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Retrofit of an existing school in Italy with high energy standards

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Abstract

The Tito Maccio Plauto school was built in Cesena during late sixties and, conformingly to the period construction technologies and standards, is characterized by poor energy performances. The retrofit of the school is implemented in the framework of the School of the Future Project, funded by 7th Framework Programme. The objective is demonstrating the technical economical feasibility of deep energy renovation for public buildings, bound to last several decades after, avoiding the land use for new construction and improving the energy performances of the existing building stock. The actual consumptions for the different energy services were monitored and the occupancy profile of the school zones was analyzed. Starting from the preliminary monitoring it was possible to design the most suitable energy to achieve the initial targets: reduction of factor 4 of space heating energy uses, reduction of factor 3 of the overall energy uses. The measures involved: external insulation of façades and roof, partial insulation of the ground floor, replacement of windows with external moveable shading devices, complete renovation of the heating system, design and installation of a remote energy management system for the municipality schools, installation of a PV plant on the roof, mechanical ventilation system for classrooms. The last measure was implemented to fulfill the improvement of the indoor environment quality, another crucial issues the EU Project had to couple with. Detailed analyses, carried out with dynamic and national reference calculation tools, demonstrated the efficacy of the implemented measures, since all the relevant target were reached, as will be monitored during the monitoring phase of the project.

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Keywords: Energy renovation, indoor environmental quality,bulding envelope materials and components.

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1. Introduction

Energy saving and efficiency in the building sector are one of the key issue to achieve environmental targets at national and EU levels [1, 2, 3]. The recent EU Directive [4] emphasizes the relevance of assessing the energy quality of buildings taking into account all the relevant energy uses, as well as the impact of the building renovation.

This issue is particularly true for Italy: the analysis of the building stock shows that: the rate of new constructions accounted for 0.5% in the last decade and the largest portion of the stock was built between 1950 and 1980, when the construction technology did not take into account energy efficient measures. It is also important noting that surveys on the safety of educational building stock carried out in Italy showed that the majority of those buildings do not have at least one among structural, sanitary or fire permits. The need of intervention on such a big number of school buildings to make them complying with the nationals laws, gives the opportunity to couple these mandatory actions with energy efficient measures. The energy refurbishment of the building stock is, as a consequence, one of the most important engines to reach the above mentioned national and EU objectives.

The School of the Future Project [5], funded by 7th Framework Program, aims at demonstrating the energy saving potentialities connected with the renovation of existing buildings with the improvement of indoor environmental conditions. The project implements a number of actions, the most important 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.

The European Commission also ask for economic effectiveness for the implementation of the needed energy measures and, as a consequence, provides a fixed fund of 100 €/m^2.

The project set the conditions to implement the first case in Italy of the full energy renovation of a not-residential existing building. Results and findings will provide relevant information about the potentialities and limits of the energy renovation in the country, taking into account energy, construction and economic issues.

2. Description of the building

The Italian case study of the School of the Future Project is the Tito Maccio Plauto secondary school in Cesena, a municipality of 100,00 inhabitants belonging to the Emilia Romagna region, in the north-east area of the country. The city with 2130 degree days, in base 20°C, belongs to the Class E in the national building climatic zoning, typical of the northern area of the country. Monthly mean air temperature and solar radiation, as recorded by the ENEA climatic data archive, are plotted in figure 1.

The building is located on the north-east part of the city, respect to the city centre, and it is part of a group of large school and tertiary buildings. This is a densely built area but the distance between adjacent buildings is sufficient to take advantage of the solar radiation on the building facades during the whole year. The building dates back to the 1960’, when no national or local codes for energy conservation in buildings were in force.

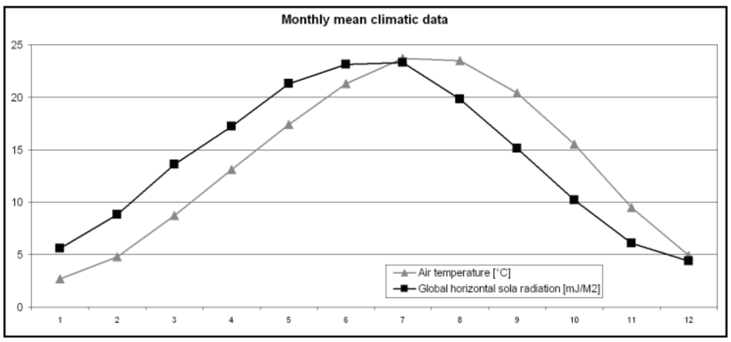

Figure 1. Cesena climatic data

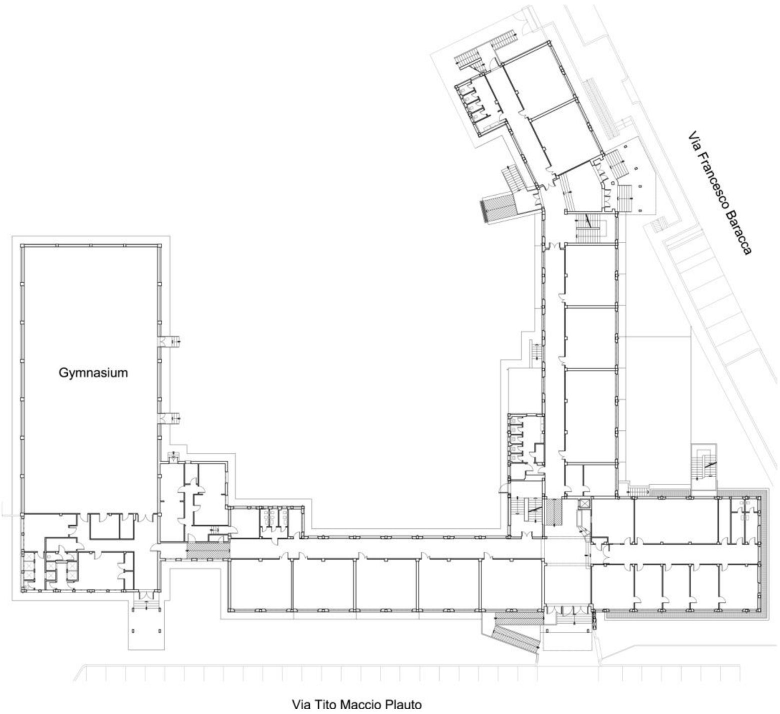

Figure 2. School ground floor (North up)

The whole structure has a gross surface of 6,400 m^2 and a gross volume of 24,500 m^3. The number of pupils varies from 380 to 400, depending on the year, and the adults are between 40 and 50, including teachers and caretakers. The building consists of the school main block and the gym hall, the two are connected by a common entrance. The main block is "L" shaped and has the typical layout of classrooms on one side and corridor on the other side. The administration area has the corridor between rooms/offices. The plan of the ground floor is in figure2. The school block consists of four floors:

- The basement floor is only in part utilized and there technical and music laboratories and the canteen are located; the remaining part is an unheated volume with high air exchange rate.
- The ground floor hosts classrooms, laboratories administration rooms. Also the former caretaker apartment is at the ground floor. This apartment is now used for recreational activities for elderly people.
- The first and the second floors host classrooms and a double height music/meeting hall at the first floor. The gym consists of the hall and of the dressing rooms.

2.1. Building and energy systems' characteristics

The building has the typical imprinting of the time 60/70'architecture: facade made in bricks (*in cortina*, as the technology is defined in Italy) and structure is in reinforced concrete in sight; only a minor area of it is plastered. Vertical walls are made of a double layer of bricks without any insulation. Windows are single glazed with thin iron frame, this provide very good daylighting but very poor thermal performances. Windows are equipped with internal venetian blinds manually operated for thermal and visual comfort. Windows are also characterized by a high air permeability, with consequent relevant air infiltration rates. U-values of the main envelope components, estimated by literature and inspection, are: main brick walls 1.9 W/m^{2}K; concrete pillars and beams 2.8 W/m^{2}K; brick walls (below radiators) 2.6 W/m^{2}K; attic floor 2.3 W/m^{2}K; ground floor 1.3 W/m^{2}K; windows 6 W/m^{2}K.

- The heating system of the school consists of the following parts:
- Two 385 kW gas boilers working in cascade. The boilers were installed in 1977, hence the technology is quite obsolete. The power provided by the boilers is a function of the outdoor temperature (climatic control): the lower the latter, the higher the power. The boiler also serves the sanitary hot water, which has also a dedicated system for the water purity treatment. The system has a 290 litres thermal buffer.
- The hot water is distributed through pipes running inside the walls or in the indoor. Pipes of the main loops are not insulated.
- The emission system consists of radiators in the school and heat convectors in the gym. Radiators are placed under the windows; high thermal losses take place through because of the thin not insulated external walls separating the radiators from the outdoor. High temperature convectors are installed in the gym.
- No room or zone temperature controls are installed.

The actual heating system has four secondary hydraulic loops, assisted by old constant speed pumps: classrooms and labs of the north/south; former janitor's apartment and gym locker rooms; block of canteen, offices and music hall; gym.

No mechanical ventilation system is installed and the air quality is ensured by manual opening of the windows during classrooms and daily cleaning, the amount of inlet fresh air cannot be adequately measured to check if complies with the minimum requirements. The lighting system consists of T8 fluorescent lamps installed in rooms, corridors and service area; no controls are installed.

2.2. Energy consumption and use

Energy consumption and costs for electricity and thermal energy are presented in table 1. The data refer to the last three years before the project kick-off, which started in January 2011. The reconstruction of the real consumption data was a complex task and required an accurate screening from different information sources; the definitive data were obtained crossing information coming from: the energy distributor data, meters' readings by energy system manager and meters' readings by the Cesena municipality staff. Only aggregated data are available, since no metering system for the different energy uses and services is actually installed in the school.

Table 1. An example of a table

Year	Thermal energy (m^3)	Cost (€)	Electricity (kWh)	Cost (€)
2010	100,098	67,888	76,342	14,390
2009	81,863	54,894	63,375	10,852
2008	81,747	56,577	68,031	11,800

The table shows that the average electricity consumption for the last three years is about 11 kWh/m^2 per year, the electricity uses are for appliances and artificial lighting. The average thermal energy consumption is: 129 kWh/m^2 and it is provided by natural gas; this amount of energy is practically in total used for the space heating, since periodic monitoring demonstrated that the consumptions for kitchen uses and the sanitary hot water almost negligible. Analyzing the energy consumption some considerations arise:

- The school is practically unused from end of May/early June until mid September. This implies that no cooling system is required in the school.
- Nevertheless the installed system is not high performing, lighting is not critical, since all the spaces, as well as the corridors, have large windows, which ensure good dalylighting.
- Sanitary hot water consumptions are negligible because the pupils and club members never use the showers of the gym after training.
- More than 90% of the school energy consumption is used for the space heating, because of the poor performances of both: the envelope and the installed systems.

Another issue affecting the energy performance of the school and the heating consumption, in particular, is the use of the building itself. The following zones are occupied in the building with different schedules:

- Classrooms – morning from Monday to Saturday from 08.00 to 13.00. Some labs are open all the working days but Saturdays in the afternoon from 14.00 to 17.00. some classrooms/labs are open two afternoons per week-
- Administration zone – morning from Monday to Saturday from 08.00 to 13.00, one room only is used during the afternoons by the caretakers. Randomly and rarely some rooms are used for teachers' meetings.
- Canteen in the basement – two hours per day at lunch time on Tuesday and Thursday.
- Music hall – partially used in the morning, it is used for curricular classes (theatre and music) in some afternoons and by city bands for rehearsals in some evenings.
- Gym – used by the school pupils in the morning and by sport clubs in the evening (depending on the day from 17.00 to 22.00). Randomly the gym is also open during the week end for the sport clubs' matches.

The above scheduling shows how articulated is the management of the school to provide the space heating service. It has also to be noted that unplanned activities, even if taking place in few classrooms, required the switching of the heating system in an entire thermal zone.

2.3. Notes on the building indoor environment

One of the objective of the School of the Future Project is the evaluation of the indoor environment and the demonstration of the positive impact that energy measures have of the environmental quality as well. In order to document this aspect a mobile micro-climatic station was equipped with several sensors (air and mean radiant temperature, air relative humidity and velocity, CO_2 concentration; additional air temperature were placed at different height from the floor) and the indoor environmental conditions were measured in several classrooms in early 2012, during a monitoring campaign carried out between mid January until the end of February. Spot measurements were also carried out to document the natural and electric lighting performance during the period.

Due to the poor performances of the building envelope and the obsolescence of the heating system, attention was paid on the thermal comfort of the classrooms, which are the zones of the building effectively and continuously occupied. The complete results will be published elsewhere, some data are following produced in order to document the actual performances of the school. A first issue to underline is that the station was mounted close to a shaded windows, since it was not possible to install it in the centre of the room during the classrooms. Due to the poor air tightness of the windows and the remote positioning respect to the room occupancy, the air relative humidity results to be lower than expected. This is evident in the red line figure 3, where this quantity is plotted for a south oriented classroom for 4 continuous days in January.

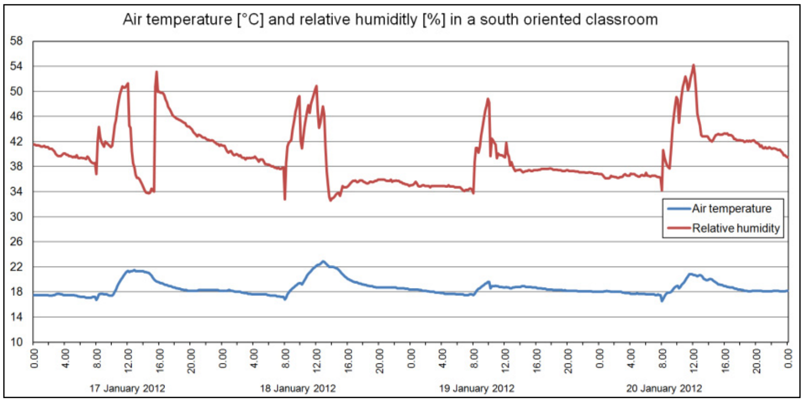

Figure 3. Air temperature and relative humidity in a south oriented classroom as monitored

The relative humidity hardly exceeds the 50% values in the morning when classes take place. The same figure presents the plot of the air temperature, plotted in blue, and a significant issue can be detected. The air temperature hardly reaches 18°C in the morning when the classes start and 20°C are reached not before 10.00, when the pupils are in the rooms since two hours. This result shows that the renovation of the schools is needed to improve the energy performances and also to ensure adequate environmental conditions for the building users.

3. Design criteria and measure

Starting from the analysis of the actual situation, the energy measures were addressed to optimize the most relevant energy service: the space heating. Measures were addressed to the increase of the building insulation and the air tightness, as well as the upgrade of the heating system.

In order to improve the energy conservation the following measures were selected: installation of new windows, insulation of the attic floor, insulation of the ground floor (only in the area corresponding to the unheated space in the basement) and insulation of the external north and west oriented walls of the school and of the whole walls of the gym. First calculation results carried out applying these hypotheses showed that the energy targets would have hardly met, as consequence it was decide to insulate all building the façades of the school, including the east and south oriented walls. This solution implied higher costs but was considered necessary to avoid the risks of not meeting the project requirements during the operational phase. Table 2 summarizes the U-value of the building envelope components after the application of the insulation layers. The table also provides information about the chosen technological solution. The ETICS solution was adopted for the school building facade, since this technique avoid most the thermal bridges due to the concrete beams and pillars. The same solution was not economically feasible for the gym, because of the extrados pillars and the internal insulation was chosen.

The design of the new windows was critical because of the impact they have on the energy, luminous and acoustics performances of the building, since they account for more than 30% of the facade surface. Several configurations were studied and the chosen solution is a double glazing unit with low-e coating and argon filled and a PVC frame. The U-value of the window depends on the configuration, being 1.2 W/m^2K for a typical window geometry; the g-value is 0.48 and the Luminous transmittance 70%.

In order to improve thermal comfort and avoid overheating during the intermediate seasons, external moveable and retractable horizontal lamellae will be installed in the classrooms (orientation south and east). It was decided to install products with a luminous reflectance not lower than 50% in order to provide adequate daylighting when in use.

Table 2. U-values of the building envelope components after renovation

Component	U-value (W/m^2K)	Technology
Brick wall façade including structure (28cm)	0.28	ETICS insulation layer of 12 and 10 cm. for (1) and (2)
Brick wall façade beside radiator (15 cm.)	0.30	ETICS insulation layer of 12 cm.
Attic	0.18	Mineral wool insulation (20 cm) placed directly on the attic floor
Floor versus the unheated basement	0.28	Polystyrene panels 10 cm.
Gym walls	0.31	Internal insulation made of mineral wool (10 cm.) and gypsum
Gym roof	0.20	Mineral wool internal insulation layer

Another important topic was how to deal with the window to wall thermal bridges. An insulation layer of 4 centimeters will be installed on the horizontal and vertical intradoses of the window and the new sill will consist made of a 4 centimeters insulation layer encased in aluminum. With this configuration the new window sash is not in contact with “cold” surfaces but with the insulation only.

Concerning the space heating, the first step was to ask the school management to plan the group the activities in single building zones as long as possible, avoiding a massive use of the heating system just to heat up few rooms. Once the school management re-designed the rooms distribution by activities, the heating systems was upgraded by the adoption of several measures. The main construction work was the creation of new hydraulic loops, able to serve independently the different thermal zones of the building. The attempt of meeting the school occupation profile led to the following zoning:

1. Classrooms and labs of the north/south line,
2. Classrooms and labs of the east/west line,
3. Laboratories in the basement,
4. Former caretakers apartment,

5. Classrooms mechanical ventilation system,
6. Canteen,
7. Offices,
8. Music hall.

Loops from 1 to 4 are physically separated. Circuits 5,6 and 7 are of single loop types but the zones will be autonomously controlled by temporized control able to switch on and off that part of the loop.

A new condensing boiler will be installed in the school building. It consists of the three boilers working in cascade, able to modulate the power according to the thermal load, with range from 13.4 to 215 kW. All the radiators will be equipped with thermo valves in order to achieve an accurate temperature control in the building zones. A couple of classrooms will be equipped with temperature sensors, in order to achieve an enhanced zone thermal control. The electric consumptions will also benefit from the installation of high efficiency electronic pumps serving the secondary loops.

The gym will be heated by a dedicated new condensing boiler, with a modulating power ranging from 14.4 to 84 kW. The old convectors will be used, in fact the operation at lower temperatures will continue ensuring enough power for the heating service because of the reduced energy demand of the gym block. Control will be based on the indoor temperature and will be of the on/off type.

In order to ensure an adequate air quality in a tighter and insulated building, some tests about the ventilation strategies were carried out, see results in the next chapter. The final decision was the installation of a mechanical balanced ventilation system will serve 23 classrooms regularly occupied, while the natural ventilation will be accurately programmed in the other building zones to ensure adequate IAQ levels. The mechanical system consists of five autonomous air treatment units, in order to minimize the air ducts' size, being this issue critical in existing buildings. The unit flow rates range from 1800 to 3250 m3/h according to the served volume; the recovery efficiencies (crossed heat flux) range from 77 to 80%. The units will be mounted in the floor storerooms (which are not regularly used) and each of them consists of:

- Hot water post-heating (always have to air at 20 ° C);
- Speed Switch;
- Double-filtration system of outside air.

Each unit will serve a group of class, close each other at the same floor, and the main duct will be placed below the corridor ceiling. The installed power of the unit fans in 4.3 kW in total. The mechanical ventilation system will be programmed to switch on and off according to the occupation schedules and the single units can be operated independently.

Taking advantage of national financial scheme, a PV system will be installed on the school roof. The plant will have a 64.68 kWp power and the technology will be mono-crystalline silicon photovoltaic. The modules will be installed on the roof and will take advantage of the actual roof tilt, without tilt optimization. The energy production on yearly basis is estimated in approximately 72,300 kWh. Comparing this figure with the available electricity consumption data and taking into account the installation of new fans and pumps, it is estimated that the school will be electricity neutral. The school performance will be continuously monitored through a building energy management system, which is already operating and able to control the energy behavior of a large number of schools in the Cesena Municipality area. The system includes new features dedicated to the metering of the Plauto School according to the difference energy use that take place in the building.

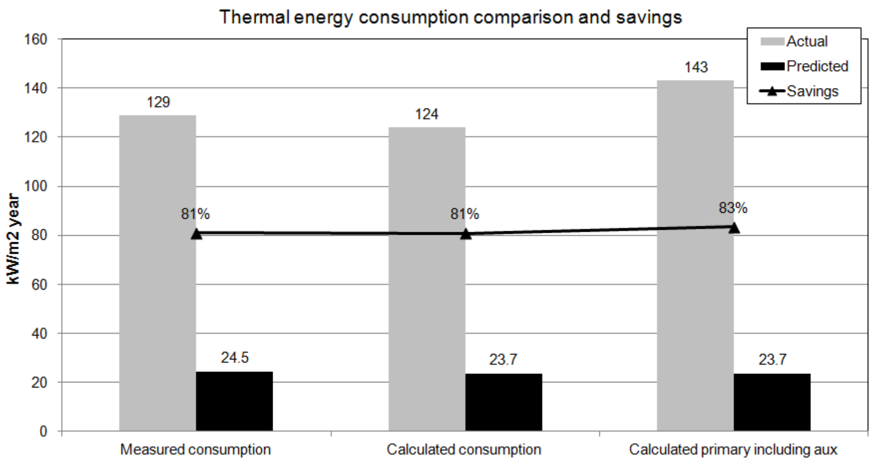

Figure 4. Predicted and measured energy consumption and savings

4. Calculation

Numerical analyses were carried out to support the implementation of the renovation measures described in the previous chapter. The objective was to test the viability of such measures and define their magnitude so that the school shall meet the target performances

4.1. Space heating calculation

Space heating account for most of the energy consumption of the building, detailed calculations were hence necessary for a reliable estimation of energy savings achievable with the insulation of the envelope and the renovation of energy and ventilation systems. The calculations were performed with a national certified software, based on the relevant national and international standards [6, 7, 8, 9]. The software allows the calculation of net, final energy and primary energy demand of buildings taking into account the following energy services: space heating, air ventilation/infiltration, sanitary hot water, electricity consumption for auxiliaries.

The school was modeled as a single zone in the actual condition and as a multi-zone after the renovation. The model was built with high accuracy taking into account the construction elements, the systems' performances and the occupancy profiles. The calculation results were compared versus the real thermal energy consumption, monitored during the previous three years. The final version of the model estimated a final energy consumption of 124 kW/m^2 per year versus a measured value of 129 kW/m^2 per year, with a difference of 4%. Once the base building was modeled, the impact of the energy measures was calculated.

For some components, as the windows, several solutions were tested, being several glazing units available on the market. An interesting result showed that the energy performance of the building did not improve if am extremely low U-values of the glazings were accompanied by a significant reduction of the solar factor.Figure 4 presents the result of the calculations: the reduction of the final thermal energy is estimated in 81%, the value rises to 83% for the primary energy, being the electricity for auxiliary completely covered by the PV system. The gas consumption is estimated to be reduced to 15 m^3 respect to the actual 90 km^3.

4.2. Ventilation calculation

The environmental quality was a relevant topic during the design process. The characteristics of the building ensured a good fresh air inlet by infiltration and natural ventilation, but the reduction of thermal losses and air infiltration might become a critical issue. Numerical analyses of different strategies were carried out to predict the environmental quality: 1. natural ventilation before renovation; 2. scheduled natural ventilation after renovation; 3. mechanical ventilation after renovation.

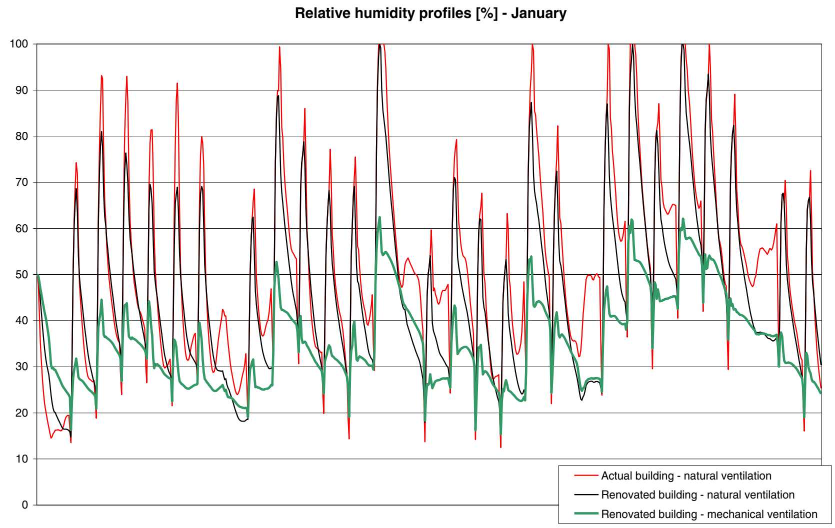

Figure 5. Relative humidity profiles for different configurations of the south oriented classrooms in January

Dynamic analyses were performed on the group of classrooms south oriented at the second floor. The software TRNSYS [7] was used for calculation, it is a calibrated calculation model based on a series of calculation routines linked each other to compose the main structure of the calculation project. The TRNSYS project implemented for this analysis included a model to evaluate the air exchanges for single side naturally ventilated spaces, as the tested classrooms are [8]. Standard and detailed windows' opening schedules were defined for the natural ventilation strategies.

Some results are presented in figure 5, where the relative humidity trends during January are plotted. The implementation of scheduled window opening (thin green line), 10 minutes during each hour class plus 30 minutes during the morning break, reduces the relative humidity respect to the actual building configuration (thin red line) but do not ensure adequate levels. Humidity levels above 70% are reached each day during several hours per day. To avoid unpleasant environmental conditions it was decided to install a mechanical ventilation system, whose airflow ensure adequate environmental conditions (thick green line).

5. First results

Part of the construction works was carried out during 2012. In particular, the installation of thermostatic valves as well as the insulation of the attic and the basement floor was not critical for the building use and the works were performed at various phases during the academic year. The insulation and the installation of new windows on the north and west oriented façades significantly interfere with the school activities and, for these reasons, carried out in summer 2012. The calculation results show that the actual consumption is reduced by 42% after the 2012 works, as shown in Table 3.

The implementation of this set of measure had an impact on the energy performance of buildings, monitored by simple readings of the gas counters of the heating systems. Attention was paid to the period between the first of November, starting of the heating season, and the 18th of December. The results are again in Table 3 where the monitored data are checked versus the energy performance achievable with the implemented measures and estimated with the reference climatic year. The comparison is performed through the Correction Consumption Coefficient, which expresses the energy consumption in kilojoules normalized respect to the building volume and the degree days of the zone. The comparison shows a good agreement between the monitored data and the estimated performances, being 10% the relative difference, and, as a consequence, the accuracy of the model implemented to predict the energy performances after renovation. Even if during a short monitoring period, the results show that the consumption data are underestimated respect to the calculation data, hence higher energy savings can be expected respect to the predicted ones.

Table 3. U-values of the building envelope components after renovation

Type of data	Consumption (m^3)	Degree Days (°Cday)	CCC (kJ/m^3°Cday)
Calculated for standard year – actual configuration	90900	2130	72.2
Calculated for standard year - after work 2012	52600	2130	41.9
Measured from 01/11/12 to 18/12/13	11526	518	37.4

6. Conclusions

The renovation of Tito Maccio Plauto school Cesena is the first ambitious Italian case of existing school building renovation. Several technicians were involved in the building design and construction in the effort of implementing those measures able to achieve the energy targets and provide an adequate environmental quality for the building users, and the pupils in particular. The task was challenging, since significant improvement were up taken for the building envelop, a complete redesign of the heating system, as well as the installation of a new mechanical ventilation systems were decided.

The design assessment show how the project targets will be met, achieving significant energy and economic savings. According to first monitored results, related to a partial implementation of the energy measures, the performances under operation are better than the design prediction. The energy consumption for space heating will be reduced by factor 4, while it is estimated that the building will become electricity neutral.

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