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Energy and environmental monitoring of a school building deep energy renovation in Italy

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Abstract

The Tito M. Plauto school in Cesena is the Italian case study in the FP7 School of the Future project. Objective was the energy renovation of school buildings with high energy and indoor environment targets, to be demonstrated by monitoring before and after the retrofit. Measures involved envelope components and energy systems, including renewable. The energy monitoring started in January 2014 and included thermal and electricity uses; as well the electricity produced by the PV plant. Data were compared to those registered for the 2008-2010 period. The environmental quality was addressed by thermal comfort and CO_2 concentration instrumental monitoring.

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Keywords: Energy renovaation, existing buildings, energy efficient schools

1. Introduction

EU and national energy efficiency strategies recognize the building sector as the most important to reach the respective targets[1, 2, 3]. It is, however, necessary the stimulate the energy renovation of the existing stock and not focus on new building only, as explicitly indicated in [4]. The issue fully applies to Italy; the evolution of the building stock, in fact, indicates that the rate of new constructions accounted for about 0.5% in the last decade. Moreover most the existing buildings were constructed between 1950 and 1980, when the energy efficiency was practically neglected in the construction technology. The sector building stock includes 48275 public schools with

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close to 8 million students/pupils. Energy potentialities of school renovation are analyzed in the Italian strategy for the energy efficiency for building renovation. In the document a national aggregate figure for the school building stock is estimated: energy uses for space heating are 130 kWh/m2; electricity uses are 50 kWh/m2. Disaggregated data by climate and age can be found at local level. This value is relevant because the zone E is the most populated of the country and major responsible of national energy consumption in the building sector; moreover the case study presented in this paper is located in a zone E city.

According to the above figures In this framework and to the documented studies about the energy consumption in schools [5], actions aimed at demonstrating the potentialities of energy savings in school are important, this applies in particular for school buildings, since their educational purpose implies a major social responsibility. Therefore energy performance in this type of building is of great importance.

The School of the Future Project [6], funded by EU 7th Framework Program, is a collaborative and demonstration project, which implements several actions aimed at pursuing energy efficiency strategies ad measures in EU school building. The core activity is the energy renovation of 4 school buildings with top level targets:

- Reduction of heating consumption of factor 4 (75%), to be demonstrated by monitoring;
- Reduction of global energy consumption by factor 3 (67%), to be demonstrated by monitoring:
- Improvement of the indoor environmental quality.

This paper presents the results of the Italian demonstration building. The design and the definition of the energy measures are described in [7], here the energy and environmental monitoring carried during 2014 and to in 2015 are presented.

2. Building description and selected energy measures

The Italian case study of the School of the Future Project is the Tito Maccio Plauto school in Cesena, a municipality in the Emilia Romagna region, in the north-east of the country, with 2130 heating degree days, in base 20°C. The building was constructed in the late 1960', when no energy code for buildings were issued at national and local level. The whole structure has a net useful of 6,000 m^2 and a gross volume of 24,500 m^3. The school hosts 380- 400 pupils (age between 11 and 14), depending on the year; teachers and caretakers are about 40-50. The building consists of the school main block and the gym, connected by a common entrance.

The school block is "L" shaped and consist of three floors plus the basement. Laboratories and classrooms are east and south oriented; the side corridors are north and west oriented. The school block has one more wing with administration offices at the ground floor and a double-height music hall at the first floor. and has the typical layout of classrooms on one side and corridor on the other side. The gym consists of the hall and of the dressing rooms. Data related to the building envelope, the energy systems and the occupation profiles can be found in [7].

The energy consumptions and associated costs to be used as reference refer to a three years period (2008-2010) and they are: 87,902 Nm^3 and 59,786 € for the gas driven thermal uses; 69250 kWh and 12,347 € for the electric uses. The latter uses are for: lighting, heating system auxiliary services, other utility power uses. The space heating service covers practically all the thermal uses, being negligible the hot sanitary water consumption.

A number of measure to upgrade the performance of the envelope and the energy systems were selected during the design phase. The envelope measures include the insulation of: the roof, the part of the ground floor in contact with a not-heated space, the facades; all the windows were replaces and those in the classrooms were equipped with external shading devices to prevent overheating in the intermediate season. The heating systems was completely re-designed in terms of: generation (new modular condensing boiler), control (thermostatic valves on al radiators and boilers controlled by the ambient temperature and the indoor air temperature, registered in two reference classrooms), distribution (insulation of the primary loop pipes and segmentation of the original loops in several independent sub-loops). A mechanical ventilation system with heat recovery was designed to ensure adequate indoor air quality in those classrooms that were continuously used. A roof PV plant was designed to cover all the electric uses of the school.

3. The construction phase

The implementation of the energy measures came along with a continuous cooperation between the building owner (the Municipality of Cesena) and the school authorities, needed to exploit the potentialities of the renovation action. The design, in fact, also included the definition of new occupation profiles aiming at the optimization of the building use. The objective was an accurate organization of classes during the afternoon: selected rooms in selected days were made available, so that the heating service could be provided when and where it was actually needed. Merging behavioral and technological aspects avoided to heat up most of the building for many hours to assure the comfort conditions in few rooms for few hours. The construction phase took about two years and all the design measures were fully implemented. The main reasons that made the construction phase longer than expected were:

- Ensure the teaching continuity for the pupils, hence works had to be concentrated during the summer breaks and the classrooms were turned during the most invasive works, e.g. the insulation of the classrooms facades.
- The economic crisis had a strong impact on the company in charge of the works, so the works went through significant delays at different stages of the process.

The energy measures were completed by the end of January 2014, only the mechanical ventilation systems went until spring 2014. The latter required additional works related to architectural and technological restraints. Since it was not possible to have a single air handling unit for the whole building, five units with heat recovery units were installed in technical rooms. They were installed at each floor to serve groups of classrooms placed along the same corridor. Figure 1 shows part of the east façade before and after the renovation, features include: shading devices protecting the new windows; external insulation and finishing layer; removal of thermal bridges.

Fig. 1. Ground floor of the T. M. Plauto school.

4. Energy monitoring

The results refer to January 2014 - January 2015 period, even if the monitoring will run until October 201, starts of the heating season. The thermal results are expressed in terms of consumption coefficient CC, the parameter obtained as the ratio of the energy consumption on the product of the heated volume and the degree days – unit $kWh/m^3°K$, calculated in base 20°C. The school CC for the observation period is 66.2 and include space heating and sanitary hot water, which cannot be separated since there is only one gas counter installed. The expected performance for 2014 has to be lower than 16.5, to achieve the target in the worst condition. Here introduce the paper, and put a nomenclature if necessary, in a box with the same font size as the rest of the paper. The results are summarized in figure 2 and are obtained by reading of the gas counter during many days of the year (bullets in the graph). To be noted that the gas include a small consumption of hot water. The graph reports: CC calculated respect to the first day (black line); CC calculated respect to the previous reading (red line); gas consumption in cubic meters (blue line); energy target (green line). According to the graph it can be observed that the energy performance of the school was in line with the expectations during most part of the period, ad additional tuning of the system dropped the annual CC below 15, which means a thermal use reduction of about 78%. To be noted that the increase of the CC in summer is due to some energy consumption in a period with 49 degree days close.

Being the thermal uses during the period from April 16th to October 23th due to hot water uses only, it is possible to estimate a annual consumption of 3300 m3 for the latter. Subtracting this gas amount from the aggregated thermal uses the following CC are calculated: 61.7 for the reference building and 11.2 for the renovated configuration, thus a 82% space heating reduction is achieved.

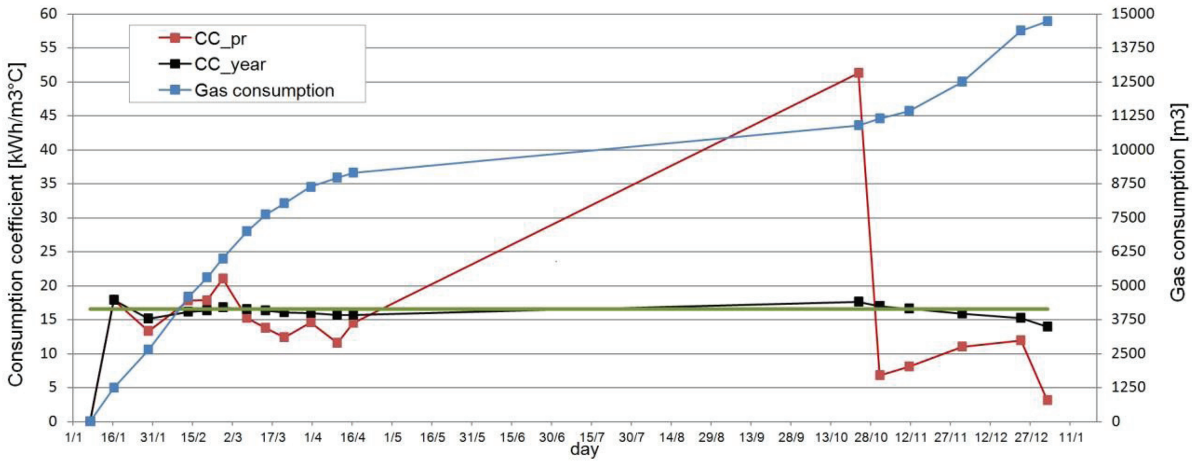

Fig. 2. Thermal uses evolution during 2014.

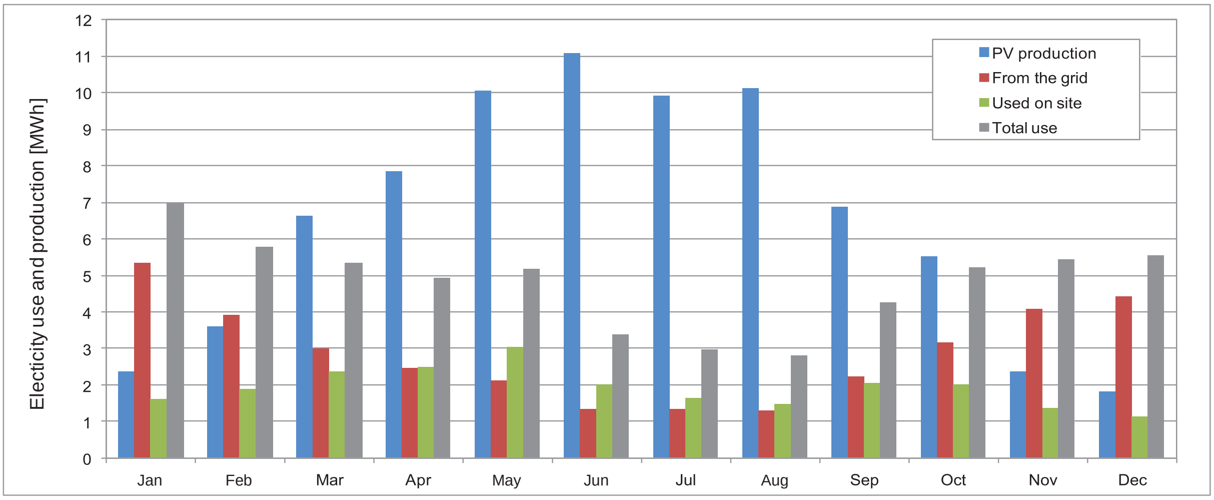

Fig. 3. Electricity uses evolution during 2014.

The building is now equipped with an electric management system, able to continuously analyze in real time all the energy fluxes: generation, on site consumption, electricity given to and taken from the grid. The system is equipped with grid analyzer with a 0.5% error. The data monitored during 2014 are summarized in figure 3 by monthly value histograms.

The energy produced by the PV system is 78.2 MWh; the energy globally used by the school for the electricity uses is 57.7 MWh, being 23 MWh auto produced and 34.7 MWh taken from the grid. A first main finding can be inferred: the electric energy uses drop by 17% respect to the consumption levels measured before the building renovation - this depends on the newly installed and more efficient auxiliary parts of the heating system (e.g. electronic pumps for the hydraulic loops), whose savings exceeds the penalty due to the daylighting availability reduction with the new windows. Another achievement is the electrify neutrality of school, being the electricity produced by the PV systems 35% more than that used by the building,

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5. Environmental monitoring

The environmental monitoring was carried during three days in January 2015, following the procedures applied for the monitoring before the energy renovation and documented in [8]. Six classrooms were monitored for a full typical day (7.30-13.00) and they were selected for different orientation, floor, occupation profile. The two monitoring stations were equipped to measures the following quantities:

- Air temperature (+/- 0.4 °C in the 0-50 °C range) ;
- Mean radiant temperature (+/- 0.5 °C in the 0-50 °C range) ;
- Air relative humidity (+/-2%) ;
- Air velocity (+/- 0.03 m/s) ;
- CO_2 concentration (+/- 50 ppm).

Sensors were placed at 110 cm from the floor and the data acquired with 1 minute time step. The environmental station was placed inside the classroom 120 cm away from the window and in the position that avoid any disturb to classes. Shading devices were activated to preserve the sensors from the solar direct radiation.

The thermal comfort was evaluated according to the procedures defined in [9]. The data showed a very stable thermal environment, the air temperature reached 20°C at 8.00 in the morning at the pupils entrance and the relative humidity was properly controlled by the mechanical ventilation system. The performance indicator PMV (predicted mean vote) fell in the comfort range (-0.5<PMV<0.5) in the six monitored classrooms. To be noted that such results were achieved during three critical days, the outdoor temperature was, in fact, below zero during the first two days early mornings.

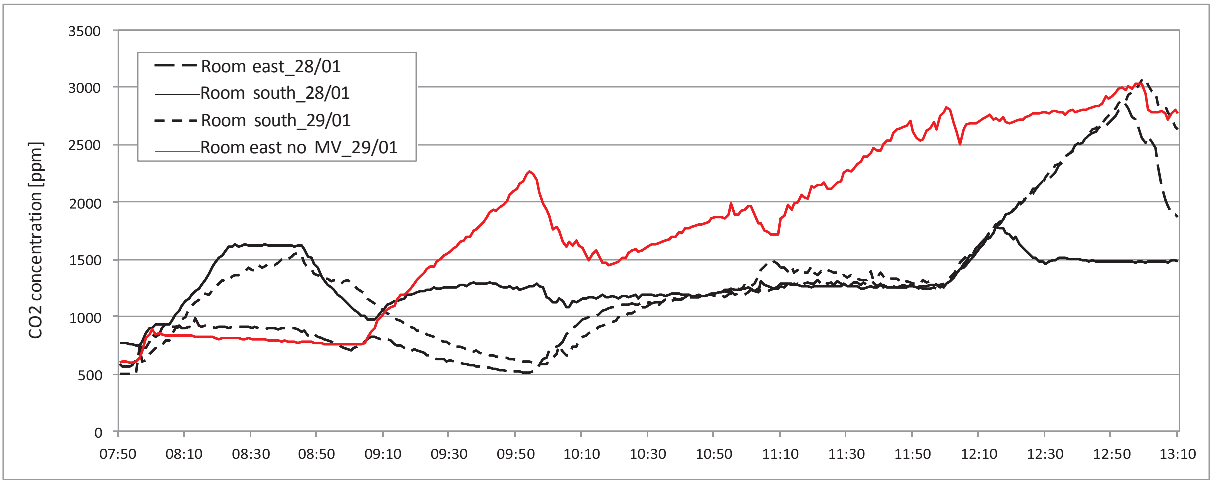

Fig. 4. Electricity uses evolution during 2014.

The CO_2 monitoring was an important task to check the indoor air quality after the renovation and the effective performance of the newly installed mechanical ventilation system. Due to architectural and technological restraints, the implementation of the system was limited to the continuously occupied classrooms, laboratories were also excluded. For the same reason, 5 decentralized units were installed in the restrooms instead of a single unit assisting the whole building. Exemplary results are presented in figure 4 and the plots show the time evolution of the CO_2 concentration in four classrooms. Black lines refer to rooms equipped with the mechanical ventilation systems, the red line is a classroom, whose ventilation is ensured by the window opening only.

The first thing to note is that the rooms are not continuously used; pupils move from the classrooms to the laboratories and to the gym during the day. The contribution of the ventilation can be easily inferred. The east oriented room with no mechanical ventilation has a CO_2 level that quickly reach 2000 ppm when the pupils are in, more over after two hours of continuous occupation the concentration reaches values up to 3000 ppm. Better results are obtained for the other three rooms, where the concentration is lower than 1500 ppm, except that in short limited period. The air supply was closed at 12.00 during the test days to evaluate the impact of the ventilation. The graph shows the quick rise of the CO_2concentration above 2500 ppm in the two classrooms occupied during the last class hour. Even if the CO_2exceeds the 1200 ppm suggested by [10], the environmental performances of the school by far improve those monitored before the renovation [8].

6. Conclusions

The results of the energy monitoring demonstrated the full achievement of the project target, space heating uses are reduced by more than 80% and the building achieved the electricity neutrality. The contribution of the sanitary hot water was extrapolated by measurements off heating season, so that it was possible disaggregating the thermal energy uses. The monitoring will continue until the end of April, so that a complete heating season will be monitored. The environmental monitoring carried out during the heating season demonstrated the full achievement of the thermal comfort. Another relevant result was the impact of the mechanical ventilation in assuring acceptable CO_2 concentrations in classrooms; conversely the same did not apply in classrooms ventilated only by window opening.

The paper documents the overall technological benefits of a deep energy renovation and the demonstration building be used as an exemplary case to spread the implementation of similar measures in a poor energy performing stock, as school buildings are.

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