Distributed energy generation: case study of a mountain school campus in Italy

M. Anderlini, L. de Santoli & F. Fraticelli
Department CITERA, University of Rome, Italy

Abstract

Distributed energy generation is a technologically feasible reality. That requires rethinking buildings as nodes in a network for energy production and utilization and implementing best strategies according to the characteristics of the site. This paper concerns an ecologically sustainable school campus in the city of Contigliano (Rieti, Italy) that has specific environmental characters. Climate in the valley is continental: very cold in winter (which lasts 140 days) and hot in summer with wide temperature ranges. For this reason the valley records the lowest temperatures in Italy during the period from April to September. The research was carried out considering envelope characteristics, infrastructures and available renewable energy sources, taking into account the economic and environmental impacts with a particular attention to CO_2 emissions reduced by 93% if compared with traditional systems. The project of the school complex was analyzed by energy analysis. This has led to excellent results with a significant reduction of greenhouse gas emissions and a considerable reduction of energy consumption.

1 Introduction

Since the beginning of the Industrial Revolution, the atmospheric concentration of carbon dioxin has increased by 30%, concentration of methane is more than twice and the concentration of N_2O has increased by 15%. In addition, recent data show that the increasing speed concentrations of this gas, despite being low during the first part of the 90s, now are comparable at the high concentrations of the 80s.

WIT Transactions on Ecology and The Environment, Vol 173, © 2013 WIT Press
www.witpress.com, ISSN 1743-3541 (on-line)
doi:10.2495/SDP130451

In developed countries, the fossil fuel used for cars, for the heating flat and as alimentation of a lot of power stations are responsible for 95% of carbon emission, 20% of methane and 15% of N_2O.

The growth of soil depletion, industrial production and mining activities, contribute to the emissions in the atmosphere. Deforestation has an important role in the increment of CO_2 concentration, because plants can reduce the percentage of CO_2 with the process of photosynthesis. Vegetal respiration and decomposition of organic matter release in the air a quantity of CO_2 10 times higher than human activities; that emissions were balanced with photosynthesis and absorption by oceans.

If the global carbon emission will be the same of last years, atmospheric concentration will reach the value of 500 ppm until the end of this century, a value that is almost twice than the pre-industrial value (280 ppm). The problem is bigger because greenhouse gases can remain in the atmosphere for hundreds years.

For the energetic production, Italy consumes as much gas as Latin America. Our consumptions are equal to the total consumptions of Turkey, Poland, Romania and Austria all together: 59 millions of people that consume as 138 millions people. Of the all energy that we need, we product only 12%, for the remaining 88% we depend on other countries. Of this 88%, 76% is produced with the importation of gas, petroleum and coal and the other 12% bought from adjacent countries and produced by an equivalent of 8 nuclear plants. So in Italy, energy costs 30% more than other countries. In 2011, energetic demand is reduced by 0.5%, from 184 to 178.4 Mtep, relative to the last year. It has recorded a loss for gas (-4%), importation of electric power (-4.5%) petroleum (-1.4%). At the same time there was an increment of demand for solid fuel (+9.2%) and renewable sources (+8.1%).

During 2010, photovoltaic plants in Italy increased by 215% (84.777 photovoltaic plants installed) and increased by 314% in terms of power (2.4 GW). During the last period this field is amazingly increased; reaching on 10^{th} April 2012, 13.06 GW for a total of 343,433 photovoltaic plants; reaching and exceeding the 12 GWP installed in 2011 photovoltaic covered 3% of electric demand in Italy, with the possibility of reaching 5.5% in 2012.

2 Italian School architecture

For a rapid description of the Italian School architecture situation, we refer to the Legambiente dossier [1], called "*ecosistema scuola*", which is an analysis instrument of the Italian School situation. With this report it is possible to evaluate and analyse data from the main cities about the quality of the structures, first and secondary school.

Legambiente's report is anything but comforting; it is strongly necessary to invest on emergency maintenance, because more than 30% of the structures need urgent interventions of maintenance.

Six schools out of ten have been built before 1974 and there is an incredible difference between North and South Italy: only 50% of South Italy's buildings have been built after 1974, in the central part of Italy the percentage is 42% and in the North, 31%.

Positive data are derived from energy conservation: the number of the schools that use low consumption illumination is increased, in the last 4 years, from 45% to 65%, in addition thanks to “Il Sole e la Scuola” there has been an awareness campaign.

From the surveys, the most active region in this program is Sicily with 80 schools, follow to Lazio, Abruzzo and Puglia with 60 schools.

In Italy will have the reduction of working expenses and make improvements to school’s structures thanks to the project “Nuovo piano di edilizia scolastica”, approved by Cipe according to the propose of “Ministero delle infrastrutture e dei trasporti”,” Ministro dell’economia e delle finanze” and the “Ministro dell’istruzione, dell’università e della ricerca”.

Once this plan will be effective, the schools will have 2 years for refurbish their structures, respecting specific technical index (art. 52).

With this measure, Italy will adapt to European standard, aligning the Country with specific laws on maximum and minimum index of energetic efficiency [2].

3 Specific situation of Rieti

The province of Rieti is an Italian province of region Lazio of 160,467 inhabitants whose capital Rieti. It covers an area of 2,749.16 km^2 and includes 73 municipalities. Founded in 1927 it is, together with Latina, one of the youngest Italian provinces. It born, therefore, as a result of a long process of gathering historical and political consolidated over time - such was the case for many of the provinces of Lombardy boasting a long tradition of such federation - but rather a result of an act that brought together an archipelago of municipalities and territories with very different histories and social identities, cultural traditions, by natural gravitation, dialects, customs and lifestyles.

Another anomaly in the province of Rieti lies in the fact that it was lapped only marginally from that vast process of industrialization and urbanization that has characterized the development stage of quantitative analysis of the 50s and 70s. This process has greatly changed the economic and social postwar background in Italy.

The climate is continental capital of the valley: very cold in the winter (which lasts 140 days) and high temperature during summer season, with large temperature ranges, which make the province under consideration the first of the Italian provinces with the lowest minimum temperatures during the period from April to September. Rainfall exceeds 1,000 mm annually; with two maxima, the largest in autumn and a secondary one in late spring. There is mist occasionally but rarely persistent for the entire day.

More rare snowfall in the valley, mainly with movement from the north-west, while the surrounding hills are numerous. There are also frequent summer thunderstorms. In 2008 average annual temperature +12.7°C, absolute minimum -10.3°C, absolute maximum +35.4°C, rainfall 1411.2 mm of rain in 106 days, average daily excursion 13.9°C, moderate excursion in August 19.2°C, 3 months (January, February and December) with average minimum temperatures below zero degrees, seven months without frost, maximum temperature of the coldest day of +3.3°C, minimum temperature of the hottest day +17.8°C [17]. The winter in Contigliano lasts about 4 months. Record cold in 1956 and 1985, respectively, -20°C and -18°C. The summer has an average life span of a hundred days.

4 Analysis of current situation

The research has touched every aspect of the educational sector in the city of Contigliano and the following paragraph describes the results of statistical-descriptive analysis and the current quality of the old school campus. In the following we will highlight the critical factors divided into 3 groups according to: technical-administrative analysis, technical and environmental analysis and energy performance analysis.

In the first one, a comparison is made between the current legislation and regulations applicable at the time of implementation, in particular the regulations being studied are L.5 August 1975, n. 412 and the l. January 11, 1996, n. 23.

In the analysis has not found a strong innovation on the part of the 1996 Act in that it takes into account purely economic and financial aspects for local authorities, ignoring current issues including the functional and morphological appearance of the building as a whole. The complex in question appears to be

Primary school

Secondary school

Figure 1: The school living complex.

devoid of a structure to accommodate the school canteen to the appropriate legislation. From the functional point of view the plexus results to be made according to a horizontal structure which faces the various classrooms, are also provided for the central areas of the collective, all in a view of the 60s.

The analysis has led to technical and environmental results for the critical noise impact due to the high intensity of vehicular passing just below the school structure in the early hours of the day. The school complex of Contigliano was built around the 60s so in the absence of energy legislation, especially it refers to the Law 10/91 and Decree 192/05 as amended [3] establishing the criteria, conditions and ways to improve the energy performance of buildings in order to facilitate the development, enhancement and integration of renewable sources and energy diversification, help to achieve the national targets for limiting greenhouse gas greenhouse set by the Kyoto Protocol and European legislation known as 20-20-20, to promote the competitiveness of the sectors by developing more advanced technology. Not taking into account the regulations in force in the school campus are to be present sanitation situation is not sufficient to ensure an acceptable level of learning capacity of the areas.

5 Description of site and description of intervention

The research was developed based on a design from scratch of a school campus to serve Contigliano and Greccio. This requirement stems from a feasibility study developed upstream of where research has evaluated the ability to adapt structurally and energetically, the old school facilities or change the intended use and convert them to office or to build a new school edge trying to achieve goals of building passive. The latter solution was the most advantageous from the standpoint of economic, regulatory and energy.

The study area is located in the municipality of Contigliano and more specifically in the area east of the old city in front of the train station that connects the town with neighboring countries and cities like Rieti, Terni and L'Aquila.

The research is geared to design scenarios for the realization of the new school complex and sustainable urban redevelopment, with the definition of the

Figure 2: Site location.

new urban edge of the city and the creation of public spaces to serve the sporting and cultural communities. The area is characterized by wide open spaces and buildings scattered expands to an area of about two hectares, from the east is the railway station from where the main road that leads through the town, the historic village. To the north of the lot there is a nursing home and a series of residential and commercial buildings to no higher than 3 floors. On the opposite side there is a sports and entertainment complex that lies on the axis leading to the main urban center of the town, which are aligned along the newly built residential buildings. On the west side of the opening scene of the beautiful historic village of Contigliano. The study area is presented as a site with excellent potential to build a place characterized by a strong identity and a high quality urban area.

A predominant factor that significantly affects the microclimate of the site chosen is the sunshine of the area, particularly the sides that slope in directions between southeast and southwest. The analysis has resulted in important basic data for the purposes of architectural design, as the zenith angle of the sun, according to the latitude where we are, is a parameter characterizing strong and together with the analysis of the wind allows us to create characterization of distribution spaces in our buildings for optimum comfort environment. To do this you must plan taking into account the zenith angle of the sun, the latitude of the place under study, equivalent to 72.00° and 24° in summer and winter [4]. The indication of the considered against the zenith angle of the sun is to have an excess of energy due to radiation during the summer; this situation is easily solved through the use of solar shading systems that allow the reduction of irradiation within the living space in summer. To take full advantage of solar energy incident on the site were used in an active and a passive one. The active system used is a photovoltaic system capable of ensuring electrical energy sufficient to power the heat pump, which is necessary to ensure the thermal requirements of the interior, and provide electricity to meet the needs of the electrical structure, while for the passive system has made use of a greenhouse bioclimatic control of hygrothermal flows through the building, aimed at improving home comfort and to reduce energy consumption: physically consists of a glazed area, located adjacent to the building and living in some periods of the year, which contributes to the heating and cooling of spaces occupied by humans. Below will be described the analytical results obtained for the different technologies used.

6 Solar greenhouse

These solar systems for environmental control are based on the use of renewable energies, mainly solar radiation to help control the environmental conditions of space with the aim of reducing energy consumption and improve comfort such systems are called passive solar systems to distinguish from the active solar systems which require auxiliary energy for operation, mainly used for the circulation of the fluid. In the case study you are working in a site characterized, in winter, just to be clear days or high frequency of overcast days while estete

warm and sunny days, so it is useful to evaluate the contribution of scattered radiation. Looking at the climate data of Contigliano is known as in winter the average monthly contribution of scattered radiation on a horizontal plane is roughly equivalent to the contribution paid by direct radiation. An analysis carried out shows there is the advantage of having a transparent cover for the purposes of an increased uptake, compared to several disadvantages including:
-a greater heat loss greater radiation;
-night summer internal in conclusion.

An opaque cover has been adopted to decrease the dispersions at night and the glass area has been increased between the heated room and the greenhouse to increase the lighting comfort of a heated room.

In scenario planning, there are three different types of solar greenhouse, for reasons related to the architectural structure also opposite to the passive structures has created a body of water which can cool the air. Figure 3 shows a plan with the localization of the three types.

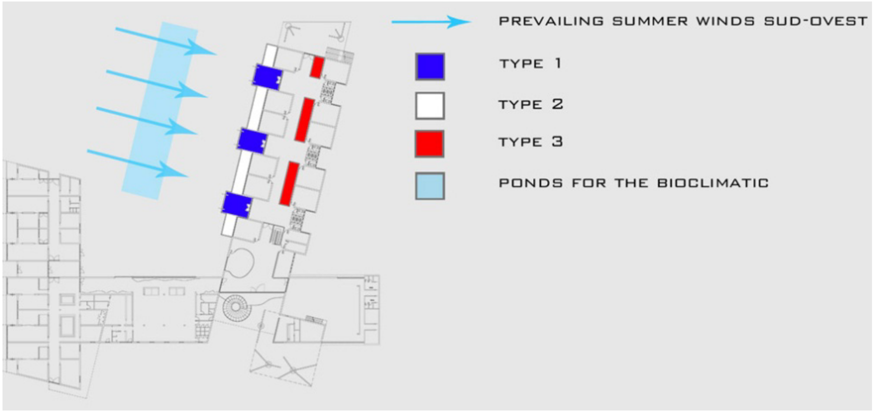

Figure 3: Position of the green house.

The third type is a solar greenhouse that is able to ensure internal levels of environmental comfort of the classrooms facing north. In the classrooms it was deemed appropriate to exploit the effect of solar chimneys to allow air inside the classrooms, in so doing has made an energy-economic benefits by reducing the energy demand for summer air conditioning.

The estimate of the benefit of a greenhouse can be developed with simulation software under thermodynamic variable which have the advantage of providing data simulated microclimate inside the greenhouse, hour by hour, on the basis of detailed climatic database. The disadvantage of these systems is the complexity of use which would result in many detailed while if they are used with other methods developed a calculation easier steady using average climate data and ignoring the fluid dynamic phenomena involved are reached acceptable results.

The software used are a transposition in the form of an automatic spreadsheet UNI EN 832 2001 and Method 5000 [5]. Both allow you to evaluate the energy

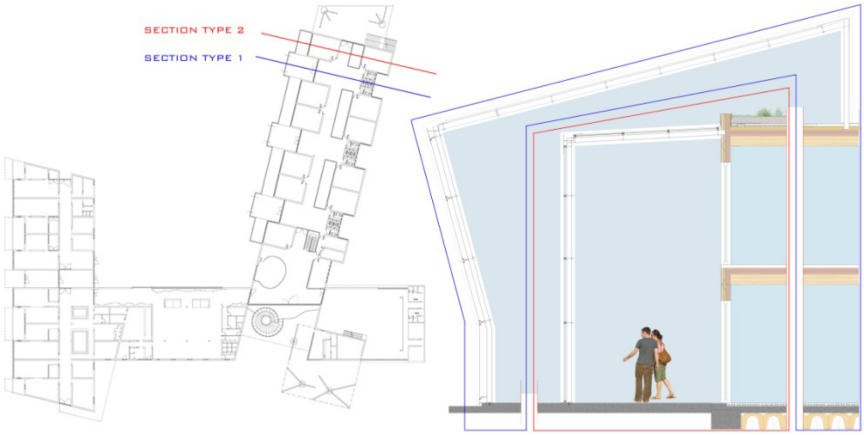

Figure 4: Section of the green house – type 1 and type 2.

contribution of the greenhouse so steady for the winter months but with software you will study the dynamics of the fluid mass of air inside the greenhouse so that it may have, in the summer, good ventilation to its procedure that ensures a high thermal comfort for users. Analysis conducted in the area identified by the greenhouse effect has led to temperature-humidity conditions to ensure it is acceptable to the occupants can enjoy a comfortable area of the building during sunny winter days.

In order to reduce overheating in summer some solutions have been prepared:

- glazed opening, controlled by appropriate sensors, to provide for heat dissipation,
- installation of semi-transparent PV panels and photovoltaic cells that serve as screens during the middle of summer days and spring.

The system allows a certain accumulation of heat due to the large glass area and its operation from the solar collector, although obviously low heat capacity. the solar radiation absorbed by the floor, or any other opaque surface, is stored and outputted based on the characteristics of emissivity of the various surfaces and to the thermal inertia of the components. Here are the results in the form of images, produced by the fluid flow analysis software GID. Fluid from the analysis carried out it has been noted how the design of the type 2 does not create air zone stagnated in all its height, while for the greenhouse 1 has been necessary to install a grid of ventilation on the balcony, the first floor, to prevent it would create an area where air stagnation, while the type 3 occurred the proper establishment of the effect of fire inside classrooms located to the north, in order to ensure a climate of spring and autumn. In addition to this analysis has verified the correct sizing of the transom windows, placed inside the northern classrooms.

The simulation results show that, in winter, the temperatures inside the greenhouse following the trend for the outdoor and are higher by 3–4°C. The only data that might seem strange is the low energy advantage brought about by the greenhouse building in October, this is because the simulation takes into

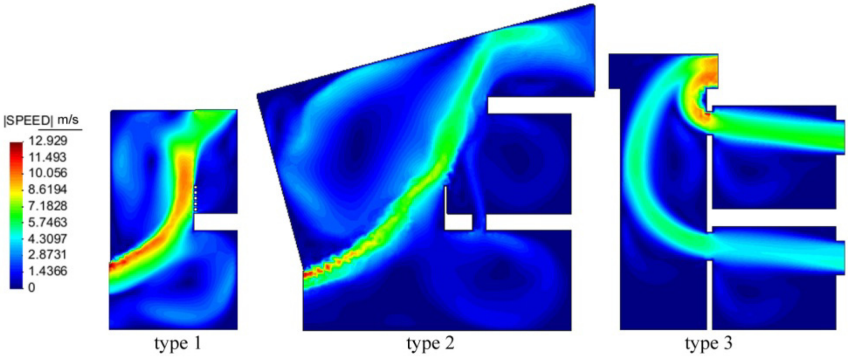

Figure 5: Computational fluid dynamics of the greenhouse.

account the thermal inertia accumulated during the summer months and sold in the autumn so the advantage of the greenhouse is lowered considerably. In conclusion, considering the size of the greenhouse and the surface of the classrooms means less greenhouse heat loss to the outside and bring benefits to the building adjacent to substantial energy.

7 Heat pump and distribution of heat

In conclusion, considering the size of the greenhouse and the surface of the classrooms means less greenhouse heat loss to the outside and bring benefits to the building adjacent to substantial energy.

For the system of generation of heat, we have chosen a solution to the geothermal heat pump energy supplied by electricity from solar photovoltaic panels positioned above the roof of the school structure. This choice was made primarily for the hours of use of school facilities, which are 8:00 AM to 4:00 PM. For this reason it was decided to exploit the effect to produce electricity with photovoltaic power a geothermal heat pump in order to have a high value of energy efficiency and cede most of the electricity to neighboring users.

In the first part of the research was a study for the evaluation of energy can be drawn from underground through the study of stratigraphic and energy characteristics of the subsoil and the definition of the heat exchanger more suited for taking energy. The second part is identified, the heat pump fitter in synergy with thermal calculations necessary for the identification of potential, estimated hours of machine operation on an annual basis, design of distribution systems between soil hydraulic and thermal power plant and verification of the refrigeration cycle between school structure and the net uptake of energy in the subsurface.

In the third part the system of distribution of thermal energy within the building is identified.

The geological analysis has led to the construction of the stratigraphy that consists of 4 layers identified with the first layer of topsoil to 1.5 m, 12 m of limestone breccia with sharp corners in the clayey matrix, 1.5 m of brown clay dark of weak consistency and finally 12 m of limestone breccia with sharp corners in the sandy clay matrix. The aquifer is located at a depth of 15 m from ground level.

The distribution of geothermal systems with horizontal probes in the Italian territory is less than those with vertical probes. the reasons for this difference is mainly due to the limited availability of land at low prices in the vicinity of building sites and in the widespread conception of the project that this type of system is less efficient and handsome than that with vertical probes.

In the study of the design scenario of Contigliano's school campus, it was decided to proceed with an absorbing surface in horizontal closed loop geothermal because it is operating in an area free of water courses, this is to use a geothermal system in open circuit, and because it has wide open spaces in which to install the module surface horizontal and in the end because the material near the ground level has good energy parameters. The solution to geothermal probes horizontal, in contrast to the vertical, uses as an energy source a volume of soil of great extension but of little depth, the overall cost of excavation of the soil, which is necessary to prepare the area to the laying of the probes, is generally not significant compared to the installation of vertical probes, the implementation of horizontal probes is simple and requires no special technical skills. Obviously, the extension of the intercepting surface is proportional to the thermal power of the heat pump.

In the winter period the reference temperature of the first subsoil is variable between 4–6°C of less than about 6–8°C with respect to those occurring at depths greater. A heat source at a lower temperature than usual for the vertical systems, if exploited in the same manner, may result in a lower thermal efficiency of the geothermal heat pump. To overcome this problem, the systems of horizontal wells are designed, for the same thermal power, with a number of meters probe uptake greater than the equivalent vertical solutions. The efficiency of the heat exchange probe-soil is improved by increasing the total surface area of exchange. Given the low cost for the construction of the trench and the pipe for the supply of exchange plastic PEAD (high density expanded polyurethane) you can afford to oversize the field capturing, however, imposes limitations on its use in future use of these areas which will not be possible to build products, planting trees to tall buildings or schedule future.

For the calculation were used the following parameters: temperature of the water in the evaporator outlet, of 8 ° C and a thermal gradient of 5°C for the capacitor, while an outlet temperature of 45°C with a thermal gradient of 5°C it reaches a torque of 4.52 with a heat output of 345.63 kW and a power input of 43.66 kW. These results are obtained using the machine coolant water to water under reference dell'aermec NXW 750 D. For the calculation of the geothermal probe can use two methods: an analytical and a tabular, you use the analytical method is preferred because it is more accurate by taking into account the heat exchange at steady state and the amount of energy in the domain of groundwater uptake. In almost all of the literature used for the study of the feasibility of the geothermal sizing of geothermal probes uses the heat exchange relationship below [6].

$$Q = L\frac{(T_g - T_W)}{R} \tag{1}$$

Q = heat flow of fluid between single probe and the ground [k];
L = total length of the probe [m];
T_g = average temperature of the ground before installing the probe [k];
T_w = average temperature of the fluid in the probe [k];
R = thermal resistance of the soil per unit length of the probe [mK/W].

In the above formula the value of the subsurface temperature along the heat flow, are the main parameters of reference necessary for assessing the economic viability of a geothermal plant. At our latitudes this value is greater than the minimum winter temperatures and less of the maximum summer. The temperature of the fluid coming from the intercepting surface, which is sent to the heat pump allows to establish the yield of the latter, the thermal output is equal to the C.O.P. (coefficient of performance) = 4.82. The value of q to be used in the above formula is equal to the difference between the thermal power output and power input to the compressor; that difference in power is equal to 301.97 kW.

The average temperature that we find in our latitudes, and at a depth of 2.5 m is about 5°C. This data was obtained by a comparison between the different experiments carried out in the geothermal field and can be found in technical literature.

Obtaining the horizontal length of the probe, by the formula quoted above, and integrating the known data with the thermal calculations carried out with the software 10 to estimate the net electrical energy necessary for the operation of the compressor but also for the handling of fluids is obtained a length equal to about 14,350 linear meters of pipes to be laid inside the lot under study. Inside the school campus has decided to use a mixed system composed of channels of air to ensure clean air and radiant panels embedded in the floor to provide thermal comfort indoors. One of the clear advantages, radiant panels, it is the optimal temperature distribution within the environment, heat only at head height and avoid the feeling of cold feet, low temperatures also allow you to transfer heat to irradiation and not by convention avoiding the handling of hot air typical of radiator systems, and the consequent lifting of dust [7]. This type of heat emission maximizes the yield of the pampa of heat that has the maximum yield just in correspondence of low temperatures of operation of the radiant heating.

8 Photovoltaic plant

The first stage of the design consists in collecting a range of information on environmental and technical conditions of the site where the intervention will be realized. The first step is the inspection and it is known exactly how to install solar power at this stage will assess any logistical difficulties during the construction of environmental constraints and obstacles that could create shade.

The next step is to prepare a parametric study of the possible consumption for the entire school year and expand by acquiring the consumption of school buildings in the town of Contigliano and Rieti.

Obviously, in this calculation was considered the use of electrical devices other than low-consumption for which the new complex of the same size will have the lowest consumption. The numerical analysis has identified a predicted consumption of about 137,000 kWh to 70,000 kWh which must be added to power the heat pump. The plant has been split into two sections, one installed on the roof of the gym and the other on the roof of solar greenhouses. The plant located on the roof of the solar greenhouse is made up of 84 polycrystalline modules with peak power of 235 Wp, that plant can supply 272,000 kWh/year while the section located on the roof of the gym is also composed of 266 modules in polycrystalline from 235 Wp for a total year of electricity equal to 873,000 kWh.

This amount of energy is much higher than needed to power the school structure, the surplus energy will be distributed to users adjacent to the structure under study.

9 Conclusion

In conclusion we can say that the plan design of the school campus of Contigliano, falls into the category of passive house reaching a value of 0.1 kWh/sq m of annual energy requirements, this value was calculated by simulating energy the project the school campus of Contigliano. The diffusion of the passive house standard brings important and significant results for climate protection through rational use of fossil energy resources [8]. The very low power requirements of passive houses, allows the use of renewable sources not only as a supplement, but as the main source of energy throughout the year [9]. The large surplus of electricity generated by the photovoltaic means that the school acts as a power plant to neighboring users in order to create a system of distributed generation.

The plant subject of this discussion, given that it consists of photovoltaic panels and heat pump, results to have a lower environmental impact as regards the emission of carbon dioxide. Assuming to realize the school pole with traditional systems, we could create a structure capable of generating a quantity of carbon dioxide equal to 160 T/year while using the systems listed in the discussion is cut down by 90% the values of CO_2 emission reaching 12 T/year.

References

[1] XII Rapporto di Legambiente sulla qualità dell'edilizia scolastica, delle strutture e dei servizi, http://www.legambiente.it

[2] Calice, C., Clemente, C., De Santoli, L., Fraticelli, F., *Guidelines for the retrofit of the school building stock for sustainable urban regeneration of the city of Rome in Sustainable City VII*, *Urban regeneration and Sustainability*, Ecology and the Environment, Volume 155 WIT Press 2012, ISBN 978-1-84564-578-6.

[3] Decreto Legislativo 19 agosto 2005, n. 192, *Attuazione della direttiva 2002/91/CE relativa al rendimento energetico nell'edilizia.*
[4] De Santoli, L., Fraticelli F., Fornari, F., Planning the integration of new technologies for sustainability: case study of a school building's restoration project in Rome, in *ECO-Architecture III*, *Harmonization between architecture and nature* WIT Press, 2010, pp. 423–434, ISBN 9781845644307.
[5] Zappone C. *Serre Solare*, Sistemi Editoriali, 2009.
[6] Tornaghi M. *Geotermia*, Sistemi Editoriali, 2010.
[7] Dascalaki, E.G., Sermpetzoglou V.G., Energy performance and indoor environmental quality in Hellenic schools, *Energy and Buildings*, Volume 43, Issues 2–3, February–March 2011, Pages 718-727, ISSN 0378-7788.
[8] Rifkin J., *Economia all'idrogeno*, Mondadori, 2002.
[9] AA.VV. Edilizia scolastica ecocompatibile . *Il Progetto Sostenibile*, 17–18, Edicom, 2008.