Solar cooling systems

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wbcsd

Table of contents

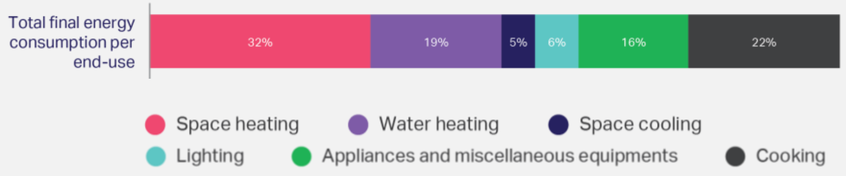
1. Background

Space cooling is largely powered by electricity, and various decarbonization solutions exist

Energy consumption from cooling and future trends

- Space cooling currently accounts for 5% of energy consumption from the buildings sector. 94% of energy consumption from cooling is electricity, and the remainder comes from natural gas.[1]
- The IEA projects that energy consumption related to cooling will triple between 2016 and 2050, driven by increased affordability of cooling systems, higher comfort expectations and a hotter climate, especially due to an increasing urban heat island effect.[2]

Current energy consumption from buildings sector:[1]



Possible solutions to decarbonize

- **Reduce cooling demand** by:
  - Reducing internal heat loads e.g. by using efficient devices.
  - Minimizing ventilation e.g. by preventing air leakages.
  - Optimizing sun protection e.g. by using window overhangs.
  - Optimizing the building shell e.g. by adequate insulation and using material with a high thermal mass.
- **Decarbonize the cooling solutions:**
  - Ensure a carbon free energy supply e.g. by using renewable energy.
  - Avoid chillers which use F-gas-refrigerants which have a high global warming potential (GWP) e.g. by using chillers with natural refrigerants or chillers without refrigerants.
- **Optimize the efficiency of cooling technologies** by using energy efficient chillers, implementing efficient cooling distribution and delivery systems, and ensuring that cooling systems are commissioned correctly.

Sources: [1] IEA, 2017: *Energy Technology Perspectives 2017*; [2] IEA, 2018: *The Future of Cooling*.

1. Background

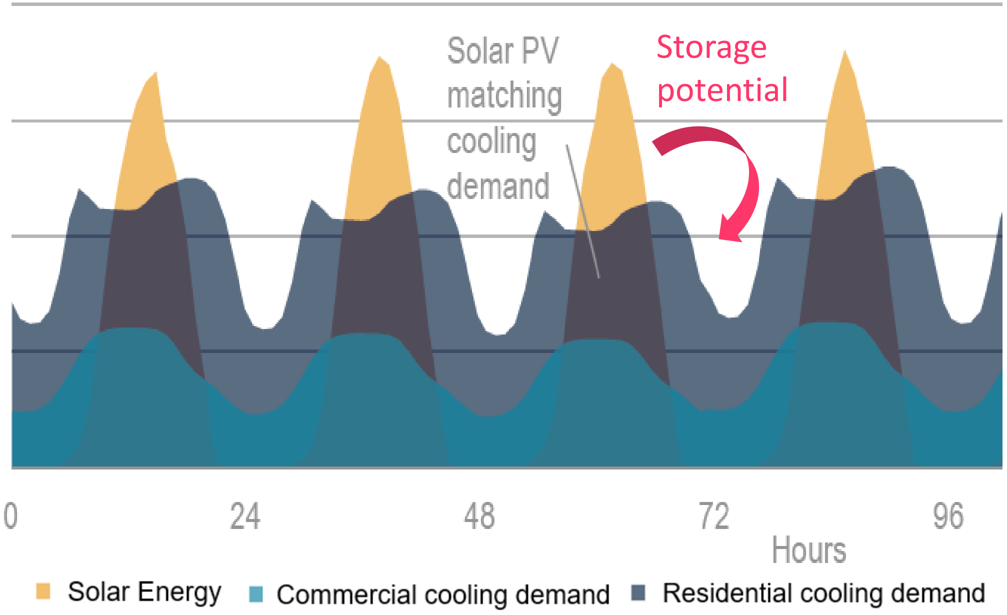
Space cooling: A critical issue

Current associated CO_2 emissions with cooling	• In 2016, over 2000 TWh of electricity was consumed for space cooling, of which 45% comes from the residential sector and 55% from the commercial sector.[1] • CO_2 emissions from space cooling were 1.1 $GtCO_2$ in 2016, or 12% of energy-related emissions from buildings sector. This excludes GHGs from leakage or inadequate disposal of refrigerants with a high GWP.[1]
Forecasted developments in a business-as-usual scenario	• In the International Energy Agency's business-as-usual scenario, space cooling **demand** is expected[1] **to triple from 2016 until 2050**, mainly due to a large increase of cooling in residential buildings. • The share of final energy for space cooling of total final energy in buildings is expected to increase from 6% in 2016 to 14% in 2050. • The related **CO_2** emissions from space cooling are expected to nearly **double from 2016 until 2050**, reaching annual emissions of more than 2 $GtCO_2$.
Obstacles for solar cooling	• High investment costs. • Installers lack experience and know-how, and investors lack knowledge of the solution. • Space constraints for decentralized solutions, insufficient (roof) space.

Source: [1] IEA, 2018: *The Future of Cooling*.

2. Description of solar cooling

Solar cooling rationale: Good match between solar energy and cooling demand



- In hot regions, there is a good match between solar energy supply and space cooling demand.
- Excess solar energy during the day can be stored to supply cooling in the evening.

Source: IEA, 2018: *The Future of Cooling* (modified).

2. Description of solar cooling

Overview

Description of the solution concept	• Two solar cooling systems are possible: 1. Solar electric cooling, which consists of solar PV panels and electric cooling. 2. Solar thermal cooling, which consists of solar thermal collectors and a thermal sorption chiller.
Rationale for developing this solution	• Reduction of operating costs. • Significant reduction of climate change impact: - Reduction of indirect CO_2-emissions from fossil-fuel based electricity generation. - Prevention of direct GHG emissions when using solar thermal cooling, or if natural refrigerants are used for solar electric cooling system.
Assessment of technology readiness status	• All necessary technologies are well proven and available on the market. • Key success factor include: - System integration including control systems to adapt the required cooling demand to available solar energy and adequate storage management. - Clarification of operational responsibilities.

2. Description of solar cooling

Two technology options can be distinguished

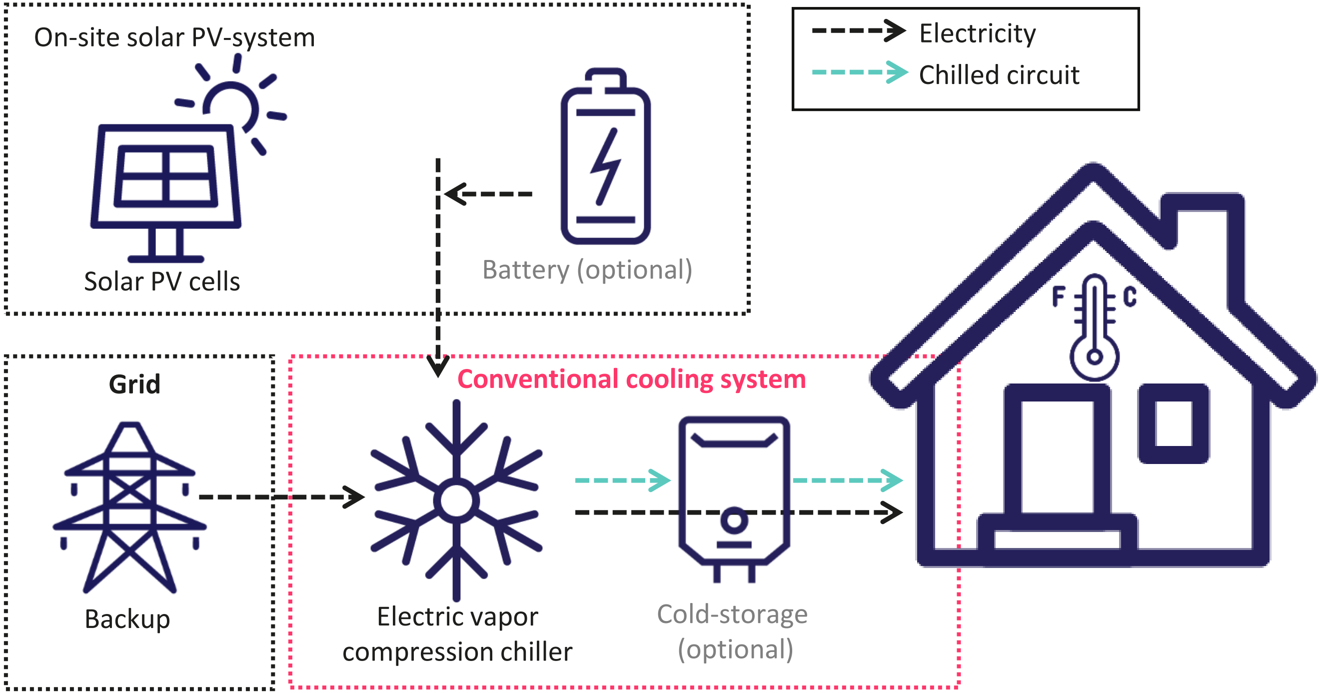
Solar electric cooling - Solar PV + electrical cooling -	**Solar thermal cooling** - Solar thermal collector + thermal sorption cooling -
• System consists of: - On-site solar PV system. - Electric vapor compression chiller.* - Optional storage (battery or cold-storage) to increase the share of usable renewable energy. Storage means that the cooling system can participate in demand response programs. - Back-up grid electricity supply. • Solution is advantageous for smaller, decentralized systems and existing cooling systems. • Excess electricity generation can be used in other applications • Typical system efficiency**: about 60 % (PV: 15 %; $SEER_{\text{electric vapor compression chiller}}$: 4).***	• System consists of: - On-site solar thermal system (flat, vacuum tube or concentrating collectors). - Thermal sorption chiller, which requires heat provided by solar thermal system and electricity to operate. - Optional thermal storage (heat and/or cold-storage) enabling the cooling system to participate in demand response programs. - Backup heat supply and/or peak-load/back-up cooling systems (usually electric vapor compression chillers). • Solution is preferable for new, bigger, centralized cooling systems. • Excess thermal energy can be used for domestic hot water. • Typical system efficiency**: about 60 % (Solar thermal collector: 50 %; $SEER_{\text{thermal sorption chiller}}$: 1.2).

*More than 95% of current space cooling uses this technology, which can also work in heat pump mode to provide heat.
**Ratio of cooling energy produced/solar energy on collector.
***SEER is the seasonal energy efficiency ratio, equivalent to the cooling output divided by the energy input during a typical cooling season.

2. Description of solar cooling

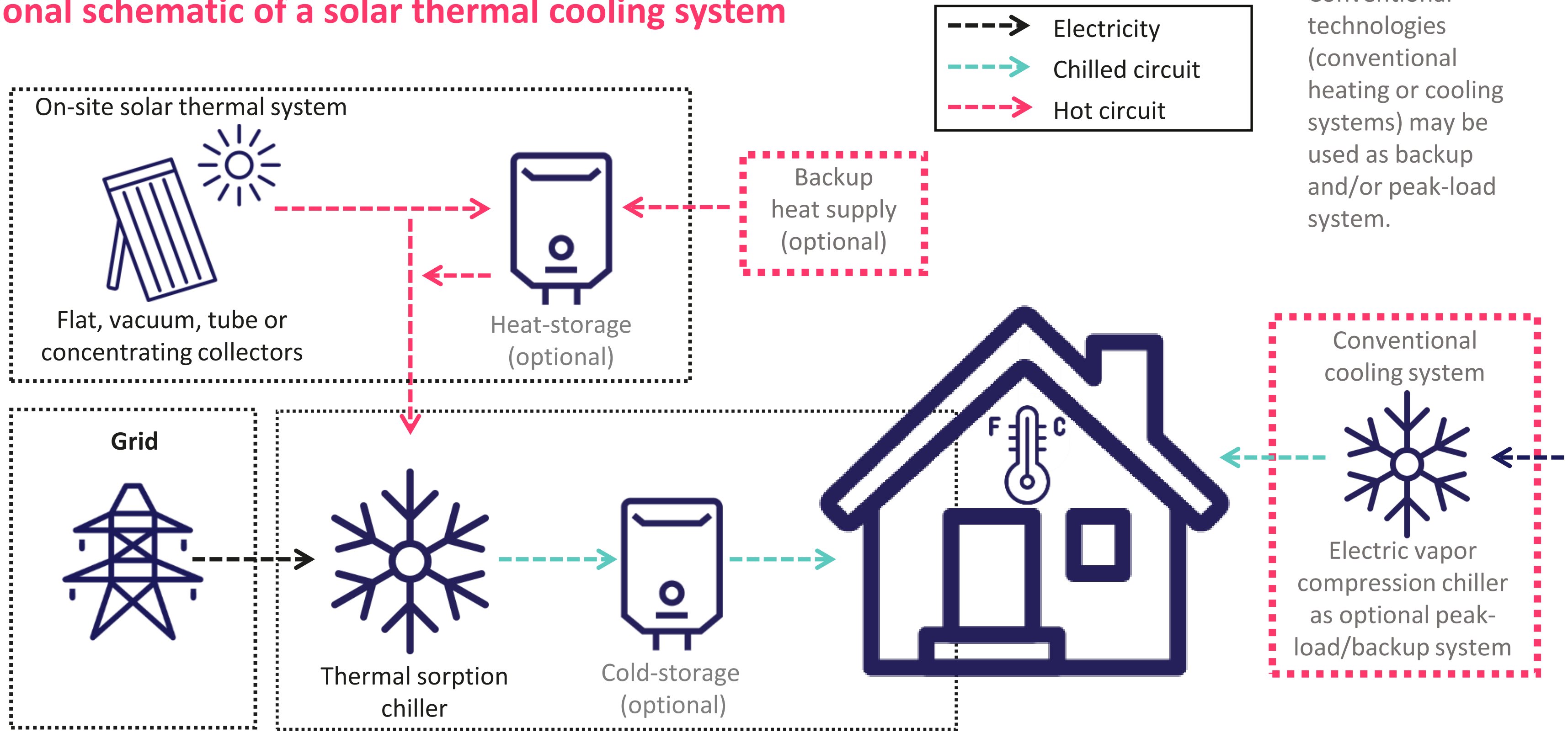
Functional schematic of an electrical solar cooling system

- To convert an existing cooling system to electrical solar cooling, PV panels, storage and a control system need to be added.



2. Description of solar cooling

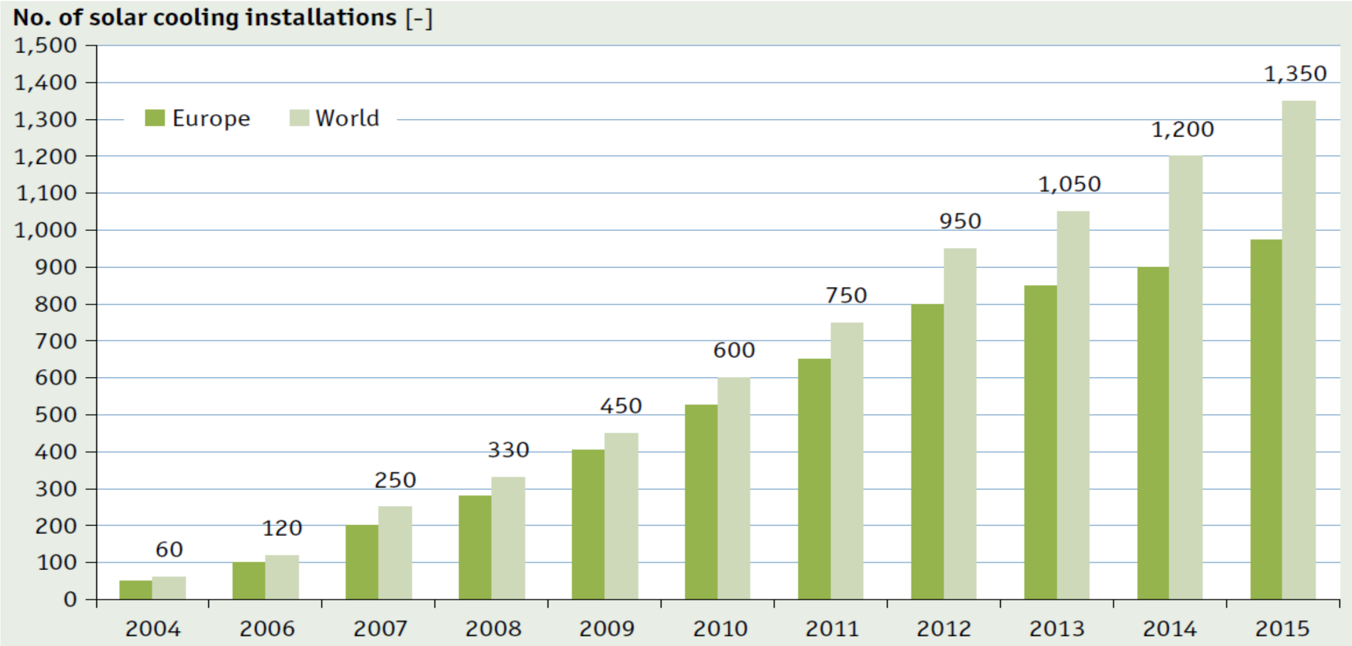
Functional schematic of a solar thermal cooling system



Conventional technologies (conventional heating or cooling systems) may be used as backup and/or peak-load system.

2. Description of solar cooling

Market development: solar thermal cooling market is growing, but still a niche market[1]



Source: IEA SHC, 2018: Solar Heat Worldwide

*The world market size of air conditioners is in a range of 100 million sold units per year.[1]
Source: [1] JRAIA, 2018: *World Air Conditioner Demand by Region*.

2. Description of solar cooling

There are still existing barriers

Economics:

- Investment costs (see following slides) for:
  - Solar collector, PV systems.
  - Back-up heat supply / peak load cooling / optional storage.
  - Chillers without F-gas refrigerants (using natural refrigerants or thermal sorption chillers).
- Investors lack understanding of solar cooling.

Lack of whole system experience:

- Collaboration between solar and cooling system installers is needed.
- Lack of experience installing solar thermal cooling.

Space constraints for decentralized solutions:

- Insufficient (roof) space, especially on top of high-rise buildings in dense urban areas.

3. GHG reduction potentials of solar cooling

Cooling related GHG emissions depend on:

- **Cooling demand,** which can range from 0-500 kWh/m². This varies depending on climate, building efficiency and usage.
- **Efficiency** of the cooling system, which is usually expressed in SEER* (range of 1 to 5).
- **Type** of cooling system: Most electric vapor compression cooling systems use F-Gases as refrigerants. Due to system leakages and disposal, direct emissions contribute between 2% to 10% of the total emissions from cooling.
- **CO_2 emission factor of electricity**, which can range from below 50gCO_2/kWh (e.g. Sweden**) to over 1000gCO_2/kWh (e.g. Estonia**). The global average is about 500gCO_2/kWh.

Annual cooling related CO_2 emissions of a typical office building (floorspace: 2,000 m², cooling demand: 250 kWh/m²):

	Annual CO_2 emissions per m²	Total annual CO_2 emissions
Conventional cooling (SEER 2.5)	50 kgCO_2/m²	100tCO_2
Solar PV*** installed for existing conventional cooling system (SEER 2.5)	25 kgCO_2/m²	50tCO_2
Solar PV*** installed with an improved conventional cooling system (SEER 5)	0 kgCO_2/m²	0tCO_2
Thermal solar cooling² with existing cooling system as backup (SEER(heat) 0.8; SEER(el): 25)****	5 kgCO_2/m²	10tCO_2

*Seasonal Energy Efficiency Ratio (SEER) expresses the ratio between provided cooling energy and electricity required for cooling.
**See e.g. IEA, 2018: *Emission Factors 2018*.
***Assumption: maximum possible solar roof coverage (50 %=> 70 kWp PV; 500 m³ flat-Collectors); annual solar radiation 1500 kWh/m²a (Southern Europe); annual harvest about 100,000 $kWh_{electrical}$; 300,000 $kWh_{thermal}$.
****SEER (heat) takes into account the heat that is the main driver for cooling production, whereas SEER(el) considers just the electrical auxiliary energy for pumps of the thermal sorption chiller.

4. Cost assessment and value proposition

Investment costs	• For solar electric cooling, the additional costs come from the PV-system (typical cost is about €1000/kWp) and optional storage and control systems. • For solar thermal cooling systems, the additional costs are due to the solar-collector system (including storage and controls) as well as the costs for the thermal chiller. Typically the additional cost is in the range of €500-2000/kW installed cooling power.
Return on investment (ROI)	• The pay-back time ranges typically between 5 years (best case) and 20 years (typical expected lifetime of the solar cooling system).
Sensitivity analysis	• ROI depends on several factors aside from investment costs: - Solar radiation: solar cooling production of a system in areas of high solar radiation can be double that of areas with low solar radiation. - Local electricity prices: higher prices reduce the payback period. - Selected technology and size: Solar thermal systems are better suited for higher cooling loads (> 15 kW). - Possibility to create value from excess solar electricity/heat: e.g. PV feed in tariffs or use as process heat.

4. Cost assessment and value proposition

Expected reduction in solar cooling investment costs in the Arab region is up to 70% by 2025

Factor	Evolution of indicator over 2015 to 2025	Cost reductions in 2025 compared to 2015 baseline
Sales scaling factor	x 10 increase in sales volume	15 to 30%
Size scaling factor	x 10 increase in system size from 100 kW_c to 1 MW_c	50 to 70%
Packaging factor	Solar cooling pre-fabrication (kits of less than 30 kW_c)	30 to 40%
Local company manufacturer factor	Manufacturing of the main components locally	5 to 10%
Technical innovation factor	Solar cooling systems adapted to hot and arid conditions of Arab region	10 to 30%

Source: UNEP/RCREEE, 2014: *Assessment on the commercial viability of solar cooling technologies and applications in the Arab region*.

4. Cost assessment and value proposition

Example of solar cooling solutions that are already economically feasible

Case study in Tunisia (medium system):
Average commercial building
Area air-conditioned: 500 to 1000 m²
Cooling capacity: ~100 kWc

Case study in Saudi Arabia (large system):
A group of buildings (using distributed cooling network) or large building
Area air-conditioned: 5,000 to 10,000m²
Cooling capacity: ~1 MWc

Measure	Unit	Electric vapor compression chiller	Solar electric cooling	Solar Thermal cooling
CAPEX	USD $	160,000	225,000	333,000
OPEX	USD $/year	22,600	8,200	9,400
LCCE	USD $/kWh	0.116	0.093	0.1
NPC	USD $ for 20 yr.	580,000	460,000	500,000

Measure	Unit	Electrical vapor compression chiller	Solar electric cooling	Solar Thermal cooling
CAPEX	USD $	304,000	1,180,000	1,370,000
OPEX	USD $/year	58,900	19,000	29.000
LCCE	USD $/kWh	0.058	0.05	0.044
NPC	USD $ for 20 yr.	2,500,000	1,850,000	2,005,000

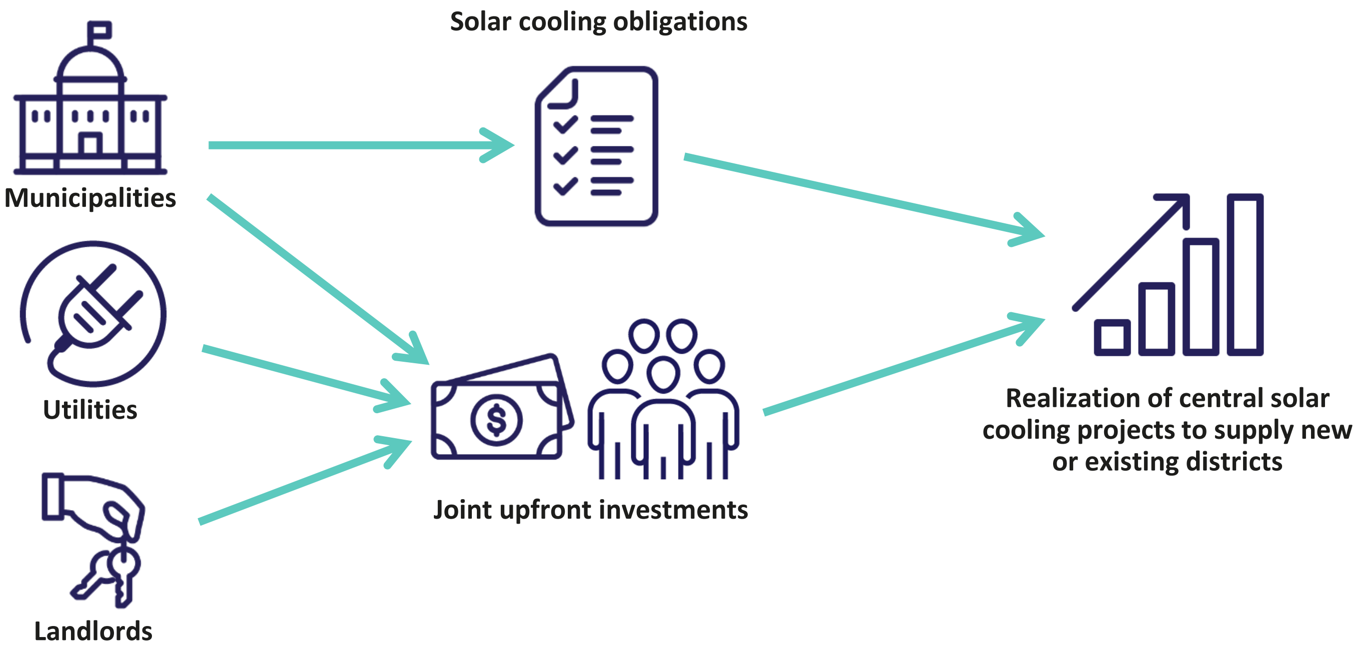
CAPEX= Capital expenditure
OPEX= Operational expenditure
LCCE=Levelized cost of cooling energy
NPC= Net present cost

→ **All solar cooling examples above are economically feasible**
(NPC and LCCE are lower than the electric vapor compression chiller).
The expected savings for the 20 year period range from:
14 % for the 100 kWc solar thermal cooling in Tunisia
26 % for the 1 MWc solar electric cooling in Saudi Arabia.

Source: UNEP/RCREEE, 2014: *Assessment on the commercial viability of solar cooling technologies and applications in the Arab region*.

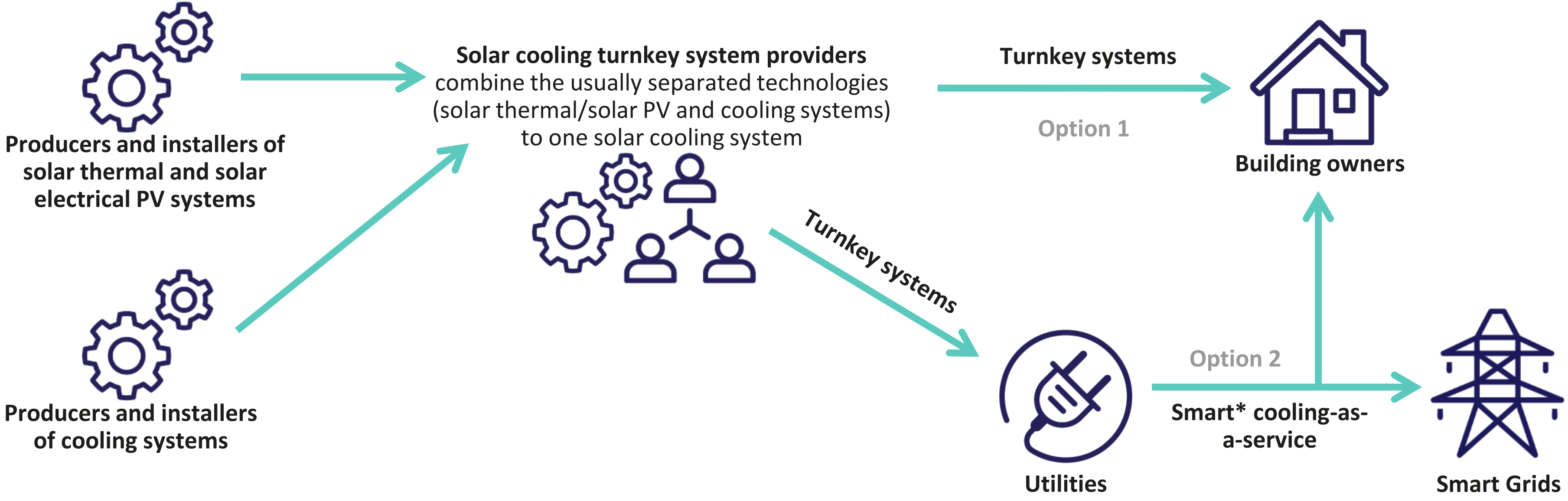
5. New partnership opportunities

Utilities and municipalities and/or **landlords** can partner to build central solar cooling projects that require high upfront investments. Municipalities can set requirements for new building projects to connect to central cooling. All parties have a reduced risk due to the municipal obligations.



5. New partnership opportunities

Producers of solar systems and cooling systems and installers can partner to build one-stop shops to offer turnkey solutions. These can be either (1) bought directly by buildings, or (2) utilities can sell these as a "smart* cooling as a service" solution to the end user. This overcomes potential mistrust in the reliability and cost savings of the new technology. It will also help to overcome the barriers of unclear system responsibility.



*If storage is installed (thermal or battery storage), the cooling system can provide demand response flexibility to the grid as a co-benefit.

6. Solar cooling SWOT analysis

Strengths

- Low OPEX as solar energy has zero fuel costs.
- Improves energy security, as it reduces peak loads of the electricity grid in countries with hot climates.
- With a supplementary installation of rooftop-PV, most of existing electrical space cooling systems can upgraded to a (partly) solar cooling system.
- Visible measure which can be used for company branding.

Opportunities

- Further decrease of CAPEX.
- Increasing environmental awareness will create pressure for more sustainable cooling solutions.
- Excess heat or electricity can be used in other applications.
- Strengthened climate policies such as renewable energy or energy efficiency obligations will improve the attractiveness of solar cooling systems.

Weaknesses

- High CAPEX because of the additional required investments in the solar thermal/PV system, controls, storage and new chiller technologies (sorption technology in case of solar thermal cooling).
- Lack of one-stop shop suppliers and experienced installers makes it currently complicated to design and operate an optimized system. In case of malfunction the responsibilities can be unclear.
- Building owners need to have sufficient space for solar PV panels/solar collectors.

Threats

- Landlords prefer lower-cost, conventional cooling systems as they might not directly benefit from lower OPEX.
- Low/subsidized electricity prices decrease the economic attractiveness - they increase the payback time.

7. Success factors

Scaling effects

- An increasing number of produced and installed solar thermal systems will reduce investment costs and increase commercial viability.

Adequate local conditions

- High solar radiation.
- Sufficient (roof-)space for a solar PV or solar thermal collector system (at least about 2 m² per kW installed cooling power
  for a 100% solar coverage of cooling demand).

Smart business models

Partnerships to provide:

- Solar "smart cooling-as-a-service" solutions, which avoid upfront investments from building owners and overcome potential mistrust in the new technologies.
- Turnkey solutions to reduce implementation barriers and guarantee quality.
- Sufficient capital to implement central solar cooling systems for new or existing districts.
- Demand response flexibility for grid (in case of system integrated storages).

Policy and regulation

- Financial policies such as subsidies for solar cooling systems, carbon taxes and reduced fossil fuel subsidies can support solar cooling systems in realizing its potential.
- Increased renewable energy and energy efficiency targets for buildings increase the attractiveness of solar cooling systems.

8. Solar cooling: Case studies (1/3)

Retail store

IKEA store: Alexandra, Singapore	
System	• Existing conventional cooling system with electric chillers (450 RT) integrated with solar thermal cooling system and absorption chiller (250 RT)
Main technical data	• CAPEX: USD $1.8 million • Yearly cost savings: USD $90,000 • Yearly CO_2 savings: 428 tCO_2

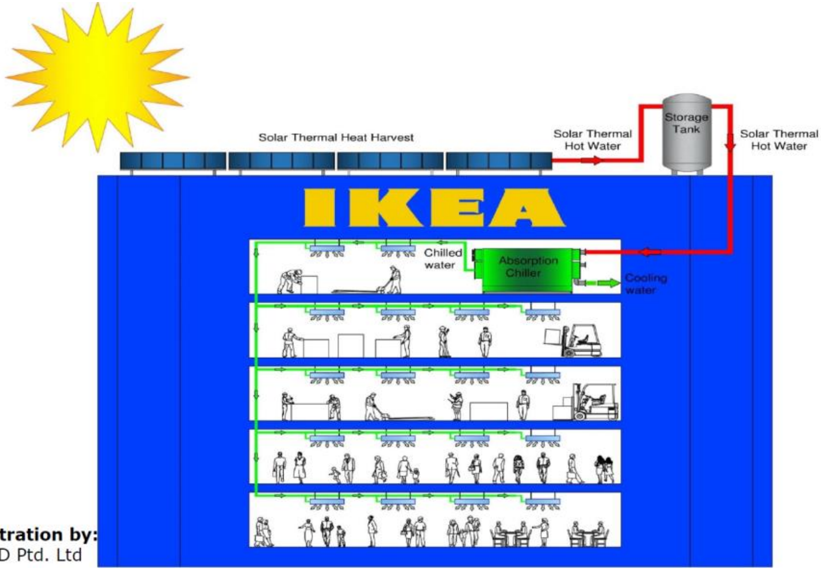


Illustration by: SOLID Ptd. Ltd

Source: Communication with IKEA.

8. Solar cooling: Case studies (2/3)

Hotel

Rethymno Village Hotel (Rethymno, Greece)	
Context	• Hotel located in Crete with a capacity of 260 beds. • Quite high cooling load in the summer with temperatures reaching up to 40 °C
Project description & objectives	• Closed cycle • 105 kW cold absorption flat-plate with selective coating- 450 m^2 aperture • System has been in operation since August 2000
Main technical data	• Average coefficient of performance (COP): 0.52 • CAPEX: EUR €146,000 • Payback: 5 years
Benefits	• Electricity savings (cooling): 70,000 kWh/year • Diesel oil savings (heating): About 20,000 L/year

Source: SOLAIR: *Increasing the Market Implementation of Solar Air conditioning Systems for Small and Medium Applications in Residential and Commercial Buildings*.

8. Solar cooling: Case studies (3/3)

Retirement home

Résidence du Lac (Maclas, France)	
Context	• Retirement home in the southeast of France • Building owner used electric compression chillers (3 monosplits), but two of them were out of order.
Project description & objectives	• Closed cycle • 10 kW cold absorption Solar thermal evacuated tube 24 m^2 absorber area • Start of operation: 2007
Main technical data	• COP (summer 2015): 0.6-0.7 • Energy production expectations: • Cooling: 4,300 kWh/year (4 months) • Heating: 8,300 kWh/year (8 months) • Annual: 12,600 kWh/year
Benefits	• Energy costs savings: EUR €1,150/year

Source: SOLAIR: *Increasing the Market Implementation of Solar Air conditioning Systems for Small and Medium Applications in Residential and Commercial Buildings*.

9. Summary

Emissions and energy	• CO_2 emissions from space cooling were 1.1 $GtCO_2$ in 2016, or 12% of energy-related emissions from buildings sector. Space cooling also accounts for 5% of energy consumption from the buildings sector. • Under a baseline scenario, the IEA expects CO2 emissions from cooling to almost double by 2050.
Solution	• Solar cooling systems are a viable solution to meet this growing demand, due to the good match between solar energy supply and cooling demand in hot regions. • Two types of solar cooling systems can be deployed: - Solar electric cooling, which consists of solar PV panels and an electric vapor compression chiller. This is the preferable solution for smaller, decentralized systems and existing electric cooling systems. - Solar thermal cooling, which consists of solar thermal collectors and a thermal sorption chiller. This system is better suited for new, bigger and centralized cooling systems.
Avoided GHG emissions and co-benefits	• Avoided indirect GHG emissions associated with consumption of electricity generated from fossil fuels. • Can also avoid direct GHG emissions from leakage of high global warming potent refrigerants. • An additional benefit is improved energy security in countries with hot climates because peak loads of the electricity grid are reduced.
Readiness status	• Individual components of solar cooling systems are proven technologies commercially available on the market. Solar cooling systems are currently nonetheless a niche market.
Barriers	• High investment costs for solar cooling system components (solar panels/solar thermal collectors and thermal sorption chillers).
Success factors	• Availability of turnkey solutions from producers and installers of solar and cooling systems. • Local electricity prices that include the costs of externalities and do not include fossil fuel subsidies, since this reduces the payback time for solar cooling systems.

10. Key sources and references on solar cooling

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- IEA SHC Task 53: New Generation Solar Cooling & Heating Systems (PV or solar thermally driven systems)
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- IRENA, 2015: Solar Heating and Cooling for Residential Applications
- JRAIA, 2019: World Air Conditioner Demand by Region
- SOLAIR: Increasing the Market Implementation of Solar Air conditioning Systems for Small and Medium Applications in Residential and Commercial Buildings
- UNEP/RCREEE, 2014: Assessment on the commercial viability of solar cooling technologies and applications in the Arab region

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