Roof BIPV/T panels (with embedded PCM) for heating outdoor air and cooling PV cells

Template completed by:
Annamaria Buonomano, Adolfo Palombo, DII - University of Naples Federico II, P.le Tecchio, 80 - 80125 Naples, Italy.
annamaria.buonomano@unina.it
adolfo.palombo@unina.it

For installations

BISTS Location: *Naples (Italy), longitude 14°16'36''12 E, latitude 40°51'46''80 N*
Climate Type: *Köppen climate classification = Csa*
Building Use: *Non-residential building (offices, expo space, conference room)*

Level of BISTS integration
Classifications: Rush = 2 and Reijenga = 3.

- ✕ New Build
- O Refurbishment
- O Other: ……………………

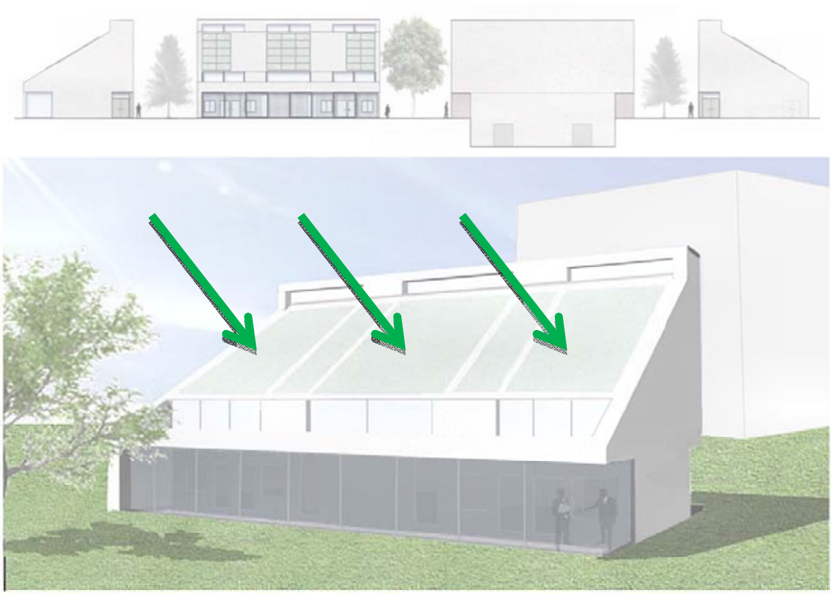

Figure 1. NZEB prototype of the Municipality of Naples (South-Italy)

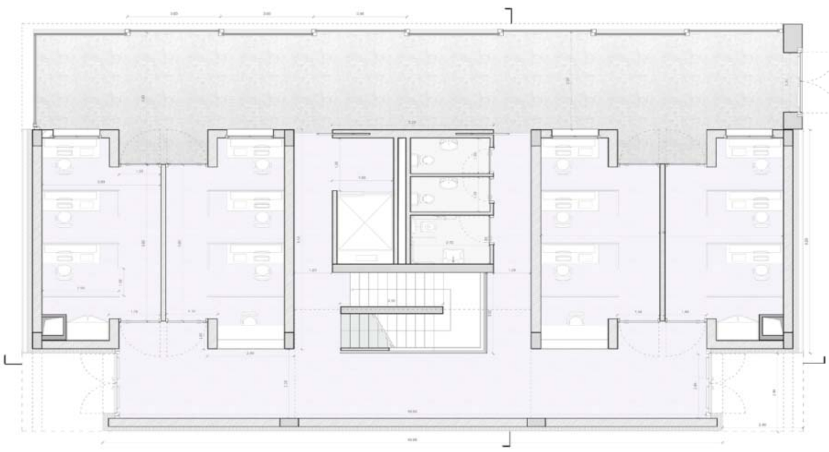

Figure 2. Plant view (offices) of the NZEB of the Municipality of Naples

Type of BISTS: hybrid

Function(s):

- ✕ Air heating
- ✕ Cooling/ventilation/shading
- ✕ PV/T
- ✕ Linked to an air-to-air heat pump

Building element:

- O Facade
- ✕ Roof
- O Other: ……………………..

Building Integrated PhotoVoltaic Thermal collectors (BIPV/T). This BISTS is active and passive, simultaneously. The active-mode regards the space heating obtained recovering the indoor/outdoor collected air to the space (middle seasons free heating, Figure 3A) and/or supplying it to an evaporator of an air-to-air heat pump (winter). For outlet temperature lower than 20°C the dampers are closed and the underlying air channel becomes an air gap. The system can be also considered as passive since it decreases the summer cooling load (exhausting the hot collected air heated by solar radiation, Figure 3B).

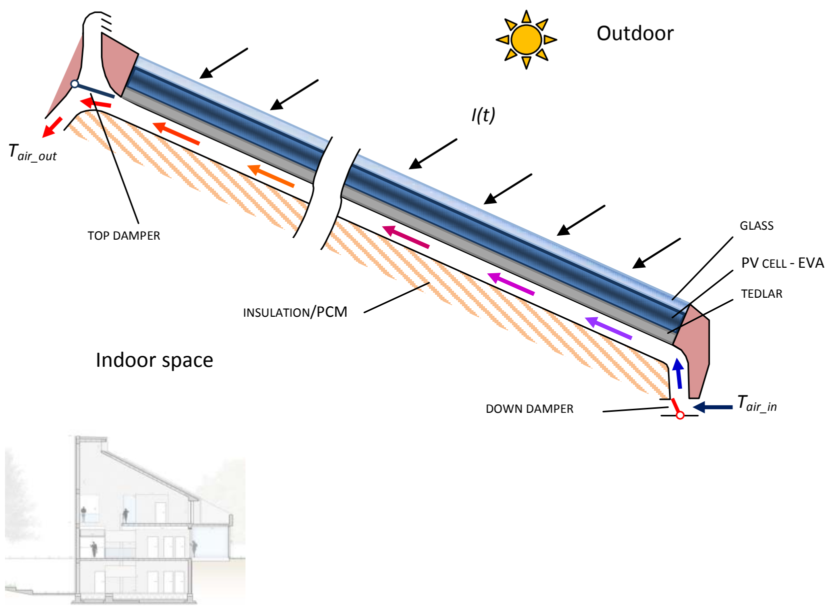

Figure 3A. Winter and middle seasons PV collector cooling (the collected air is recovered)

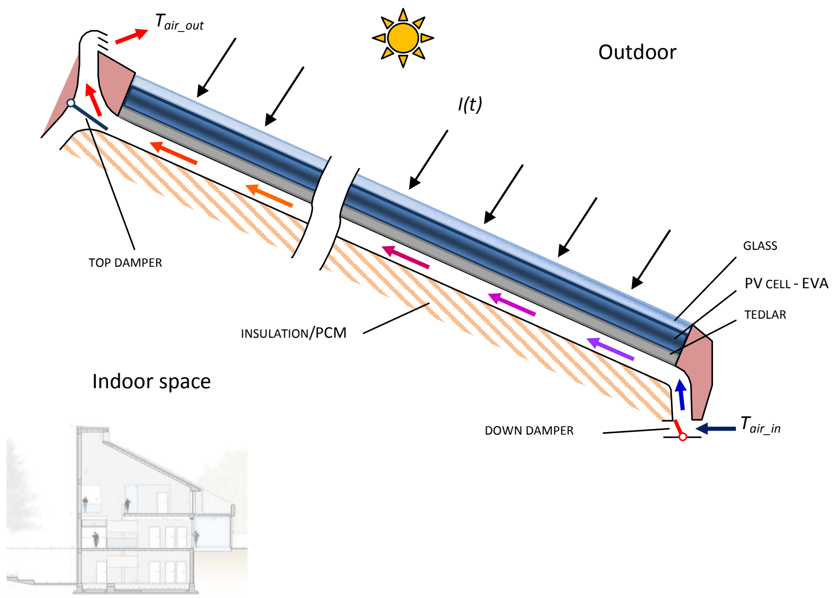

Figure 3B. Summer PV collector cooling (the collected air is exhausted)

BISTS characteristics:

Technology: BIPV/T obtained by mono-crystalline silicon PV panels
Collection area: 135 m^2(total), each module is 1694 mm length x 998 mm width
Inclination/Orientation: 30º/South roof
Peak power installed: 16.5 kW (total)
Produced electricity: 19.9 MWh/y
Contribution to building load: 100%
Pre-fabrication off-site: No

The South oriented tilted roof is designed with a slope of 30° in order to maximize the yearly energy performance of solar field. Here, PV collectors (three large rows of modules, see Figure 1) are integrated in the building roof. PV modules were made up of mono-crystalline silicon cells (156 ×156 mm each one) with a nominal efficiency of 14.7% and a peak power of 205 W at standard test conditions. The PV area is about 135 m^2. An air flux is collected through a rectangular channel underlying and integrated to the PV panels. Different operating modes can be selected.

- *Heating season* (Figure 3A) - The thermal energy released by the PV panels is suitably exploited for heating the air ventilation flow rate to be supplied to the building spaces. Such effect is achieved by a hybrid ventilation: natural convection (obtained by stack effect due to the tilted roof) and mechanical ventilation (obtained by an air flow rate of 0.5 kg/s, if necessary according to the ventilation demand). During the middle seasons the heat obtained by the BIPV/T system is often sufficient to fulfil the indoor thermal comfort requirements. During winter time the recovered energy is exploited: i) in the AHU as outdoor pre-heated air; ii) for supplying the evaporator of an air-to-air heat pump. Heating of the indoor recirculation air could be optionally selected. If necessary, the dumpers are closed and the underlying PV channel becomes an air gap;
- *Cooling season* (Figure 3B) - In summer, the damper at the top of the BIPV/T air channel is set to waste part of the solar radiation load through the exhausted air stream (as a ventilated roof). This can be achieved by using outdoor or indoor air as a function of the desired operating conditions. In any cases two different benefits are obtained: i) an increased PV electricity efficiency; ii) a decreased building cooling load.

Stage of Development:

✕ Idea/Patent
✕ Prototype
✕ Demonstration
O Integral building element
O Commercially available

Responsible: *DII – Department of Industrial Engineering, University of Naples Federico II, P.le Tecchio, 80 - 80125 Naples (Italy).*

BISTS description and context

The building project initiative stems from the action ED6 of the Sustainable Energy Action Plan (SEAP, Covenant of Majors of the European Community, August 3rd 2012) and from an explicit Resolution (n. 517 on April 21st 2011) of the Municipality of Naples. The building is designed on three levels and at this moment is the first Italian non-residential NZEB project. The building will be built up on three floors (two of them above the ground level) and it will host offices (ground floor), expo spaces and a conference room (first floor), Figure 1.

In order to meet passive heating and cooling criteria, the building is conceived with a rectangular shape (15.0 × 24.5 m, East-West oriented longitudinal axis) and without windows on the eastern, northern and western façades. The floor area of the conditioned spaces is 554 m^2. The building roof slope is 30°, the S/V ratio is 0.38. The window to wall surface area ratio is low (about 15%), while it becomes high (about 70%) when referred to the southern façade (for maximizing the winter solar heat gain). The first floor terrace windows are equipped by external horizontal variable tilt solar shadings, while horizontal overhangs are modelled on the top of the roof windows. At the southern side of the ground floor, a sunspace is designed in order to maximize the winter passive heating gain (suitable absorptive dark surfaces are considered for the related opaque elements). In summer, such space becomes (by completely opening the external sliding windows) a shaded open porch (S/V ratio decreases to 0.36). The porch ceiling width and height are conceived in order to avoid the indoor space superheating. The building envelope is designed with a high thermal capacitance and insulation (high superficial masses of the opaque building elements as well as suitable thicknesses of thermal insulation are taken into account).

The main features of the NZEB envelope are reported in Table1. The external opaque envelope is designed as remarkably reflective (reflective cool paint). The building shape and the interior design are conceived in order to maximise the natural ventilation. The porch width and height, as well as other design and operating parameters are optimized for the maximum NZEB energy efficiency. More details are reported in [1].

Building element	**Density** [kg/m^3]	**U-value** [W/m^{2}K]	**Embedded PCM layer**	**Note**
Vertical walls	800 (brick layer)	0.23	Yes (3 cm)	-
Tilted roof	1050 (concrete slab)	0.23	Yes (3 cm)	-
Sunspace (exterior), East office, conference room windows	-	1.6	No	Emissivity = 0.10. 6/13/6 glazing filled by Argon. SHGC = 0.58
Other windows	-	0.9	No	Emissivity = 0.10. 6/8/6/8/6 glazing filled by Krypton. SHGC = 0.46

Table 1. NZEB envelope features

Modelling and simulation tools developed/used

In order to analyse the BISTS performance and to design the NZEB from the energy point of view a suitable dynamic energy simulation model was purposely developed in MATLAB environment (DETECt 2.2, the code was validated by the BESTEST procedure [1-4]). By such tool the energy analysis of the proposed solutions and their interactions with the building (e.g. BISTS thermal passive effects) can be analysed. DETECt 2.2 was also utilised for the optimization procedure of several building envelope operating and design parameters (for minimising the heating and cooling building energy demand). Such code includes several tools for the energy performance analysis of different BISTS typologies, such as the considered BIPV/T system also equipped with underlying PCM panels. A sketch of the developed (RC) thermal network is reported in Figure 4. In Figure 5, as an example, the performance comparison of BIPV collectors with and without PCM panels is reported for a spring sample day. Note that by comparing the BIPV/T system coupled to an underlying PCM layer vs. a standard BIPV/T system an yearly efficiency increase of about 3.2% is achieved. The overall NZEB energy performance of the investigated optimal scenario is finally reported in Table 2.

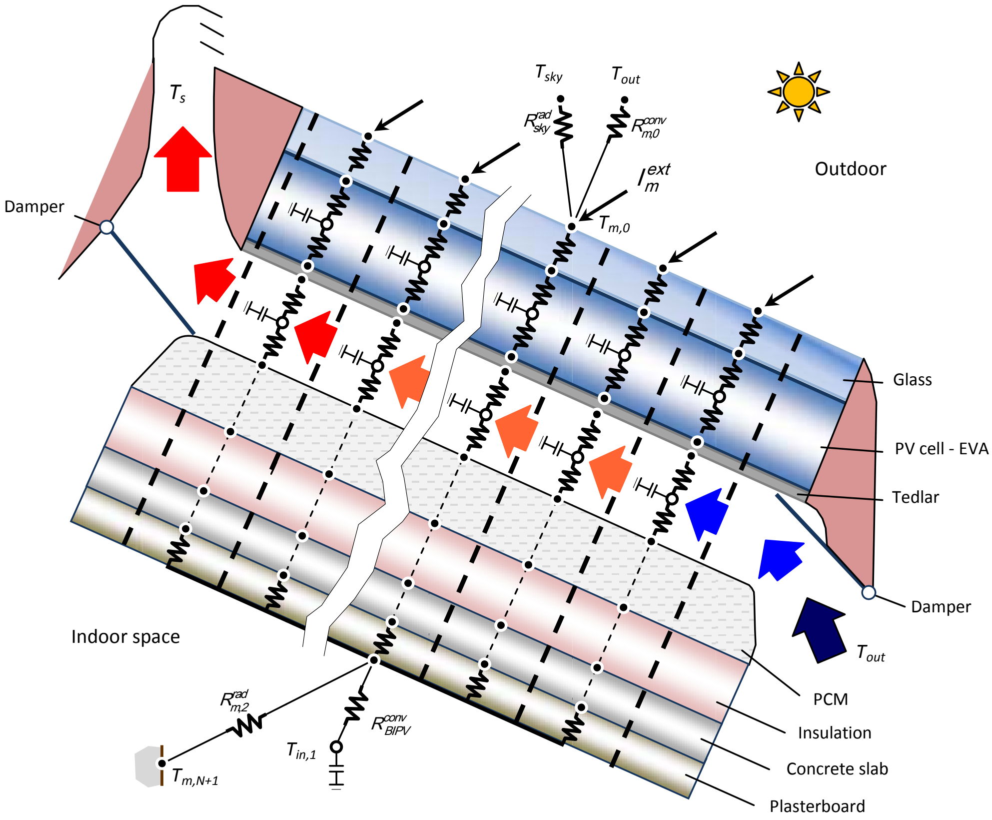

Figure 4. Cross section of the modelled BIPV/T system (summer configuration)

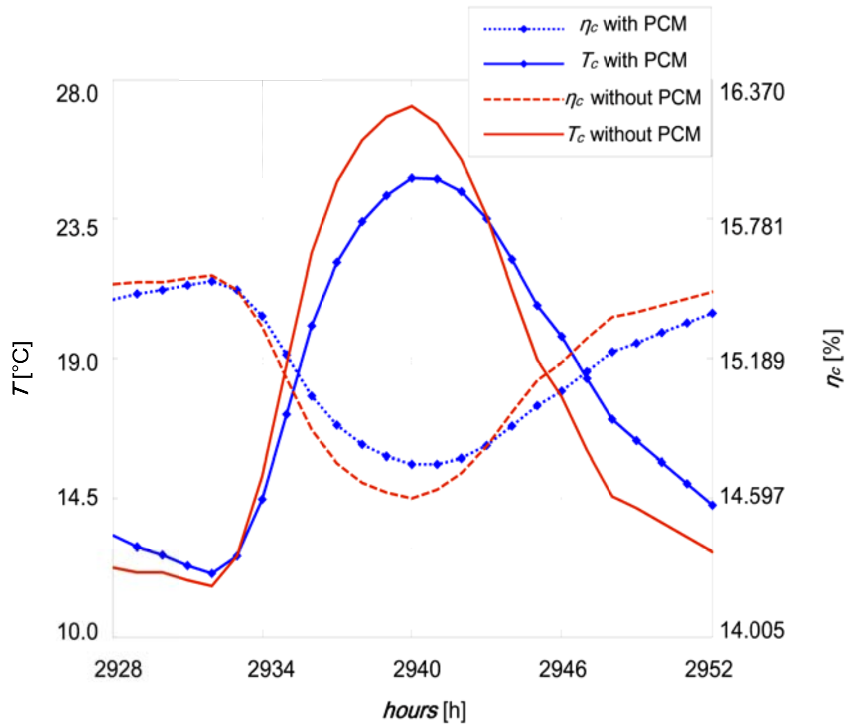

Figure 5. May 3rd: average temperature and efficiency of the PV cell with and without PCM

Energy demands [kWh/m²·y]		Heating	DHW	Cooling	Electricity: Ventilation	Electricity: Light	Electricity: Appliances	Electricity: Fans, pumps and cooling tower
Total		3.90	1.85	6.70				
Carrier	**Electricity**	0.13	0.21	0.19	2.50	3.51	5.96	2.18
	Solar	3.47	1.21	5.62				

Renewable energy [kWh/m²·y]	Electricity
Produced on site	45.2
Exported	30.6

Primary energy [kWh/m²·y]	Produced on site	Produced and consumed on site	Exported	Imported	RESs
	153.9	45.9	108.0	32.0	235%

Energy needs and class (Italian guidelines)	Methodology	Primary energy for heating [kWh/m³·y] (Class)	Energy for cooling (not primary) [kWh/m²·y] (Class)
	UNI TS 11300 (Italian release of EN 13790)	1.92 (A+)	9.39 (I)

Table 2. BISTS performance calculated by DETECt

In Figure 6, the heating and cooling performances, obtained with the investigated scenarios related to the roof integrated solar field are reported. When no solar technologies are applied to the NZEB an increase of the heating demand of 21.0% and a decrease of the cooling one of 10.2% is detected vs. BIPV/T system. These opposite effects almost counterbalance each other (a reference electric heat pump/chiller COP of 3/2.5 is taken into account). Thus, a negligible reduction of the overall primary energy (E_p), is detected (2.2%), Figure 6.
Note that, for all the investigated cases the primary energy saving achieved by the electricity production of the PV collectors resulted much higher than the primary energy demand due to heating, cooling, lighting and equipment. The extra-production of electricity and thermal energy is sold to the national grid (at 0.08 €/kWh following the present Italian rule).

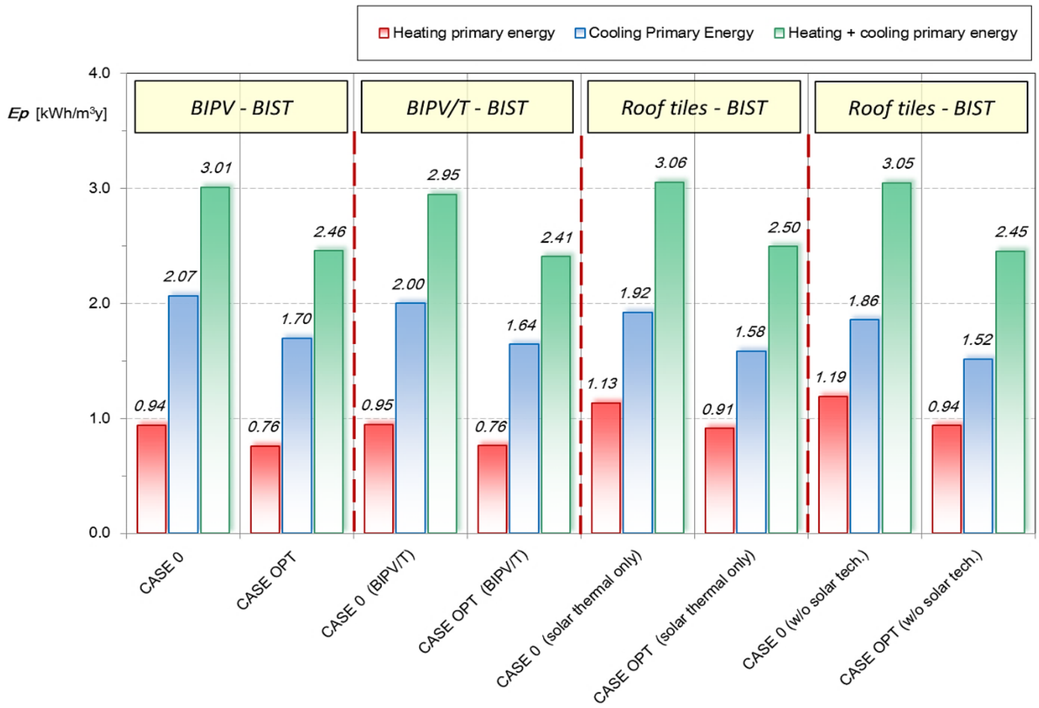

Figure 6. Primary energy demand as a function of the implemented solar technologies

BISTS Performance data

Based on:

O Estimation

× Detailed simulation by DETECt (in-house developed dynamic simulation code for the building-plant energy performance analysis)

O Measurement/testing

O Long-term monitoring

Performance parameters

Solar savings fraction: 90%
BISTS U-value: 0.21 W/m^{2}K
BISTS Ms: 320 kg/m^2

Additional information

The contribution on the overall balance of renewable energies is remarkable (given the need to provide electricity, heating and cooling to an existing large public building adjacent to this NZEB).

Sources and references

[1] Buonomano A., De Luca G., Montanaro U., Palombo A.. Innovative technologies for NZEBs: an energy and economic analysis tool and a case study of a non-residential building in Mediterranean climate. Energy and Buildings. 2015; http://dx.doi.org/10.1016/j.enbuild.2015.08.037

[2] Buonomano A., Palombo A.. Building energy performance analysis by an in-house developed dynamic simulation code: An investigation for different case studies. Applied Energy 113, 788-807, 2014

[3] Buonomano A., Palombo A.. NZEBs design and simulation: a new tool for dynamic energy performance analyses. ECOS 2014 - 27th International Conference on Efficiency, Costs, Optimization, Simulation and Environmental Impact of Energy Systems, Turku, Finland; 06/2014

[4] Buonomano A., Calise, F., Palombo A.. Solar heating and cooling systems by CPVT and ET solar collectors: A novel transient simulation model. Applied Energy, 103, 588-606, 2013