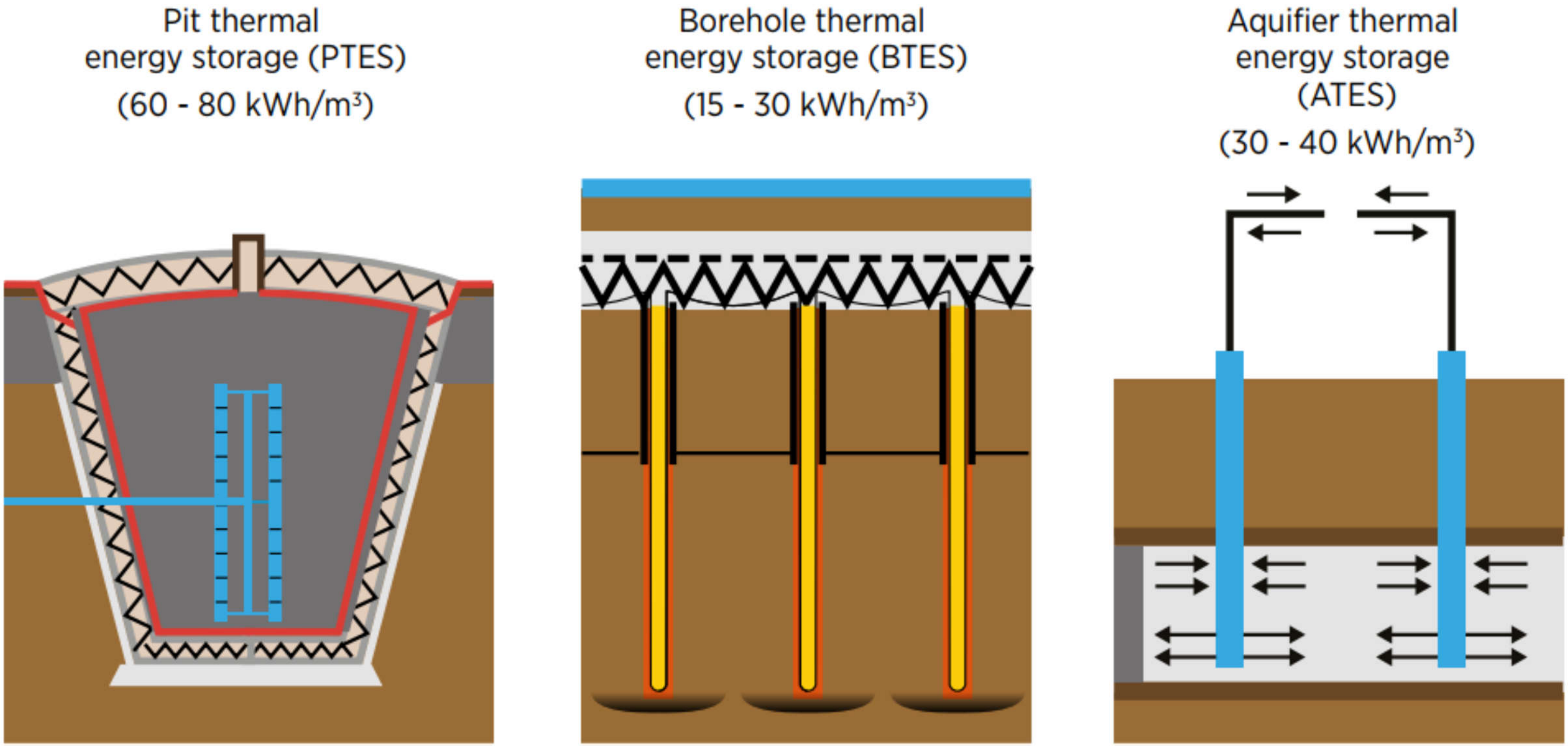
- Thermal storage tanks can be located above ground, partially buried, completely buried or incorporated into the building structure
  - Such as chilled water thermal storage
  - Thermal stratification & storage tank insulation
  - Storage in aquifers (underground)
- Storage tank options:
  - Steel tanks (need corrosion protection)
  - Concrete tanks (precast or cast-in-place)
  - Plastic tanks (prefabricated modular units)

Chilled water thermal storage system process flow diagrams



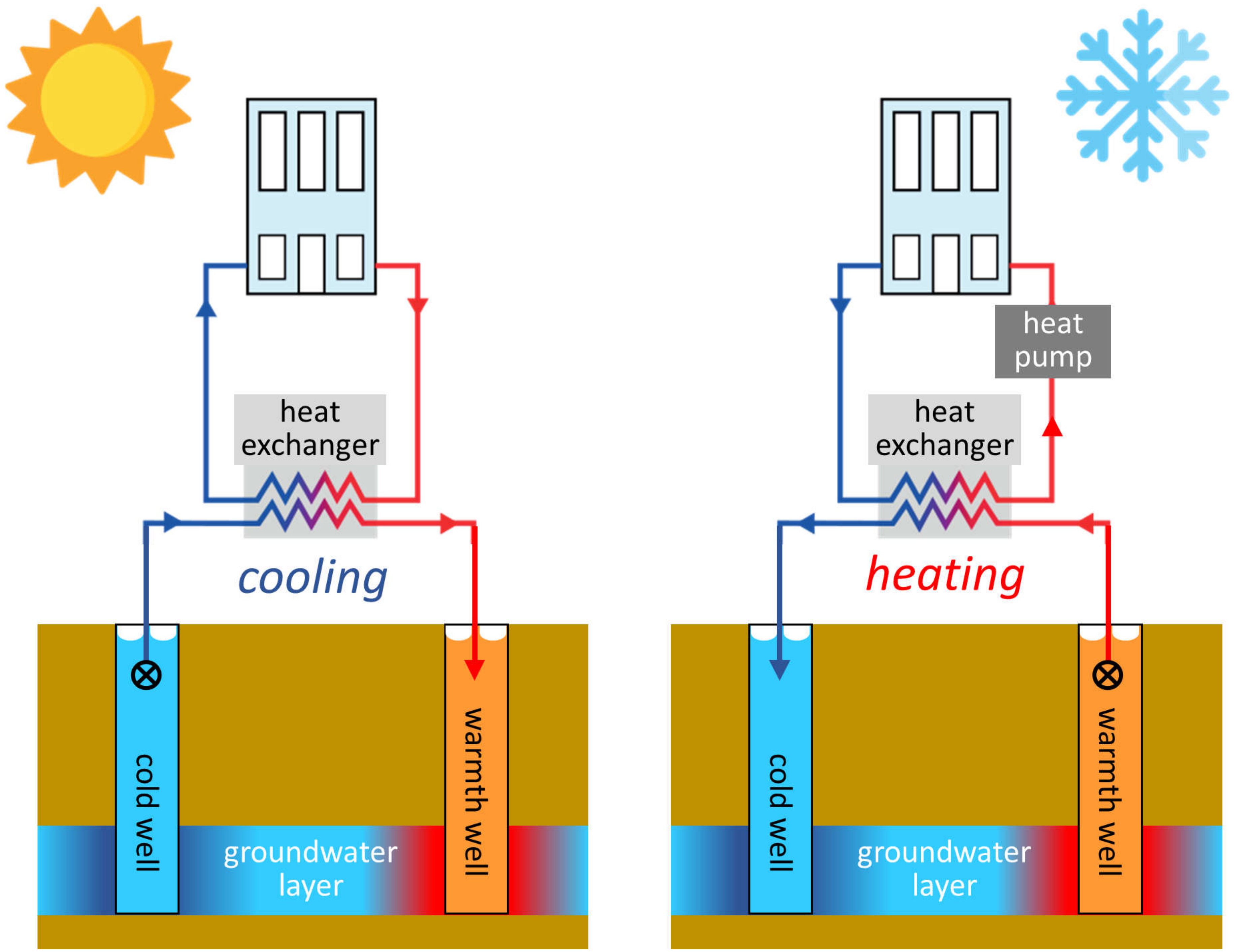
(Source: Reliable Chilled Water Using Thermal Storage http://www.powersurety.com/reliable-chilled-water/)

Underground energy storage concept



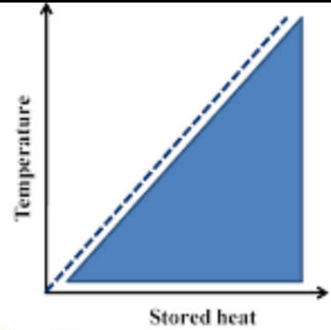
(Source: IRENA, 2020. *Innovation Outlook: Thermal Energy Storage*, International Renewable Energy Agency (IRENA), Abu Dhabi. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Nov/IRENA_Innovation_Outlook_TES_2020.pdf)

Aquifer thermal energy storage



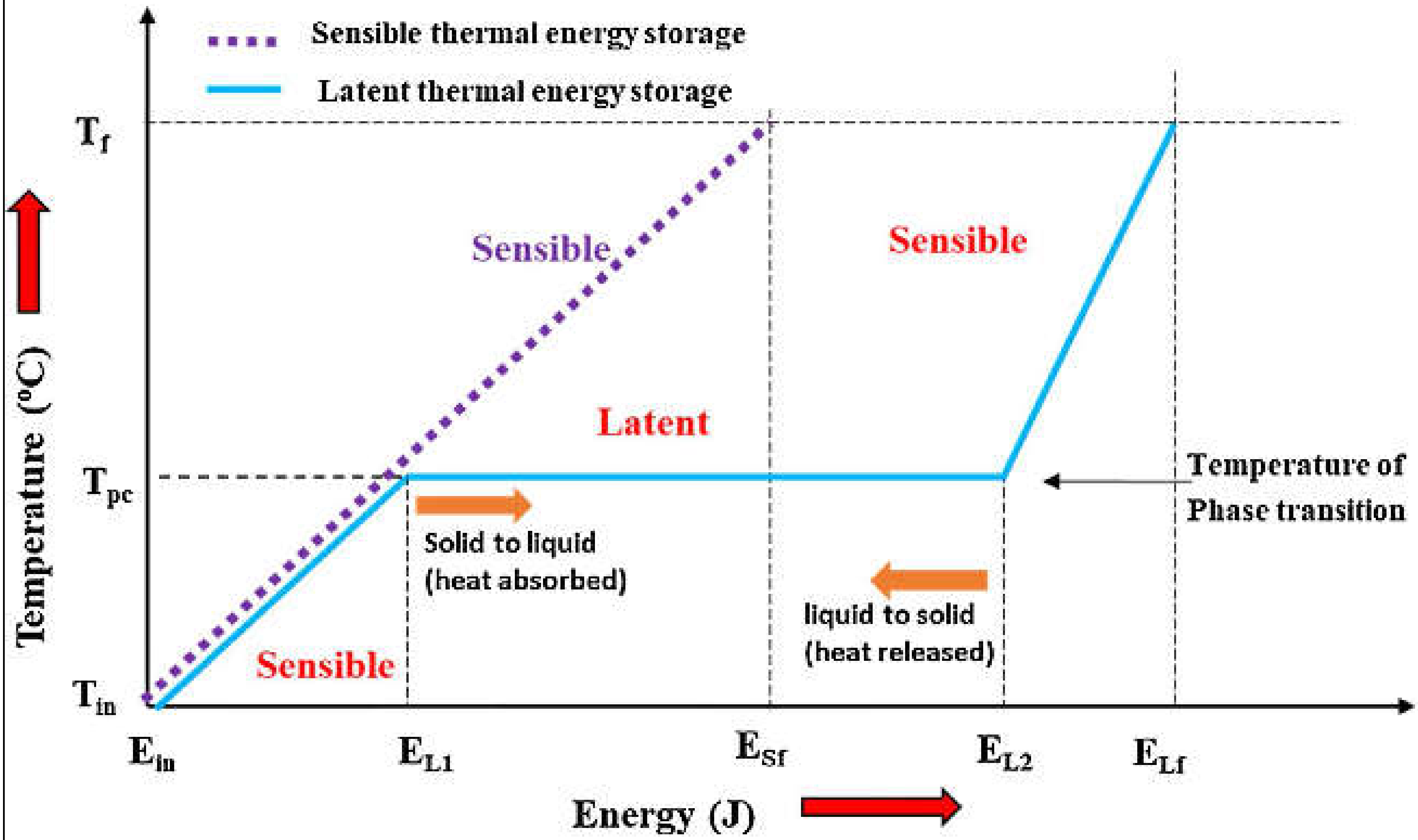
(Source: https://www.wur.nl/en/show/aquifer-thermal-energy-storage.htm)

Sensible thermal storage



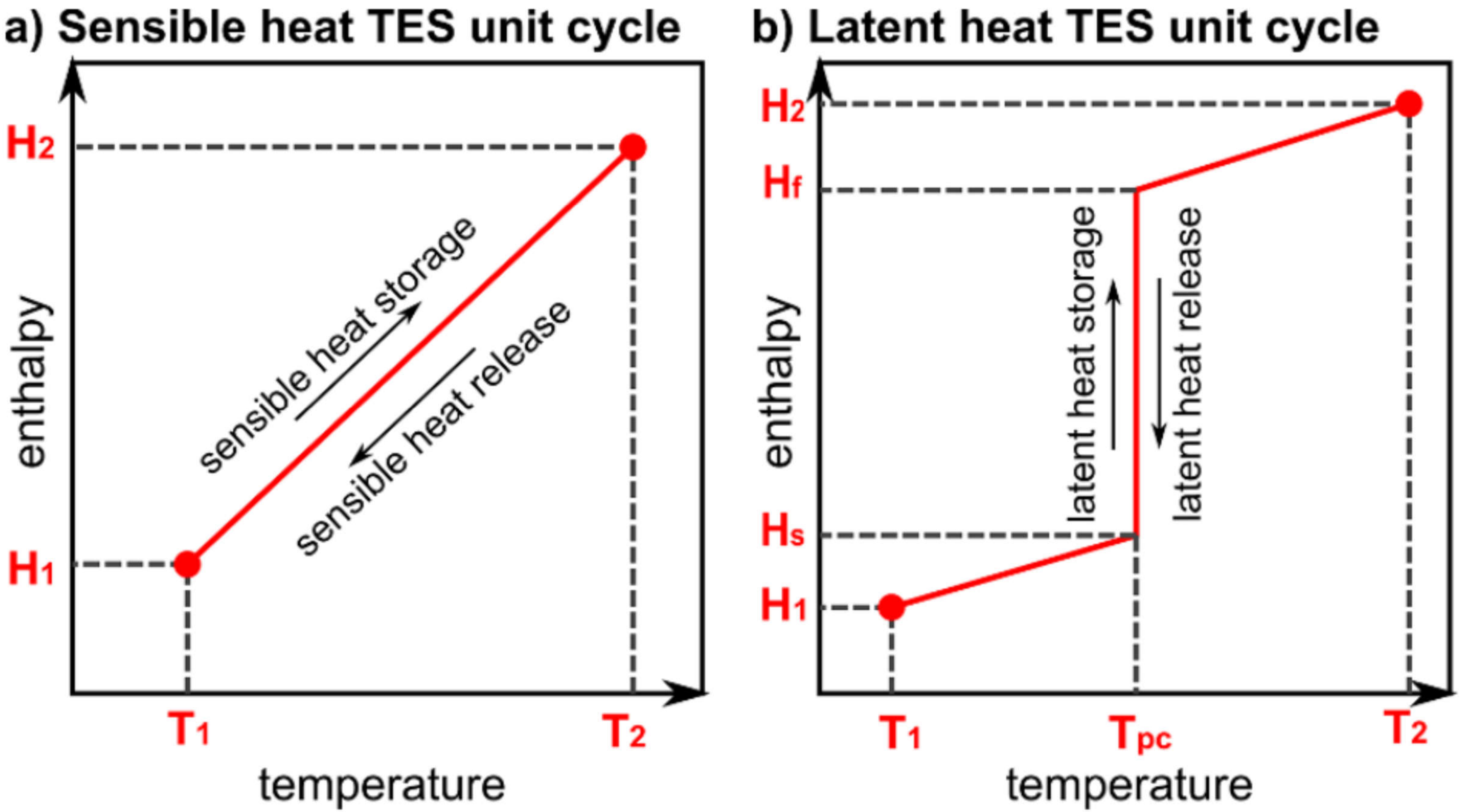
- Chilled water thermal storage sizing options
  - Full storage: the system is sized so that on the peak day, with the exception of chilled-water distribution pumps, the chiller plant can be completely turned off for a certain period of the day (usually the utility company's on-peak period)
  - Partial storage: the system is sized such that, on the peak cooling day, the smallest chiller plant possible can meet the peak cooling load by operating at a constant rate throughout the day in conjunction with the thermal storage system
    - Require the chiller plant to operate during the entire day

Principle of sensible and latent thermal energy storage



(Source: Reddy K., 2018. Review of latent heat thermal energy storage for improved material stability and effective load management, *Journal of Energy Storage*, 15: 205-227. https://doi.org/10.1016/j.est.2017.11.005)

Variation of enthalpy of the storage medium as a function of its temperature in sensible and latent thermal storage



(Source: Fredi G., Dorigato A., Fambri L. & Pegoretti A., 2020. Multifunctional structural composites for thermal energy storage, *Multifunctional Materials*, 3: 042001. https://doi.org/10.1088/2399-7532/abc60c)

Thermal Energy Storage	Specific Heat, kJ/kg K	Thermal Conductivity, W/m K	Density, kg/m^3	Latent Heat of Fusion, kJ/kg
Rock bed	1	3.26	2240	-
Brick	790	0.90	1920	-
Concrete	840	0.79	1600	-
Pebble bed	0.8	2.9	1430	-
Paraffin wax	2.1-8.4	24.06×10^{-2}	920-795	189
Hytherm oil	0.73	0.97	725	-
Glauber's salt	2.5	2.25	1330-1460	251
Organic PCM	2	-	800	190
Inorganic PCM	2	-	1600	230
Granular carbon	0.93	0.11	460	-
Water	4178	0.612	998	334
Al composites	0.89	0.21	2707	-
Iron gravels	0.56	37	7200	-

Thermo-physical properties of commonly used sensible and latent heat storage materials

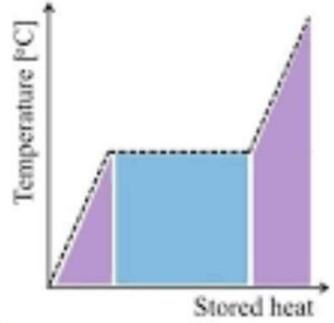
(Source: Haldorai S., Gurusamy S. & Pradhapraj M., 2019. A review on thermal energy storage systems in solar air heaters, International Journal of Energy Research, 43 (4) 1-17. https://doi.org/10.1002/er.4379)

Comparison between sensible and latent thermal storage techniques

	Operating Principle	**Benefits**	**Materials**	**Application Domains**
Sensible thermal storage	Temperature change (Increase/ Decrease)	• Inexpensive • Simple operation	Water, rock, concrete, etc.	• Concentrated solar power (CSP) • Plants or desalination • Building heating
Latent thermal storage	Phase change (Solid-Liquid)	• Large storage density • Large latent heat • Stable temperature	Paraffins, salt hydrates, metallics, etc.	• Solar applications • Building heating/cooling • Heat pump • Thermal control • Industrial waste heat storage

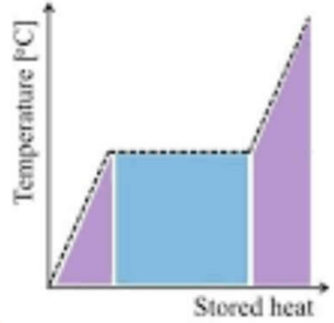
(Source: Mabrouk R., Naji H., Benim A. C. & Dhahri H., 2022. A state of the art review on sensible and latent heat thermal energy storage processes in porous media: mesoscopic simulation, *Applied Sciences*, 12 (14) 6995. https://doi.org/10.3390/app12146995)

Latent thermal storage



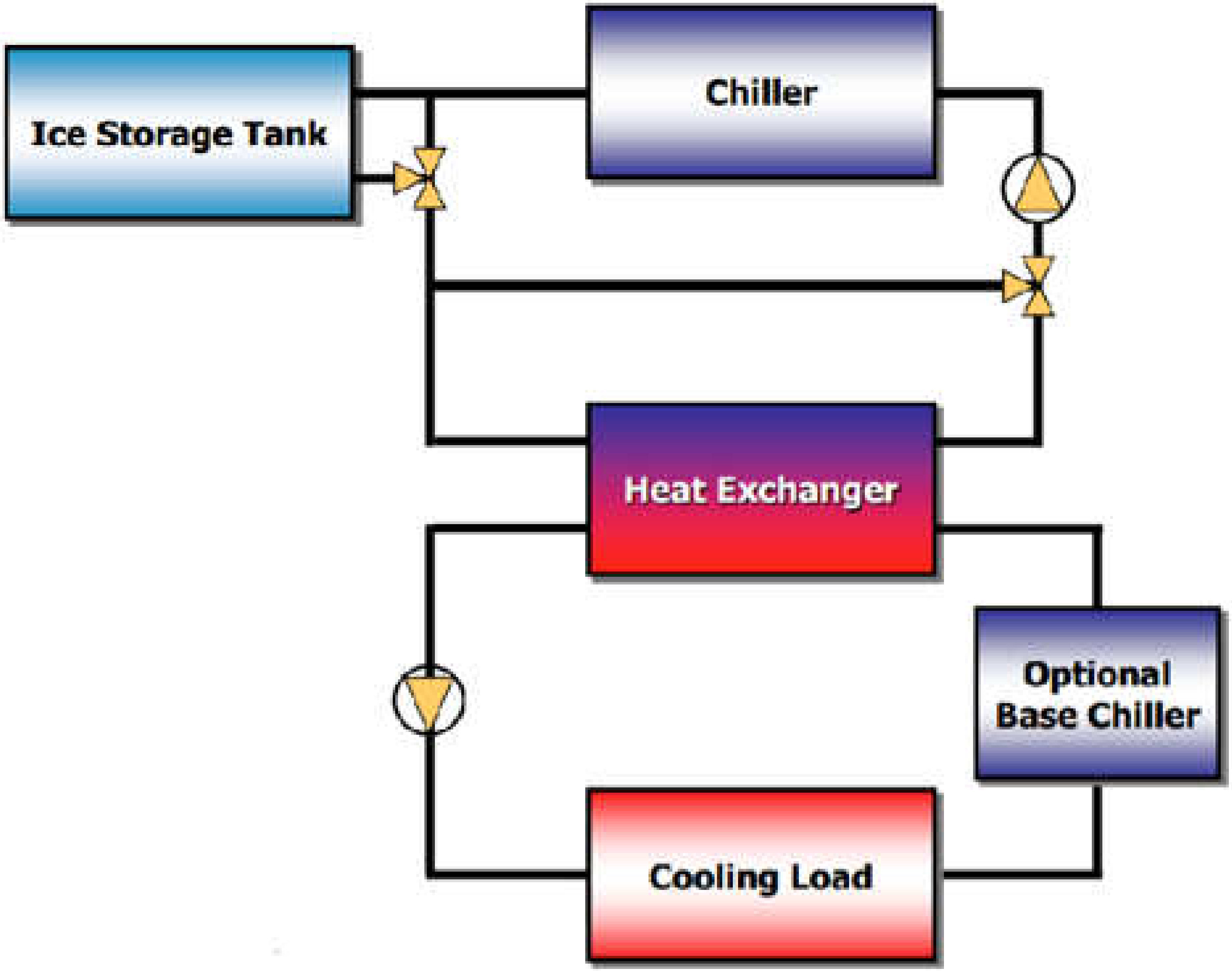
- It utilises a medium that transfers heat by changing state (e.g. liquid to solid)
  - Given this additional phase change capability, latent thermal systems have greater capacity to store energy than those of sensible thermal storage
- Main methods of HVAC latent thermal storage:
  - 1. Ice storage (to cool the chilled water)
  - 2. Phase Change Material (PCM) e.g. eutectic salts
  - 3. PCM building fabric (increase thermal mass)

Latent thermal storage



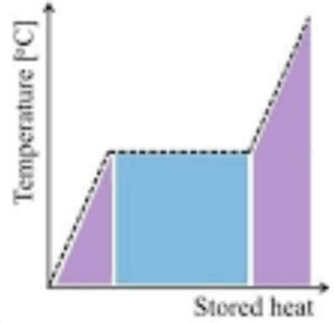
- Examples of latent thermal storage systems
  - Ice harvester (produce sheet ice, tube ice, ice cubes)
  - Ice-on-coil-internal melt (using water-glycol)
  - Ice-on-coil-external melt
  - Encapsulated ice (e.g. small plastic balls)
  - Ice slurry (pumpable ice slurries)
  - Paraffin wax slurries
  - Passive phase change material (PCM)
  - Eutectic salts
  - Triple point carbon dioxide

Basic concept of ice thermal storage system



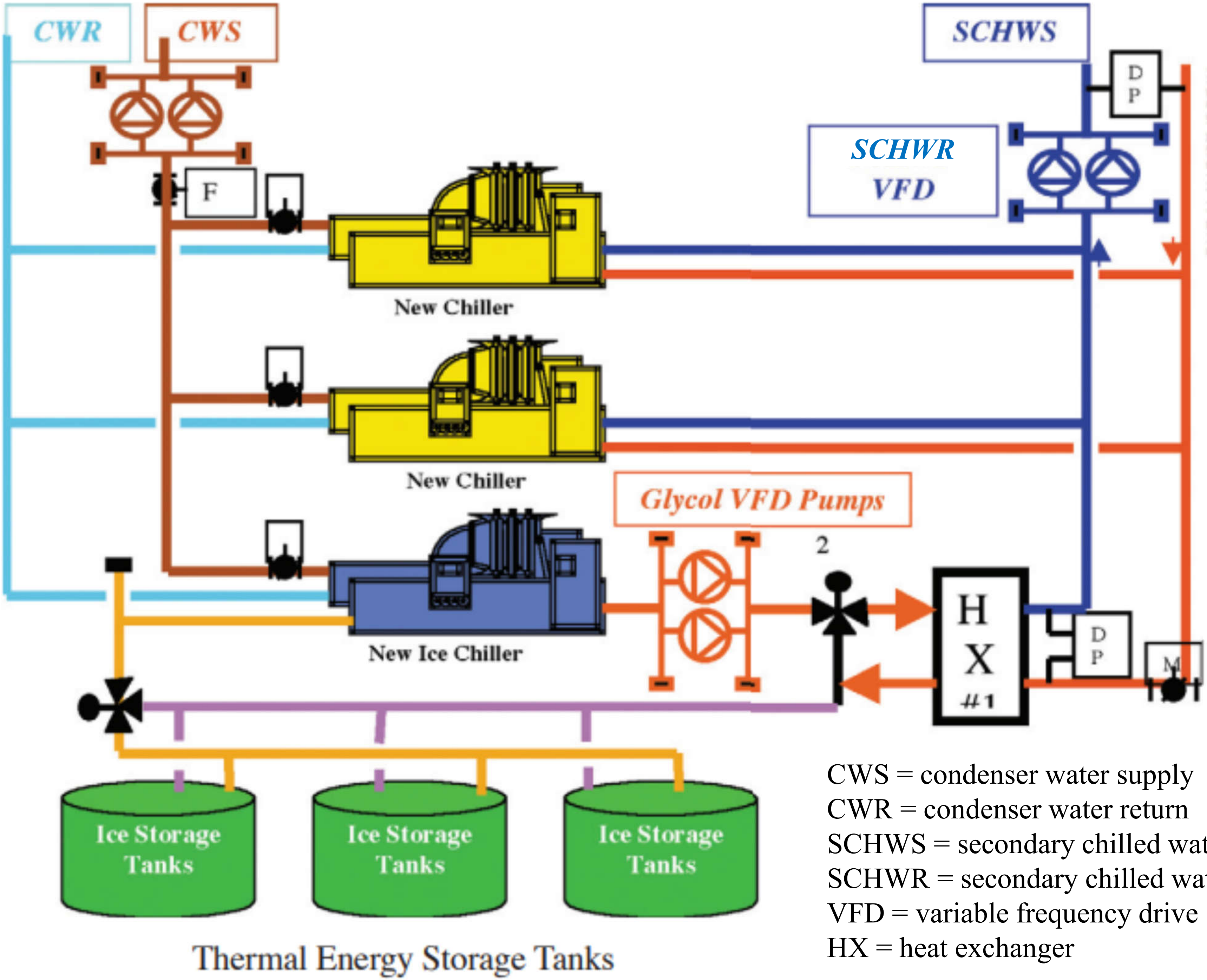
(Source: http://www.danielrdgz.com/development-of-a-three-ton-source-of-cool-air.html)

Latent thermal storage



- Ice thermal storage systems
  - Ice is stored in a tank or other containers to provide cooling for buildings in on-peak hours or on- and partial-peak hours
  - Coolants used (lower freezing temperature): brine, glycol-water
  - The chillers work continuously to produce ice during night, and the ice is melted the next day when the air-conditioning is required

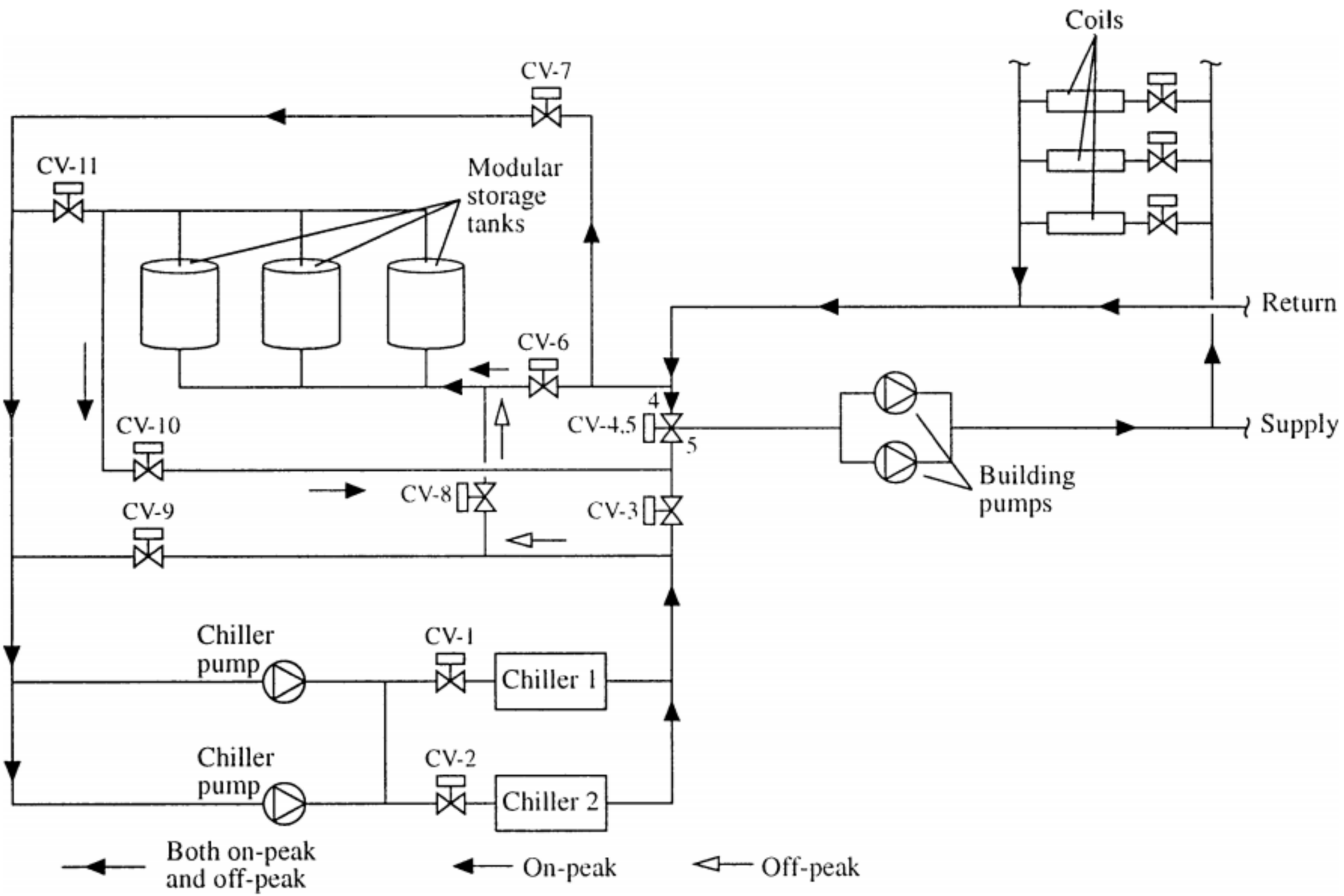
An example of ice thermal storage system



CWS = condenser water supply
CWR = condenser water return
SCHWS = secondary chilled water supply
SCHWR = secondary chilled water return
VFD = variable frequency drive
HX = heat exchanger

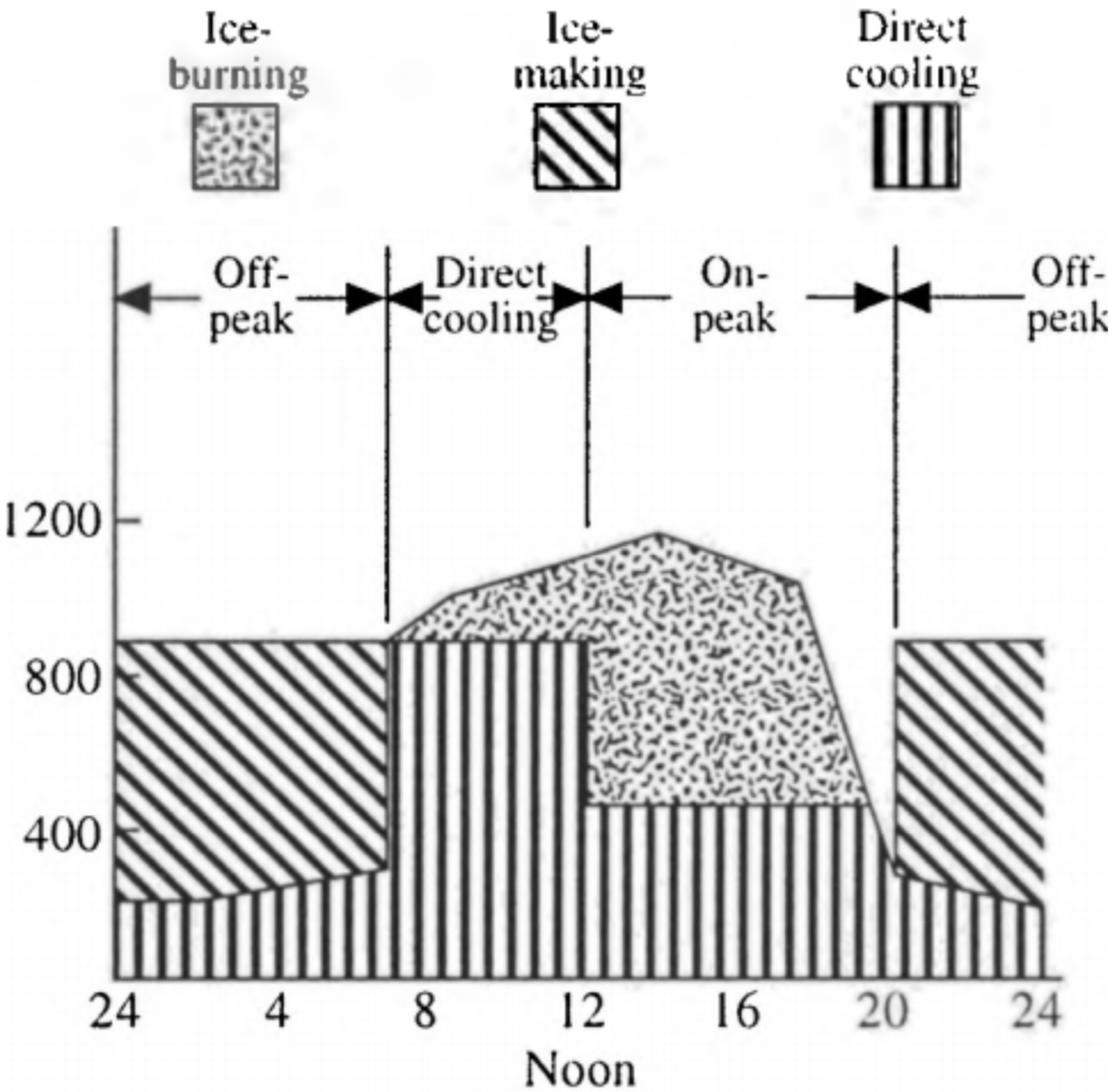
(Source: Trane)

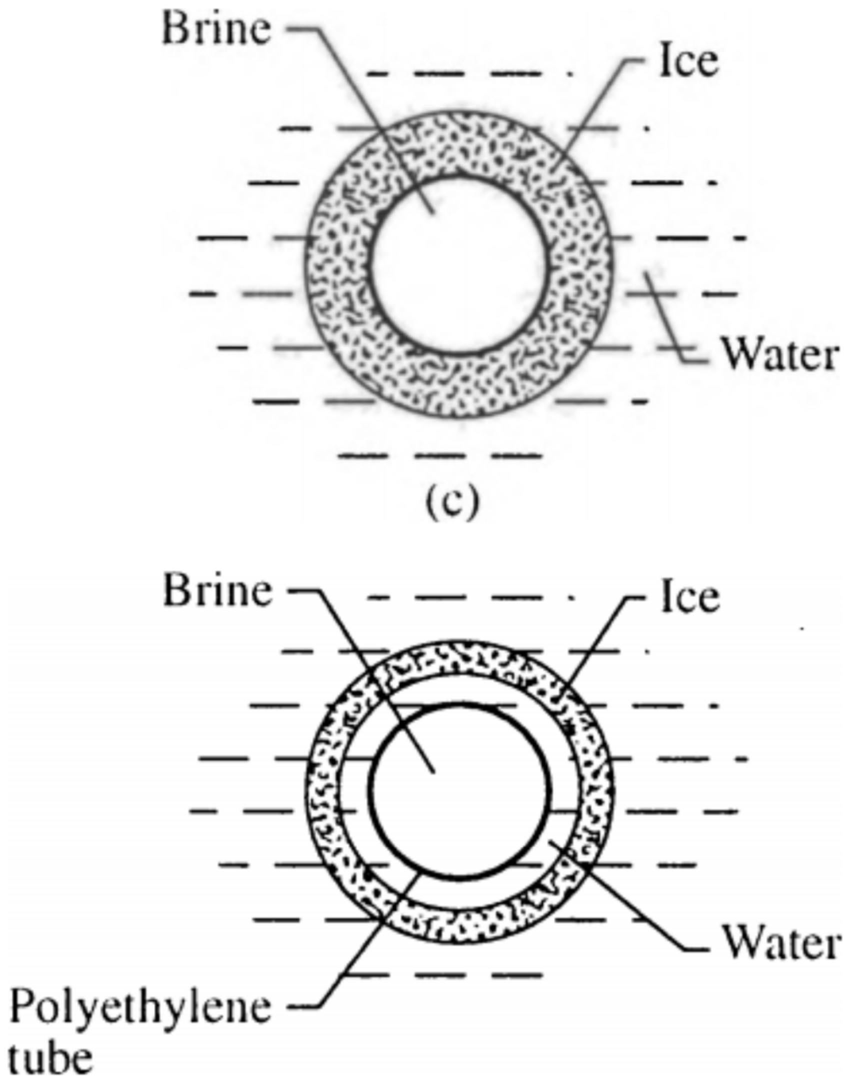
Schematic diagram of a brine ice thermal storage system



(Source: Wang S. K., Lavan Z. and Norton P., 2000. *Air Conditioning and Refrigeration Engineering*, CRC Press, Boca Raton.)

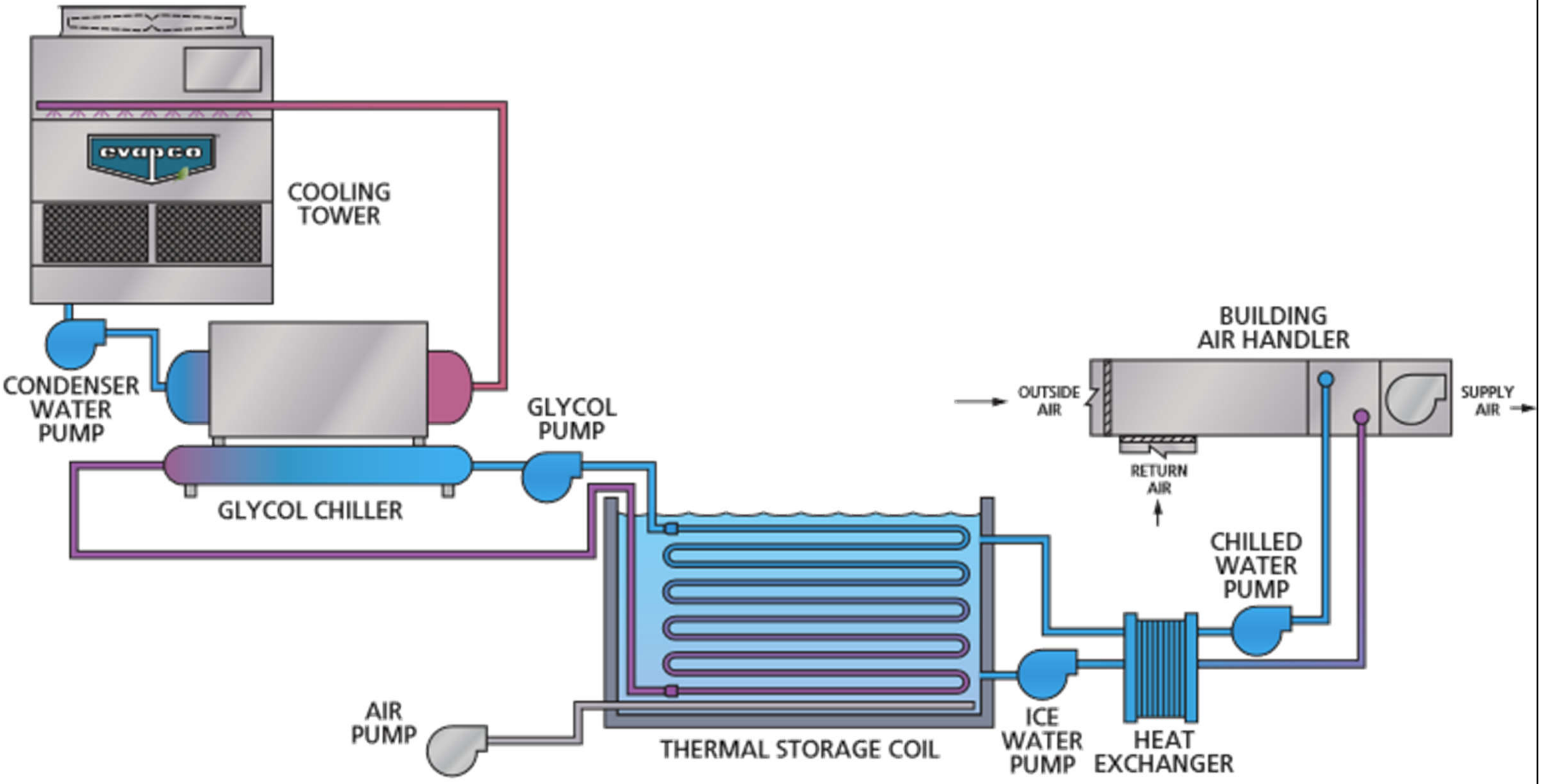
Partial storage time schedule of a brine ice thermal storage system





(Source: Wang S. K., Lavan Z. and Norton P., 2000. *Air Conditioning and Refrigeration Engineering*, CRC Press, Boca Raton.)

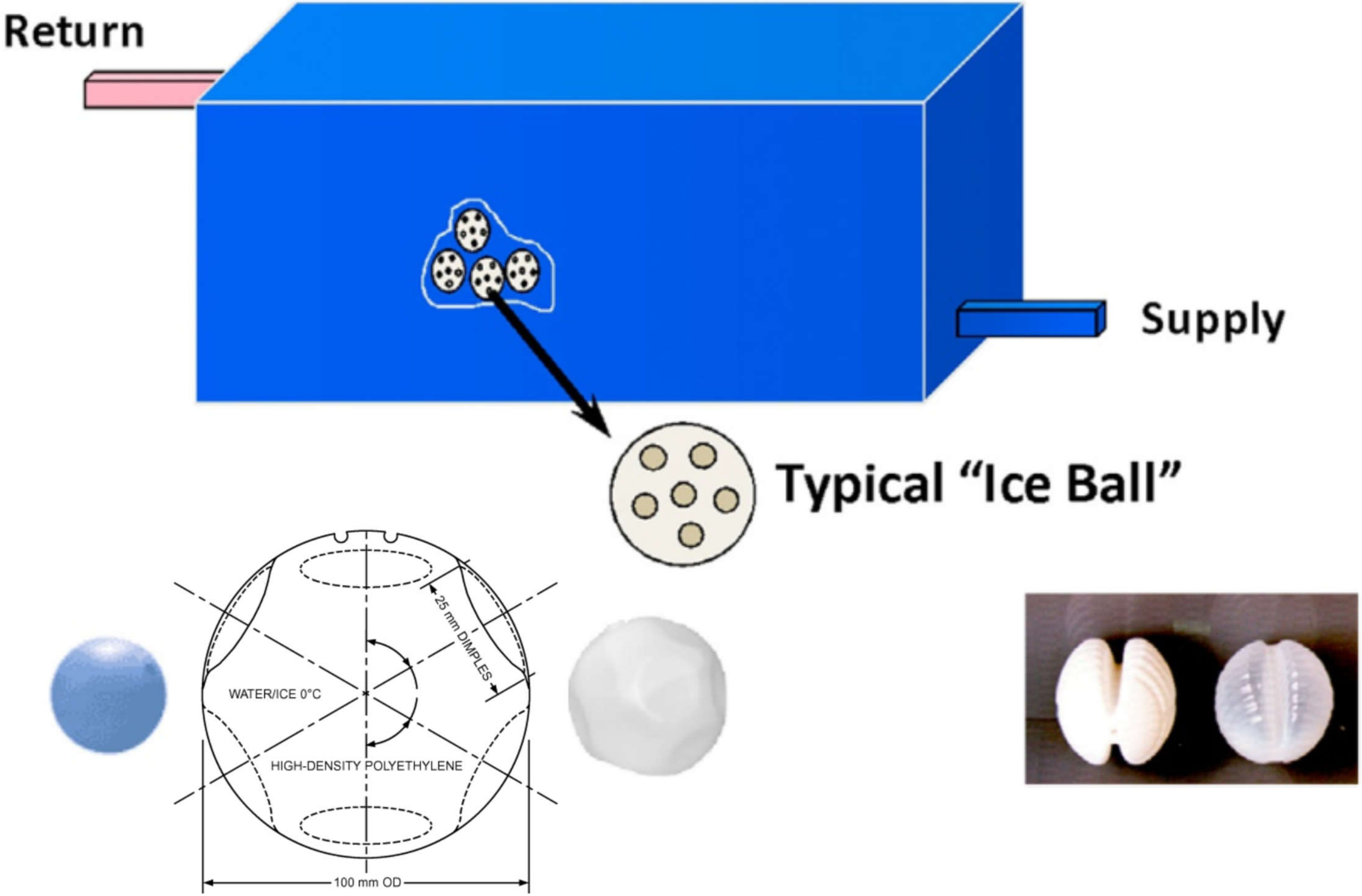
Thermal storage system using ice coil



Thermal Storage System Schematic

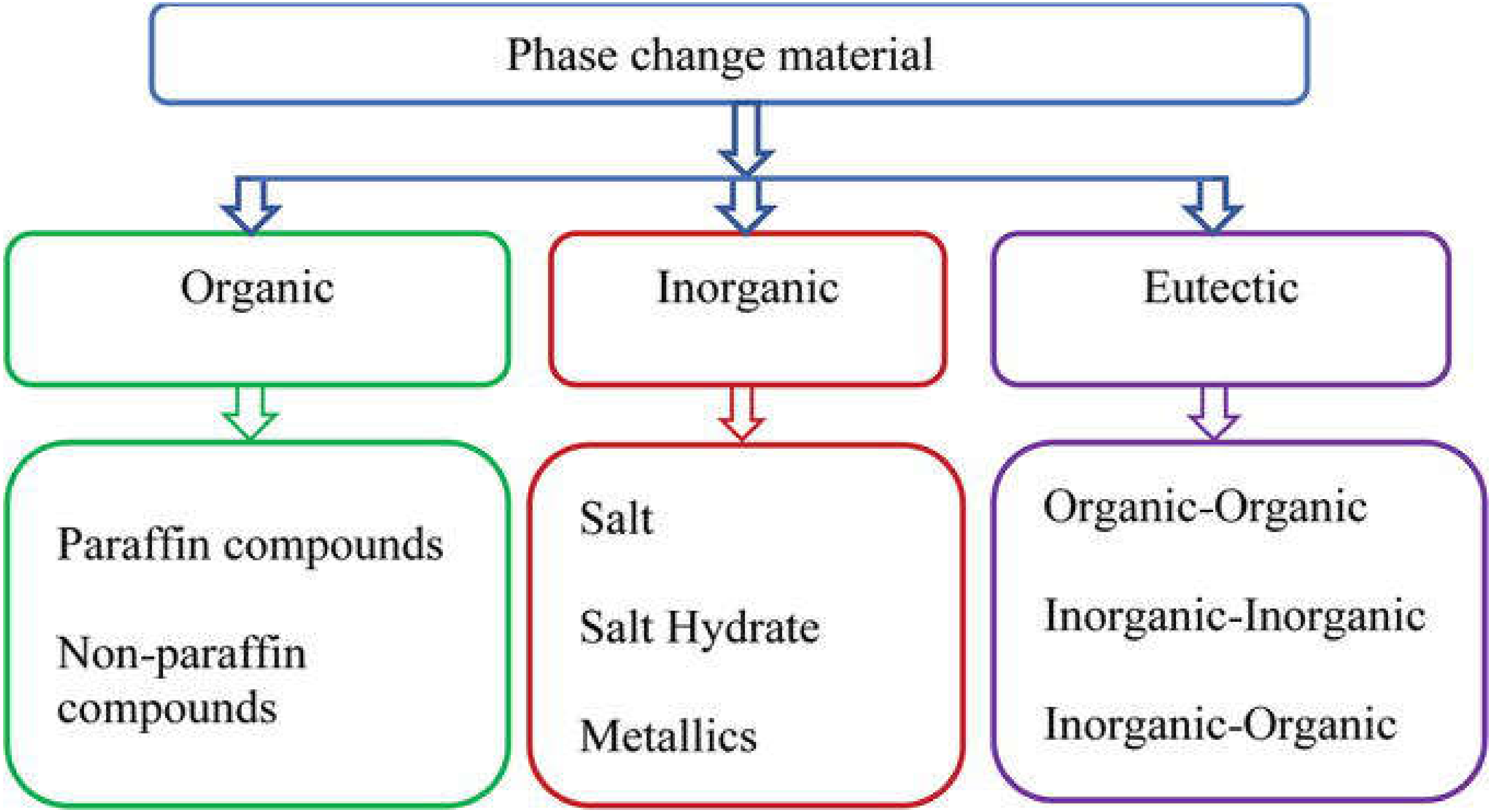
(Source: https://www.evapco.com.au/products/thermal-energy-storage/extra-pakr-ice-coil)

An encapsulated ice storage tank with typical ice balls



(Source: Brun K., Allison T. & Dennis R. (eds.), 2021. *Thermal, Mechanical, and Hybrid Chemical Energy Storage Systems*, Academic Press, London. https://doi.org/10.1016/C2019-0-00430-X)

Classification of phase change materials (PCMs)



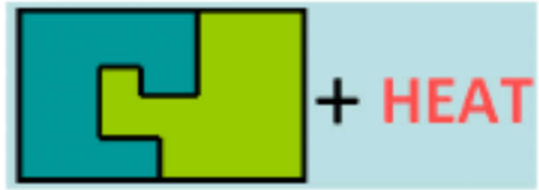
(Source: https://www.intechopen.com/chapters/63027)

Benefits and drawbacks of different phase change materials (PCMs)

Classification	**Benefits**	**Drawbacks**
Organic PCMs	• No subcooling • No supercooling • No phase segregation • Large storage capacity • High latent heat • Recyclable substances • Certain renewable substances (fatty acids and alcohols) • Available for all temperature range • Compatible with other materials	• Low thermal conductivity • (~ 0.2 $W.m^{-1}.K^{-1}$) • Flammable • Large volume change • Certain non-renewable substances
Inorganic PCMs	• High thermal conductivity • High latent heat • High storage capacity • Small volume change • Availability and low cost	• Supercooling • Corrosion • Presentation of chemical instability
Eutectics	• No segregation • High storage density • Adjustable phase transition • temperature	• Lack of test data for certain • thermophysical characteristics • Same drawbacks of pure organic or inorganic PCMs

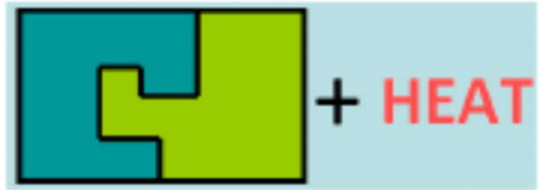
(Source: Mabrouk R., Naji H., Benim A. C. & Dhahri H., 2022. A state of the art review on sensible and latent heat thermal energy storage processes in porous media: mesoscopic simulation, *Applied Sciences*, 12 (14) 6995. https://doi.org/10.3390/app12146995)

Thermochemical storage



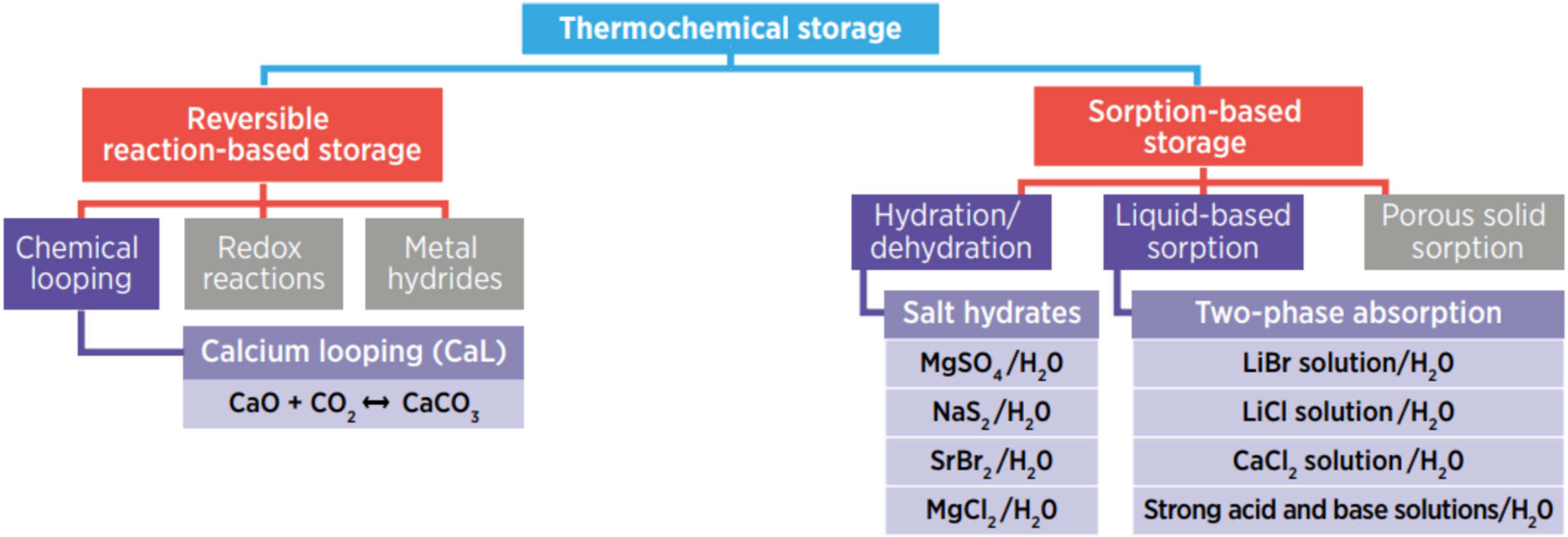
- It has a higher energy density than sensible and latent thermal storage
  - Using thermo-chemical materials (TCM)
- It can be divided into:
  - 1. Reversible reaction-based storage
    - Two separate chemical substances where a high amount of energy is generated as a result of an exothermic synthesis reaction
  - 2. Sorption-based energy storage
    - Heat is stored by breaking the binding force between the sorbent and the sorbate in terms of chemical potential

Thermochemical storage

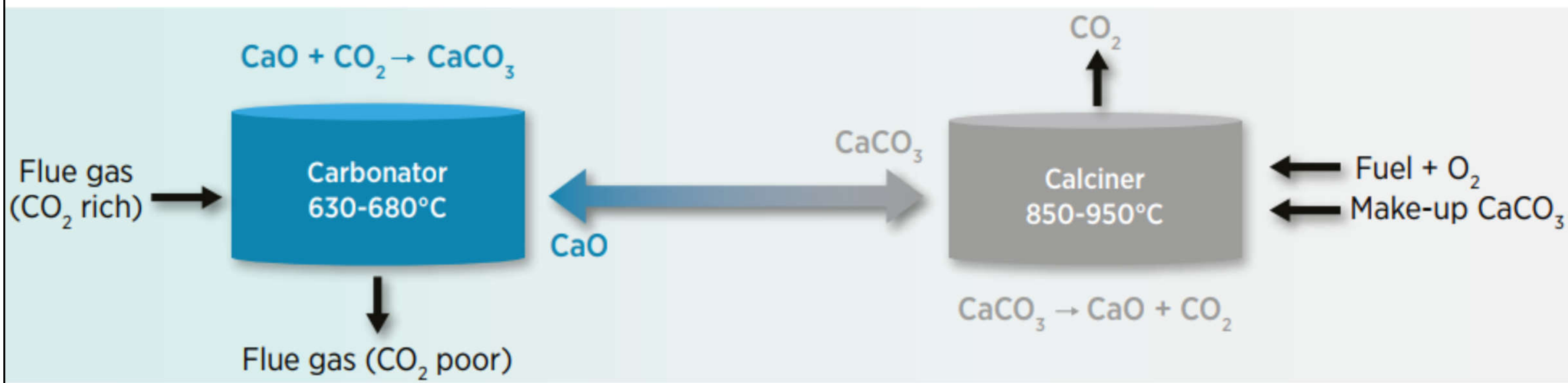


- Common methods:
  - Chemical looping (e.g. Calcium looping)
    - Such as use of the reversible reaction between calcium oxide (CaO) and carbon dioxide (CO_2) to form calcium carbonite ($CaCO_3$)
  - Salt hydrates sorption (using hydration reactions)
    - Absorbs and releases energy through the hydration and subsequent dehydration of a solid salt
  - Absorption systems
    - Heat/cold can be generated in real time using solar absorption heat pumps and stored for later use

Thermochemical storage methods and materials

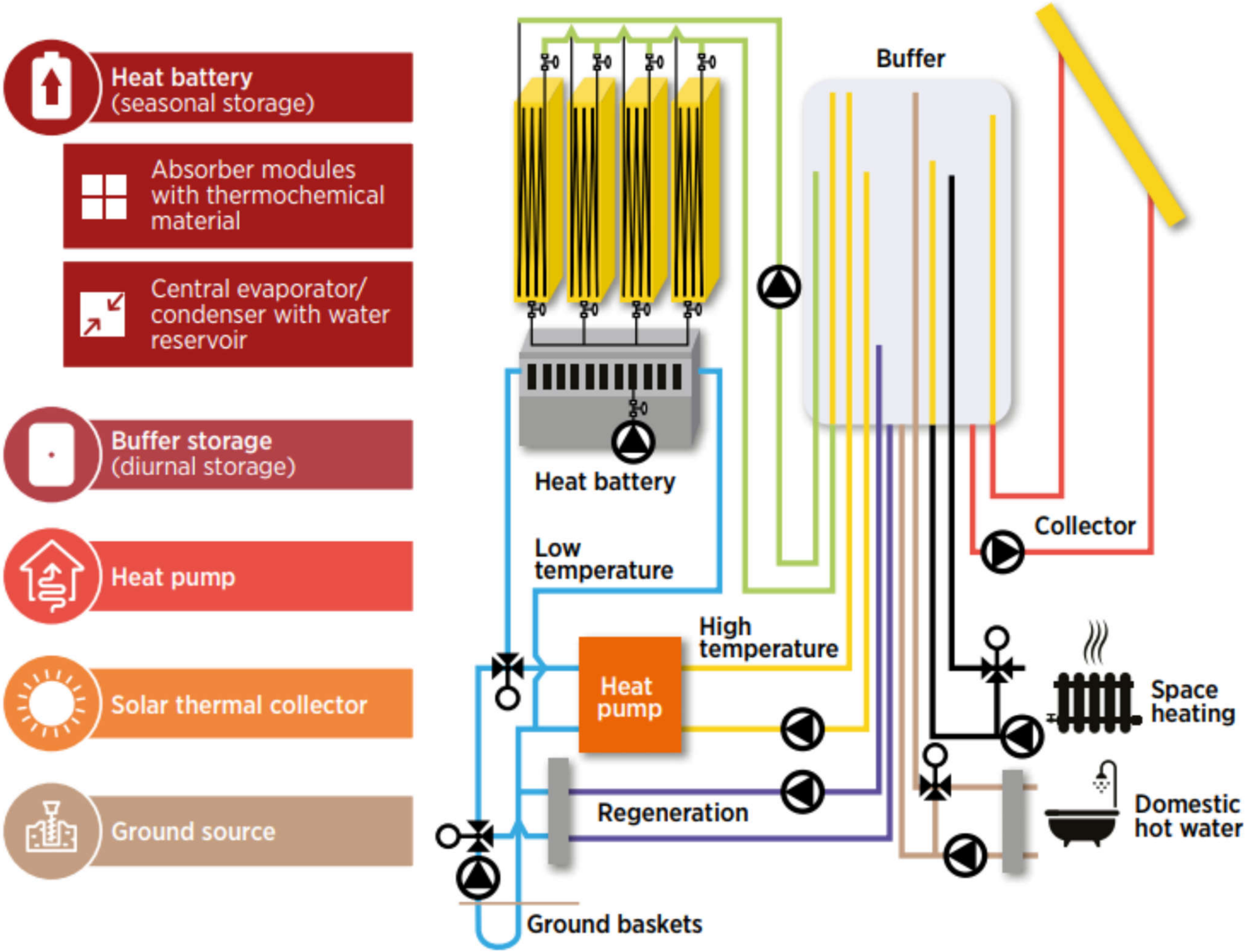


Chemical calcium looping (CaL) process scheme



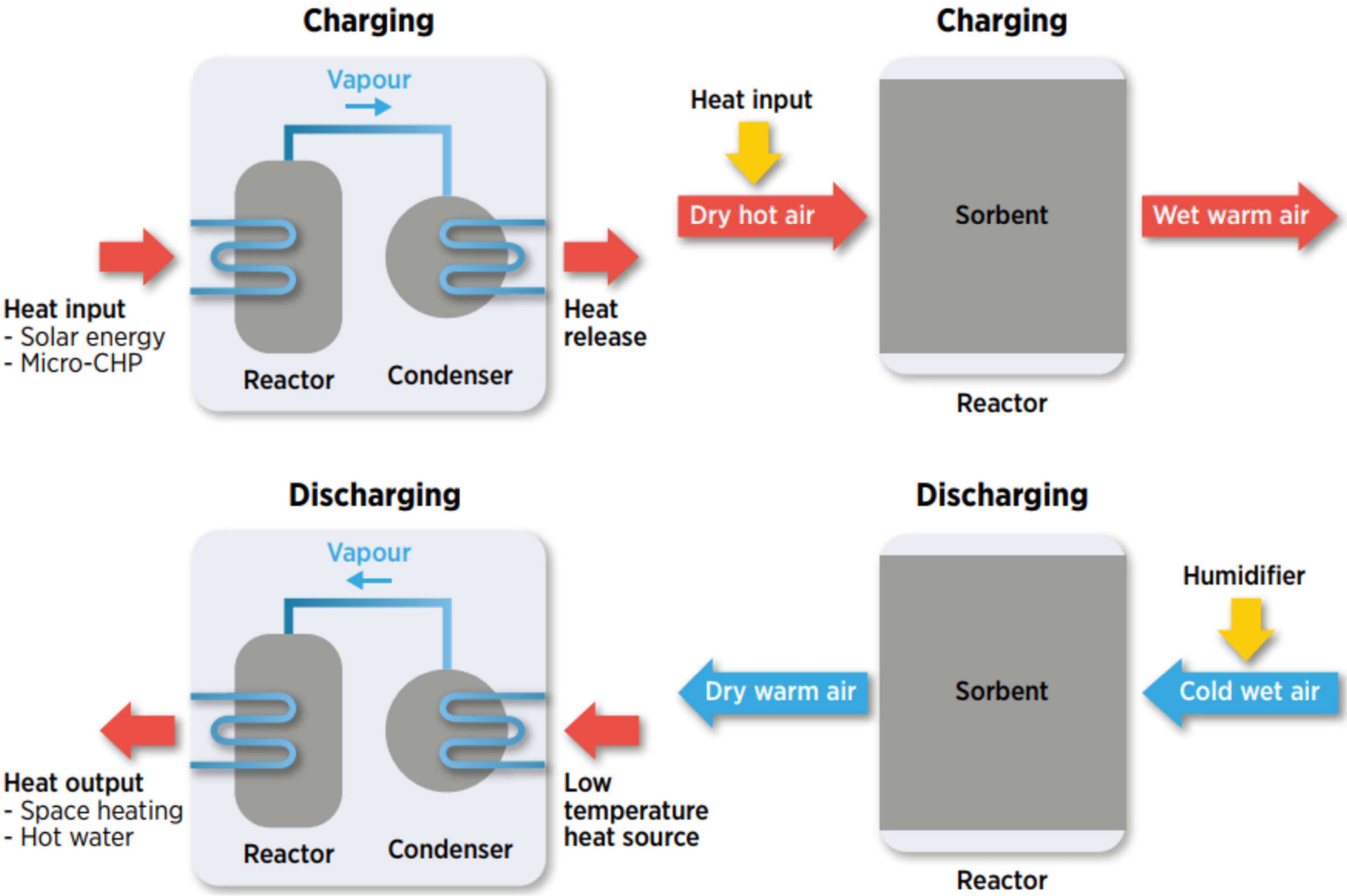
(Source: IRENA, 2020. *Innovation Outlook: Thermal Energy Storage*, International Renewable Energy Agency (IRENA), Abu Dhabi. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Nov/IRENA_Innovation_Outlook_TES_2020.pdf)

Example of salt hydration thermal storage system



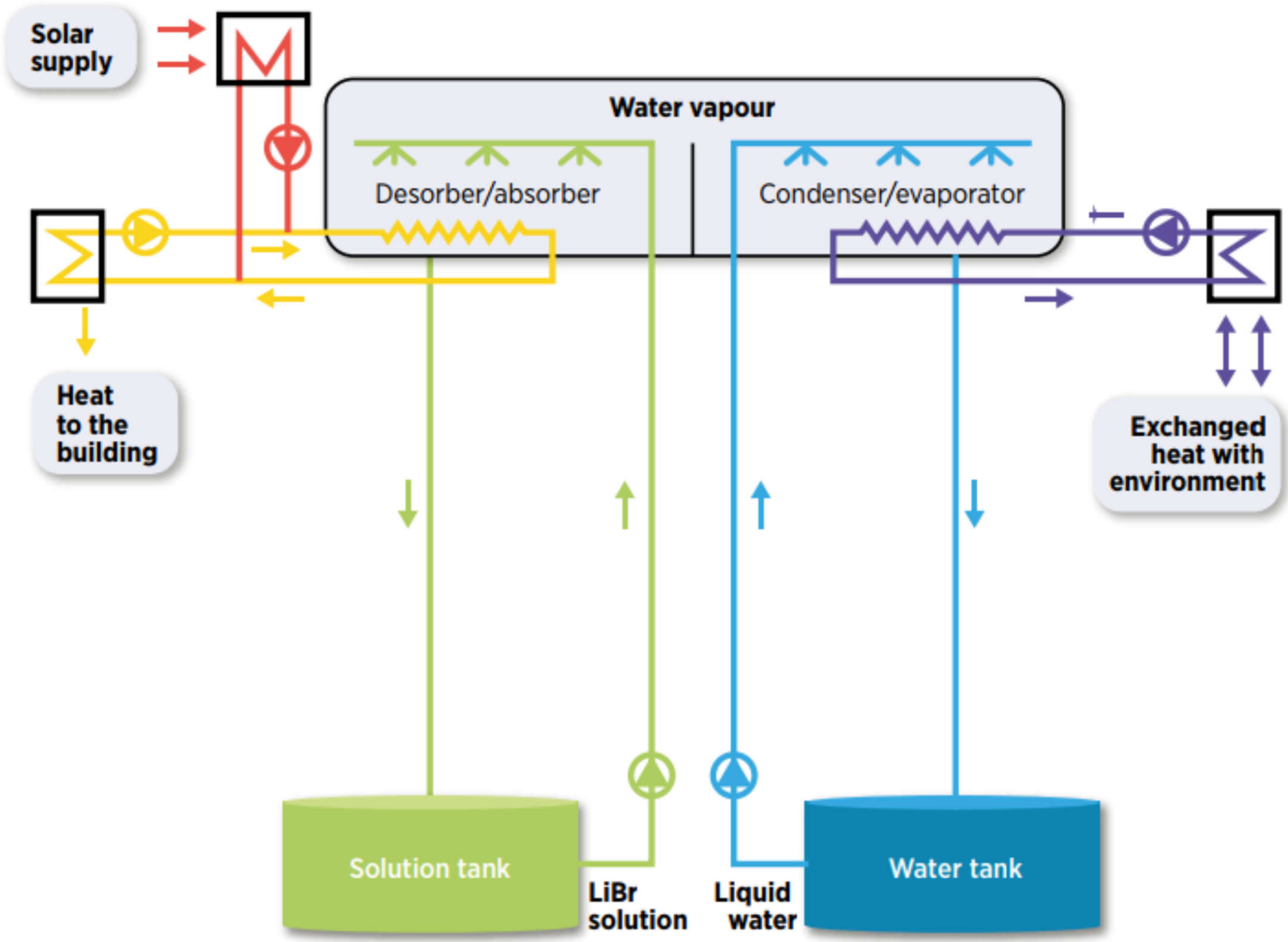
(Source: IRENA, 2020. *Innovation Outlook: Thermal Energy Storage*, International Renewable Energy Agency (IRENA), Abu Dhabi. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Nov/IRENA_Innovation_Outlook_TES_2020.pdf)

Configuration of closed and open system for salt hydrates



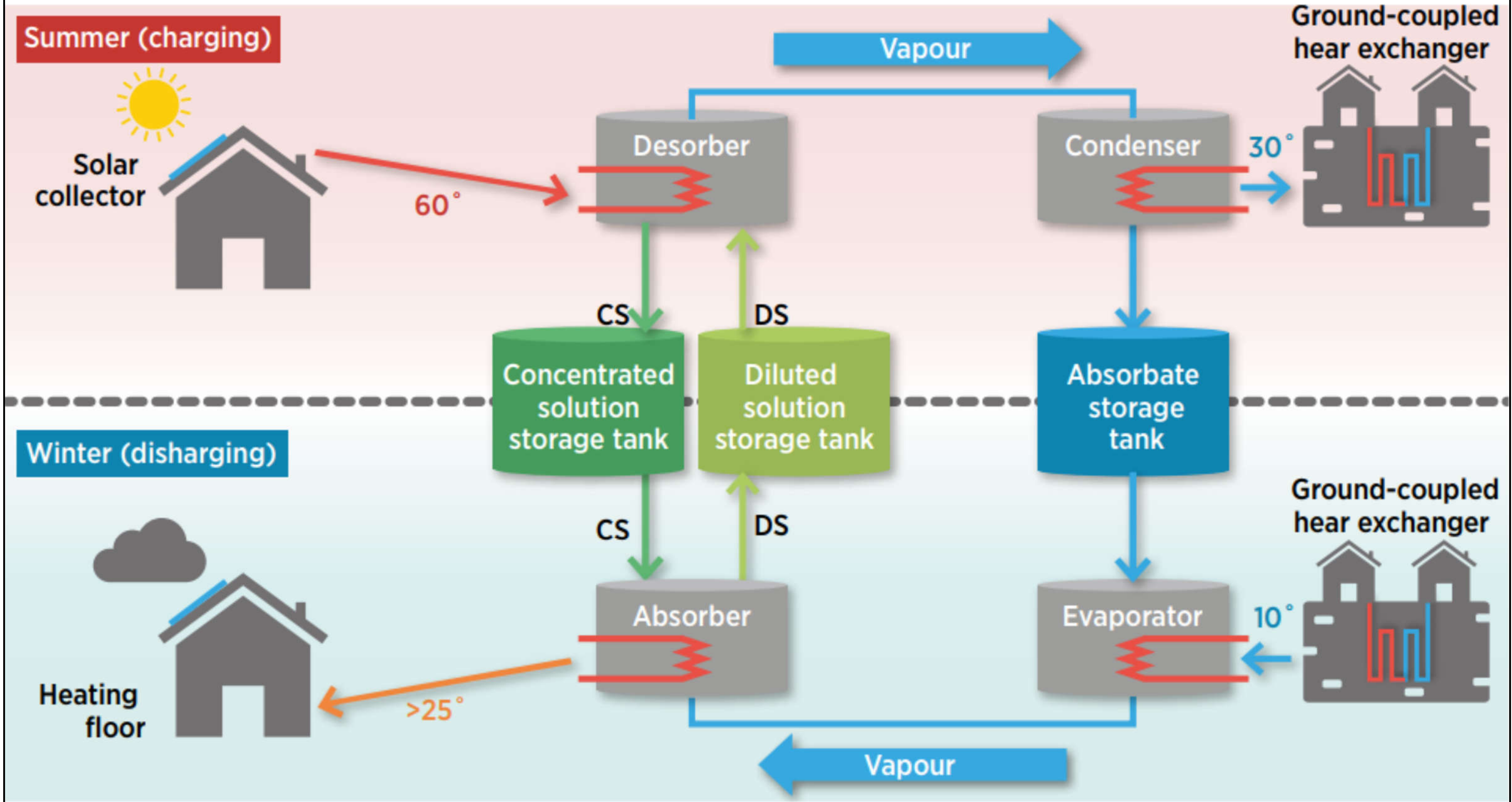
(Source: IRENA, 2020. *Innovation Outlook: Thermal Energy Storage*, International Renewable Energy Agency (IRENA), Abu Dhabi. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Nov/IRENA_Innovation_Outlook_TES_2020.pdf)

Absorption system configuration with separator reactor



(Source: IRENA, 2020. *Innovation Outlook: Thermal Energy Storage*, International Renewable Energy Agency (IRENA), Abu Dhabi. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Nov/IRENA_Innovation_Outlook_TES_2020.pdf)

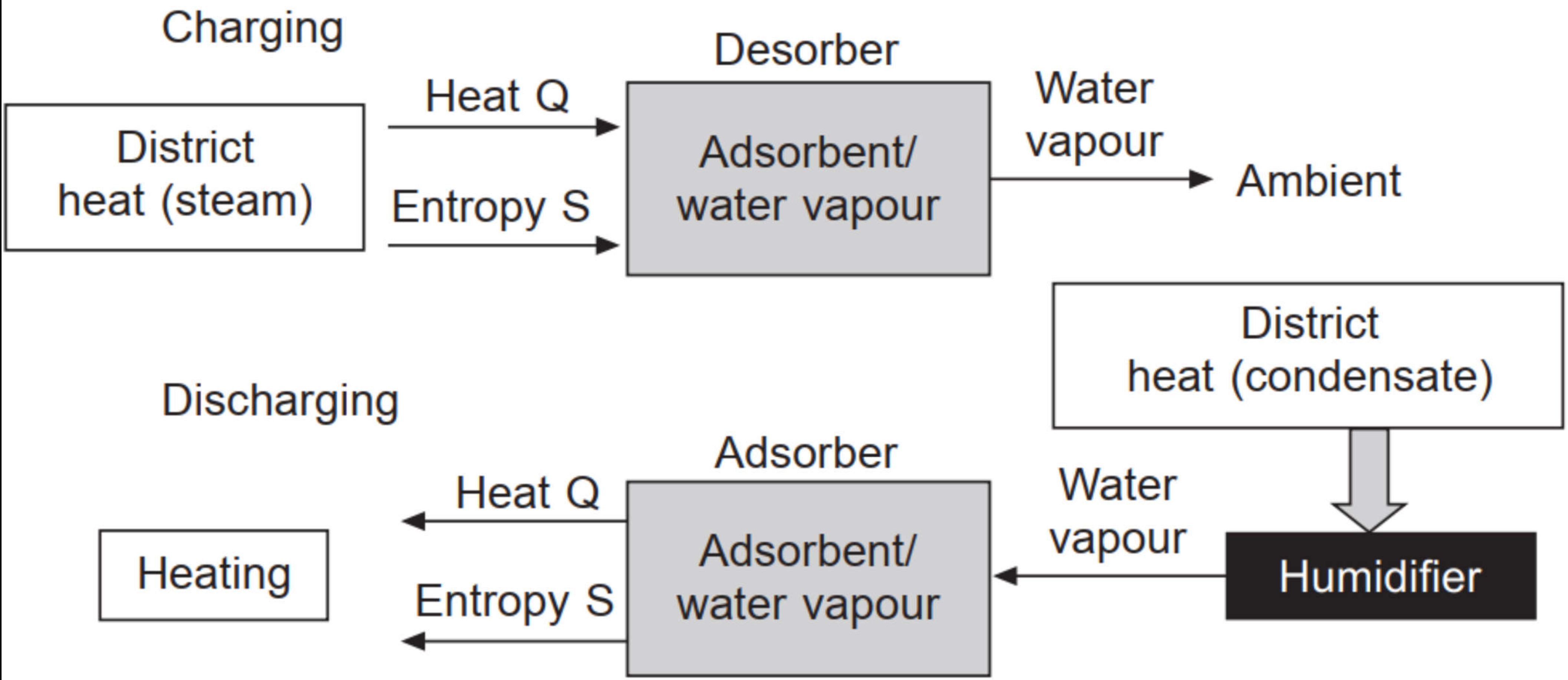
Absorption storage system scheme



Notes: CS = concentrated solution; DS = diluted solution

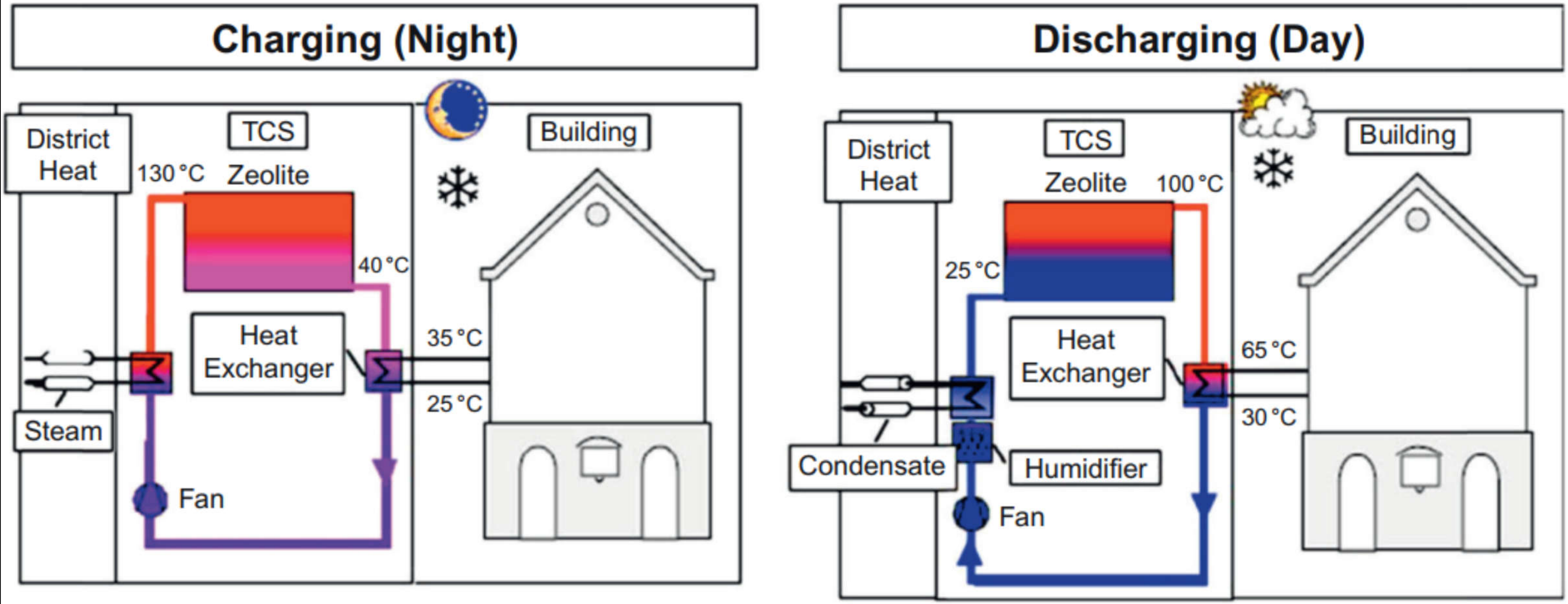
(Source: IRENA, 2020. *Innovation Outlook: Thermal Energy Storage*, International Renewable Energy Agency (IRENA), Abu Dhabi. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Nov/IRENA_Innovation_Outlook_TES_2020.pdf)

Open adsorption storage system for heating connected to a district heating system



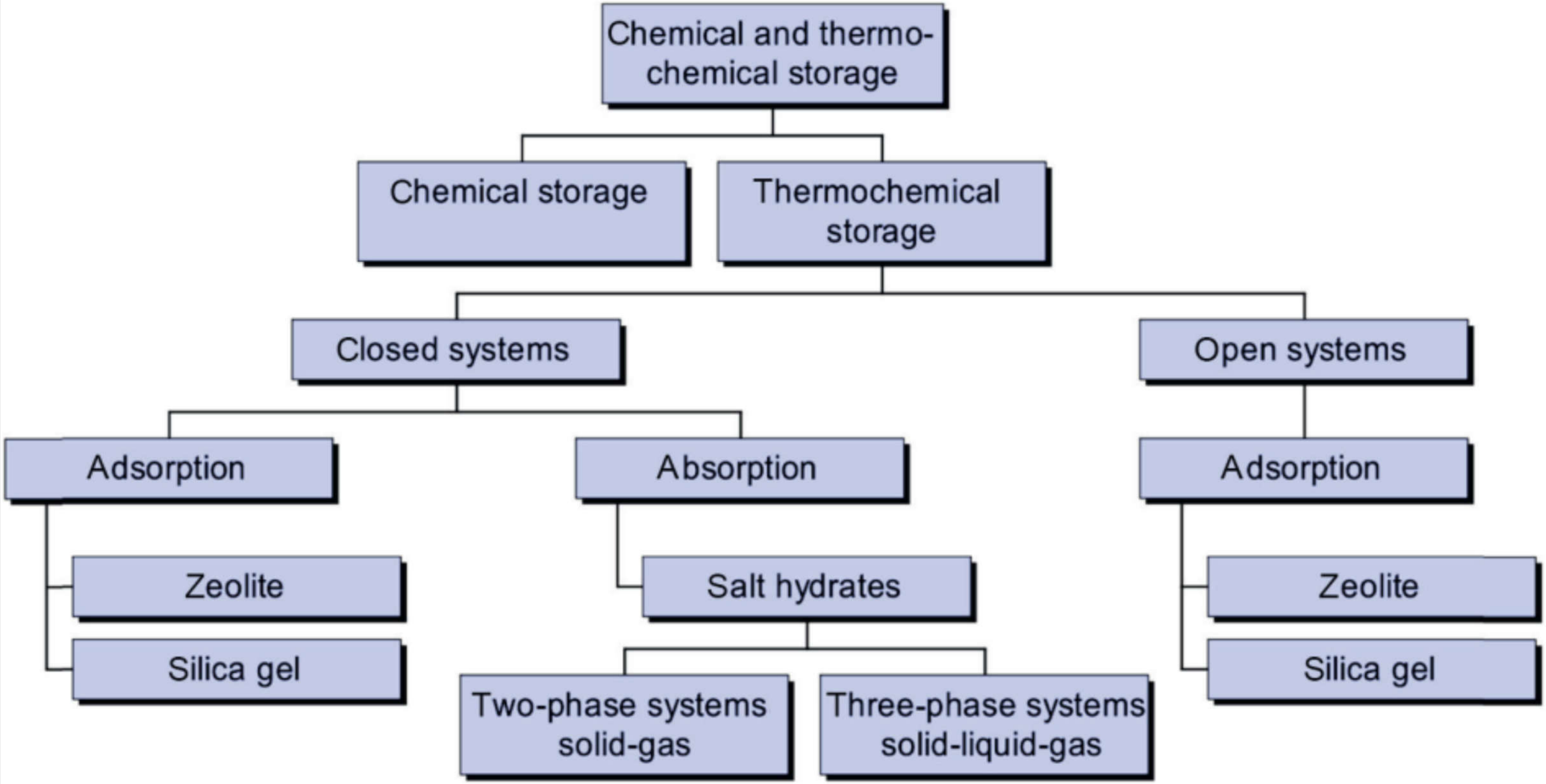
(Source: Cabeza L. F. (ed.), 2015. *Advances in Thermal Energy Storage Systems: Methods and Applications*, Woodhead Publishing. https://doi.org/10.1016/C2013-0-16453-7)

Charging and discharging mode for a district heating system with thermochemical storage (TCS) using Zeolite

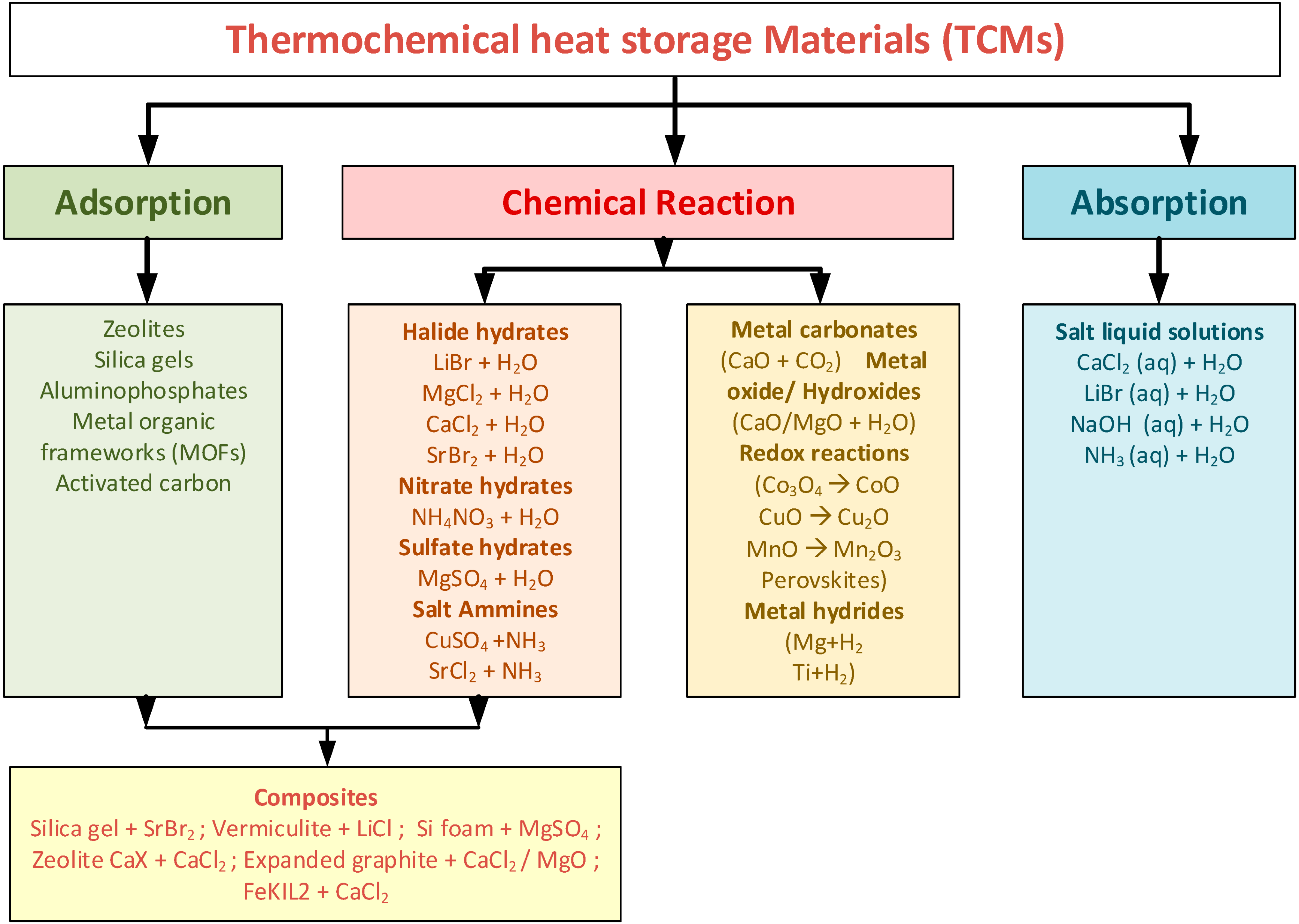


(Source: Kalaiselvam S. & Parameshwaran R., 2014. *Thermal Energy Storage Technologies for Sustainability: Systems Design, Assessment and Applications*, Academic Press. https://doi.org/10.1016/C2013-0-09744-7)

Classification of chemical and thermochemical processes for heat storage applications



(Source: Kalaiselvam S. & Parameshwaran R., 2014. *Thermal Energy Storage Technologies for Sustainability: Systems Design, Assessment and Applications*, Academic Press. https://doi.org/10.1016/C2013-0-09744-7)



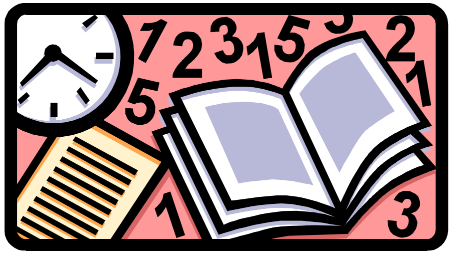
(Source: Gunasekara S. N., et al., 2021. Thermal energy storage materials (TESMs)—what does it take to make them fly?, *Crystals*, 11 (11) 1276. https://doi.org/10.3390/cryst11111276)

Further Reading

- Thermal Energy Storage https://celsiuscity.eu/thermal-energy-storage/
- HVAC factsheet - Thermal storage https://www.energy.gov.au/publications/hvac-factsheet-thermal-storage
- Videos on thermal heat energy storage:

  - Thermal Energy Storage: Sensible Heat (11:10) https://youtu.be/9mjMF4qX__w
  - Thermal Energy Storage: Latent Heat (10:03) https://youtu.be/Tmeb5MM-51U
  - Thermal Energy Storage: Thermo Chemical Energy Storage (11:04) https://youtu.be/2DGldaPbVe8

References (books)



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