SELECTION OF SOLAR COLLECTORS TECHNOLOGY AND SURFACE FOR A DESICCANT COOLING SYSTEM BASED ON ENERGY, ENVIRONMENTAL AND ECONOMIC ANALYSIS

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OUTLINE

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- SIMULATION MODEL
- PERFORMANCE ASSESSMENT
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- CONCLUSIONS

AIMS

- Investigation of a solar desiccant cooling system (SDCS);
- SDCS based on an air handling unit (AHU) with rotary desiccant wheel (DW);
- Energy, environmental and economic analysis;
- Comparison with a reference system based on a conventional air conditioning system;
- Four thermal energy sources are considered for DW regeneration:
  - Air collectors (scenario A)
  - Flat-plate collectors (scenario B)
  - Evacuated-tube collectors (scenario C)
  - Natural gas fuelled boiler (scenario D)

INTRODUCTION:
ADVANTAGES OF SOLAR COOLING

Desiccant-based AHUs can guarantee significant technical and energy/environmental advantages, mainly when the regeneration of the desiccant material is obtained by means of a renewable energy source, such as solar energy:

- solar radiation availability coincides with the cooling demand;
- summer peak demand of electricity, due to extensive use of electric air conditioners, can be lowered;
- black-out risks can be attenuated;
- reduction in fossil fuels use and related environmental impact;
- energy sources differentiation.

INTRODUCTION: ADVANTAGES AND DRAWBACKS OF DESICCANT COOLING

The main advantages of these systems, in comparison with conventional ones (cooling dehumidification with electric vapor compression system), are:

+ sensible and latent loads can be controlled separately;

+ the chiller has a lower size and operates at a smaller temperature lift with a higher COP (lower electricity requirements);

+ primary energy savings;

+ reduction of environmental impact;

+ accurate humidity control and better IAQ.

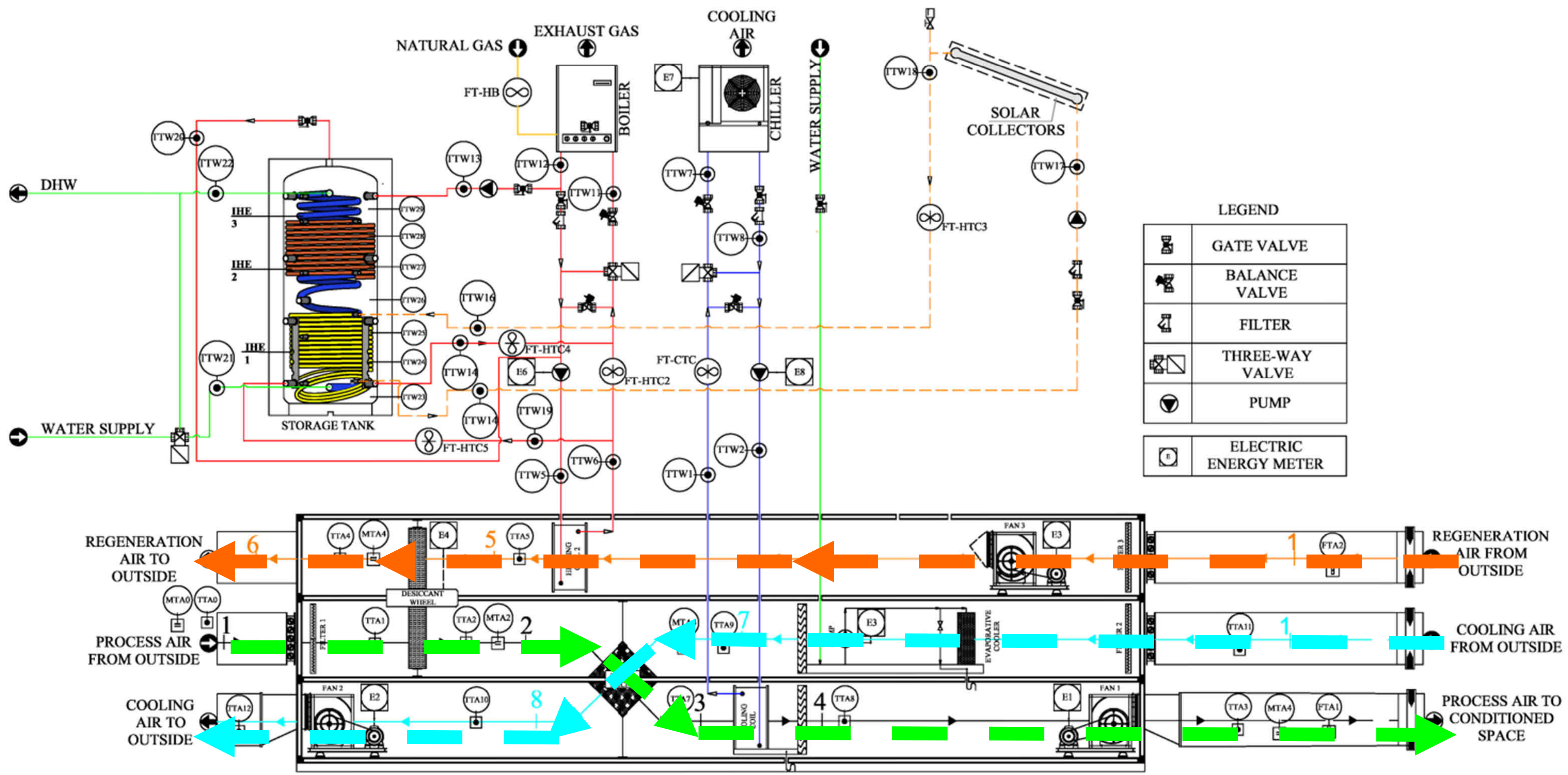
+ moderate regeneration temperature, suitable for solar cooling applications;

The drawbacks of this technology are:

- high investment costs;

- high thermal energy requirements to regenerate the wheel.

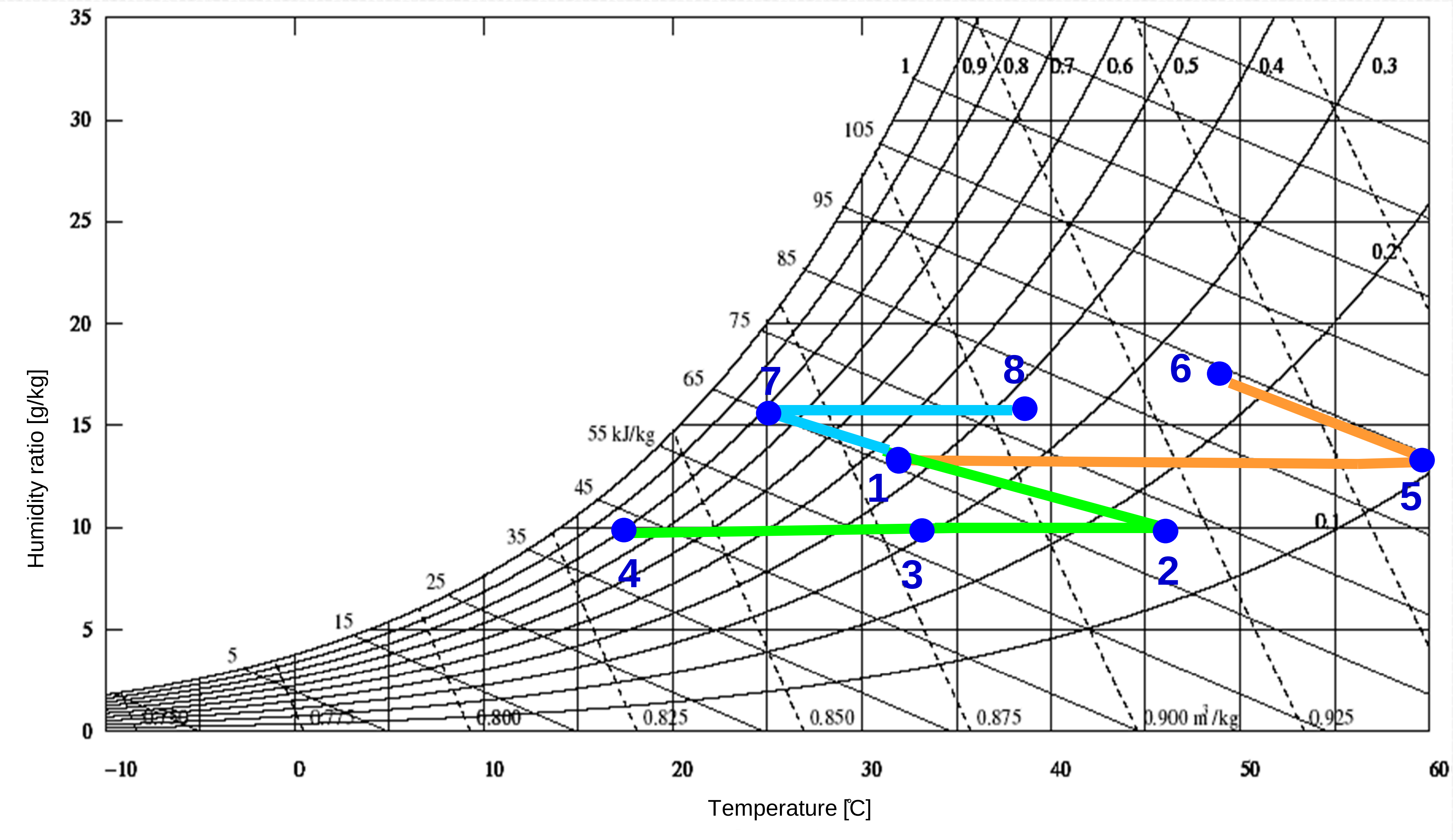
THE TEST FACILITY AT UNIVERSITA' DEGLI STUDI DEL SANNIO - I



THE TEST FACILITY AT UNIVERSITA' DEGLI STUDI DEL SANNIO - II

- air-cooled water chiller: 8.50 kW cooling capacity, COP 3.00;
- boiler: 24.1 kW thermal power, 90.2% thermal efficiency;
- storage tank: carbon steel, 1000 dm^3 capacity, 855 dm^3 net storage volume, insulated with a 100 mm thick layer of polyurethane (thermal conductivity 0.038 W/mK), 3 internal heat exchangers;
- desiccant wheel: silica-gel (regeneration at 60-70 °C), 50 kg weight, 700 mm diameter, 200 mm thickness, 60% of the rotor area is crossed by the process air, 40% by the regeneration air, nominal rotational speed 12 RPH.

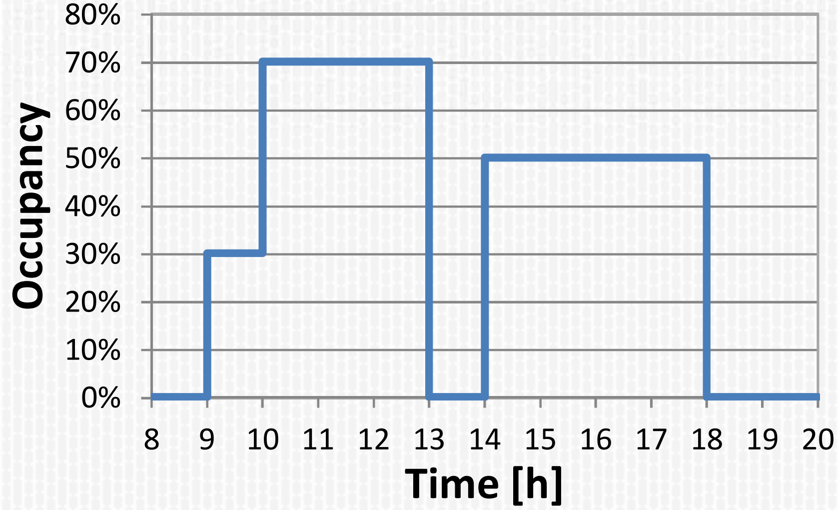
DESICCANT-BASED AHU



Process air *Regeneration air* *Cooling air*

THE USER

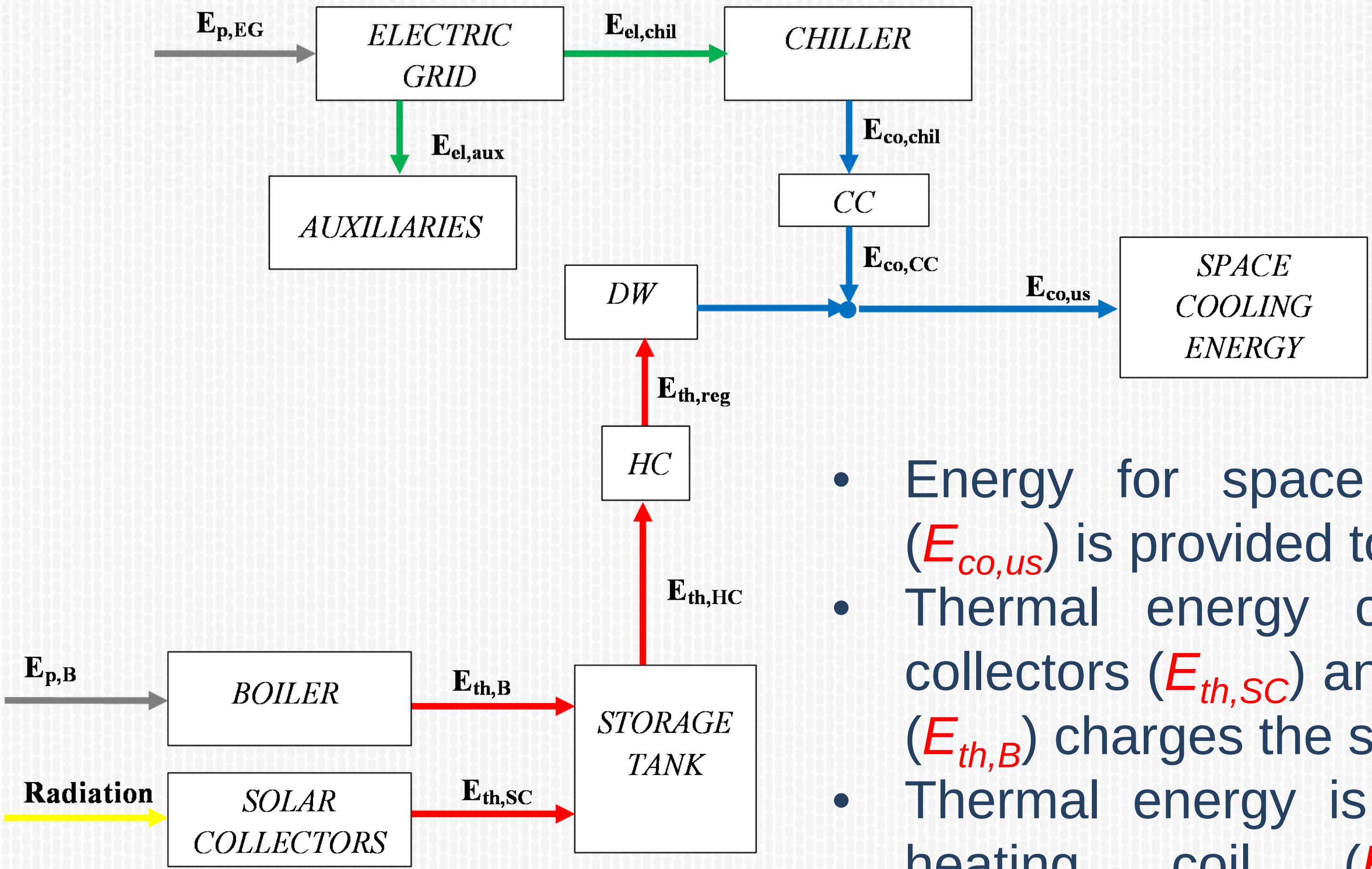
- Lecture room with a floor area of 63.5 m^2 located in Naples;
- 30 seats, occupancy schedule expressed as percentage of the maximum capacity;
- activation schedule from Monday to Saturday, 8:30-18:00;
- summer set-point 26 ºC and 50% RH.



	Opaque Components				*Transparent Components*		
	Roof	External walls (N/S)	External walls (E/W)	On the ground floor	North	South	East/ West
U [W/m²K]	2.30	1.11	1.11	0.297	2.83	2.83	2.83
Area [m²]	63.5	36	15.87	63.5	8.53	9.40	0.976
g [-]	-	-	-	-	0.755	0.755	0.755

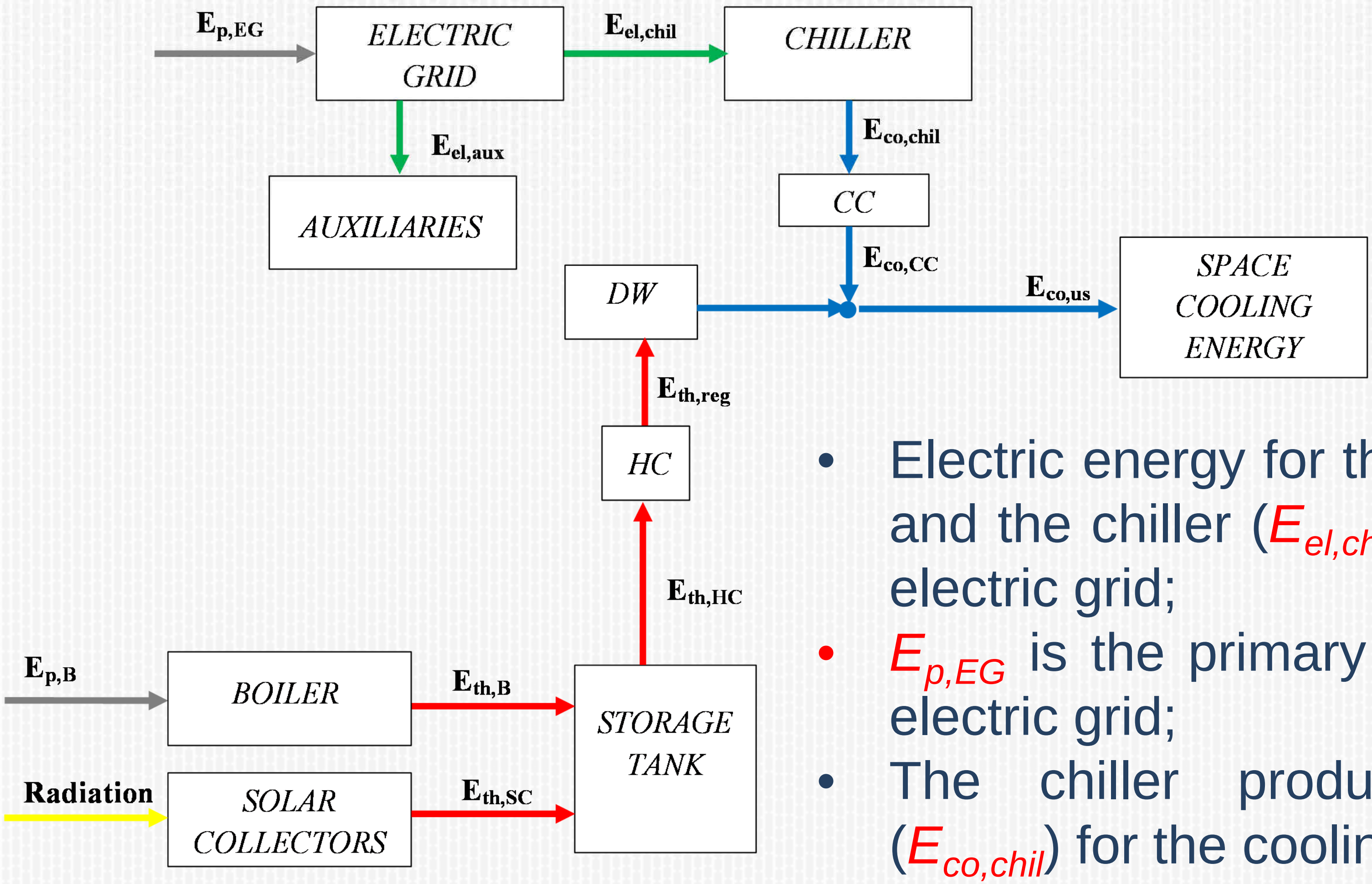
Thermal energy for DHW is provided to a nearby multifamily house with 10 persons and an average requirement of 40 l/(person·day).

ENERGY FLOWS - I



- Energy for space cooling purposes ($E_{co,us}$) is provided to the building;
- Thermal energy coming from solar collectors ($E_{th,SC}$) and natural gas boiler ($E_{th,B}$) charges the storage tank;
- Thermal energy is transferred to the heating coil ($E_{th,HC}$), for the regeneration of the DW ($E_{th,reg}$);
- $E_{p,B}$ is the primary energy input of the boiler;

ENERGY FLOWS - II



- Electric energy for the auxiliaries ($E_{el,aux}$) and the chiller ($E_{el,chil}$) is drawn from the electric grid;
- $E_{p,EG}$ is the primary energy input of the electric grid;
- The chiller produces chilled water ($E_{co,chil}$) for the cooling coil (CC);
- Cooling energy is transferred from the chilled water to the process air in the CC ($E_{co,CC}$).

METHOD

- The performance of the four desiccant cooling scenarios have been evaluated and compared with a reference system, in terms of:
  - Annual avoided primary energy consumption, $E_{p,av} = E_p^{RS} - E_p^{SDCS}$
  - Annual avoided equivalent CO_2 emissions, $CO_{2-eq,av} = CO_{2-eq}^{RS} - CO_{2-eq}^{SDCS}$
  - Annual avoided operating costs, $OC_{av} = OC^{RS} - OC^{SDCS}$
  - Simple Pay Back Period, $SPB = \frac{Extra\ Cost}{\left(OC^{RS} - OC^{SDCS}\right)}$
- Reference system (RS) equipped with electric chiller (for cooling dehumidification) and natural gas boiler (for air post-heating and DHW).
- The dynamic simulation software TRNSYS 17.1 was used.
- Simulations were performed on an annual basis, with a time step of 0.5 h.
- Slope and the azimuth of the solar collectors surface set to 20° and 0°, respectively.
- Gross solar collectors surface varied in the range 4 – 16 m^2, with a 2 m^2 step.
- Experimental and manufacturer data were used to simulate component models.

MAIN SIMULATION MODELS

Component	*Main parameters*	*Value*	*Units*
Solar air collectors	Overall reflectance of the collector surface	0.053	-
	Emissivity of the top and back surfaces of the collector	0.85	-
	Emissivity of the top and bottom surface of the flow channel	0.85	-
	Conductive resistance of the back insulation layer	3.6	$m^2 \cdot K/W$
	Conductive resistance of the absorber plate and structural layer	0.036	$m^2 \cdot K/W$
	Specific heat capacity of air	1.007	$kJ/(kg \cdot K)$
Flat-plate solar collectors	Tested flow rate	0.0213	$kg/(s \cdot m^2)$
	Intercept efficiency	0.712	-
	Efficiency slope	3.53	$W/(m^2 \cdot K)$
	Efficiency curvature	0.0086	$W/(m^2 \cdot K^2)$
	Fluid specific heat	3.84	$kJ/(kg \cdot K)$
Evacuated solar collectors	Tested flow rate	0.0213	$kg/(s \cdot m^2)$
	Intercept efficiency	0.72	-
	Efficiency slope	0.97	$W/(m^2 \cdot K)$
	Efficiency curvature	0.0055	$W/(m^2 \cdot K^2)$
	Fluid specific heat	3.84	$kJ/(kg \cdot K)$
Desiccant wheel	Effectiveness η_{F1}	0.207	-
	Effectiveness η_{F2}	0.717	-
Cross flow heat exchanger	Effectiveness	0.446	-
Humidifier	Saturation efficiency	0.551	-
Heating coil	Effectiveness	0.842	-
Cooling coil	By-pass fraction	0.177	-

PERFORMANCE ASSESSMENT METHODOLOGY - I

Numerical values of the parameters refer to the Italian situation:

- average energy performance factor of electricity supply η_{EG}=42.0%;
- thermal efficiency of the boiler η_B=82.8%;
- specific emission factor of electricity drawn from the grid, α=0.573 kg/kWh$_{el}$;
- specific emission factor related to natural gas consumption, β=0.207 kg/kWh$_p$;
- lower heating value of natural gas LHV=9.52 kWh/Nm^3;
- unitary cost of natural gas c_{NG}=0.612 – 0.964 €/Nm^3;
- unitary cost of electricity c_{el}=0.221 €/kWh;

PERFORMANCE ASSESSMENT METHODOLOGY - II

- major cost of desiccant-based AHU with respect to conventional one is 10,000 €;
- investment cost of storage tank equal to 3,000 €;
- investment cost of chiller: 3000 € for the SDCSs, 6000 € for the RS;
- specific cost of collectors: 275 €/m^2 for air collectors; 360 €/m^2 for flat-plate collectors; 602 €/m^2 for evacuated collectors;
- Italian subsidy mechanism for 2 years:

  $I_{a,tot} = C \cdot S$;

  annual incentive = valorization coefficient (255 €/m^2) x gross solar collectors area

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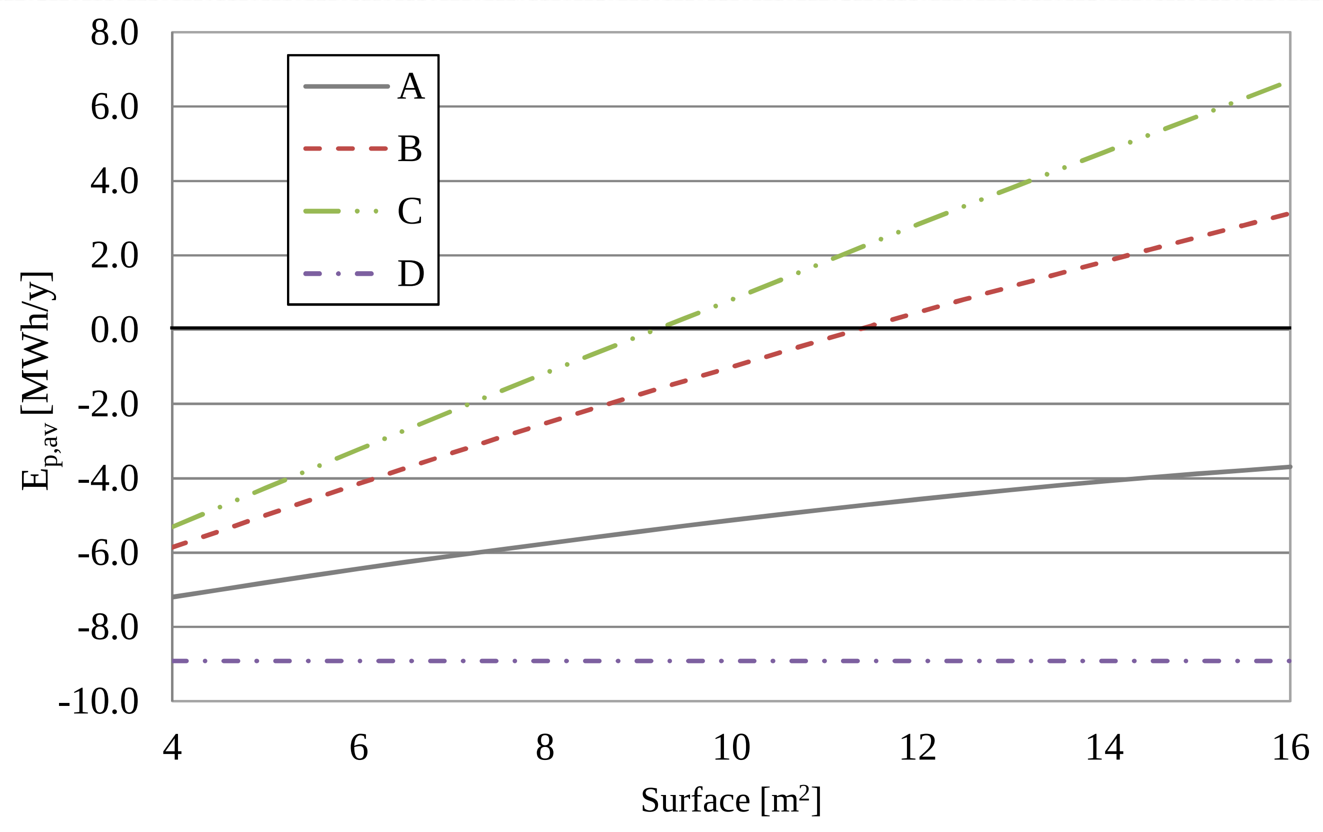
RESULTS: ANNUAL AVOIDED PRIMARY ENERGY CONSUMPTION

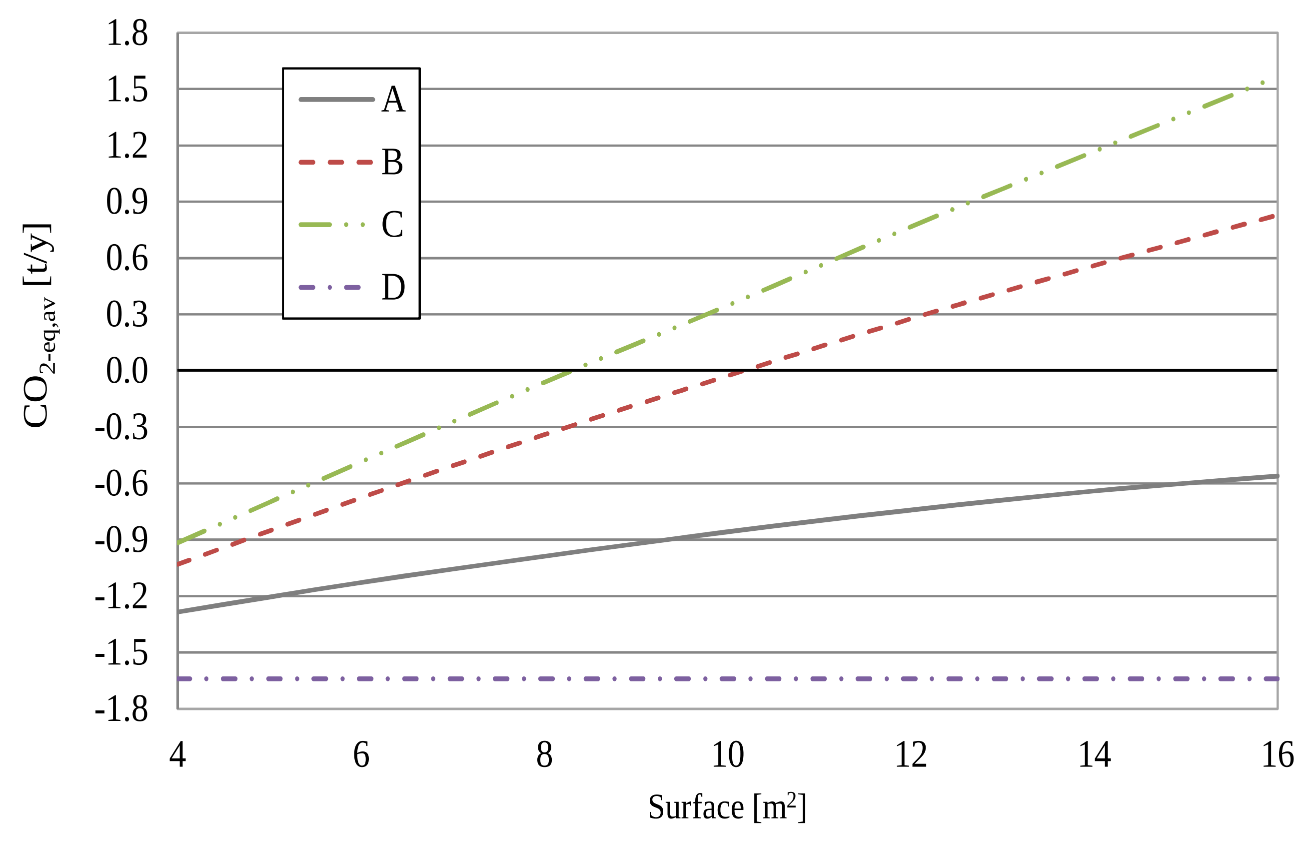


The annual avoided primary energy consumption ($E_{p,av}$):

- rises with the solar surface;
- is higher with evacuated collectors (scenario C);
- is positive for scenario C and B only beyond a certain surface;
- is negative with air collectors (scenario A) for any surface.

Scenario D has a higher primary energy consumption (about 8.91 MWh/y more than the reference system).

RESULTS: ANNUAL AVOIDED EQUIVALENT CO_2 EMISSIONS



The annual avoided equivalent CO_2 emissions ($CO_{2\text{-}eq,av}$):

- rises with the solar surface;
- is higher with evacuated collectors (scenario C);
- is positive for scenario C and B only beyond a certain surface;
- is negative with air collectors (scenario A) for any surface.

Scenario D has higher annual equivalent CO_2 emissions (about 1.64 t/y more than the reference system).

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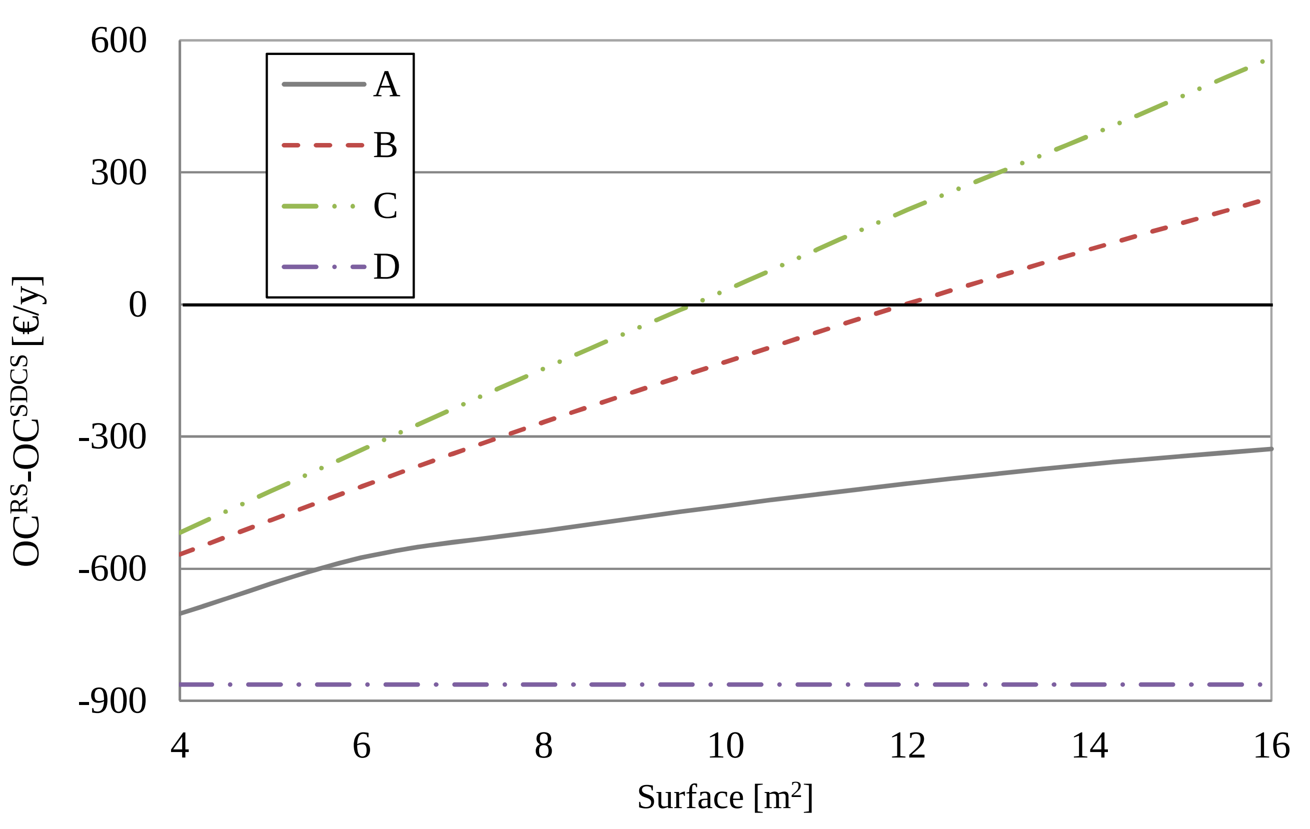
RESULTS: OPERATING COSTS

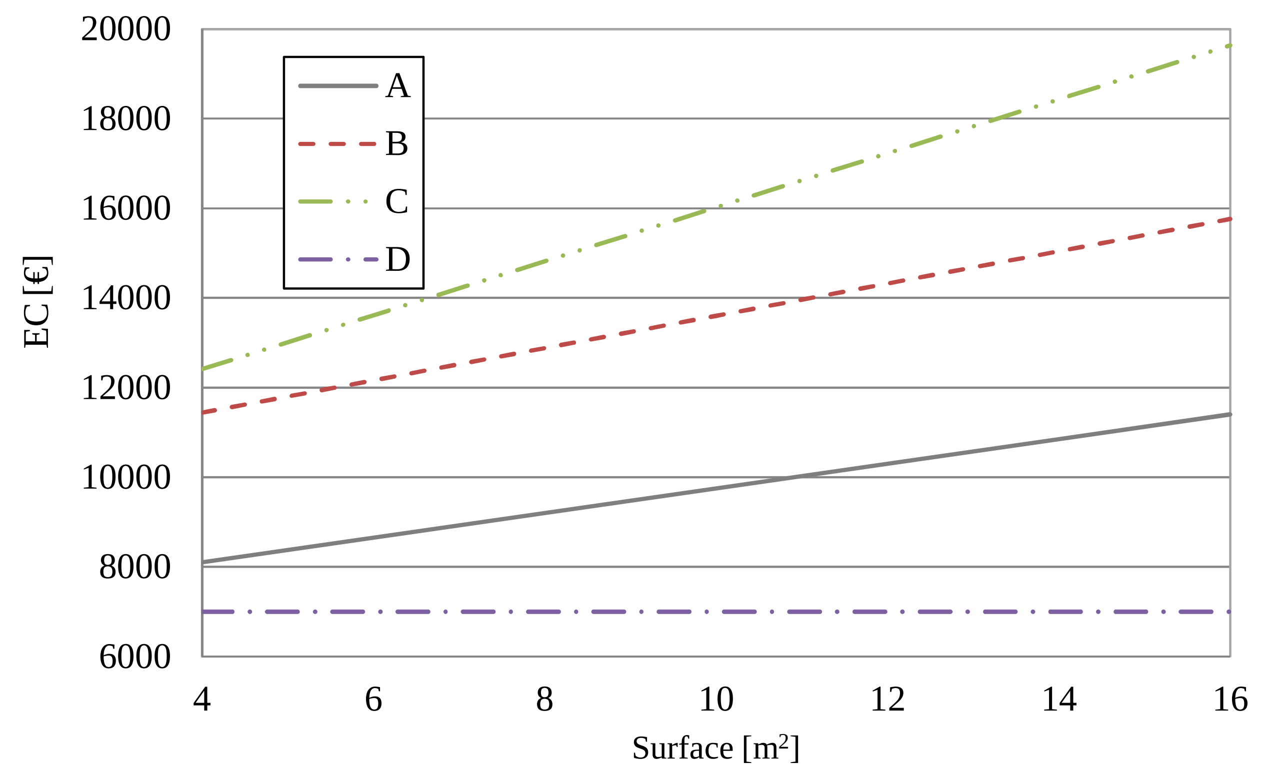


The difference in operating costs between the RS and the SDCS (*OC^{RS}-OC^{SDCS}*):

- rises with the solar surface;
- is higher with evacuated collectors (scenario C);
- is positive for scenario C and B only beyond a certain surface;
- is negative with air collectors (scenario A) for any surface.

Scenario D has higher operating costs (about 864 €/y more than the reference system).

RESULTS: EXTRA COST, SUBSIDY MECHANISM AND SIMPLE PAY BACK PERIOD



The *EC* of the SDCS is never recovered in scenarios A and D. For flat-plate collectors, the SPB is longer than the technical life of the system. For evacuated collectors (scenario C), 16 m^2 of solar surface provide a SPB of about 20 years.

The installation extra cost (*EC*) with respect to RS:

- rises with the surface;
- is higher for scenario C;
- does not include the storage tank for scenarios A and D.

The subsidy mechanism:

- is not provided for air collectors;
- starts from 8 m^2;
- is the same for flat-plate and evacuated collectors;
- it ranges from 2040 to 4080 €/y;
- it is provided for two years.

CONCLUSIONS: SELECTION OF SOLAR COLLECTORS TECHNOLOGY AND SURFACE

In the final selection process:

- Scenario A is excluded, due to the low energy and environmental performance, and for the absence of economic incentives;
- Scenario D is discarded, due to the lower techno-economic performance with respect to the RS;
- Scenario B is excluded as well, as it does not achieve a suitable economic pay-back period;
- the final choice should be 16 m^2 of evacuated collectors (scenario C);
- the selected solution provides a reduction of 50.2% of primary energy consumption, a reduction of 49.8% of avoided equivalent CO_2 emissions, with an extra cost of about 19.6 k€ and a (quite long) SPB of about 20 years.
- a further possibility (to be investigated) could be the installation of flat-plate collectors with a surface higher than 16 m^2; the economic analysis showed that the SPB reduces if the solar area is increased, for all types of collectors.