Hybrid Photovoltaic-Thermal Technology and Solar Cooling: The CRF Solar Façade Case Study

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ABSTRACT

The solar façade of the FIAT Research Center (CRF) was realized recently near Turin in Italy, under cooperation between CRF and Politecnico di Milano. The photovoltaic elements, that has a total power of 19.5 kW_p, produces electric energy, while the forced air circulation beneath the modules recovers the thermal fraction of captured solar radiation and cools the cells as well. The electricity generated by the photovoltaic panels is used to feed a heat pump and internal electrical requirements. The produced heat is used by the air conditioning plant of the kitchen: in winter for pre-heating of the renewal air and in summer to feed the system of dehumidification (desiccant cooling) This integrated solar façade is being monitored on-line by a highly sophisticated monitoring system, managed by the technicians of CRF. At present, the system performance data is available for more than one-year period. In this paper, the monitored performance data on solar façade are presented and an estimated data for thermal and electrical performances using the developed simulation model is also shown.

1. INTRODUCTION

Over the last few years there has been a growing interest in hybrid Photovoltaic/Thermal Collectors. The hybrid systems integrate the features of the photovoltaic and the solar thermal (water or air) systems in one combined product/system. A typical hybrid system contains a solar thermal collector in which a PV laminate is used as a thermal absorber. In this kind of system, besides generating renewable electricity, it is possible to recover the thermal energy, which is otherwise lost to atmosphere, decreasing simultaneously the operational temperature of the photovoltaic cells and increasing, therefore, the PV conversion efficiency. The basic concept of the hybrid systems is rather simple and is based on the removal of waste heat from photovoltaic cells for its successive utilization through the convective airflow behind the PV panels.

In the last few years, most of the research work and applications conducted in this field (IEA, 2002) are converging on two alternate solutions: the first one, which is the most effective one, is to recover heat through natural or forced (mechanized) ventilation inside the panels; the second one, in which the heat can be transferred to another medium, such as water. However, because of various technological and performance problems, these solutions remained at proto-type level only. Further, it has been strongly felt that the potential for architectural integration of this technology is considerable high and allows realizing a solar building envelope that produces energy to consume directly at the site.

This paper describe the technical details of the CRF solar façade and the *Ecomensa* project. The experimental performance data on solar façade are presented and an estimated data for thermal and electrical performances using the developed simulation model is also shown.

2. THE TIS (INTEGRATED SOLAR ROOF) SYSTEM

The system TIS (Integrated Solar Roof) was born as a result of the experimental and theoretical research work, carried out at the Politecnico di Milano, on the development of active solar systems as the commercial building components (Aste *et al.*, 2002 and 2003). In fact, in 2000, the SeccoSistemi Spa, a solar manufacturing company, under the coordination of the Politecnico di Milano, has developed a modular building envelope system, in which it is possible to introduce various kind of solar collectors viz. hybrid photovoltaic-thermal, thermal to air and thermal to water collectors. The varied typologies can be used and sized according to the choice and the requirement, and all together can replace entirely the façade/roof of the building. The various components of a basic TIS system are shown in figure 1.

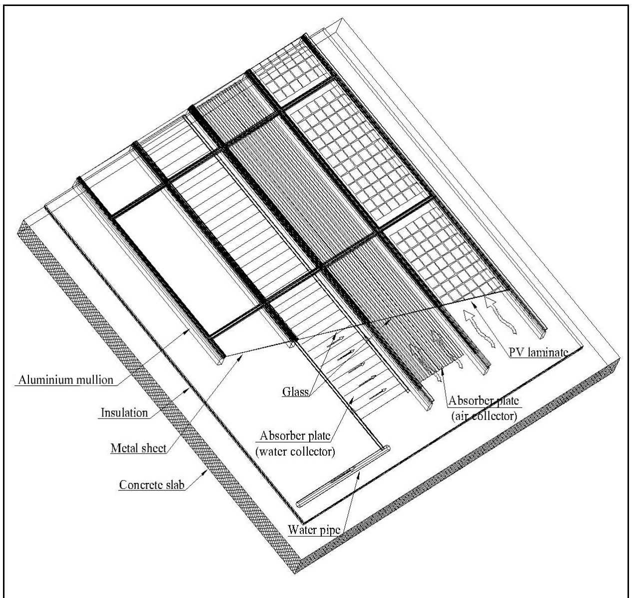

Figure 1. TIS (Integrated Solar Roof) system

3. THE HYBRID FAÇADE OF FIAT RESEARCH CENTRE

The hybrid photovoltaic-thermal façade of the Fiat Research Centre (CRF) at Orbassano, Italy represents the first commercial realization of the TIS system. In 2001, on the occasion of the first regional call for financing under the Photovoltaic Roof Programme promoted by the Ministry of Environment, the CRF commissioned an intervention of energy retrofit of the south façade (inclined at 53° from horizontal) of the building premise that accommodates the office canteen.

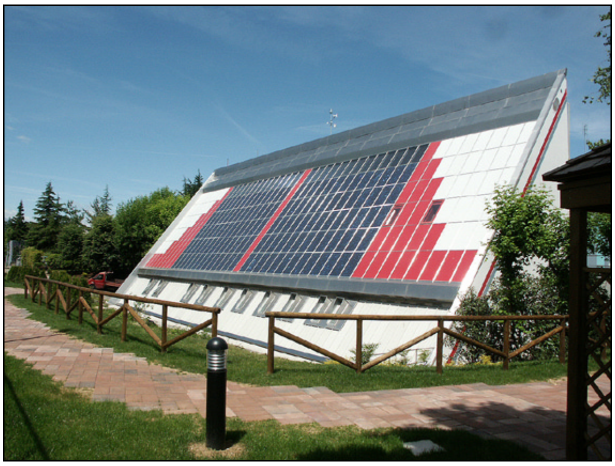

Figure 2. Solar façade at Fiat Research Centre (CRF)

The intervention is consisted in the realization of a ventilated façade/roof covered with the system TIS, capable to produce solar energy and improve the thermal features of the building envelope. The solar roof, shown in figure 2, occupies the central part of the sloping wall for a total surface area of about 426 m^2 (including the area of completion). It consists of a hybrid photovoltaic-thermal system with total surface area of 160 m^2, composed mainly from 130 modules containing silicon polycrystalline cells, installed on the façade such a way to create parallel channels with continuous air-gap for ventilation. The photovoltaic elements produces electric energy, while the forced air circulation beneath the modules recovers the thermal fraction of captured solar radiation and cools the cells as well, resulting an increment in the system conversion efficiency. The hybrid collectors are supplemented further by boosters (solar air collectors without PV elements), having a total surface area of 32 m^2, to allow the post-heating of collector outlet air for its use in higher air temperature range.

All solar modules are provided with ventilation gap and thermal insulation at the base. The air inside the ventilated façade is circulated to outside through a channel equipped with grills at the base of strings and then is transported to upper channels installed inside the building used for the air-conditioning purpose. The design details of hybrid PV-T collector are shown in figure 3.

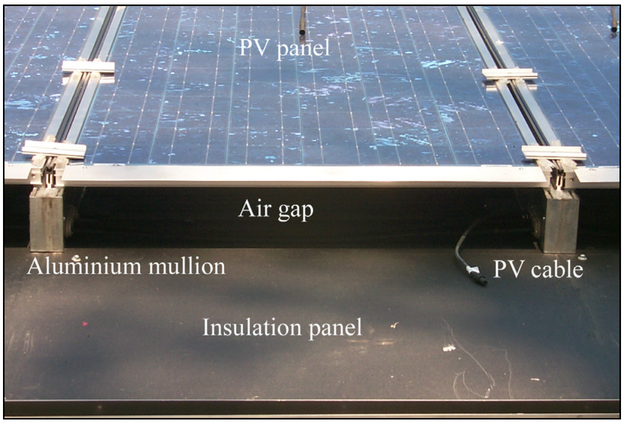

Figure 3. Design details of hybrid PV-T system

The photovoltaic plant, that has a total power of 19.5 kW_p, is constituted from 130 PV modules of type BP SX 150 L, provided with appropriate frame to integrate in the TIS system. The nominal power of each module is 150 W_p. The modules are configured in 22 strings connected in series, 21 are composed of 6 modules and 1 is of 4 modules. The inverters (2 units) are installed inside the building to convert the DC to AC; one is of 18 kW serving 21 strings and other of 700 W serving the single string of 4 modules. Both the inverters are isolated transformer type, operating at the maximum power point (MPPT operation) and create AC at the exit with PWM (Pulse Width Modulation) technique. In the central part of the façade, the solar panels are substituted by a metal duct, in which all the electrical cables are installed to connect the PV modules to inverter, electric substation and monitoring system. The data display monitor connected to the solar façade is shown in figure 4.

The thermal operation of the façade is ensured by a system of forced ventilation operating with airflow of 9000 m^3/h. The air is heated up inside the hybrid and booster collectors and reaches at the temperatures up to 60°C, according to the specific climatic conditions. The air conditioning plant of the kitchen uses the produced heat: in winter for pre-heating of the renewal air and in summer to feed the system of dehumidification (desiccant cooling).

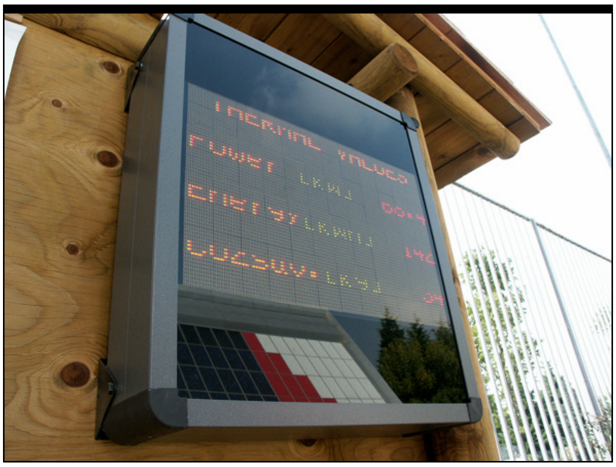

Figure 4. Data display monitoring system

3. PROJECT *ECOMENSA*

The technological demonstration Project *Ecomensa* developed at the Fiat Research Centre, introduces the hybrid façade in a more spacious and articulated manner. This Project represents a complex plant, focussed on the synergetic exploitation of different innovative energy technologies for the premise of CRF office canteen. By means of an intelligent control system, that manages simultaneously the operation and optimises the energy performance of different sub-components. A simulation model based on the optimised control strategies for the performance prediction of solar assisted desiccant cooling system of *Ecomensa* project is developed by Politecnico di Milano (Adhikari *et al.* 2004).

The system (Figure 5) is constituted from a hybrid photovoltaic-thermal generator, a combined heat and power system (CHP) cogeneration system, a reversible heat pump and a desiccant wheel dehumidification plant, connected to the electric grid and the air conditioning plant of the building. During all the year, the PV and the cogeneration plants feed the heat pump and the internal electrical loads. During summer months, the heat recovered from the hybrid façade and the cogenerator is used for dehumidifying the renewal air, while the heat pump is employed for cooling application. In winter, however, the heat generated from both the façade and cogenerator is used for the heating.

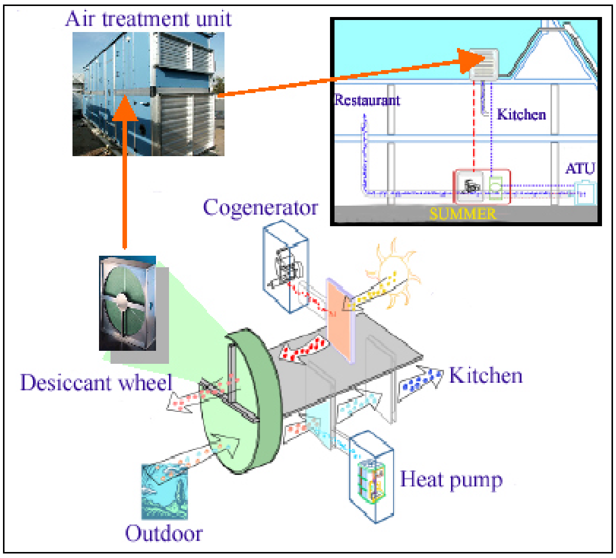

Figure 5. Project *Ecomensa*, Fiat Research Centre

4. PERFORMANCE RESULTS OF THE HYBRID FAÇADE

The monitored data of solar façade include the meteorological data e.g. ambient temperature, relative humidity, wind velocity and solar radiation; façade thermal data e.g. collector air inlet and outlet temperature at different points inside the duct (air gap); façade electrical data e.g. current, voltage, power and frequency output. At present, the system performance data is available for more than one-year period.

Figure 6 shows the monthly electrical output of the solar façade for the period May 2003-June 2004. It should be mentioned here that during the month of August 2003, the façade is operated only for 10 days .

It can be seen that during the whole operational period (May 2003-June 2004), the PV element of the hybrid façade produces an electrical contribution of energy about 22.1 MWh with an annual electrical output of more than 20 MWh.

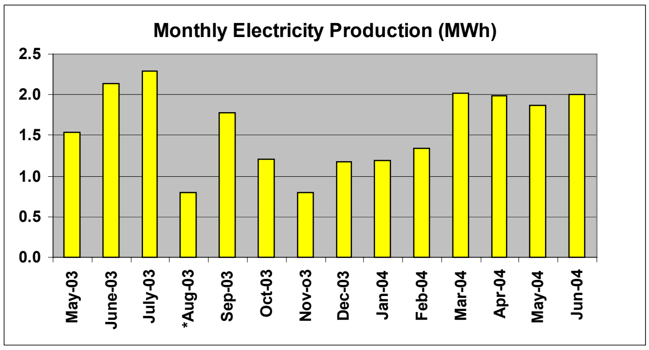

Figure 6. CRF Solar facade – monthly electricity production

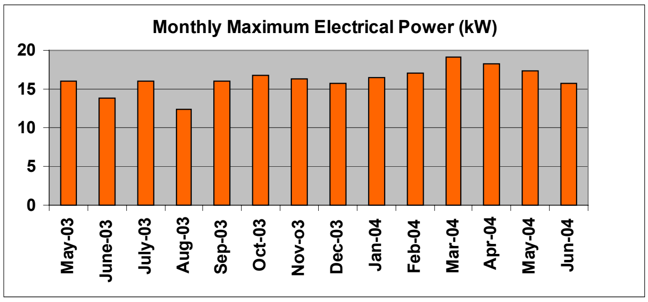

Figure 7. CRF Solar facade – monthly maximum electrical power

It is estimated that in this case, the performance is around 10% higher with respect to a traditional PV installation, thanks to the increment in electrical efficiency because of the ventilation of PV façade by circulating air beneath the PV cells.

The maximum monthly power output of the PV element is shown is figure 7. It is evident from the figure that the PV plant operates very well and many times also reach at the peak power (March 2004).

The monitoring data regarding the thermal performance of the system is not presented here. It is because of the fact that the temperature sensors for monitoring of the collector air outlet temperature seems to provide inaccurate values sometimes. Therefore, an error analysis has to be made before carrying out a detailed data analysis. However, an estimation was made, using the simulation model (Aste *et al.*, 2003 and Adhikari *et al.*, 2003), developed by Politecnico di Milano, for thermal and electrical performances of hybrid façade, and the monthly results are shown in figure 8.

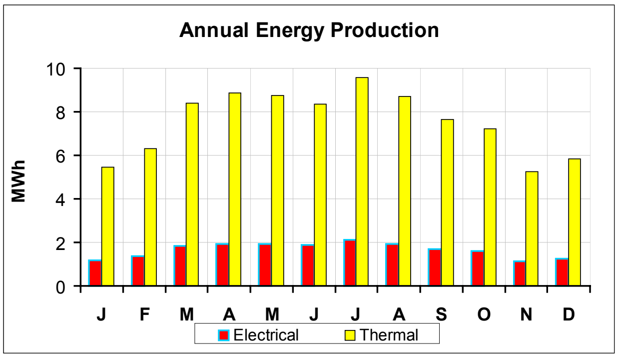

Figure 8. CRF Solar facade – estimated monthly thermal and electrical energy production

It is estimated that the hybrid façade at CRF is able to produce about 20 MWh of electricity and 100 MWh of thermal energy annually. The calculation of electricity production takes in to account the inverter efficiency of 95%. Further, the model also takes into account all the electrical and thermal losses in the system with respect to the studies carried out previously.

5. CONCLUSIONS

The hybrid façade of the *Ecomensa* project at Fiat Research Centre is an example of the integration of hybrid PV-T system as an innovative building component for energy savings and environmental protection. The main advanced features of the hybrid façade represent the exploitation of produced electricity as well as the recovered heat. In particular, it shows the possibility of the use of warm/hot air in the summer period, which otherwise, in analogous realizations, dissipated to the atmosphere. According to the estimation made, and also revealed from the first set of monitored data, the annual production of electricity and heat from the hybrid façade contributes to a total primary energy savings of about 185 MWh, corresponding to 36 tons of CO_2 emission reduction to the atmosphere annually.

Further, it was estimated that the project *Ecomensa*, as a whole, could contribute a considerable amount of environmental benefits, achieving an energy saving of about 398 MWh and the emission reduction of 75 tons of CO_2, annually. Moreover, the energy saving obtained also contributes an added value to the project with the improvement of service quality offered to the user, as previous (old) system had not an option to dehumidify the air.

The shown figures illustrate undoubtedly the effectiveness of this realization in the field of building integrated photovoltaic-thermal hybrid systems, currently the largest in Italy and among the largest ones in the world. This type of realization, based on the interaction between university and industry, provide the possibilities to demonstrate the feasibility and to disclose the relative knowledge to the technological innovation and its application potential.

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