A solar multifunctional roof: photovoltaic and thermal coupling

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ABSTRACT

Integration of solar energy systems in architecture is becoming more important in order to achieve energy savings and optimize the introduction of RES in the real estate sector.

The role of the public institutions must be seen as a leader for the private customers by demonstrating the effectiveness and feasibility of energy projects with real and exemplary interventions.

Under a collaborative project between the Lombardy Region and Politecnico di Milano, a complete solar roof has been installed on the Center of Professional Formation (CFP) of Casargo (Lecco), during the technical and functional refurbishment of the whole building.

1. DESCRIPTION OF SOLAR SYSTEM

The refurbishment and adjustment program on the CFP of Casargo is concerned with the technical systems for thermal energy supply for various building application, that's to say sanitary warm water, air-conditioning and ventilation. The adopted technological solution is the TIS system with modular structure, which can be easily integrated on the existent roof (in concrete in this case) and is able to produce both electrical and thermal energy from sun. The TIS system is produced by SeccoSistemi Spa, a company based at Treviso in Italy.

The solar integrated system has a total surface area of 390 m^2, installed on the whole south facing part of the roof, sloped at 17° respect to horizontal (Fig. 1). The covering is continuous, uniform and modular and also contributes to aesthetic aims (Fig. 2). It provides double functions as protection from external agents, answering at all requirements of a traditional roof, and as an energy generator from the sun.

The functional characteristics of the modules are as follows:

- water solar collectors, to produce warm water for sanitary use (two plants on the sides of the roof, 112 m^2);
- air solar collectors, to supply a thermal contribution (pre-heating) to air ventilation of indoor spaces (in the central part of the roof, 114 m^2);
- hybrid photovoltaic thermal panels, to provide a small part of electric energy for the building internal loads (23 m^2, 3.9 kW_p).

The dimensions of the modules and the components of the systems permit a fast and simple installation in different phases.

Two strips of steel sheets that divide the functional plants are used for installing the electric cables and pipes for water system. This "blind" modules, with closing steel sheets, were projected to allow the system to maintain flexibility and extension possibility. In this case,

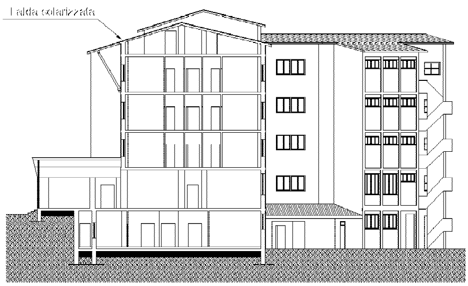

Figure 1: Building section, the south facing roof.

they are necessary to the functional configuration and organisation of system's distribution parts.

The TIS system act as thermal insulation and impermeable layer for the covering, together with the energy functions of its external shutting layers (photovoltaic modules and glass for solar thermal collectors). The main components of the TIS are:

- aluminium mullions, to support all the functional layers;
- thermal and acoustic insulation panels in contact with the existent structure;
- photovoltaic modules or tempered glass with aluminium frame;
- absorbing plate (copper corrugated sheet or copper slab with pipes with titanium oxide coating);
- air gap between insulation layer and PV or glazing modules, to recover warm air and permit heat exchange;
- "blind" panels steel sheet with thermal insulation.

The functional strips canalize pre-heat air to recovery channels to the air-conditioning system, placed in the attic space. The water pipes are extended to the technical spaces at the ground level, where the heat exchangers are installed inside the storage tanks.

1.1 Solar water system

The water solar system is realised with single glazed selective solar collectors, integrating hydraulic pipes. The collectors are connected in series, forming longitudinal strips following the roof slope line. The strips are connected in parallel to the principal collectors. At left side 13×3 modules (13 strips of 3 modules) and at right side 13×5 modules (13 strips of 5 modules) are installed. This asymmetrical configuration has been adjusted with the help of a calibration valve to balance hydraulic system. The primary circuit of solar collectors is divided from secondary circuit (consumers circuit) by the heat exchanger in the tanks. The water circulation is assured by 2 groups of 2 pumps, regulated by an electric controller, based on temperature sensor to avoid the heat loss in the absence of solar radiation.

Figure 2: View of the solar integrated roof.

1.2 Solar air system

The solar air system occupy the central zone of the roof and it is the major part of the functional energy plant (26×4 modules) forming 26 strips in which warm air flows inside the continuous air gap. The solar collectors are covered with single glazing pane and integrate selective absorbing corrugated plates. The plant can work in three following operational methods to satisfy different needs:

- heating of the air circulating from internal spaces;
- heating of external ventilation air;
- mixed procedure.

The capacity of each series of modules is 87 m^3/h, the air speed 0.3 m/s and the resulted load losses are smaller than 0.5 Pa/m. The system operation scheme is as follows:

- air coming from the unit of air treatment passes through channels to solar collectors at lower level of the roof;
- the air heated by solar radiation in the collectors air-gap is recovered in the upper channel;
- this air is used to pre-heat external air or recovery air in the unit of air treatment.

The section and configuration of all air recovery channels guarantee the auto-balance of the system. The system is used in winter period to heat the air; in summer period is under study a solution to employ solar thermal energy in cooling processes (desiccant and evaporative cooling). The project comprises a conference room equipped with "solar cooled" or heated air by a desiccant cooling plant.

1.3 Hybrid photovoltaic thermal system

The first component of each strips of air collectors is a hybrid photovoltaic thermal panel (Fig. 3) that pre-heat the air in the gap for the removal of heat from PV laminate, improving at the same time the photovoltaic cells efficiency.

The PV laminates are BP Solar 150 L, with a power of 150 W_p each one. They respect regulation on photovoltaic (IEC 61215) and through aluminium frames can resist to wind and snow loads. The produced energy covers partially electric loads due to thermal systems (circulation pumps and unit of air treatment).

2. ENERGY PERFORMANCE EVALUATION

The energy performance assessment of the solar roof was made by means of the simulation model PVT04 (Aste et al., 2002, 2003), developed by the Politecnico di Milano to evaluate the features of hybrid systems, and of the f-CHART method (Duffie et al., 1977). The evaluation concerns:

- electrical and thermal energy production by PV/T plant;
- average monthly electrical and thermal efficiency of PV/T plant;
- thermal energy produced by solar air system;
- percentage of warm sanitary water needs covered by solar water system.

For each hybrid PV/T module, it is possible to calculate electric photovoltaic energy, heat produced and average efficiency (Figs. 4 and 5).

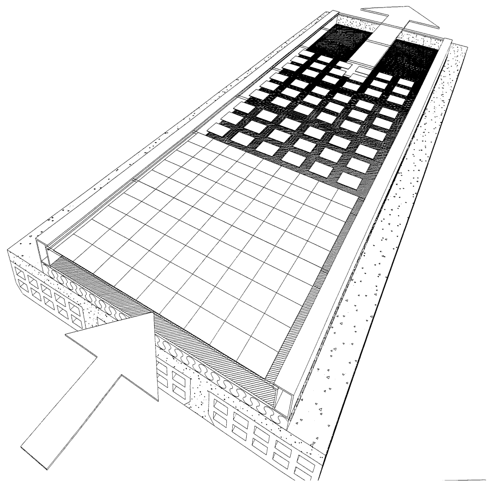

Figure 3: Hybrid PV/T module operation outline.

The total electrical energy produced by the PV/T plant (26 hybrid modules) amounts to about 5 MWh/year (taking into account the BOS efficiency) and the thermal energy amounts to about 8.7 MWh/year.

Solar air system takes pre-heat air from PV/T plant and proceeds to warm the flow collected to superior channel, placed at the top of the roof. Total thermal energy produced during the year is about 34.8 MWh/year, that summed to thermal energy produced by PV/T plant reaches 43.5 MWh/year, of which 21.2 MWh during the

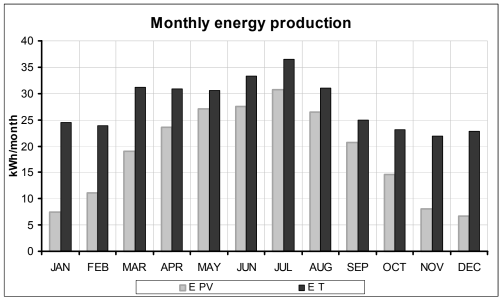

Figure 4: Electric and thermal energy produced by each PV/T module.

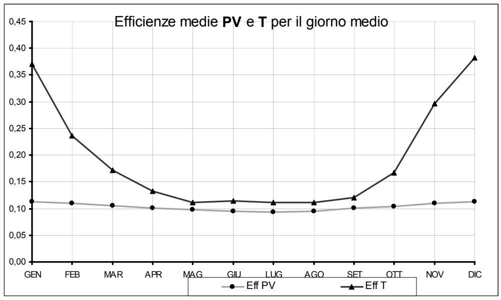

Figure 5: Photovoltaic and thermal monthly average efficiency.

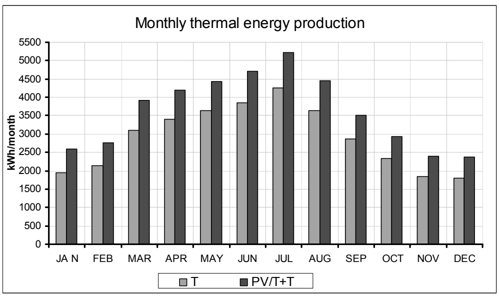

Figure 6: Monthly thermal energy of only solar air system and total thermal energy produced by solar air system and photovoltaic system together.

heating period (Fig. 6).

The f-chart method is used to evaluate the fraction of the total heating load, due to warm sanitary water, supplied by solar energy. The parameter "f" represents the solar load factor and results from solar energy tapped connected to building energy needs (7,500 litres/day of warm sanitary water).

The annual "f" factor of the solar water plant is 52%, about the optimal value estimated to avoid over-measuring of the system. Totally covering warm water requirements in winter period, in fact, succeeds an energy surplus in summer that can compromise economical suitability of the system. From Figure 7 it is possible to note that the maximum "f" factor is 87% registered in July. Thermal energy produced by the solar water system amount to 60.5 MWh/year.

3. MONITORING SYSTEM

The TIS system has been installed in summer 2004 and there is a monitoring plant to survey meteorological data (solar radiation, external air temperature, wind direction and speed, humidity, etc.) and solar system performance (PV cells temperature, air collectors temperature on glass and absorbing plate, water collectors temperature, etc.). The monitoring system, constituted by 40 sensors and a data-logger, is in phase of installation and it will be interesting to compare the assessment based on simulation models with the real monitoring results in the next months.

4. CONCLUSIONS

The solar plant installed on the CFP of Casargo roof permits energy savings for space heating, warm sanitary water and electric internal loads. The major part of thermal energy produced during summer period can be used for the regeneration of desiccant wheels of the dehumidification system. The school building employed during winter to conduct professional training courses, becomes also in summer period a cultural reference for the whole zone by organising conferences, courses and activities and therefore, needs air conditioning for indoor spaces. The whole technical system uses solar radiation to satisfy different energy requirements, through specific equipments that can convert sun's energy into enjoyable energy for users.

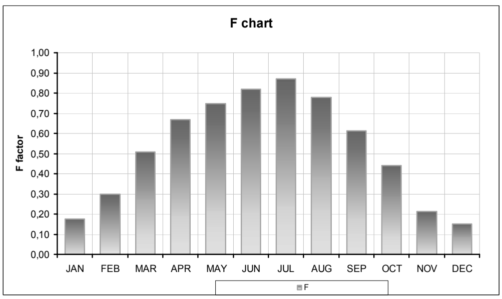

Figure 7: F-Chart for water solar system.

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