International Solar Alliance Expert Training Course: Session 44

Solar Heating and Cooling: Technologies and Case Studies

In partnership with the Clean Energy Solutions Center (CESC)

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CLEAN ENERGY SOLUTIONS CENTER

ASSISTING COUNTRIES WITH CLEAN ENERGY POLICY

Overview of Training Course Modules

This Training is part of Module 8, and focuses on the issue of Solar Heating and Cooling

Eight Modules

Expert Content and Analysis

Up-to-date Market Insights

1. Policies for Distributed PV
2. Policies for Large-Scale PV
3. The Future of Solar Policy
4. Technical Integration of Solar
5. Market Integration
6. Socio-Economic Aspects
7. Off-grid Solar
8. Solar Heating & Cooling

Overview of the Presentation

1. Introduction: Learning Objective
2. Main body of presentation
3. Concluding Remarks
4. Further Reading
5. Knowledge Check: Multiple-Choice Questions

1. Introduction: Learning Objective

Learning Objectives

- Understand solar heating and cooling technologies
- Understand how they work, and what their main advantages and disadvantages are
- Understand which technologies are currently most widespread
- Understand different case studies of solar H&C technologies in practice

2. Solar Heating and Cooling

Solar H&C

Solar H&C systems can be small-scale, targeted at single-family homes; medium-scale, for schools, hospitals, and universities; or large-scale, targeting industrial applications, or providing heating and cooling to entire districts and communities.

Can also be used in conjunction with existing district thermal networks

In countries like Barbados, Cyprus, and Israel, between 80-90% of residential homes have domestic solar hot water systems

Solar H&C

In cold climates, heat demand represents 60-87% of energy demand in residential buildings, and 30-40% in warmer climates (due mainly to hot water use)

Solar heating systems are increasingly affordable : the return on investment can be as little as 3-6 years.

Solar H&C systems can help residents, businesses, as well as governments save money on their heating and cooling costs

https://www.solarthermalworld.org/sites/gstec/files/news/file/2015-02-27/irena-solar-heating-and-cooling-2015.pdf

Solar H&C

Water heating, space heating, and space cooling account for over 70% of the energy used in an average household in the U.S. -

https://www.solarthermalworld.org/sites/gstec/files/news/file/2015-02-27/irena-solar-heating-and-cooling-2015.pdf

Solar H&C

In most countries, solar thermal systems are relatively simple: often manufactured locally by SMEs, less quality control, high variation in system performance between countries

Designs also differ: China's "thermo-syphon" systems for domestic hot water are 10x cheaper than Australia's (!), but have a shorter lifespan

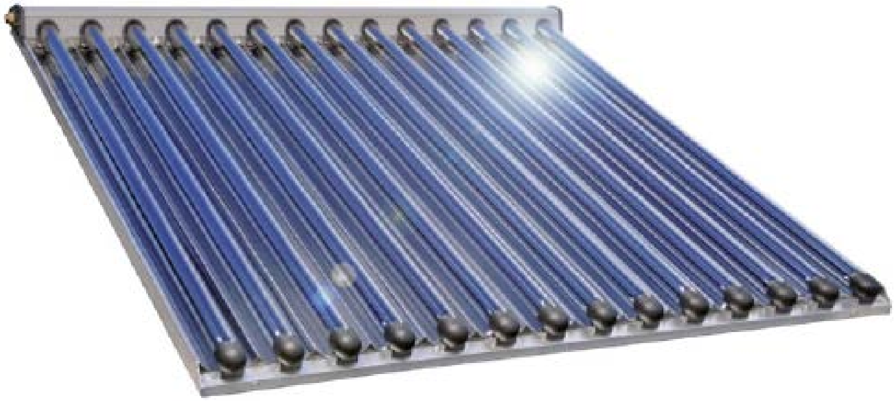
https://www.solarthermalworld.org/sites/gstec/files/news/file/2015-02-27/irena-solar-heating-and-cooling-2015.pdf

Solar Heating Technologies

One commonly seen option is the **solar evacuated tubes aka. Vacuum tubes)** model:

- Single tubes collected to a pipe: tube are empty, i.e. evacuated
- Must be mounted at an angle to allow the condensed internal fluid to return to the heat absorber

However, solar evacuated tubes are being replaced in key markets like China in favor of **flat plate collectors**



http://www.sci-network.eu/fileadmin/templates/sci-network/files/Resource_Centre/Innovative_Technologies/SOTA_solar_heating___cooling.pdf

Solar Heating Technologies

Most common technology remains the solar **flat plate collector**

Heat-conducting fluid delivers heat to a storage tank.

More efficient

Easier to maintain

http://www.sci-network.eu/fileadmin/templates/sci-network/files/Resource_Centre/Innovative_Technologies/SOTA_solar_heating___cooling.pdf

Solar Heating Technologies

Another option is direct solar air heating technologies:

- Some models can be made at home; commercial models also increasingly available

- Hot air is fed into the house
- Hole must be tight for the system to work well
- Mainly to ***supplement*** heating, not replace existing heating systems

Solar Heating Technologies

Solar thermal systems are typically connected to a large storage system, either mounted on the roof, or near the building

Source: https://solartribune.com/solar-storage/

Solar Thermal Technologies

- **Concentrating solar thermal collectors** are another potentially promising solar thermal technology that can be used to provide solar heating and cooling energy

- Concentrating solar energy onto a tube allows higher energy output using less roof space

https://blog.csiro.au/cool-sun-breakthrough-solar-air-con-efficiency/

Solar Cooling Technologies

Enough about heating.

Let's talk about cooling!

Solar Cooling Technologies

- ***Active*** solar cooling technologies are comparatively more recent, and less established in the market (passive solar cooling principles via the use of shade, narrow streets, etc. have been around for millennia)

- One key advantage of active solar cooling technologies is that their production coincides well with high cooling demand, mainly during the summer months (e.g. Mediterranean, MENA, Africa, Asia, tropical climates)

- **The importance of cooling technologies is likely to grow significantly in the years ahead**

The Importance of Solar Cooling

- As income levels rise in lower- and middle-income countries around the world, air conditioning demand continues to grow at a rapid pace.

- Air conditioners a growing cause of **power outages**

- The total number of household air conditioners in use in **India** has grown from roughly 2 million in 2006 to approximately 30 million in 2018

https://www.straitstimes.com/asia/south-asia/making-the-world-hotter-indias-expected-ac-explosion
International Energy Agency, (2018). Future of Cooling,
http://www.iea.org/publications/freepublications/publication/The_Fu-ture_of_Cooling.pdf

The Importance of Solar Cooling

- Air conditioning accounts for approximately 40% of the electricity demand in cities like Mumbai (India), while **over half of Saudi Arabia's entire peak summer electricity demand** is attributed to air conditioning

- Of the 2.8 billion people worldwide living in the hottest parts of the world, **only 8% currently have air conditioning systems**.

- This is compared to rates of over 90% in parts of the U.S. and Japan.

https://www.seforall.org/sites/default/files/gather-content/SEforALL_CoolingForAll-Report.pdf

The Importance of Solar Cooling

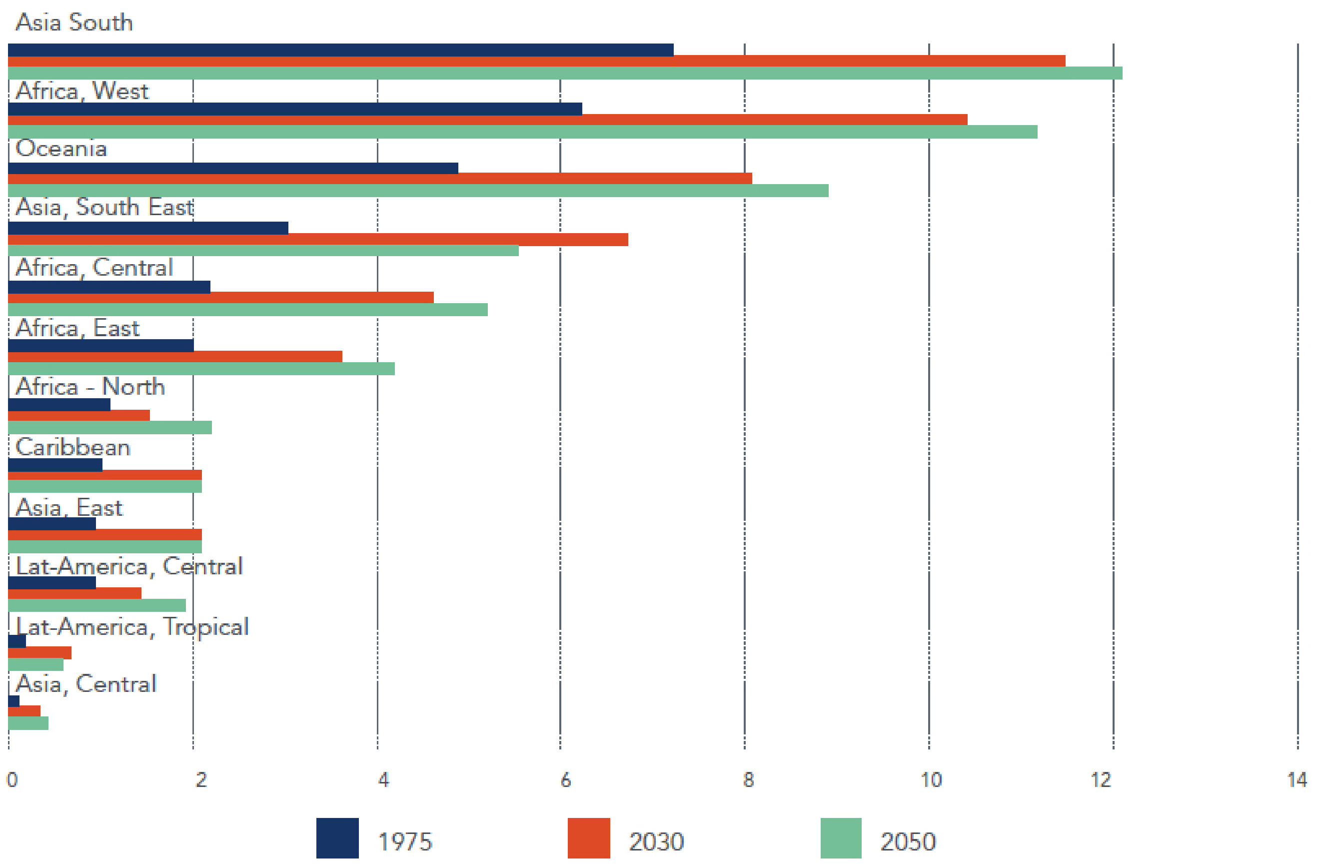
- An analysis of 52 of the most vulnerable countries in the world recently found that **1.1 billion people worldwide face immediate cooling-related risks**.

- Not just in Africa and Asia: a heat wave that hit Europe in 2003 is estimated to have been responsible for over 14,800 deaths in France alone, with the dead toll Europe-wide estimated in the range of 70.000.

https://www.seforall.org/sites/default/files/gather-content/SEforALL_CoolingForAll-Report.pdf

The Importance of Solar Cooling

FIGURE 6: ESTIMATES OF DAYLIGHT WORK HOURS LOST DUE TO EXCESSIVE HEAT BY REGION IN 1975, 2030 AND 2050



Source: Kjellstrom and Lemke, 2013

https://www.seforall.org/sites/default/files/gather-content/SEforALL_CoolingForAll-Report.pdf

The Importance of Solar Cooling

Lee Kwan Yew, founding father of Singapore, made Air Conditioning a leading development priority

Upon coming into power, he mandated the installation of air conditioners in all public buildings to improve the productivity of the civil service

https://www.vox.com/2015/3/23/8278085/singapore-lee-kuan-yew-air-conditioning

The Importance of Solar Cooling

"*Air conditioning was a most important invention for us, perhaps one of the signal inventions of history. It changed the nature of civilization by making development possible in the tropics*"

– Lee Kwan Yew, founding father of Singapore (1923– 2015)

https://www.vox.com/2015/3/23/8278085/singapore-lee-kuan-yew-air-conditioning

Solar Cooling Technologies

Advantages:

- Availability of high solar radiation when the cooling is actually needed (i.e. on sunny days)
- Thermal energy drives the system, leading to higher overall energy efficiency
- Low operating costs
- Low electrical power rating
- Durability
- Cost savings on energy bills
- Can be used in combination with other cooling and air conditioning systems

Solar Cooling Technologies

Disadvantages:

- Higher upfront installed cost
- Lack of skilled experts and installers
- Require suitable space to install
- Back-up systems often required (i.e. redundancy)

Solar Cooling Technologies

Three main solar cooling technologies

1. **Absorption Chillers**
2. **Adsorption Chillers**
3. **Desiccant Cooling systems (using drying)**

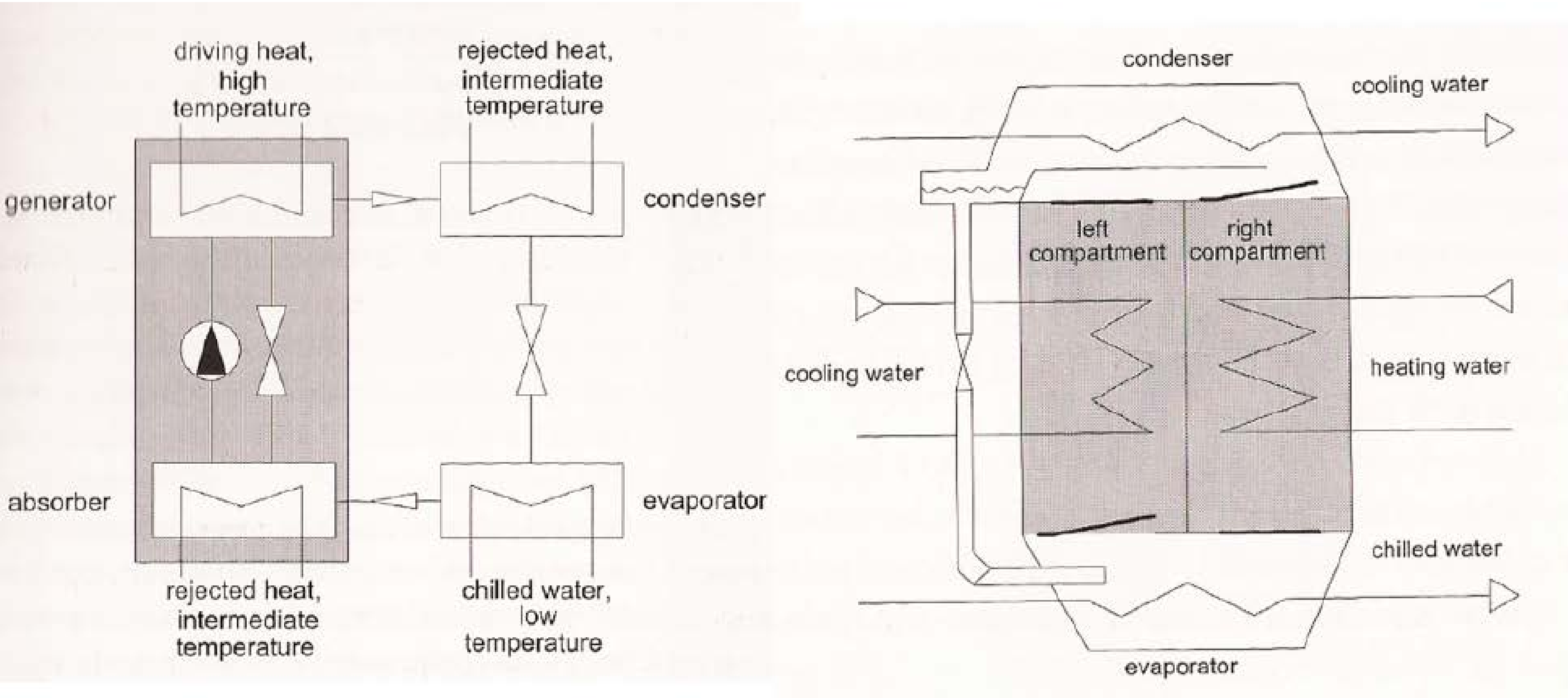
Solar H&C: Absorption Chillers

1. Absorption Chillers:

- Use hot water from solar collectors to absorb already pressurized refrigerant from a refrigerant mixture
  - E.g. water-lithium bromide, ammonia-water, etc.)
- Condensation and evaporation of the refrigerant vapour provides the same cooling effect as that provided by mechanical cooling systems
- Still require electricity, but a small fraction compared to the electricity needs of a conventional air conditioner.
- Electricity can be supplied directly via solar PV

http://www.sci-network.eu/fileadmin/templates/sci-network/files/Resource_Centre/Innovative_Technologies/SOTA_solar_heating___cooling.pdf

Solar Cooling Technologies



Solar Absorption Chiller (Left) and Adsorption Chiller (Right)

http://www.sci-network.eu/fileadmin/templates/sci-network/files/Resource_Centre/Innovative_Technologies/SOTA_solar_heating___cooling.pdf

Solar H&C: Adsorption Chillers

- Solar powered **adsorption chillers** use a solid sorption material instead of a liquid solution (e.g. silica gel)
- Two sorbent compartments: one evaporator and one condenser
- Still require electricity, but a small fraction compared to the electricity needs of a conventional air conditioner, as there is not internal pump to pump the fluid around
- Capacity of these chillers range from 50kW to 500kW
- Adsorption chillers considered fairly robust and simple in construction: no danger of crystallization
- One main disadvantage is that they are considerably **heavier**

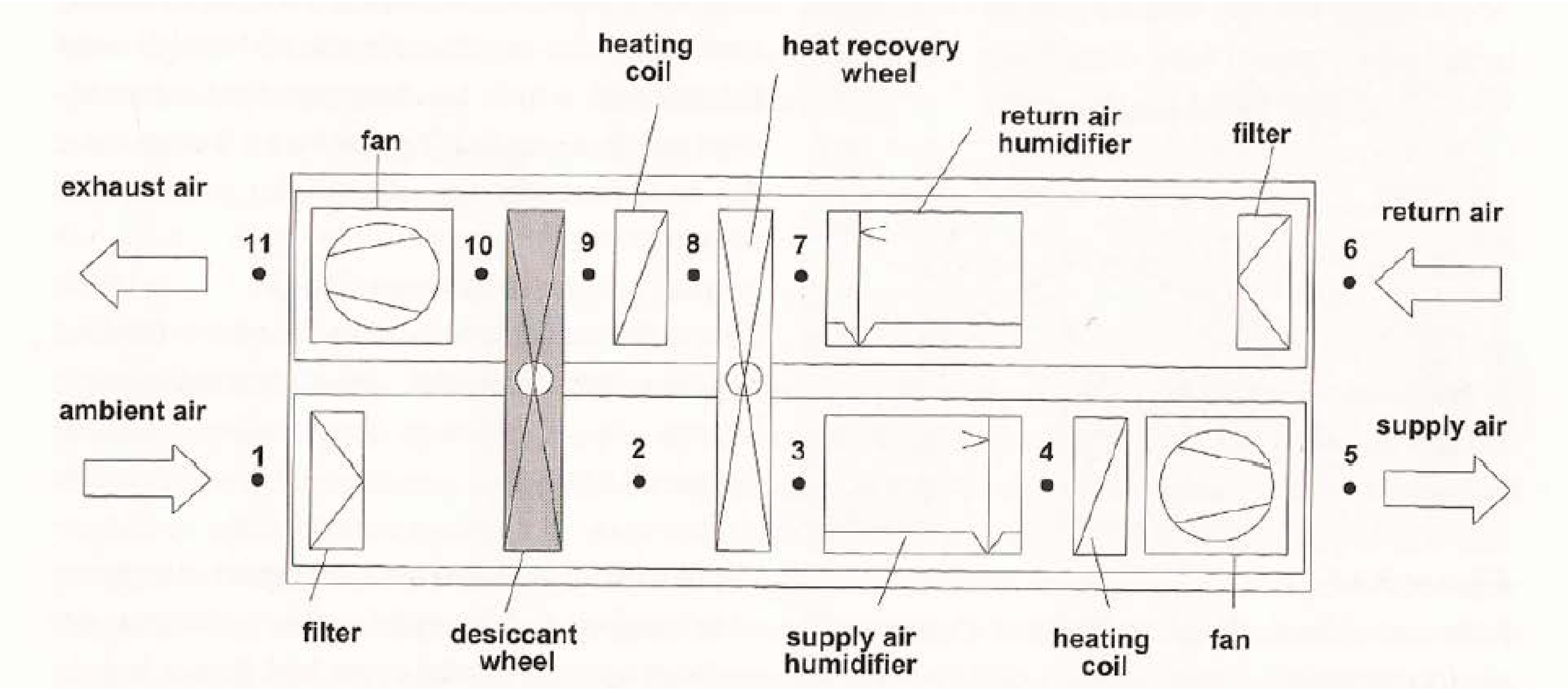
http://www.sci-network.eu/fileadmin/templates/sci-network/files/Resource_Centre/Innovative_Technologies/SOTA_solar_heating___cooling.pdf

Solar H&C: Desiccant cooling systems

- Open cycle systems that use water as a refrigerant in direct contact with air
- Thermally driven cooling cycle
- Combined evaporative cooling with air dehumidification by means of a desiccant (a drying material)
- Liquid or solid materials can be employed as desiccants
- Commonly use rotating desiccant wheels, equipped with silica gel or lithium chloride as a sorption material
- **Solar assisted desiccant cooling technologies use solar thermal energy to dry out or regenerate the desiccant**
- Produce conditioned fresh air directly

http://www.sci-network.eu/fileadmin/templates/sci-network/files/Resource_Centre/Innovative_Technologies/SOTA_solar_heating___cooling.pdf

Solar H&C: Desiccant cooling systems



http://www.sci-network.eu/fileadmin/templates/sci-network/files/Resource_Centre/Innovative_Technologies/SOTA_solar_heating___cooling.pdf

Solar H&C: Desiccant cooling systems

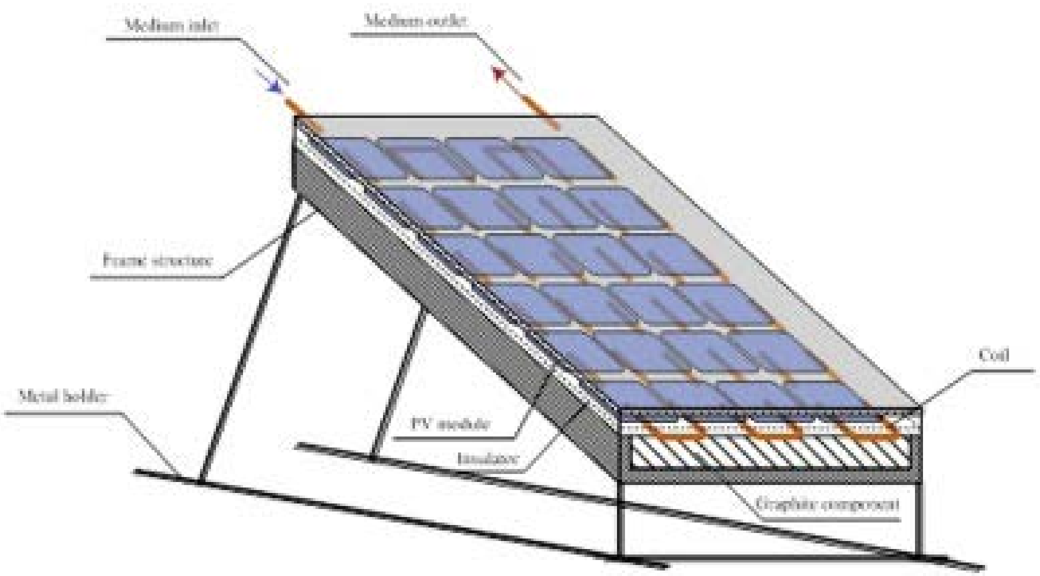
Advantages of desiccant-based systems:

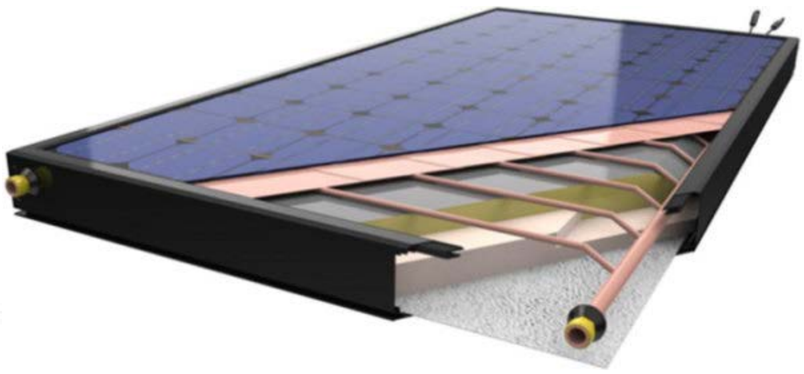
- Increased comfort (as temperature and humidity are controlled independently)
- Lower operating costs
- Heat recovery options
- Improved indoor air quality
- Reduced building maintenance as a result of high humidity levels

http://www.sci-network.eu/fileadmin/templates/sci-network/files/Resource_Centre/Innovative_Technologies/SOTA_solar_heating___cooling.pdf

Solar H&C: Hybrid Solar PV + thermal

A new development is the rise of hybrid solar PV + solar thermal systems integrated into one panel system





Solar H&C: Hybrid Solar PV + thermal

Advantages:

- More energy output (electricity + thermal) from the same surface area
- Can increase solar PV output by contributing to cooling the PV panels, which increases module efficiency
- Can reduce visual impact on buildings of having two different kinds of panel types (e.g. solar thermal evacuated tubes + solar PV)

3. Case Studies of Solar H&C

Case Study: Home in Washington, DC

- In 2016, a residential solar thermal system was installed on a **private home** with a large outdoor pool in DC
- System is configured to transfer heat from the house into the pool, while evacuating excess heat through the collectors
- Active year-round and can operate 24-hours a day
- Household annual electricity consumption dropped from 80MWh to 7MWh
- The system meets 92% of the home's space, water, and pool heating needs, as well as 100% of the cooling needs
- **Rated Power Output: 15.5kW thermal**
- **CO2 reduction per year: 10.000kg**

Case Study: Residential system in Bradenton, FL

- In 2016, 40kW of hybrid solar PV-thermal panels were installed at a **large private home**, generating both electricity and collect heat
- Technology referred to as Solar PV-Thermal, or PVT
- Can produce up to 4x the power of solar PV alone
- Because of the cooling effect of the thermal collectors, they can boost the PV system output by 20%

- **Rated Power Output: 57.8kW combined PV-thermal**
- **Yearly energy savings: 49.400 kWh (combined)**
- **CO2 reduction per year: 36.800 kg**

Case Study: Havre, Montana

- Large hybrid solar PV-Thermal system installed at a large **apartment complex** with 52 units
- Part of a comprehensive renovation project
- Residents benefit from more comfortable living spaces and lower energy bills

- **Rated Power Output: 32.9kW thermal**
- **Yearly energy savings: 20.700 kWh thermal**
- **CO2 reduction per year: 3.770 kg**

Case Study: Larkspur Commons, Bozeman, Montana

- Solar hot water collectors installed across 136 units in a **large residential complex**
- The complex is for households with lower incomes (50-60% of the area's median income)
- Residents benefit from lower energy bills and cleaner energy supply
- Each unit is equipped with 216 gallon storage tank (818 Litres)

- **Rated Power Output: 212.8kW thermal**
- **Yearly energy savings: 138.000 kWh thermal**
- **CO_2 reduction per year: 25.132 kg**

Case Study: Elks Lodge, Palo Alto, CA

- Large solar PV and hot water systems installed at a **lodge** in Palo Alto
- System provides hot water for the facility's pool (307m^2)
- The aim of the project is to reduce natural gas consumption for the majority (85%) of the year.

- **Rated Power Output: 78 kW thermal**
- **Yearly energy savings: 400.000 kWh thermal**
- **CO2 reduction per year: 72.727 kg**

Case Study: Hotel in Bakersfield, CA

- Hybrid solar PV + solar thermal system, including both 42 hybrid PV + thermal collectors, plus 18 PV-only panels, installed at a **hotel** in California.
- Hybrid panels collect electricity via PV panels from the front, and thermal energy from behind
- System heats the hotel's hot water and the pool
- Backup heating provided by two heat pumps and two gas boilers

- **Rated Power Output: 27kWth, 15kW PV**
- **Yearly energy savings: 2.442 therms**
- **CO_2 savings per year: 13.000kg**

https://www.seia.org/sites/default/files/2018-07/SEIA%20SHC%20Case%20Study%20-%20Bakersfield%20Hotel%20v2.pdf

Case Study: Wailea Inn, Maui, Hawaii

- Large hybrid solar PV-thermal system installed at an **Inn** on the island of Maui
- The system delivers hot water, heating, as well as cooling 24-hours a day
- The system comes equipped with 240 gallons of storage (908 Litres)

- **Rated Power Output: 56 kW thermal**
- **Yearly energy savings: 56.470 kWh thermal**
- **CO_2 reduction per year: 31.800 kg**

Case Study: Wheaton College, MA

- In 2017, the college installed a solar hot water system for its athletic centre, featuring an Olympic sized pool
- Received a rebate of USD $89.600 via MA's commercial-scale solar hot water rebate program
- System provides facility's hot water needs
- System includes a 360 gallon storage capacity (1.362 Litres)

- **Rated Power Output: 83.2kW thermal**
- **Yearly energy savings: 2.480 therms (72,700kWh_{th})**
- **CO2 reduction per year: 13.240kg**

Case Study: Solar Cooling in Arizona (1)

- School covered with double-glazed collectors,
- Lithium Bromide chiller with a capacity of 1750kW provides cooling
- During the summer, the system meets all of the school's cooling needs, with back-up occasionally from the old electric chillers onsite
- Owned by a dedicated company (ESCO-like) which sells cooling as a service to the school.
- Subsidies per metered unit of energy are paid by the local utility to compensate for the savings from deferring grid investments

https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Mar/IRENA_REmap_DHC_Case_Studies_2017.pdf?la=en&hash=963DB0F2449088164CAB724EC4CA8BAEB21D1141

Case Study: Solar Cooling in Arizona (2)

Properties of particular large-scale solar cooling systems

	Commissioned	Collector surface	Collector capacity	Chiller capacity	Peak coefficient of performance[2]	Total cost (USD million)	Storage
Desert Mountain High school	2014	5 000 m^2	3 500 kW	1 750 kW	0.7-0.77 (thermal)	10	34.5 m^3 hot water
United World College South East Asia	2011	3 900 m^2	2 730 kW	1 500 kW	0.8 (thermal)	5	60 m^3 cold water/ 7 m^3 hot water
Sheikh Zayed Desert Learning Center	2012	1 108 m^2	N/A	400 kW	N/A	N/A	5 m^3 cold water/ 26 m^3 hot water

Source: SOLID, 2014; IEA SHC, 2012; SOLID, 2016a

Case Study: Solar Cooling in Australia (1)

- Desiccant-based solar cooling system recently installed on a shopping centre in Australia (Stockland Wendouree, in Ballarat, Victoria)
- Cooling loads represent as much as 60% of the total energy demand of large commercial spaces like shopping centers
- The system uses a closed-loop design with two desiccant wheels to remove moisture from the air, acting as a dehumidifier
- A high temperature wheel uses solar heat for regeneration while the low temperature wheel functions without any external heat to deliver greater efficiency
- An indirect evaporative cooler reduces the temperature of the dehumidified air without altering the moisture content of the air

https://blog.csiro.au/cool-sun-breakthrough-solar-air-con-efficiency/

Case Study: Solar Cooling in Australia (2)

- Concentrating Solar Thermal system is installed on the roof of the shopping center
- Heat is stored in a thermal tank
- **The system uses 40% less roof space** than a traditional single-stage desiccant air conditioning system

https://blog.csiro.au/cool-sun-breakthrough-solar-air-con-efficiency/

Case Study: Cargill plant in Fresno, CA

- Large Solar Thermal system installed at a **beef processing facility**
- Contract structured as a bilateral PPA, struck at a price 40% lower than what Cargill was paying before
- Savings guaranteed from day-1.
- Zero upfront cost to the company

- **Rated Power Output: 793kW thermal**
- **Yearly energy savings: 705.676 kWh thermal**
- **CO_2 reduction per year: 146.388 kg**

Case Study: Solar Heating in Graz (Austria)

- Large-scale district heating systems powered in part by solar thermal
- Local district heating systems in neighborhoods operate at lower temperatures to facilitate the future integration of VRE
- Between 2002 – 2016, several new solar thermal installations have been connected to the network
- Collector area of over 15.000m2
- Weekly timescales to provide long-term thermal storage
- Some systems installed on a retired landfilled site

https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Mar/IRENA_REmap_DHC_Case_Studies_2017.pdf?la=en&hash=963DB0F2449088164CAB724EC4CA8BAEB21D1141

Case Study: Solar Heating in Graz (Austria)

Existing and planned solar district heating projects in Graz

System	Collector area (m^2)	Storage volume (1000 m^3*)	Capacity	Annual heat generation (MWh**)	Project cost (million USD)	Status
Fernheizwerk/ AEVG	7 750	0	-	3 000	-	Start of operation 2006
Andritz waterworks	3 800	0	2.7	-	-	Start of operation 2009
Berliner Ring	2 600	0	-	988	-	-
Merkur Arena	1 407	0		540		Start of operation 2002
HELIOS	10 000	2.5	10	-	4.2 incl. CHP	2016
Big Solar Graz	450 000	1 800	250	254 000	200	Feasibility assessment

https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Mar/IRENA_REmap_DHC_Case_Studies_2017.pdf?la=en&hash=963DB0F2449088164CAB724EC4CA8BAEB21D1141

Case Study: Solar thermal in Munich (Germany)

- New residential area in Munich using a district heating network based mainly on solar thermal
- Am Ackermannbogen was built between 2005-07 on former military barracks
- High efficiency housing
- 3600m2 of rooftop solar collectors
- 6000m3 tank for hot water storage
- Satisfies approximately 50% of the community’s heat demand

4. Concluding Remarks

Concluding Remarks

- There are countless applications for solar heating and cooling technologies in a wide range of applications:
  - Sports and recreation facilities
  - Spas
  - Hotels,
  - Shopping centres
  - Commercial sites with large hot water needs
  - Schools, hospitals, and other public buildings
  - Residential homes
  - Multi-unit residential buildings
  - Etc.

Concluding Remarks

- The market for solar cooling in particular is virtually untapped, leaving tremendous potential for growth
- District thermal energy applications are opening up new market potential for solar heating and cooling technologies, enabling individual systems to feed their thermal energy into larger district thermal networks
- The potential of solar cooling is also growing rapidly, as demand for cooling explodes in many parts of the world

Concluding Remarks

A number of more advanced solar H&C technologies are emerging, and starting to gain ground as the industry matures

More work needed to make solar H&C mainstream

https://www.solarthermalworld.org/sites/gstec/files/news/file/2015-02-27/irena-solar-heating-and-cooling-2015.pdf

5. Further Reading

Further Reading

- http://iea-retd.org/wp-content/uploads/2011/10/Renewables-for-Heating-and-Cooling_book.pdf
- http://iea-retd.org/wp-content/uploads/2011/09/IREHC-Final-Report-20100726.pdf
- http://iea-retd.org/wp-content/uploads/2011/09/IREHC-Best-Practices-Guide-20100726.pdf
- https://ec.europa.eu/energy/en/topics/energy-efficiency/heating-and-cooling

Further Reading

- http://publications.jrc.ec.europa.eu/repository/bitstream/JRC72656/eur%2025407%20en%20-%20heat%20and%20cooling%20final%20report-%20online.pdf
- http://www.sci-network.eu/fileadmin/templates/sci-network/files/Resource_Centre/Innovative_Technologies/SOTA_solar_heating___cooling.pdf
- https://setis.ec.europa.eu/system/files/Technology_Information_Sheet_Heating_and_Cooling.pdf
-
- https://ec.europa.eu/energy/sites/ener/files/documents/overview_of_eu_support_activities_to_h-c_-_final.pdf
- https://ec.europa.eu/transparency/regdoc/rep/1/2016/EN/1-2016-51-EN-F1-1.PDF

Further Reading

- https://de.slideshare.net/amanece13/solar-heating-and-cooling-system
- https://www.seia.org/initiatives/solar-heating-cooling
- https://ec.europa.eu/energy/en/topics/energy-efficiency/heating-and-cooling
- IRENA and IEA-ETSAP (2015). Solar Heating and Cooling for Residential Applications: https://www.irena.org/publications/2015/Jan/Solar-Heating-and-Cooling-for-Residential-Applications
- International Energy Agency, (2018). Future of Cooling, Opportunities for Energy-Efficient Air conditioning. Available at http://www.iea.org/publications/freepublications/publication/The_Future_of_Cooling.pdf

Thank you for your time!

INTERNATIONAL SOLAR ALLIANCE

E3 ANALYTICS

IET International Energy Transition

Factor
Ideas for change

CLEAN ENERGY SOLUTIONS CENTER

ASSISTING COUNTRIES WITH CLEAN ENERGY POLICY

6. Knowledge Checkpoint: Multiple Choice Questions