LIFE CYCLE ENERGY PERFORMANCES AND ENVIRONMENTAL ANALYSIS OF SOLAR DEC FREESCOO UNITS

Authors: Marco Beccali [a], Pietro Finocchiaro, [b], Sonia Longo[a], Luigi Randazzo[a]

[a]DEIM – University of Palermo, ITALY
[B] SOLARINVENT srl, ITALY

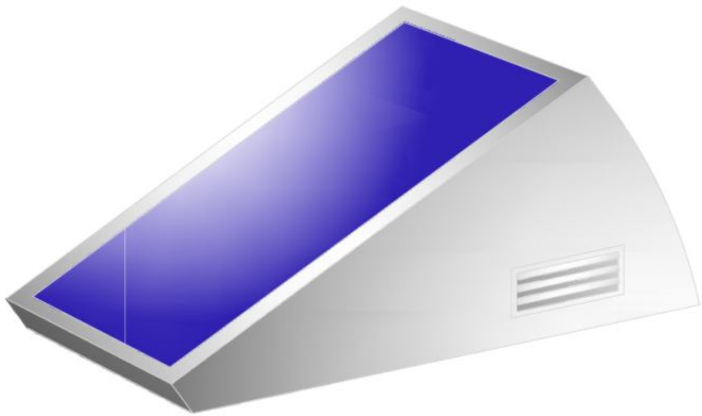
marco.beccali@unipa.it

freescoo

UNIVERSITÀ DEGLI STUDI DI PALERMO

DEIM - **D**ipartimento di **E**nergia, ingegneria dell'**I**nformazione, e modelli **M**atematici

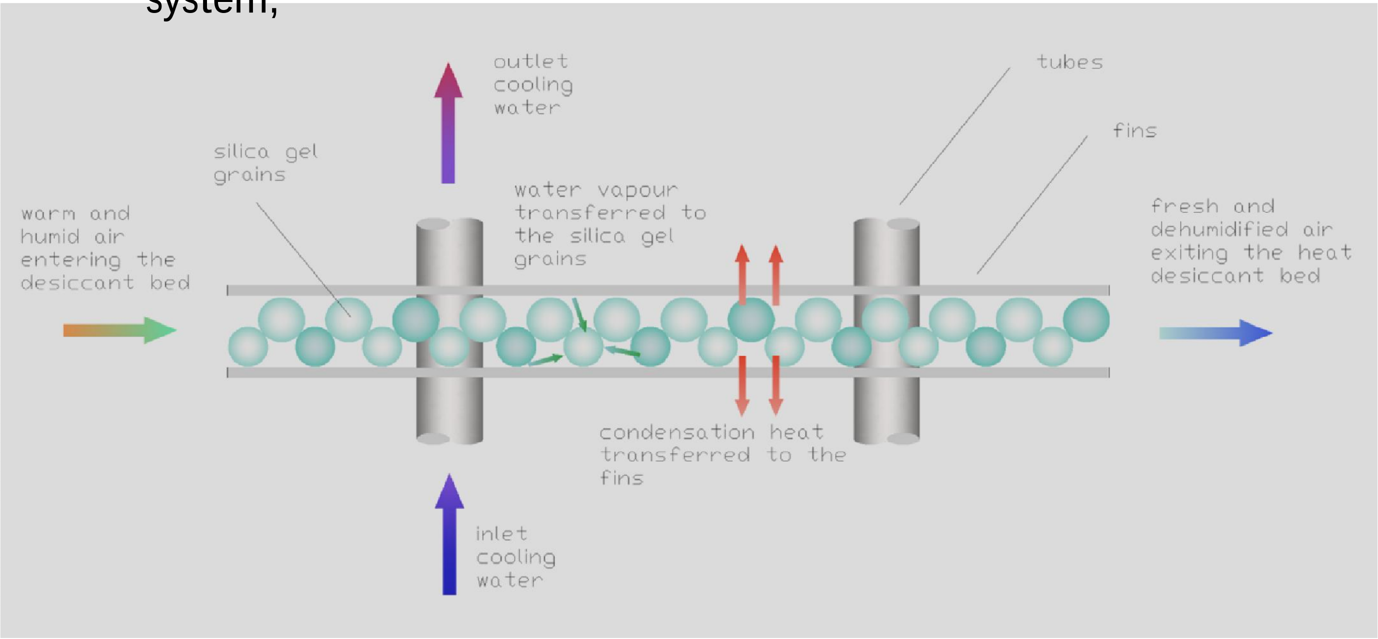
INTRODUCTION



- Freescoo (from **FREE** **S**olar **COO**ling) is an innovative patented solar DEC air conditioning concept based on fixed and cooled adsorption beds and efficient evaporative cooling process
- It is a project lead by the startup company SOLARINVENT SRL
- In the framework of a Research Project funded by the Italian Ministry of Economic Development, a second generation of Freescoo prototypes were installed and tested in summer 2004 at the University of Palermo (UNIPA) and at the ENEA Research Center Casaccia (Rome, Italy)
- UNIPA has been committed to test the prototypes “2.0”

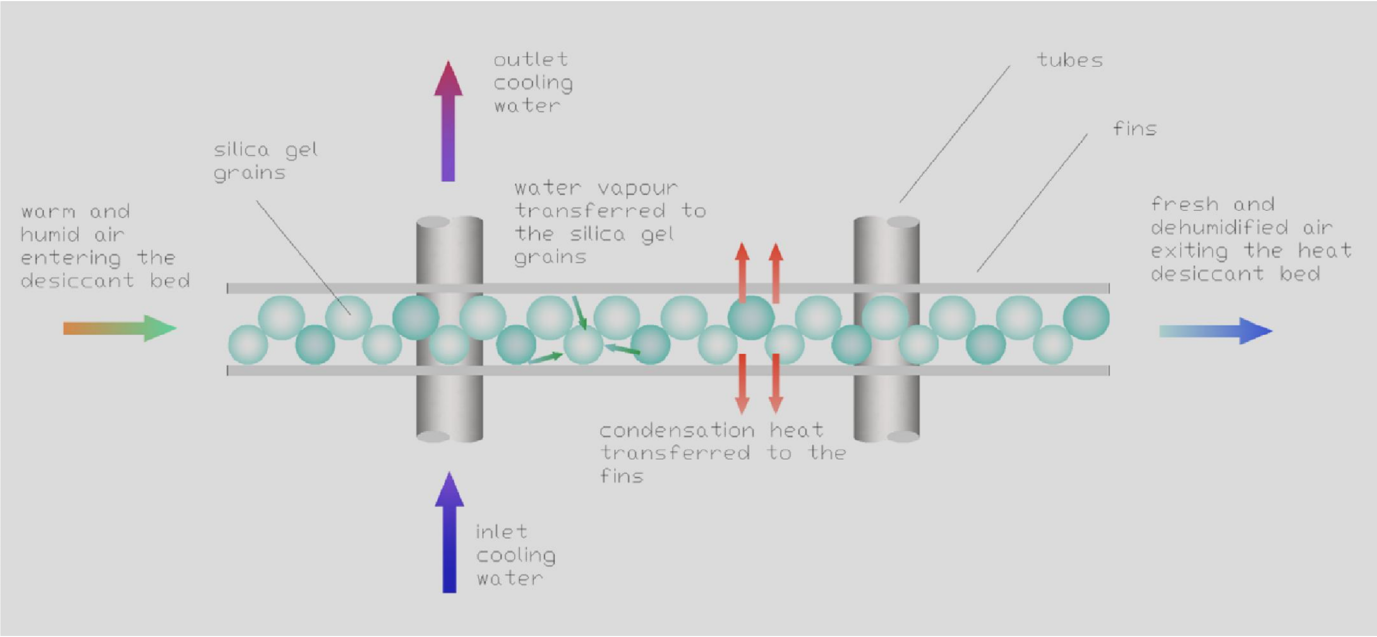
INNOVATIVE FIXED AND COOLED ADSORPTION BED

- The main component for dehumidification is a **fin and tube heat exchanger** commonly used in the air conditioning sector, wherein the spaces between the fins are filled with silica gel grains
- The developed component allows a simultaneous **mass transfer** between the moist air and the adsorbent media and **heat exchange** between the air and the water flowing into the heat exchanger tubes;
- **Cooling of the desiccant** material during the adsorption process allows high dehumidification performances of the bed and in better overall energy performances of the system;



INNOVATIVE FIXED AND COOLED ADSORPTION BED

- Water temperatures for cooling the bed can be easily achieved with a **cooling tower**;
- **Higher amount of silica gel** can be used than in rotor;
- Adsorption and desorption processes happen in different times in a couple of beds;
- Solar energy can be efficiently stored in the desiccant in terms of adsorption capacity which can be used later when regeneration heat is not available, strongly reducing the necessity for thermal storage;



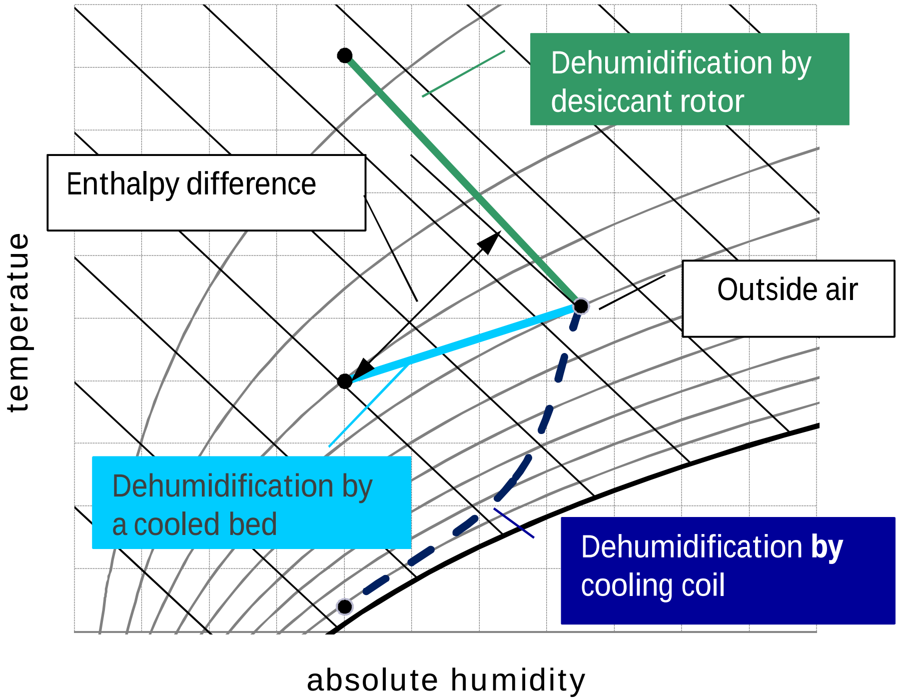
COMPARISON OF THE ADSORPTION PROCESSES

Dehumidification by desiccant rotor

- Adsorption process realized by means of desiccant rotors is a quasi–isoenthalpic transformation
- It presents the disadvantage of causing a temperature increase of the desiccant material
- No enthalpy difference between in and out

Dehumidification by cooled desiccant bed

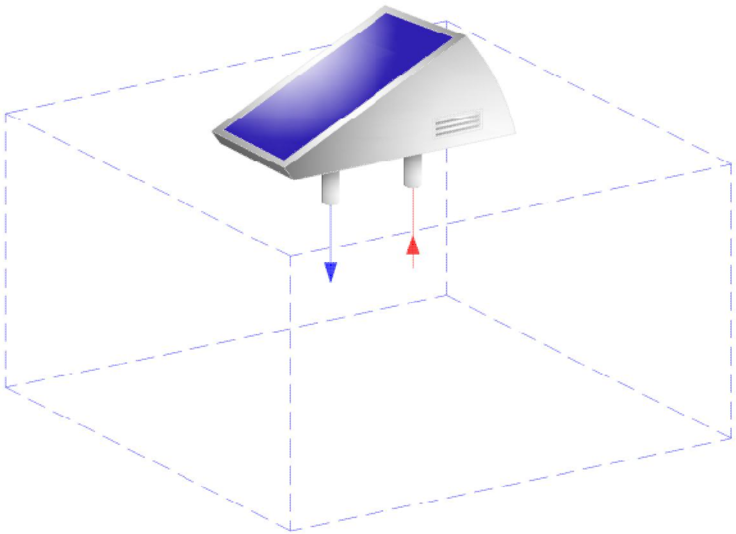
- Condensation heat can be rejected
- The thermodynamic process causes an enthalpy difference between inlet and outlet air conditions
- In general, the temperature of air exiting the adsorption bed can be lower than the one of incoming air
- Downstream indirect evaporative cooling process can be operated at lower temperature



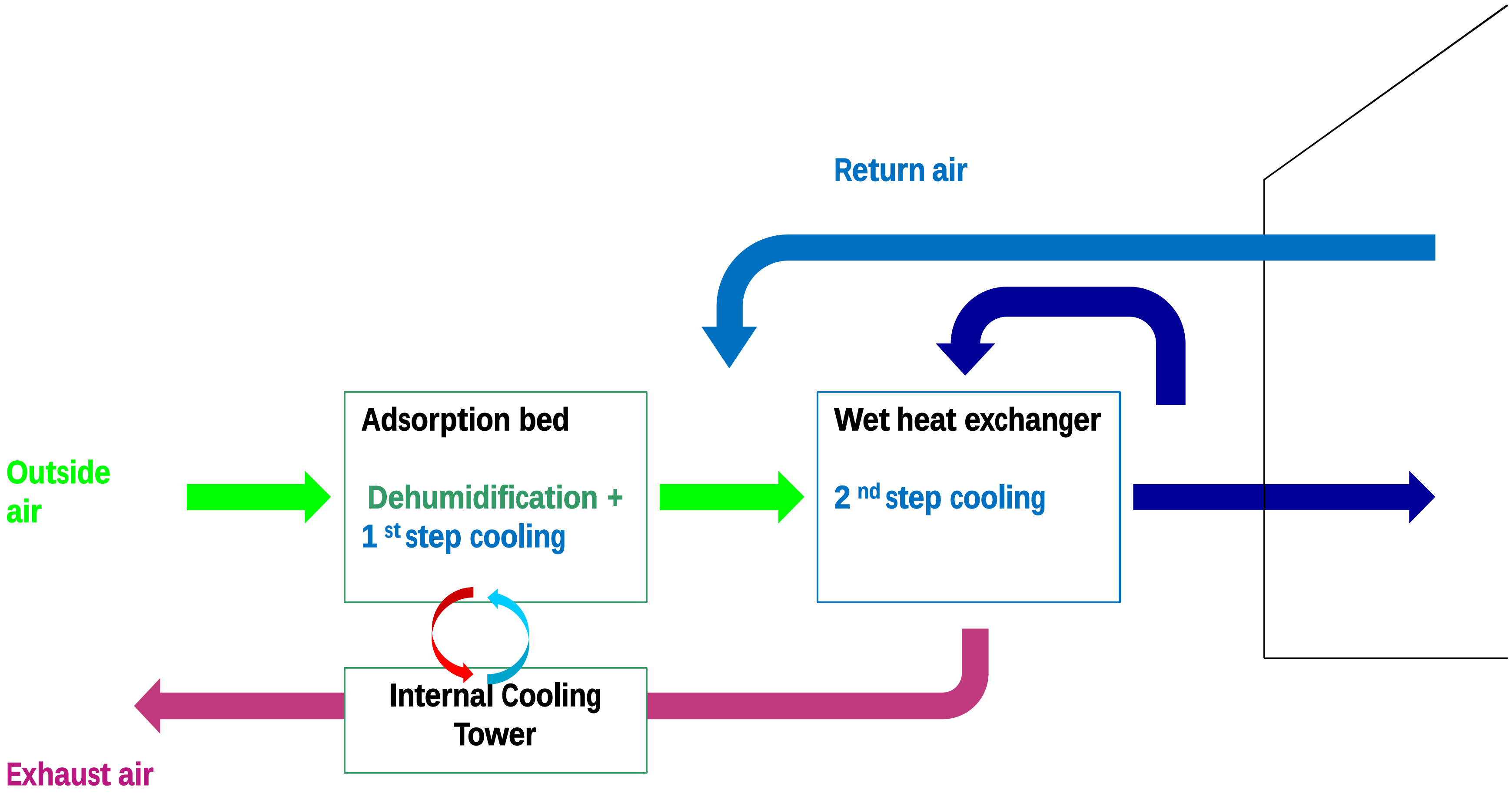
DESIGN CONCEPT OF THE NEW DEC CYCLE

MAIN SYSTEM FEATURES

- Designed for small scale applications with air ventilation, dehumidification and cooling needs
- Based on fixed and cooled adsorption beds and high efficient evaporative cooling concepts
- Use of solar PVT air collector
- Minimization of parasitic energy consumption
- Nearly Solar autonomous, no use of auxiliary energy source for cold production but only for auxiliaries
- Compact, all in one, reliable, and easy to install

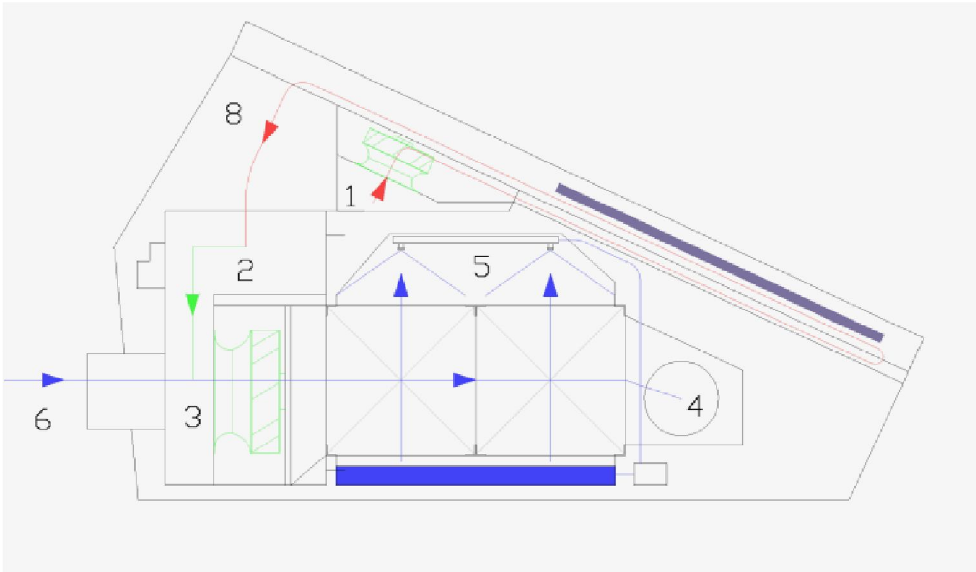


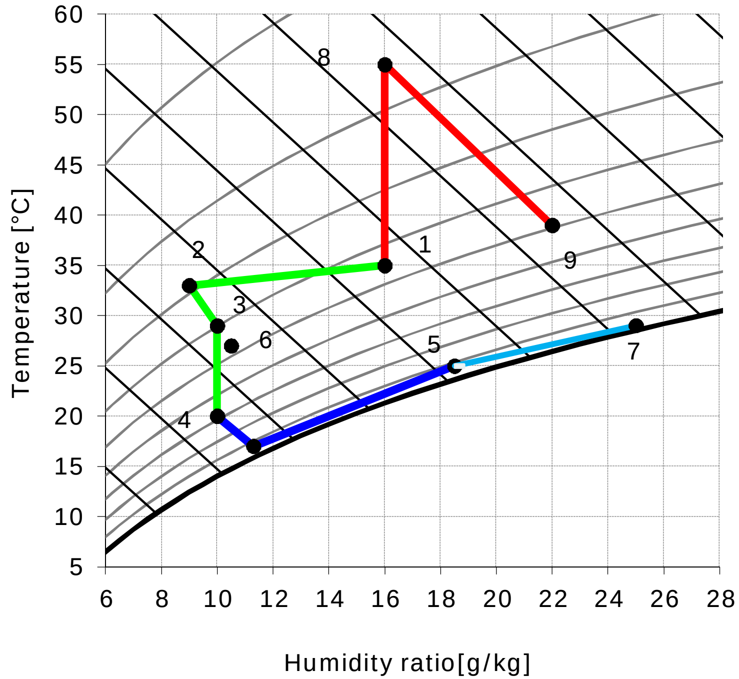
DESIGN CONCEPT OF THE NEW DEC CYCLE



DESCRIPTION OF THE NEW DEC CONCEPT (COMPACT)

- The new compact system developed is based on the use of two fixed packed desiccant beds of silica gel operating in a batch process and cooled by cooling tower, and two wet heat exchangers connected in series
- Adsorption bed designed to be operated in “low flow” mode (air velocity =0.16 m/s)
- A portion of the primary air flow rate exiting the wet heat exchanger is drown into the secondary side





International PCT pending

marco.beccali@unipa.it

UNIVERSITÀ DEGLI STUDI DI PALERMO

MONITORING OF TWO SYSTEMS

Location:

Palermo

- Solar air collector area: 2,4 m2
- Two desiccant beds, with 13 kg of silica gel each
- Nominal flow rate: 500 m^3/h
- Max power absorbed: 150W
- Max cooling power: 2,7 kW

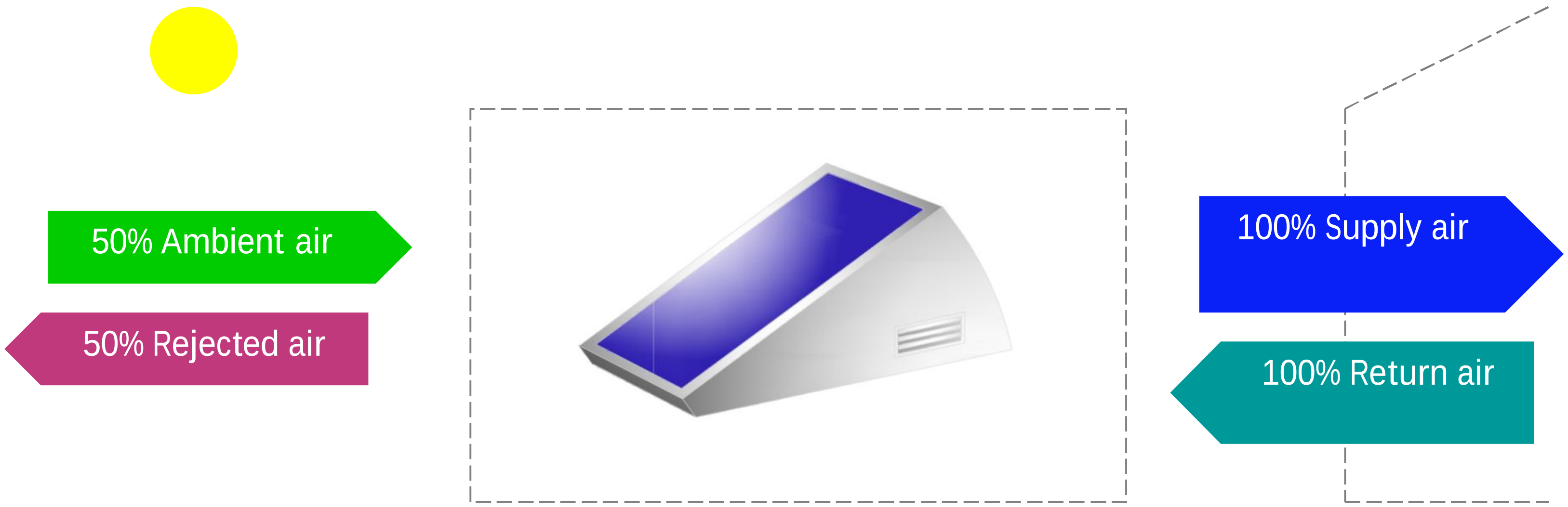
  (T_{out} = 35°C, RH_{out} = 50%, T_{bui} = 27°C, RH_{bui} = 50%)
- Total weight ≈ 230 kg
- Area of conditioned space = 46 m^2
- Volume of conditioned space = 190 m^3
- Occupation pattern = small office
- Auxiliary device installed: Split system
- About 3 weeks of monitoring carried out this summer
- Selection of one day

Rome

- Solar air collector area: 4.8 m^2
- Two desiccant beds, with 25 kg of silica gel each
- Nominal flow rate: 1000 m^3/h
- Max power absorbed: 250W
- Max cooling power: 5,5 kW

  (T_{out} = 35°C, RH_{out} = 50%, T_{bui} = 27°C, RH_{bui} = 50%)
- Total weight ≈ 400 kg
- Area of conditioned space = 46,5 m^2
- Volume of conditioned space = 125 m^3
- Occupation pattern = seminar room
- Auxiliary device installed: 5 x 2,5 kW fan coil
- About 1,5 months of monitoring carried out this summer
- Selection of 15 days continuous operation

MAIN PERFORMANCE INDICATORS USED



$$MR = \frac{\dot{m}_{outside}}{\left(\dot{m}_{supply} + \dot{m}_{outside}\right)}$$

$$Cooling\ energy_{ADS\ BED} = \dot{m}_{outside}\,(h_1 - h_2) \qquad Cooling\ energy_{WET\ HX} = \left(\dot{m}_{outside} + \dot{m}_{supply}\right)(h_3 - h_4)$$

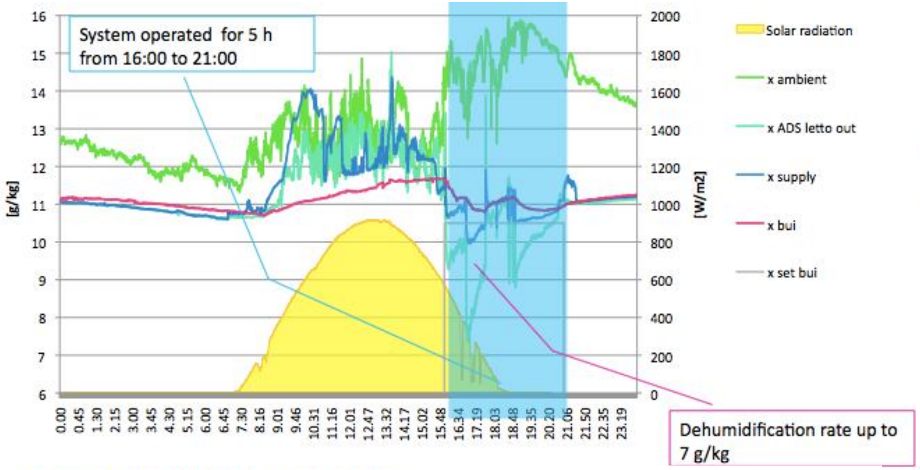
$$Total\ cooling\ energy\ delivered = \left[\dot{m}_{outside}\,(h_1 - h_2) + \left(\dot{m}_{outside} + \dot{m}_{supply}\right)(h_3 - h_4)\right](1 - MR)$$

$$EER = \frac{Total\ cooling\ energy\ delivered}{Total\ electricity\ consumed} \qquad COP_{th} = \frac{Total\ cooling\ energy\ delivered}{Solar\ Heat\ delivered}$$

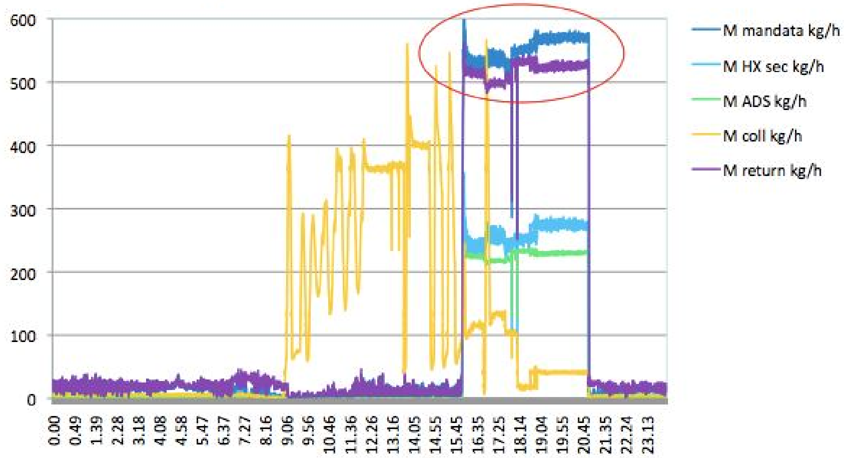
INSTANTANEOUS ENERGY PERFORMANCES

Results of freescoo prototype installed at University of Palermo

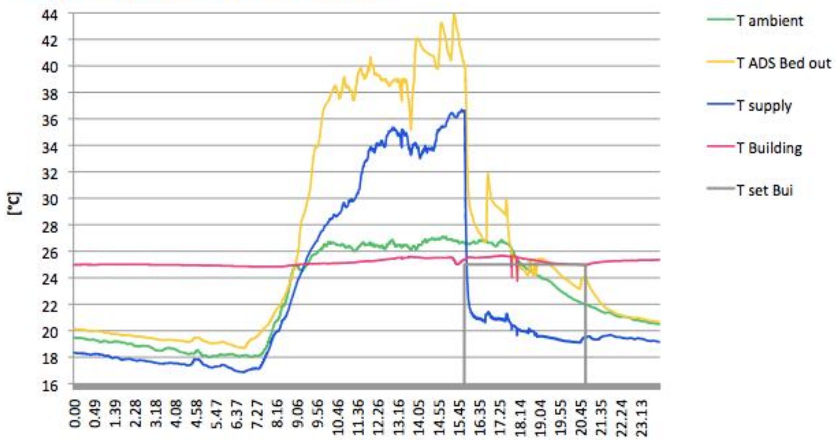
Dehumidification



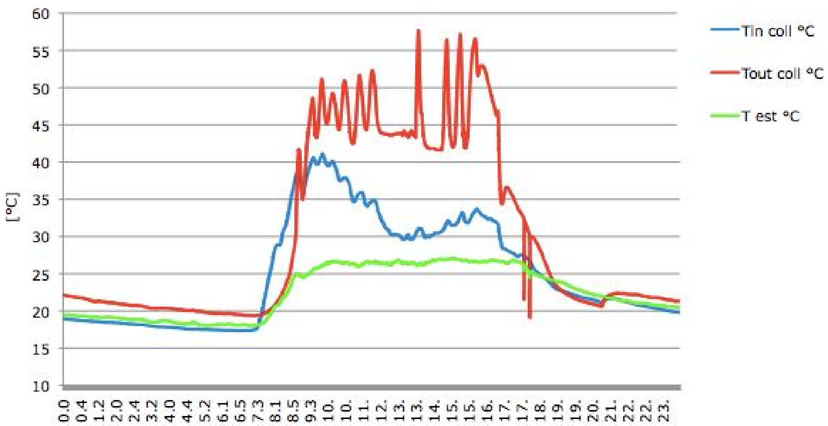
Flow rates of the system



Temperature profiles in the machine



Temperature profiles - solar collector



freescoo

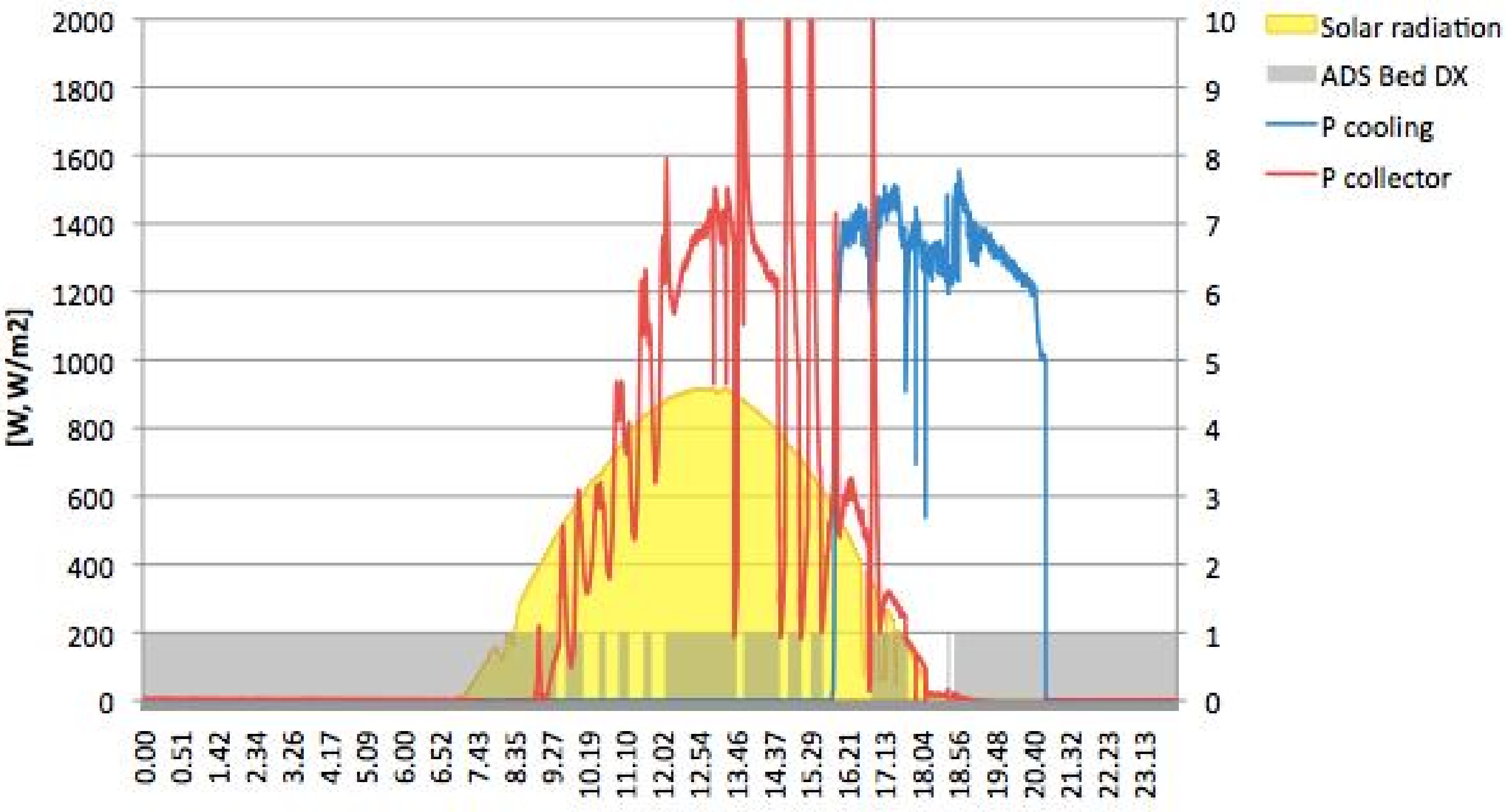
marco.beccali@unipa.it

UNIVERSITÀ DEGLI STUDI DI PALERMO

INSTANTANEOUS ENERGY PERFORMANCES

Results of freescoo prototype installed at University of Palermo

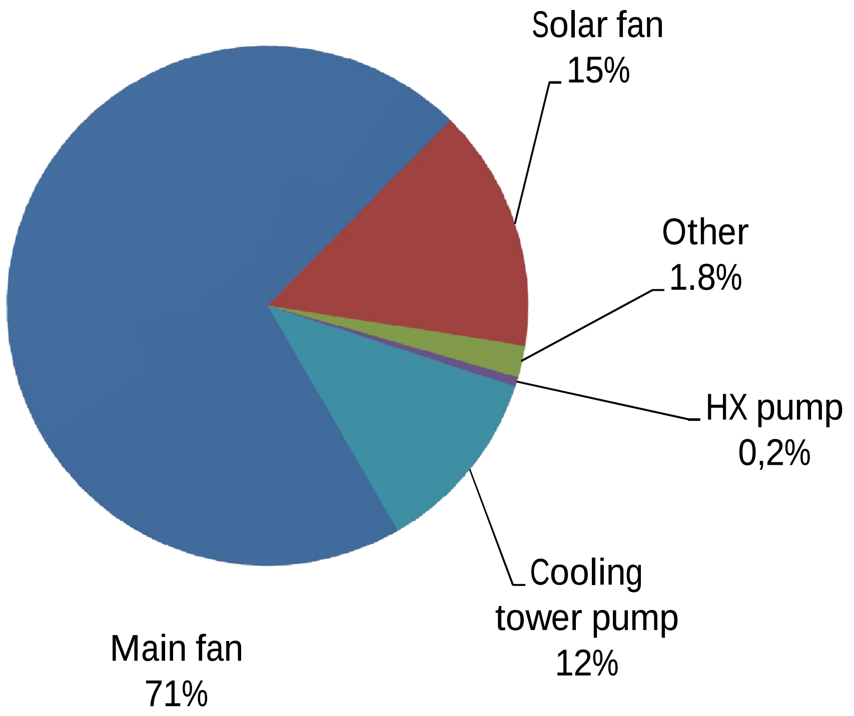
Cooling after the sunset



DAILY ENERGY PERFORMANCES

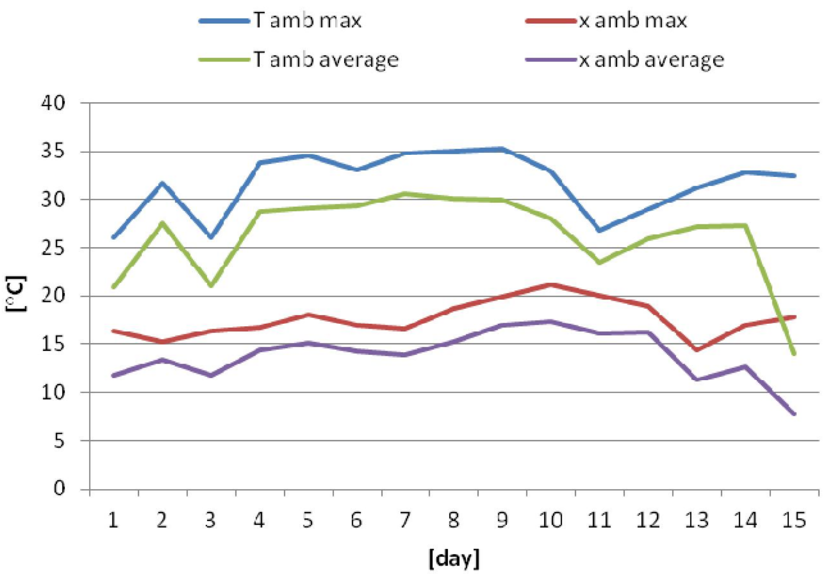
Results of freescoo prototype installed at University of Palermo

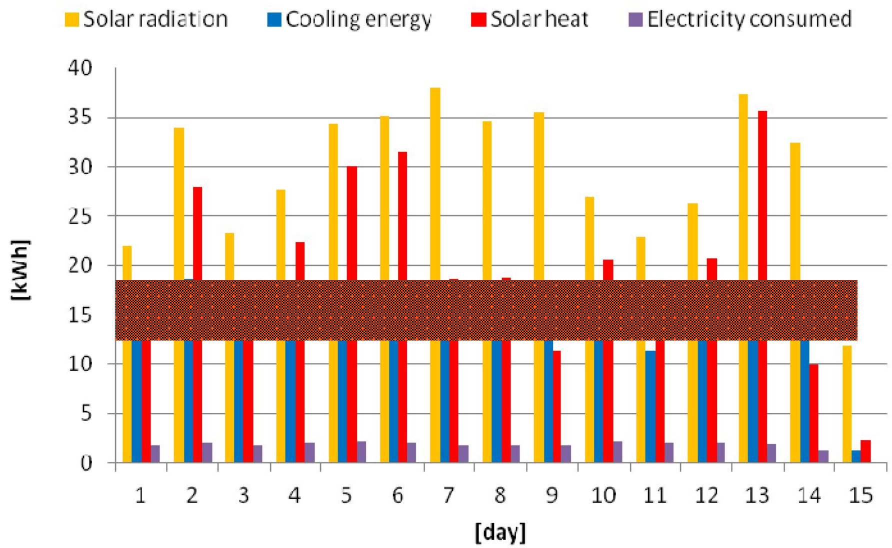
Electricity distribution among the components



- Daily EER = **8,8** **NOT** taking into account the PV production
- Daily EER_{grid} = **17.1** taking into account only the electricity taken from the grid
- Daily thermal COP_{coll} = **0,88** if $\Delta T = T_{coll\ out} - T_{coll\ in}$ is considered
- 51% of electricity taken from the grid
- 49% of electricity produced by PV

FREESCOO AT ENEA MID-TERM ENERGY PERFORMANCES

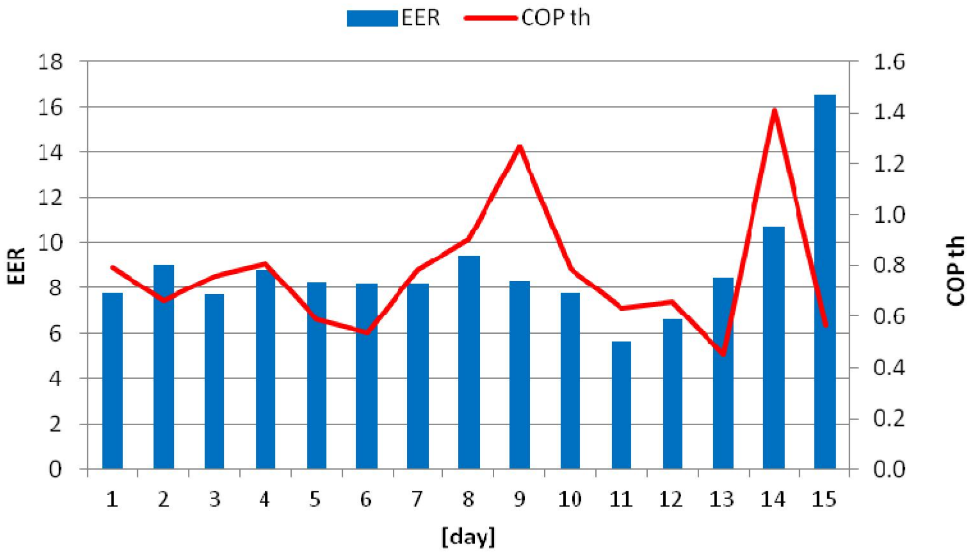




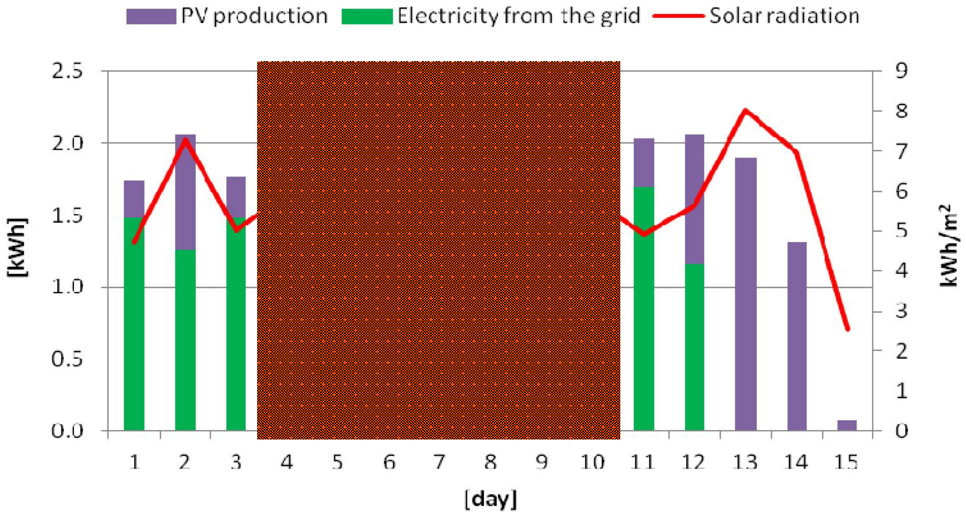
- Two weeks of operation without any interruption of the monitoring
- Out Temperature raised up to 35°C
- Humidity ratio raised up to 20 g/kg
- About 15 kWh of cooling energy/day

Results of ENEA freescoo prototype

FREESCOO AT ENEA MID-TERM ENERGY PERFORMANCES



- Average EER = **8,2 NOT** taking into account the PV production
- Average EER_{grid} = **30.7** taking into account only the electricity taken from the grid
- Average thermal COP = **0,72**



- Seven days of continuous **stand-alone operation**
- 27% of electricity taken from the grid
- 73% of electricity produced by PV

Results of ENEA freescoo prototype

marco.beccali@unipa.it

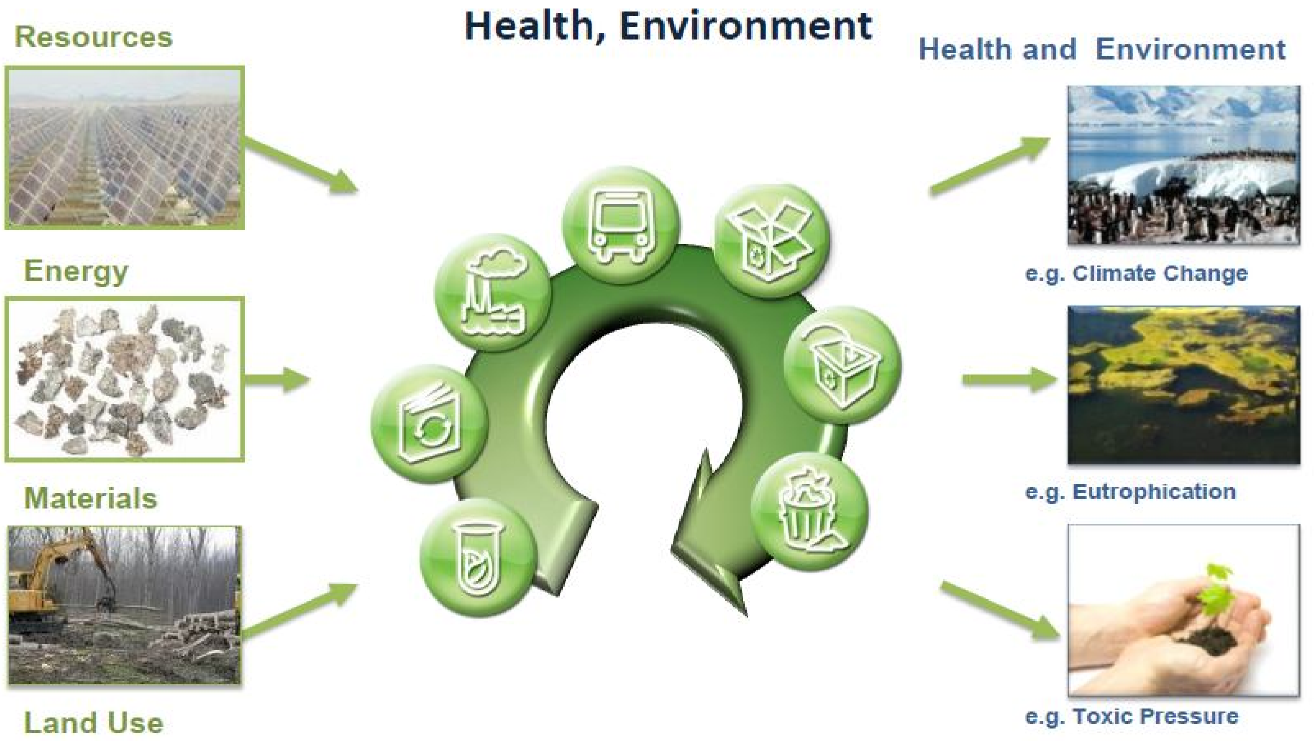
UNIVERSITÀ DEGLI STUDI DI PALERMO

SUMMARY OF MAIN RESULTS OF TESTS

- Low temperature of the regeneration of the desiccant (40-60°C)
- Desiccant bed is used as sorption storage permitting to supply cooling energy several hours after the sunset
- Control of the dehumidification process acting on the temperature of the bed is possible
- Pre-heating of regeneration air flow rate due to the metal casing of the machine
- Good performances both in terms of EER and thermal COP values registered
- Nominal cooling power never reached during the monitoring period
- Low electricity power (150W and 250W, resp. for the small and the bigger machine)
- Off-grid operation possible thanks to the internal PV production
- Control strategy of the desorption process of each desiccant bed can be optimized

LIFE CYCLE ASSESSMENT

Life Cycle Assessment (LCA) is a compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle (Norma ISO 14040).
LCA is a useful tool to estimate resource use (raw materials and energy), energy and environmental burdens related to the life cycle of products and services.



LIFE CYCLE ASSESSMENT: GOAL AND SCOPE DEFINITION

The main goal of the LCAstudy is to assess the energy and environmental impacts of the manufacturing of *Freescoo*.

FUNCTIONAL UNIT

The functional unit (FU), which is defined as the reference unit through which the performance of a product system is quantified in a LCA, is one unit of Freescoo.

BOUNDARIES

The system boundaries include the supply of raw materials and energy sources, and the manufacturing of the examined product

The other life-cycle steps as transports, operation and end-of-life, are not included in this analysis.

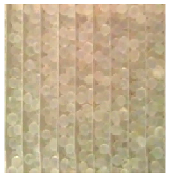
LIFE CYCLE ASSESSMENT: LIFE-CYCLE INVENTORY

The inventory analysis is carried out in order to quantify inputs and outputs of the examined system by means of a mass and energy balance.

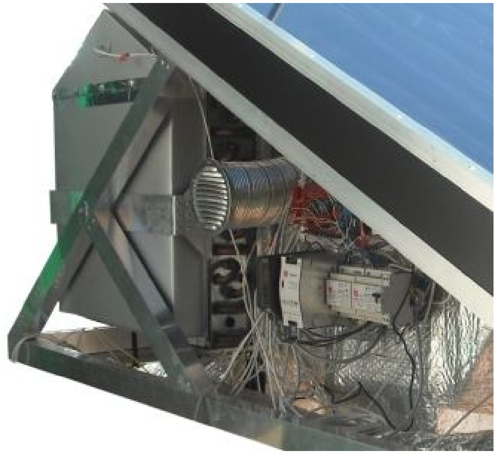
This step allows for the estimation of resource consumption, air, water and soil emissions, and waste production, during the life cycle of the FU.

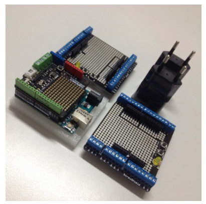
The eco-profiles of materials and energy sources are mainly referred to the Ecoinvent database

LIFE CYCLE ASSESSMENT: LIFE-CYCLE INVENTORY



COMPONENTS
ADSORBENT BEDS (2)
SOLAR BATTERIES (2)
AIR DUCTS
ELECTRICTRICY WIRES
PUMPS (2)
SOLAR PVT
TROTTLE VALVE (2)
AIR FILTERS
THERMAL INSULATION
EVAPORATIVE COOLING SUBSYSTEM
CASE
ELECTRIC SWITCHBOARD
CONTROL BOARD
SERVOMOTOR
INTERNAL FRAME
MAIN STRUCTURAL FRAME
COOLING TOWER
PLUMBINGS
4-WAY TROTTOLING VALVE
FANS (2)

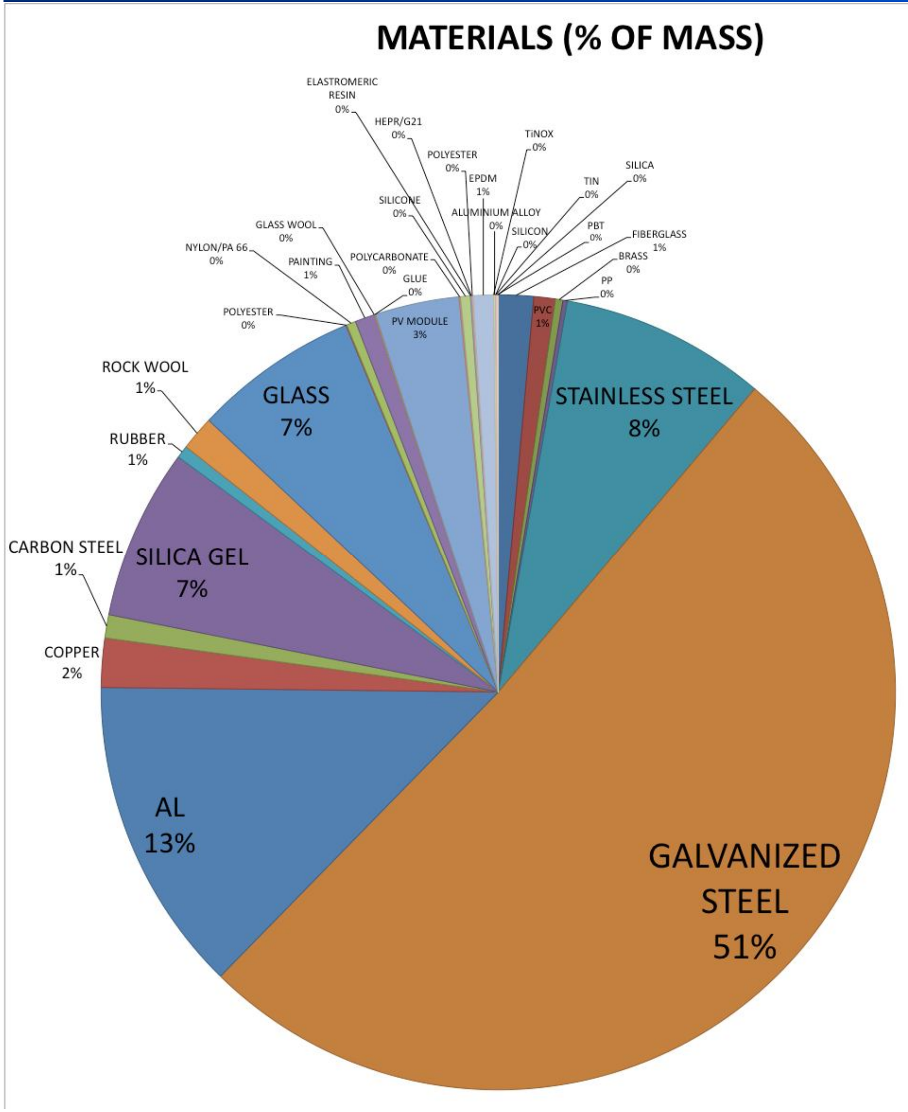




marco.beccali@unipa.it

UNIVERSITÀ DEGLI STUDI DI PALERMO

LIFE CYCLE ASSESSMENT: LIFE-CYCLE INVENTORY



MATERIAL	MASS (kg)
FIBERGLASS	5,0
PVC	3,057
BRASS	1,064
PP	0,637
STAINLESS STEE	29,354
GALVANIZED ST	179,118
AL	44,994
COPPER	6,966
CARBON STEEL	3,312
SILICA GEL	24,4
RUBBER	1,78
ROCK WOOL	4,897
GLASS	23,562
POLYESTER	0,139
NYLON/PA 66	1,315
PAINTING	2,791

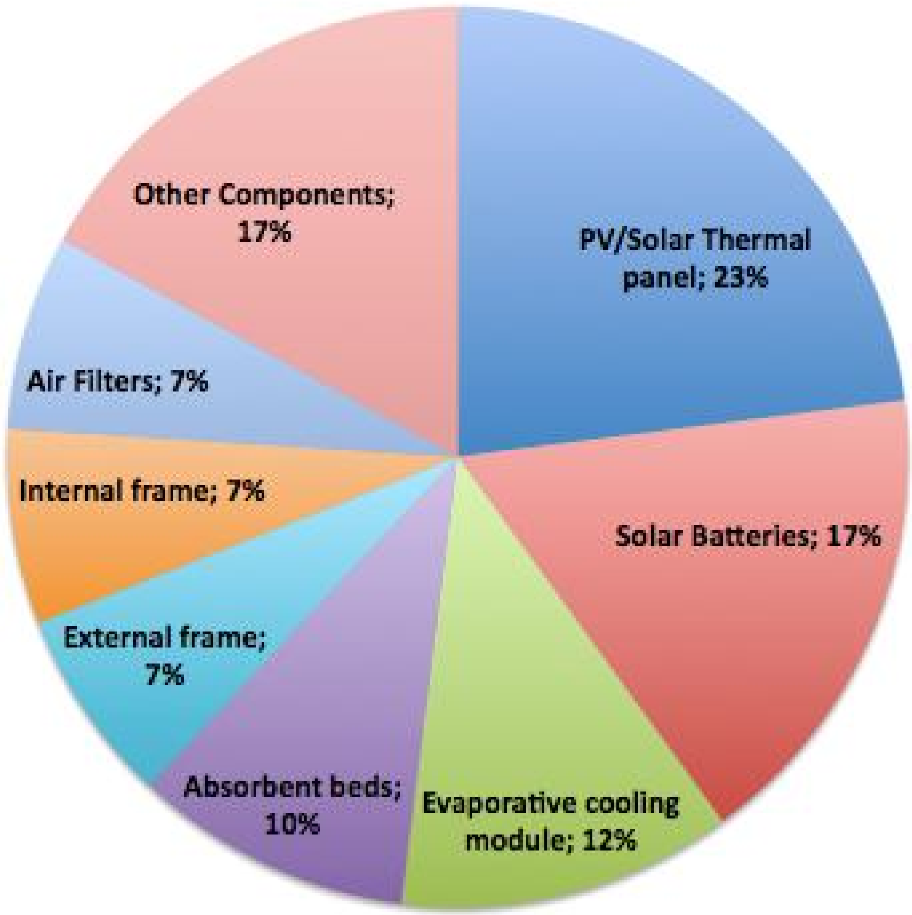
MATERIAL	MASS (kg)
GLASS WOOL	0,02
GLUE	0,138
PV MODULE	12
POLYCARBON/	0,222
SILICONE	1,393
ELASTROMERI	0,097
HEPR/G21	0,097
POLYESTER	0,18
EPDM	2,902
TiNOX	0,0049
ALUMINIUM A	0,27
SILICON	0,019
TIN	0,021
PBT	0,3381
SILICA	0,0028

Global energy requirement (GER)

	Primary energy consumption	Total (MJ)
88.4% of the total	Non renewable, fossil	20,191.51
	Non-renewable, nuclear	3,878.99
	Non-renewable, biomass	0.12
11.6% of the total	Renewable, biomass	258.17
	Renewable, wind, solar, geothermal	42.72
	Renewable, water	2,858.02
	Total	27,229.53

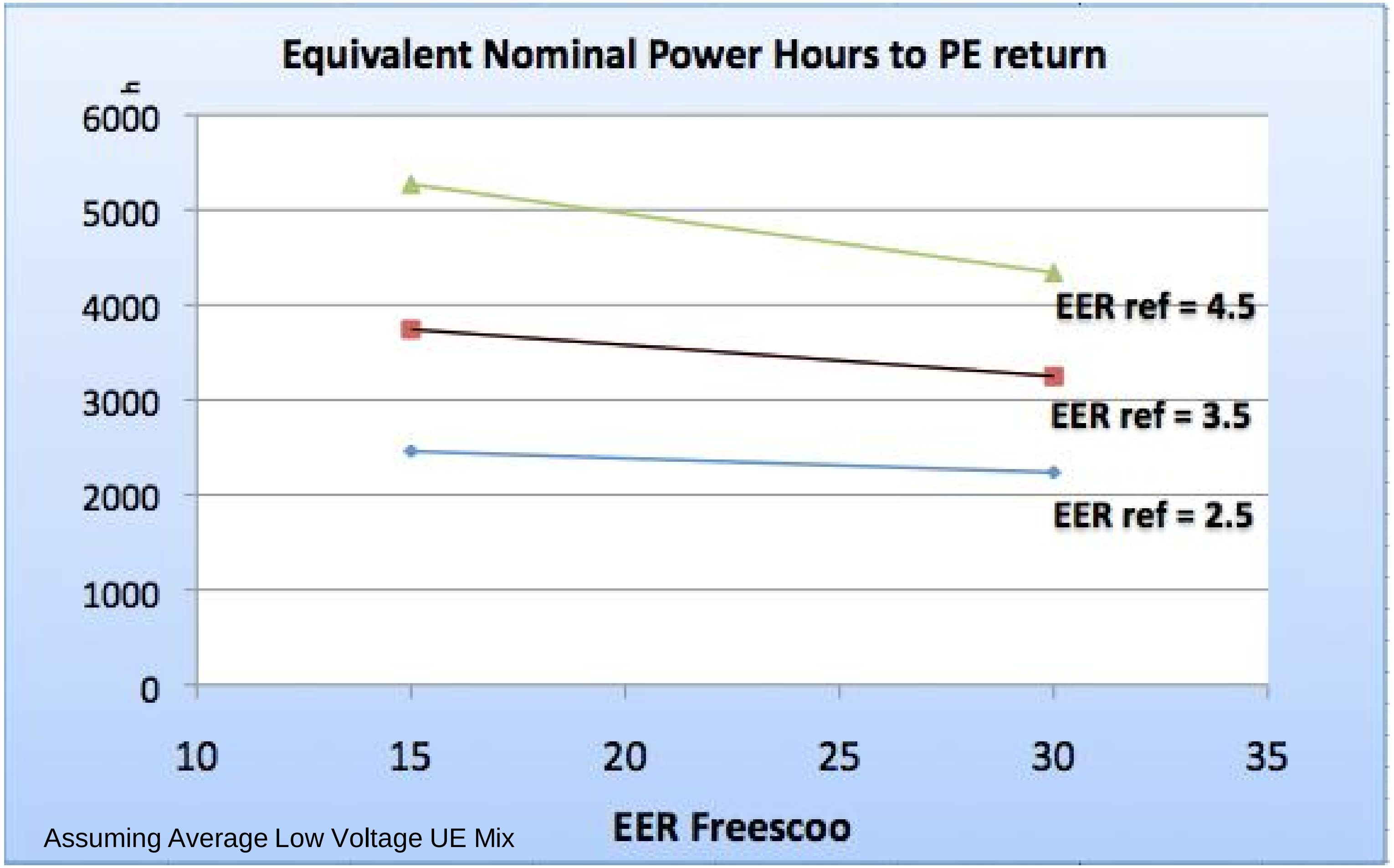
INCIDENCE OF COMPONENTS ON GER

Global Energy Requirement



ROUGH ASSESSMENT OF PRIMARY ENERGY PAYBACK

Return of the total GER of the System



LIFE CYCLE ASSESSMENT:
IMPACT ASSESSMENT AND INTERPRETATION

Environmental impacts	Total
Global Warming Potential - GWP (kg CO_{2eq});	1.59E+03
Ozone Depletion Potential - ODP (kg CFC-11_{eq})	1.61E-04
Human toxicity (cancer effect) - HTc (CTU_h)	6.91E-04
Human toxicity (non-cancer effect) - HTn-c (CTU_h)	2.28E-03
Particulate Matter - PM (kg PM $2,5_{eq}$);	1.19E+00
Ionizing Radiation (effect on human health) - IRh (kg $U235_{eq}$);	3.68E+02
Ionizing Radiation (effect on ecosystem) - IRe (CTU_e);	1.11E-03
Photochemical Ozone Formation - POF (kg $NMVOC_{eq}$)	5.20E+00
Acidification - Ac (mol $H+_{eq}$)	1.15E+01
Terrestrial Eutrophication - TE (mol N_{eq})	1.69E+01
Freshwater Eutrophication - FE (kg P_{eq})	1.56E+00
Marine Eutrophication - ME (kg N_{eq})	1.64E+00
Freshwater Ecotoxicity - FET (CTU_e)	5.52E+04
Land Use - LU (kg deficit C)	1.79E+03
Water Resource Depletion - WRD (m^3 $water_{eq}$)	4.60E+03
Mineral, Fossil, Renewable Resources Depletion - RD (kg Sb_{eq})	3.14E-01

The main contribution to the other environmental impacts is due to **solar batteries** except for:

-ODP, IRh, IRe, WRD and RD, that are mainly caused by **PV/solar thermal panel**.

CONCLUSIONS

- The study aimed at evaluating the energy and environment impacts of the manufacturing step of *Freescoo*. The analysis was carried out through the application of the LCA methodology, in accordance with the standards of the ISO 14040 series.
- The analysis highlighted that the main energy and environmental impacts related to the manufacturing of the selected FU are caused by PV/solar thermal panel, solar batteries, evaporative cooling module and adsorbent bed.
- The results of the research can represent a “knowledge basis” to assess the real advantages arising from the use of new all-in-one compact solar Desiccant Evaporative Cooling air conditioner systems as *Freescoo*.
- Further analyses of the *Freescoo* technology will include the impacts assessment of the other life-cycle steps as transports, operation and end-of-life.

Thank you for your attention

Prof. Marco Beccali **e-mail: marco.beccali@unipa.it**

Dipartimento di Energia, Ingegneria dell'Informazione e Modelli Matematici
University of Palermo,
Viale delle Scienze Ed.9, 90128 Palermo, Italy