SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

Task53 Workshop on the New Generation of Solar Cooling and Heating Systems driven by Photovoltaic or Solar Thermal Energy

"Life Cycle Analysis and solar cooling"

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Introduction

The development of renewable energy technologies (RETs) is important for reducing fossil fuels consumption while contributing to the climate change mitigation.

However, RETs cannot be considered totally clean. They have energy and environmental impacts that cannot be neglected during their life cycle.

Need of enlarging the boundaries of the analysis by including the total life cycle of RETs.

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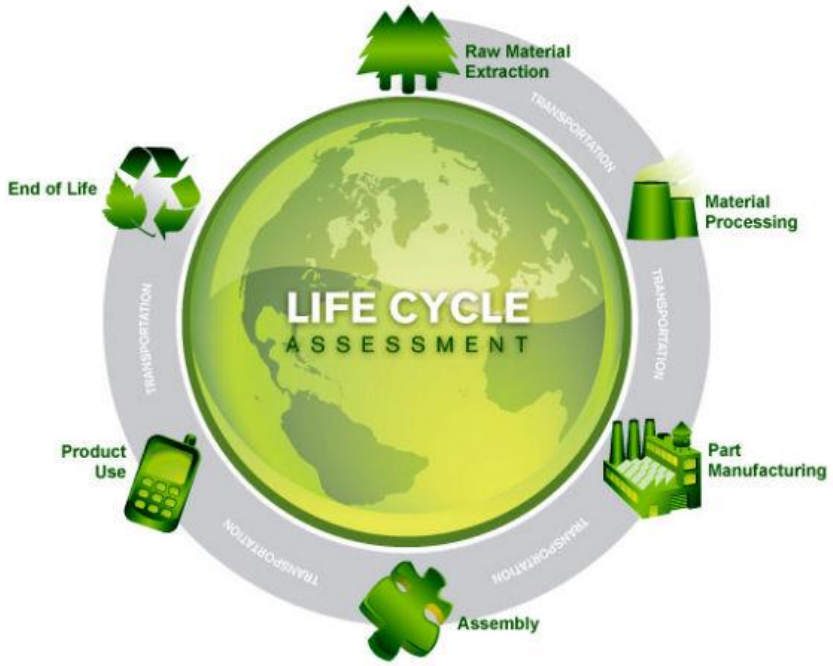
The Life Cycle Assessment

The Life Cycle Assessment (LCA) is a methodology for assessing the energy and environmental impacts of products and services during their life cycle.

LCA is one of the main pillars driving the European policy toward the low-carbon economy, the sustainable use of resources, the sustainable consumption and production, the application of eco-design and eco-innovation strategies, the waste prevention and waste recycling.



LCA allows to have a global overview of the product throughout its life cycle.

The Life Cycle Assessment

- It prevents to move problems from one life-cycle step to another or
- It prevents to move problems from an impact category to another;
- It captures the complexity hidden behind a product;
- It is a useful tool to compare products and services on a scientific basis.
- It can be used to investigate new technologies and can help decision makers to evaluate the energy and environmental advantages of a technology within a specific climate.

The LCA and the IEA Solar Heating & Cooling Programme

IEA SHC Task 38 “Solar Air-Conditioning and Refrigeration”
Subtask D “Market transfer activities” - Activity D3 “Life cycle assessment”

IEA SHC Task 48 “Quality Assurance & Support Measures for Solar Cooling Systems”
Subtask A “Quality Procedure on Component Level” - Activity A2 “Life cycle analysis at component level”
Subtask B “Quality procedure on system level” - Activity B3 “Life cycle analysis at system level”

IEA SHC Task 53 "New Generation Solar Cooling & Heating Systems (PV or solar thermally driven systems)“
Subtask A “Components, systems and quality” - Activity A5 “LCA and techno-eco comparison between reference and new systems”

The LCA of SHC systems

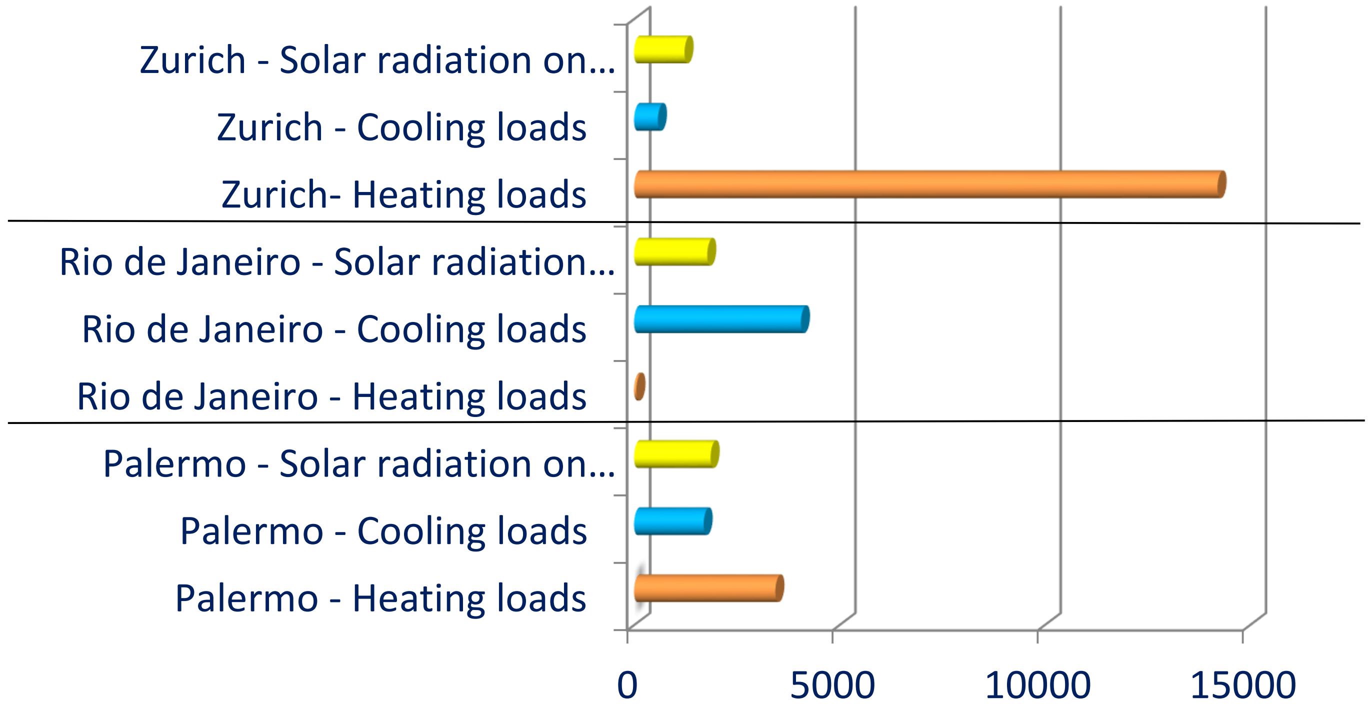
Goals of the LCA study:

- ✓ assessment of the energy and environmental life-cycle impacts of solar heating and cooling (SHC) systems with small (12 kW) absorption chillers in three different locations: Palermo (Italy), Zurich (Switzerland) and Rio de Janeiro (Brazil);
- ✓ comparison of the above impacts with those of conventional compression chiller systems also assisted by photovoltaic.

The research aims to provide a more comprehensive investigation of the performances of two families of solar assisted cooling systems, which is important for studies concerning effective systems to exploit solar energy for cooling purposes.

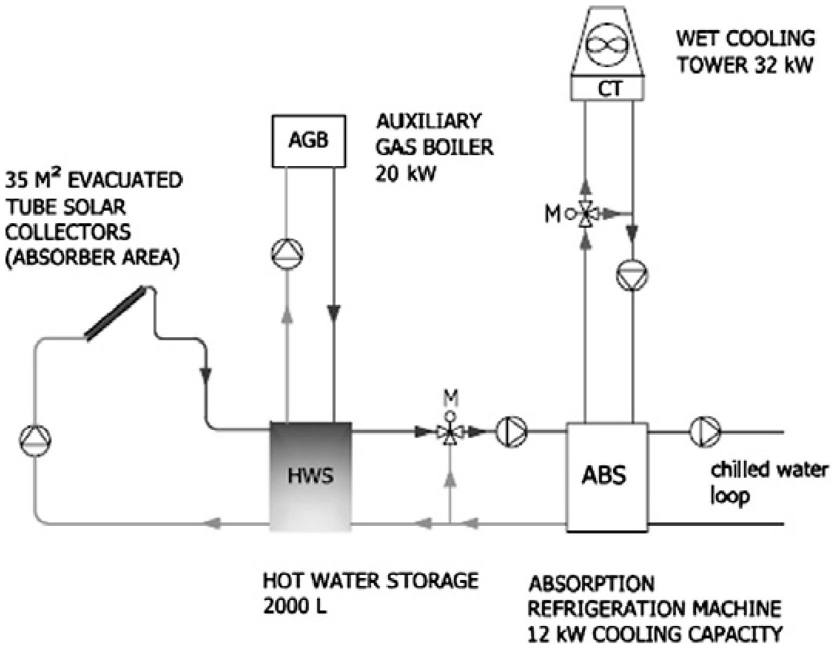
The LCA of SHC systems

Annual solar radiation on tilted surface [kWh/m^2], cooling and heating loads [kWh] of the three chosen locations.

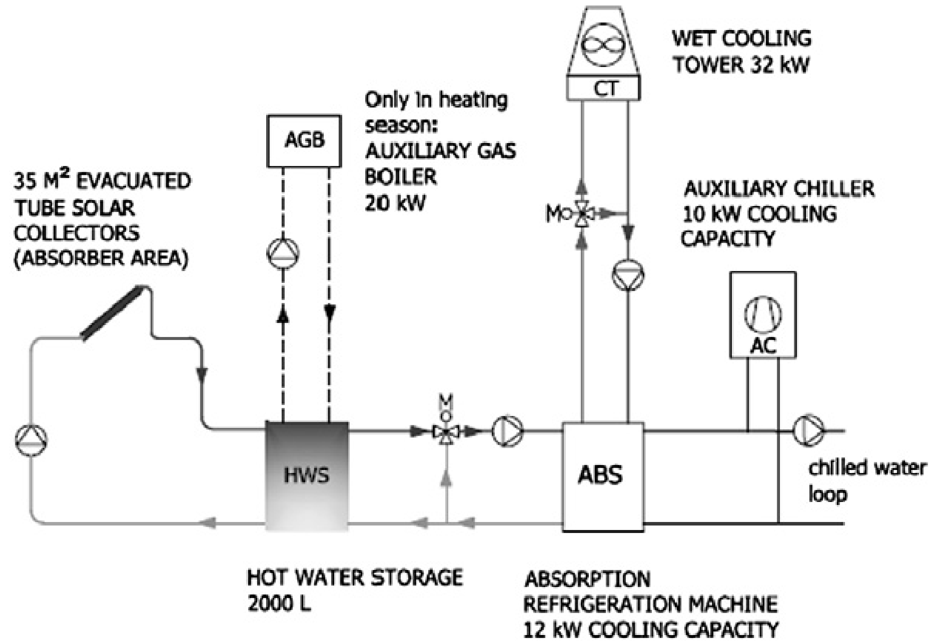


The LCA of SHC systems

The SHC system:



Hot back-up



Cold back-up

The LCA of SHC systems

The conventional systems:

Without PV	With PV grid connected	With PV stand-alone
Heating: natural gas burner. **Cooling:** conventional compression chiller connected to the electricity grid.	**Heating:** natural gas burner. **Cooling:** conventional compression chiller. The electricity demand is totally produced by a grid connected multi-Si PV system.	**Heating:** natural gas burner. **Cooling:** conventional compression chiller connected . The electricity demand is totally produced by a stand-alone multi-Si PV system.

PV systems are sized to generate the electricity required by the chiller and the auxiliaries.

The LCA of SHC systems

The energy and environmental impacts, calculated by applying the LCA, were referred to each system (SHC or conventional).

The life-cycle steps included in the analysis are:

Manufacturing:

it includes the supply of raw materials and the production and assembly of the main components of the system.

Operation:

it includes the energy sources (electricity from the grid and natural gas) consumption during the useful life (25 years) of the system.

End-of-life:

it includes the treatment of waste at the end-of-life of the system.

The LCA of SHC systems

Operation step:

All the systems were simulated with detailed TRNSYS models for three locations: Palermo (Italy), Zurich (Switzerland) and Rio de Janeiro (Brazil).

Three reference buildings, tailored to have the same peak cooling demand (about 12 kW), have been defined and modeled.

The life cycle of each system component was estimated to be 25 years, except for batteries (about 8 years), charge regulators (about 8 years) and inverters (about 12 years).

The LCA of SHC systems

Operation step:

		Palermo		Zurich		Rio de Janeiro	
	[kWh]	Heating	Cooling	Heating	Cooling	Heating	Cooling
Conventional system	Electricity	0	1,995	0	1,046	0	4,542
Conventional system with PV (grid connected and stand-alone)	Electricity	0	0	0	0	0	0
Conventional system with and without PV	Natural gas	2,754	0	14,951	0	103	0
SHC Hot backup	Electricity	52	937	81	655	74.4	2,062
	Natural gas	414	246	10,165	177	0	2,956
SHC Cold Backup	Electricity	52	1,065	81	686	74.4	3,005
	Natural gas	414	0	10,165	0	0	0

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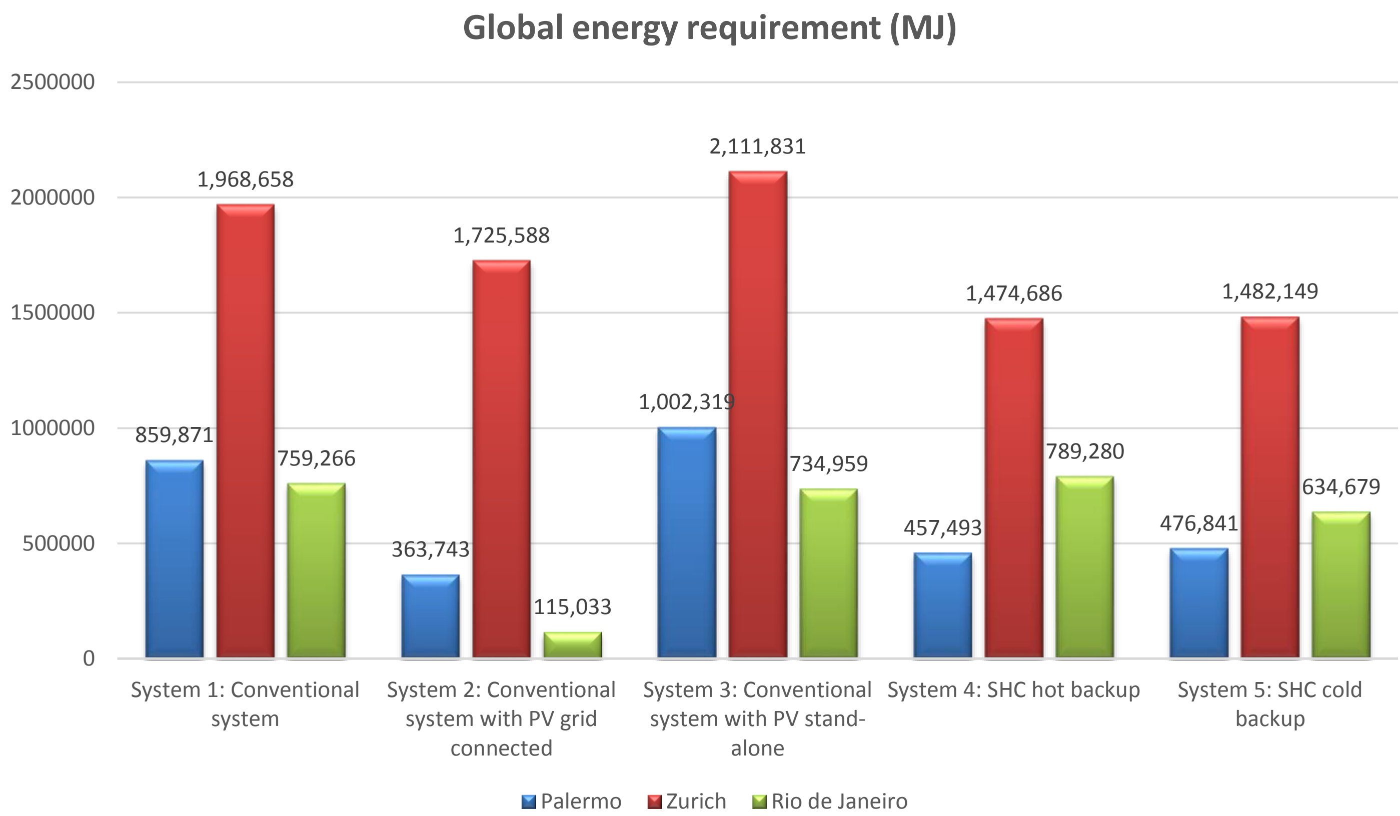
The LCA of SHC systems

LCA results: Global Energy Requirement (GER)



System 2 is the best system in the two hottest locations (Palermo and Rio de Janeiro).

SHC systems perform better than conventional systems in Palermo and Zurich.

SHC systems perform better than systems 1 and 3 in Palermo.

System 3 has the worst performance in Palermo and Zurich.

System 4 has the worst performance in Rio de Janeiro.

The LCA of SHC systems

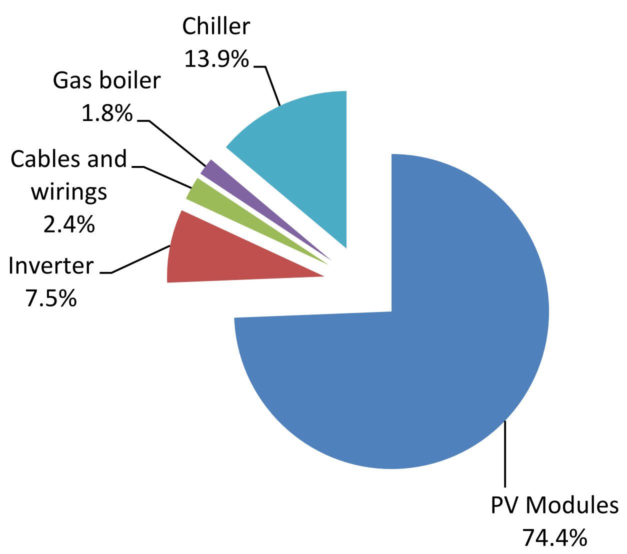
LCA results: Global Energy Requirement (GER)

		Conventional system	Conv. system with PV grid connected	Conv. system with PV stand-alone	SHC with hot backup	SHC with cold backup
Palermo (MJ)	Production	14,357	55,048	667,046	117,000	129,505
	Operation	845,485	308,616	308,616	340,029	346,860
	End-of-life	29	78	26,656	464	476
	Total	859,871	363,743	1,002,319	457,493	476,841
Zurich (MJ)	Production	14,357	50,088	420,347	119,101	131,605
	Operation	1,954,272	1,675,426	1,675,426	1,355,121	1,350,068
	End-of-life	29	75	16,058	464	476
	Total	1,968,658	1,725,588	2,111,831	1,474,686	1,482,149
Rio de Janeiro (MJ)	Production	14,357	103,383	696,382	117,000	129,505
	Operation	744,880	11,543	11,543	671,816	504,699
	End-of-life	29	107	27,034	464	476
	Total	759,266	115,033	734,959	789,280	634,679

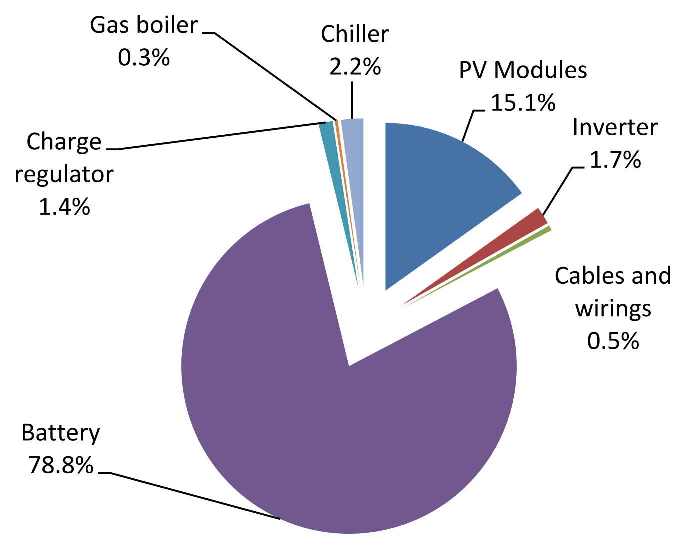
The LCA of SHC systems

LCA results: Global Energy Requirement (GER)

System 2 Conv. with PV grid connected - Rio de Janeiro

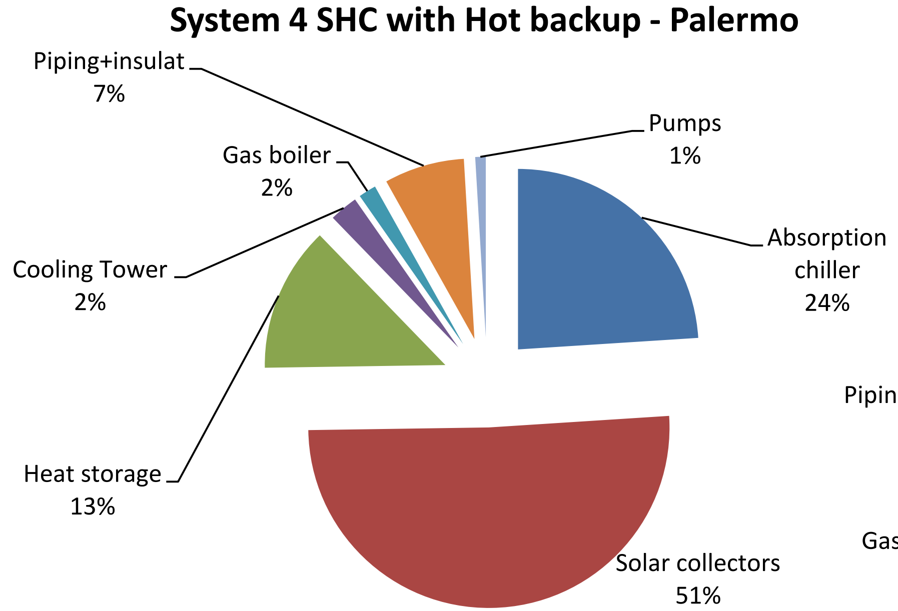


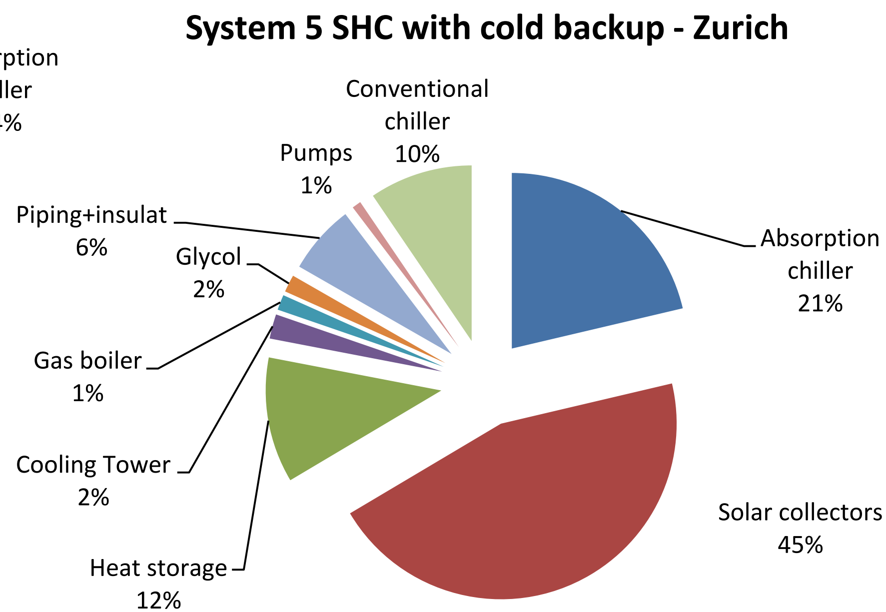
System 3 Conv. with PV stand-alone – Palermo



The LCA of SHC systems

LCA results: Global Energy Requirement (GER)





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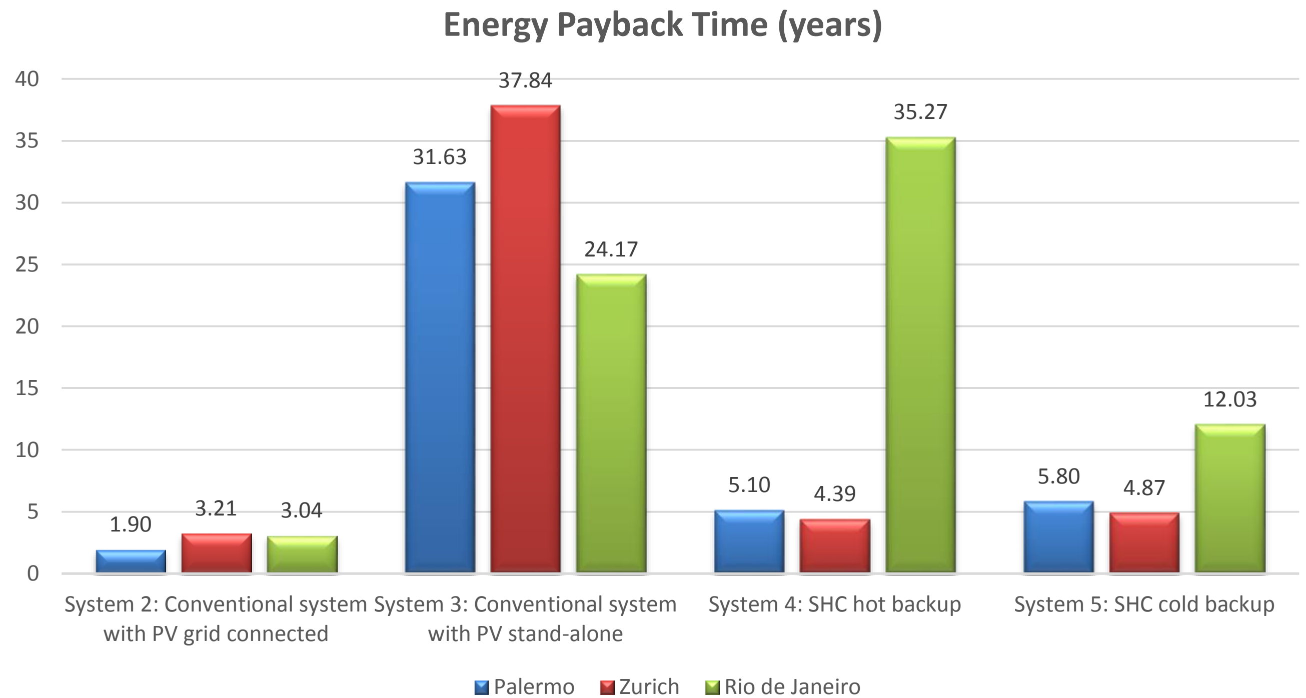
The LCA of SHC systems

LCA results:

Energy Payback Time (EPT): time (years) during which the system must work to harvest as much energy as is required for its production and disposal.



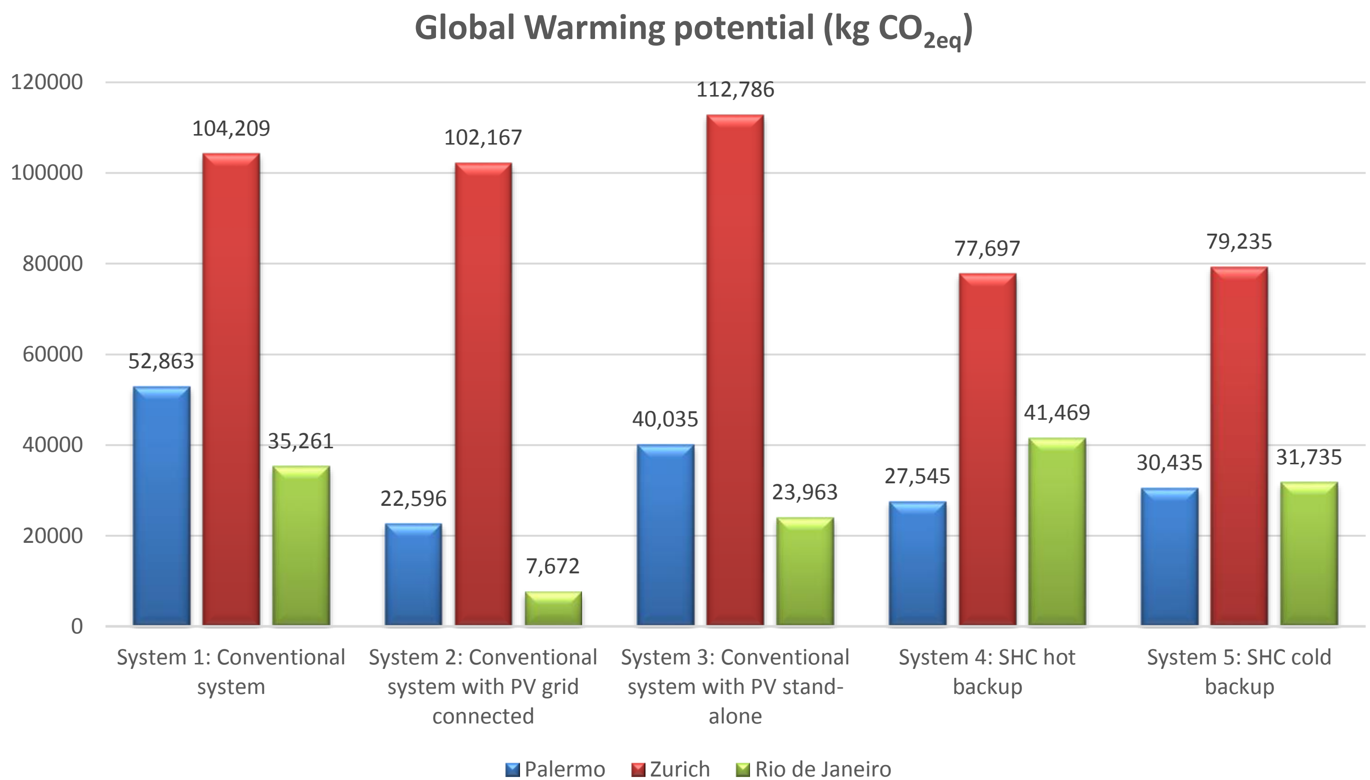
Best EPT: systems 2, 4 and 5 for Palermo and Zurich, and system 2 for Rio de Janeiro.

EPT higher than 25 years for system 4 in Rio de Janeiro, which has GER higher than the conventional system.

Very high EPT values for the stand-alone systems, due to the battery incidence on the total GER.

The LCA of SHC systems

LCA results: Global Warming Potential (GWP)



Incidence of each life-cycle step on the total GWP: consideration similar to GER can be made for GWP.

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The LCA of SHC systems

Conclusions:

- In hot climates (**Palermo and Rio de Janeiro**), the systems with the **PV grid connected** plant (that not requires storage) performed best, as they have low GER and GWP values and payback times.
- The PV systems with stand-alone configuration performed worse than the PV grid connected systems and the solar thermal assisted systems in nearly all the analysed cases. The impact of storage manufacturing is large so only more efficient, durable and "green" technologies can overcome this impact.
- In a cold climate (Zurich), the SHC systems perform better. There is the opportunity to use these systems to meet the cooling load and also the high heating load.
  This consideration is not true for PV assisted systems, which do not contribute to save natural gas.

The LCA tool

A user-friendly LCA tool for assessing the energy and environmental impacts of solar heating and cooling systems following the life cycle approach was developed within the Task 48 “Quality Assurance & Support Measures for Solar Cooling Systems” of the International Energy Agency.

The LCA tool aims to support researchers, designers and decision-makers in evaluating the life cycle energy and environmental advantages related to the use of SHC systems in substitution of conventional ones, considering specific climatic conditions and building loads.

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LCA METHOD TOOL

Task 48
Quality Assurance & Support Measures for Solar Cooling Systems

Sheet	Description	Go to the sheet
1	SHC system	Click here
2	Conventional system	Click here
3	Specific impacts SHC system	Click here
4	Specific impacts conventional system	Click here
5	Total impacts SHC system	Click here
6	Total impacts conventional system	Click here
7	Impacts comparison	Click here
8	Payback indices	Click here

Key
- (yellow) = Input data
- (orange) = Information data
- (green) = Output data

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The LCA tool

LCA modelling steps

Step 1: Entering data of SHC and conventional system → Step 2: Examining data of specific energy and environmental impacts → Step 3: Examining the results

The tool allows for calculating the following indices, both for SHC and for conventional systems:

- Global energy requirement (GER);
- Global warming potential (GWP);
- Energy payback time (EPT);
- GWP payback time (GWP-PT);
- Energy return ratio (ERR).

The LCA tool

Step 1: Entering data of SHC and conventional system

COMPONENTS OF THE SHC SYSTEM	U.M.	QUANTITY
Absorption chiller (12 kW)	unit	1
Absorption chiller (19 kW)	unit	
Adsorption chiller (8 kW)	unit	
Ammonia	kg	15
Auxiliary gas boiler (10 kW)	unit	1
Auxiliary conventional chiller (10 kW)	unit	1
Cooling tower (32 kW)	unit	1
Evacuated tube collector	m^2	35
Flat plate collector	m^2	
Glycol	kg	
Heat storage (2000 l)	unit	1
Heat rejection system (24 kW)	unit	
Pipes	m	60
Pump (40 W)	unit	8.25
Water	kg	10

ENERGY SOURCES	U.M.	QUANTITY
Electricity, low voltage, Italy (including import)	kWh/year	1117
Natural gas, burned in boiler modulating, <100 kW, Europe	kWh/year	414

OTHER INFORMATION	U.M.	QUANTITY
Useful life of the system	year	25

COMPONENTS OF THE CONVENTIONAL SYSTEM	U.M.	QUANTITY
Battery lead-acid	kg	
Battery lithium-iron-phosphate	kg	
Battery lithium-ion-manganate	kg	
Battery nickel cadmium	kg	
Battery nickel cobalt manganese	kg	
Battery nickel metal hydride	kg	
Battery sodium-nickel-chloride	kg	
Battery v-redox	kg	
Conventional chiller (10 kW)	unit	1
Electric installation (PV system)	unit	
Gas boiler (10 kW)	unit	1
Inverter (500 W)	unit	
Inverter (2500 W)	unit	
Photovoltaic panel, a-Si	m^2	
Photovoltaic panel, CdTe	m^2	
Photovoltaic panel, CIS	m^2	
Photovoltaic panel, multi-Si	m^2	
Photovoltaic panel, ribbon-Si	m^2	
Photovoltaic panel, single-Si	m^2	
Pipes	m^2	
Pump (40 W)	unit	

ENERGY SOURCES	U.M.	QUANTITY
Electricity, low voltage, Italy (including import)	kWh/year	1995
Natural gas, burned in boiler modulating, <100 kW, Europe	kWh/year	2882

OTHER INFORMATION	U.M.	QUANTITY
Useful life of the system	year	25

The LCA tool

Step 2: Examining data of specific energy and environmental impacts

	GLOBAL ENERGY REQUIREMENT (GER)			GLOBAL WARMING POTENTIAL (GWP)		
COMPONENTS	MANUFACTURING STEP	END-OF-LIFE STEP	U.M.	MANUFACTURING STEP	END-OF-LIFE STEP	U.M.
Absorption chiller (12 kW)	26005.37	3.13	MJ/unit	1382.34	12.55	$kgCO_{2eq}$/unit
Absorption chiller (19 kW)	42850.54	4.69	MJ/unit	1996.00	18.83	$kgCO_{2eq}$/unit
Adsorption chiller (8 kW)	24187.00	12.00	MJ/unit	1380.00	21.00	$kgCO_{2eq}$/unit
Ammonia	41.953	0	MJ/kg	2.10	0	$kgCO_{2eq}$/kg
Auxiliary gas boiler (10 kW)	6781.86	61.51	MJ/unit	365.71	12.04	$kgCO_{2eq}$/unit
Auxiliary conventional chiller (10 kW)	8131.10	7.83	MJ/unit	1550.46	25.82	$kgCO_{2eq}$/unit
Cooling tower (32 kW)	2950.69	10.74	MJ/unit	149.98	3.13	$kgCO_{2eq}$/unit
Evacuated tube collector	1579.69	12.98	MJ/m^2	86.97	3.94	$kgCO_{2eq}/m^2$
Flat plate collector	1742.09	10.18	MJ/m^2	99.03	4.24	$kgCO_{2eq}/m^2$
Glycol	52.17	0.18	MJ/kg	1.59	1.43	$kgCO_{2eq}$/l
Heat storage (2000 l)	14811.72	21.32	MJ/unit	783.31	12.71	$kgCO_{2eq}$/unit
Heat rejection system (24 kW)	14348.00	9.00	MJ/unit	770.00	105.00	$kgCO_{2eq}$/unit
Pipes	65.48	0.33	MJ/m	2.63	0.10	$kgCO_{2eq}$/m
Pump (40 W)	118.18	0.37	MJ/unit	6.91	0.08	$kgCO_{2eq}$/unit
Water	0.019	0	MJ/kg	7.94E-04	0	$kgCO_{2eq}$/kg

The LCA tool

Step 3: Examining the results

For each system the LCA results include:

- The total life cycle impact;
- The total impact for each component/energy source;
- A dominance analysis on the life cycle steps (manufacturing, operation and end-of-life) that cause the main energy and environmental impacts;
- A dominance analysis on the components that are responsible of the main impacts in the manufacturing and end-of-life step.

The LCA tool

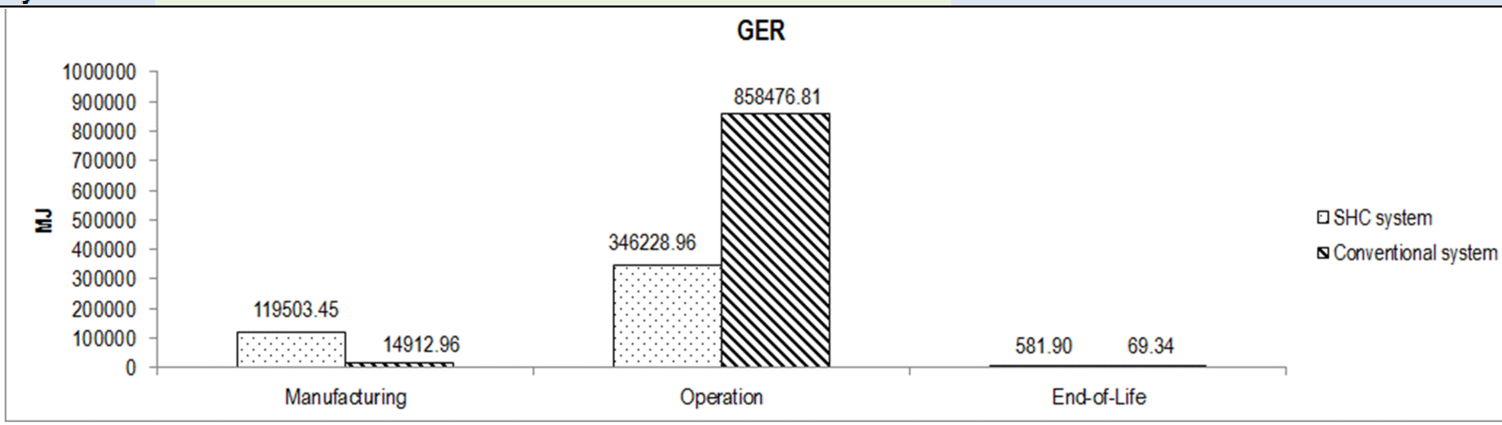
Step 3: Examining the results

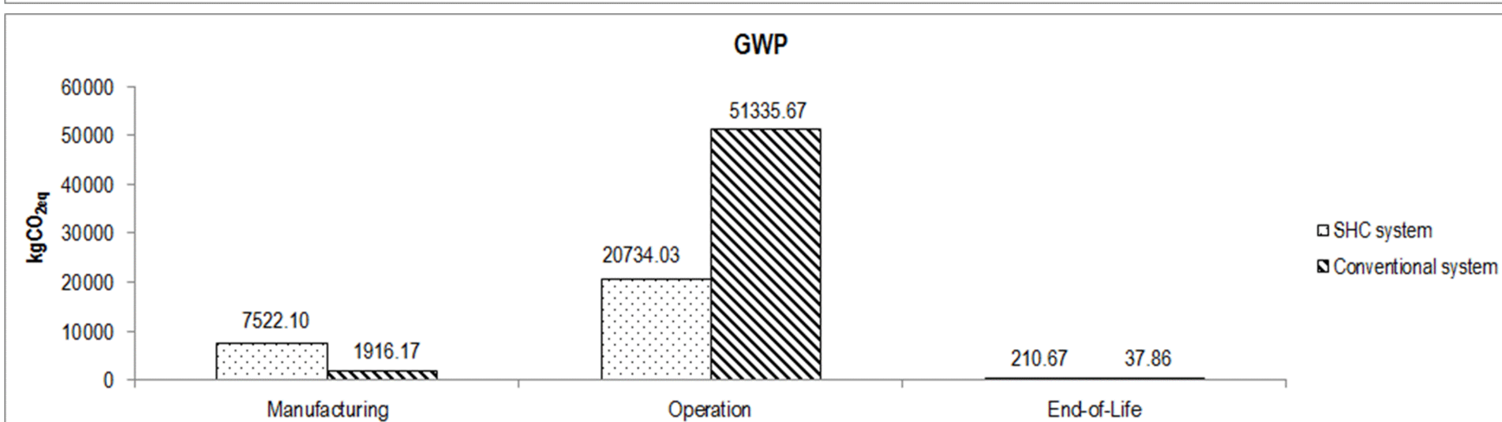
COMPONENTS OF THE SHC SYSTEM	GLOBAL ENERGY REQUIREMENT (GER) (MJ)				GLOBAL WARMING POTENTIAL (GWP) (kg CO_{2eq})			
	Manufacturing	Operation	End-of-Life	Total	Manufacturing	Operation	End-of-Life	Total
Absorption chiller	26005.37	-	3.13	26008.50	1382.34	-	12.55	1394.89
Absorption chiller	0.00	-	0.00	0.00	0.00	-	0.00	0.00
Adsorption chiller	0.00	-	0.00	0.00	0.00	-	0.00	0.00
Ammonia	629.30	-	0.00	629.30	31.44	-	0.00	31.44
Auxiliary gas boiler	6781.86	-	61.51	6843.37	365.71	-	12.04	377.75
Auxiliary conventional chiller	8131.10	-	7.83	8138.93	1550.46	-	25.82	1576.28
Cooling tower	2950.69	-	10.74	2961.43	149.98	-	3.13	153.11
Evacuated tube collector	55289.29	-	454.37	55743.66	3043.85	-	137.94	3181.78
Flat plate collector	0.00	-	0.00	0.00	0.00	-	0.00	0.00
Glycol	0.00	-	0.00	0.00	0.00	-	0.00	0.00
Heat storage	14811.72	-	21.32	14833.04	783.31	-	12.71	796.02
Heat rejection system	0.00	-	0.00	0.00	0.00	-	0.00	0.00
Pipes	3928.98	-	19.92	3948.90	157.98	-	5.82	163.80
Pump	974.95	-	3.09	978.04	57.03	-	0.66	57.69
Water	0.19	-	0.00	0.19	0.01	-	0.00	0.01
Electricity, low voltage, Italy (including import)	-	299835.66	-	299835.66	-	17970.14	-	17970.14
Natural gas, burned in boiler modulating, <100 kW, Europe	-	46393.30	-	46393.30	-	2763.89	-	2763.89
Total	**119503.45**	**346228.96**	**581.90**	**466314.31**	**7522.10**	**20734.03**	**210.67**	**28466.80**

The LCA tool

Step 3: Examining the results

System	GLOBAL ENERGY REQUIREMENT (GER) (MJ)				GLOBAL WARMING POTENTIAL (GWP) (kg CO_{2eq})			
	Manufacturing	Operation	End-of-Life	Total	Manufacturing	Operation	End-of-Life	Total
SHC system	119503.45	346228.96	581.90	466314.31	7522.10	20734.03	210.67	28466.80
Conventional system	14912.96	858476.81	69.34	873459.11	1916.17	51335.67	37.86	53289.70





The LCA tool

Step 3: Examining the results

Energy Payback Time=($GER_{SHC\text{-}system}$-$GER_{Conventional\text{-}system}$)/$E_{year}$			
Energy Payback Time is defined as the time during which the SHC system must work to harvest as much primary energy as it requires for its manufacturing and end-of-life. The harvested energy is considered as net of the energy expenditure for the system use.			
$GER_{SHC\text{-}system}$	=	120085.35	MJ
$GER_{Conventional\text{-}system}$	=	14982.30	MJ
E_{year}	=	20489.91	MJ/year
Energy Payback Time	=	5.13	year

GWP Payback Time=($GWP_{SHC\text{-}system}$-$GWP_{Conventional\text{-}system}$)/$GWP_{year}$			
GWP Payback Time is defined as the time during which the avoided GWP impact due to the use of the SHC system is equal to GWP impact caused during its manufacturing and end-of-life.			
$GWP_{SHC\text{-}system}$	=	7732.77	$kgCO_{2eq}$
$GWP_{Conventional\text{-}system}$	=	1954.03	$kgCO_{2eq}$
GWP_{year}	=	1224.07	$kgCO_{2eq}$/year
GWP Payback Time	=	4.72	year

Energy Return Ratio=$E_{overall}$/$GER_{SHC\text{-}system}$			
Energy Return Ratio represents how many times the energy saving overcomes the global energy consumption due to the SHC system.			
$GER_{SHC\text{-}system}$	=	120085.35	MJ
$E_{overall}$	=	512247.85	MJ
Energy Return Ratio	=	4.27	

The LCA tool

Conclusions

The tool's advantages:

- Ease of use, it can be used both by LCA practitioners and non-professional users;
- The results depend on the geographical context;
- It allows for the comparison of energy and environmental performances of SHC and conventional systems;
- It enables users to evaluate if there are real benefits due to the installation of a SHC system in substitution of a conventional one;
- It allows for the calculation of the energy and environmental payback time indices.

The LCA tool represents an original and easy-to-use tool that enables researchers, designers, and decision-makers to take environmentally sound decisions in the field of SHC technologies.

The tool is freely available on the website of Task 48 of IEA: http://task48.iea-shc.org/

The Italian LCA Network Association

The main objectives of the Italian LCA network are:

- **Promoting the dissemination of the Life Cycle Assessment (LCA) methodology at national level;**
- **Promoting the exchange of information and best practices on the LCA in Italy;**
- **Encouraging networking processes among different stakeholders for the realization of national and international projects.**

Web-site: www.reteitalianalca.it

To join the Italian LCA Network, write to: **lca@enea.it**

The Italian LCA Network Association

Working group "Energy and sustainable technologies"

Goals:

- **Assessment of the energy and environmental performances of energy generation, transformation and use systems, aiming at the promotion of eco-efficiency on any level, following the approach from «resource» to «waste».**
- **Analysis of the state-of-the-art of LCA studies on energy and sustainable tecnologies.**
- **Exchange of experiences regarding LCA applied to energy and sustainable technologies.**

THANK YOU FOR YOUR ATTENTION

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