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A case study of Energy Efficiency Retrofit in social housing units

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Abstract

The always higher demand of social housing sets in the foreground the need to redevelop the estate public housing heritage, in order to deal with the emergency caused from the increasing requests by citizenry. Many of the social housing in Italy are often obsolete with inadequate conditions of comfort and high energy consumptions. The renovation of social housing provides an interesting opportunity for the reduction of energy consumption and increasing the comfort of residents. Improving the thermal insulation of the building envelope and introduce the use of renewable energy sources (RES), as solar thermal and PV systems, leads to energy savings and also increases the indoor comfort. This paper presents the energetic retrofit of a social housing units in view to reduce the building's energy need and increase the indoor thermal comfort. The research shows some preliminary results related to the reduction of the energy consumption obtained by means the designed interventions.

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Keywords: energy saving, social housing retrofit, renewable energy sources.

1. Introduction

1.1. Italian Regulation

Italy sets up the promotion of energy efficiency among the priorities of its national energy policy, at which it associates the achievement of security of energy supply, the reduction of energy costs for enterprises and citizens, the promotion of innovative technological production chains with the reduction

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of greenhouse gas emissions and environmental protection [1]. The transformations and innovations introduced by the current regulations on the energy efficiency of buildings, address the Italian Government and the Italian Regions towards the introduction of new standards, methodologies, new regulatory instruments for new buildings and for redevelopment, especially regards public buildings. In recent years, thanks to the decisive impulse of the EU, it has emerged the need to promote energy efficiency of the Member countries, considering the specific actions on energy efficiency as well as the size of economic and social development. In July 2007, Italy begun to comply with the National Action Plan for Energy Efficiency (PAEE 2007), in accordance with EU Directive 2006/32/EC, that proposed a significant number of measures to achieve the objectives of energy efficiency improvement and energy services. The same issues have been dealt, in accordance with EU Directive 2010/31/EC, with PAEE 2011, that remarked the role of energy efficiency as an essential tool for reducing consumption in with Member countries, the aim to reach the most ambitious target to reduce energy consumption at least 20% within 2020. At the same time, it was enacted the National Action Plan for Renewable Energy (PAN), in accordance with EU Directive .

Nomenclature

Y_{nm}	dynamic thermal transmittance (W/m^2K)
Y_{nn}	thermal admittance (W/m^2K)
λ	thermal conductivity ($W/m\cdot K$)
s	material thickness (cm)
R	thermal resistivity (m^2 K/W)
U	thermal transmittance (W/m^2K)
θ	temperature (°C)
n,m	thermal zone
f	decrement factor
T	time period (h)
Δt_Y	time lag (h)
q_m	heat flow rate (W/m^2)

2009/28/EC, providing guidelines for renewable energy sources. The impulse to improve energy efficiency in buildings has been provided mainly by the European Directive 2002/91/EC, known as the EPBD (Energy Performance of Buildings Directive), adopted with the aim of improving the energy performance of building sector for years recognized as one of the sectors that has the biggest consumption in end-use energy and the highest greenhouse gas emissions at European and National level. The matter is actual in Italy, as country with buildings characterized by poor energy performance [2]. The Directive has thus started off a series of actions and measures which, in our country, have led to an update of the national regulations. This Directive has been amended, then, by the new Directive 2010/31/EC which reinforces the objective of reducing fuel consumption and requires nearly zero energy needs for all new public and private buildings from 2020. In this scenario the Government and the Regions have issued laws and regulations aimed at achieving the maximum energy efficiency in buildings. Among the regulations, issued by the Ministry of Economic Development, there was the National Guidelines for the Buildings Certification (Decree 192/2005), in accordance with EU Directive 2002/91/EC on the energy performance of buildings, the Legislative Decree 115/08 enacted in accordance with EU Directive 2006/32/EC on energy end-use efficiency for energy services and Legislative Decree n.28 (3 March 2011) in accordance with Directive 2009/28/EC. The PAEE 2011 [3] has the target to ensure the implementation of energy efficiency programs. An examination of the current situation shows that the measures chosen will have immediate impacts in terms of ensuring the reduction of energy .The need to define interventions aimed at the redevelopment of this large segment of the housing stock is recognized and encouraged by a number of Italian instruments of integrated planning: PRU (Programs of Urban Renewal), PRIU (Urban Regeneration Programs), PRUSST (Urban Regeneration Programs and Sustainable Development Planning), District Contract I and II, which, since the 90s, have allowed to experiment with programming and managing tools of operations including large scale regeneration. Sustainable development and regeneration of degraded settlements are considered priority targets by the European Commission (Green Paper on Urban Development and Urban Community Intervention Programs 1 and 2) and, although with different approaches, many European countries are implementing actions to recover the settlement of social housing, with particular focus on energy efficiency and environmental sustainability [4].

2. The case study

The research group of Environmental Technical Physics [5] has set up an experimental program on maintenance and environmental restoration of social housing units located in Bronte city, in accordance with the innovative urban planning instrument called District Contracts II. The complex of building is located in a suburb area, called Sciarotta, of the Bronte city and was built between November 1978 and September 1981 by the Territorial Institution for Social Housing. The complex is made up of 54 apartments distributed in two buildings (width of the building about 11.00 m), with identical and symmetrical "L" shape, oriented with the longer side in the north-south constructed direction. Each building has four floors and an attic served by four stairs. The buildings are realized in reinforced concrete (RC) structure with an envelope in double brick walls. Windows are double-glazed with external shutters.

Fig. 1. social housing units

2.1. Methodology

The research was carried out according to the standard procedures on Energy Audit (EA) that apply to existing buildings (ANSI/ASHRAE/IESNA 100-2006) aiming to reduce energy usage. The EA process starts with forming an appropriate Energy Audit Team (EAT) that clearly specifies the audit scope. It is crucial for the researcher to look at the available resources to frame the time and budget for the audit and together all necessary building information before starting the audit [6-7].The EA three levels defined by the ASHRAE 100-2006 standard as the following level: 1) "walk-through assessment"; 2) "energy survey and analysis"; and 3) "detailed analysis of capital intensive modifications". The procedures leaving the EAT to make decisions on what data to gather and which improvements to evaluate. The results of conducting each level of energy audits should produce a list of Energy Conservation Opportunities (ECOs). The EAT have collected information about the building, conduct by site inspections and measurements, and analyse the data to complete the EA process. In order to characterize the energy performance of the as-built building the following investigations were carried out:

- visual and endoscopic inspections
- infrared thermographic survey of the building envelope [8] in order to verify the presence of thermal bridges, detect faults of thermal insulation, etc.
- thermofluximeter survey in order to determine the transmittance value of the external walls;
- survey of the outdoor meteorological conditions
- survey of indoor microclimate conditions to measure the following parameters: dry-bulb temperature, wet-bulb temperature, mean radiant temperature, humidity ratio and air velocity.

2.2. Visual and endoscopic inspection

The endoscopic inspection, carried out with a flexible tube optical fibre endoscope in order to identify the layers making up, gives the layers shown in Table 1. This information was useful to calculate, according to UNI EN 12831:2006, the theoretical values of the heat transmission rates (U_{Tante}) before the application of the external thermal insulation to the outside wall. The result of this calculus gives a value of the thermal transmittance U_{Tante}= 0.469 W/m^2 K.

2.3. Thermo-graphic survey

Subsequently, it was carried out a non-destructive analysis of the building envelope with an infrared thermo-camera type ThermaCAM B4- Flir. This study, along with theoretical and experimental values of the transmittances of the structures, has allowed determining the dispersions of the envelope and identifying the weakness points of the thermal insulation system of the building envelope. All the images of the infrared thermo-camera were recorded and then post-processed through specific dedicated software. Figure 2a shows an exemplum of the termo-graphic survey of the external envelope before the intervention of energy retrofit. The exemplum images clearly shows the beams and pillars that are characterized by a different temperature compared to that of the brick walls. In addition, it is possible to identify the rows of bricks and mortar between the bricks. Therefore, it is evident the discontinuity of materials that characterizes the building envelope: these discontinuities, as well known, cause the formation of thermal bridges which contribute to an increase of thermal dispersions.

2.4. Thermofluximeter survey

The thermal transmittance "U" can be determined by thermofluximeter equipment in function of the heat flow through the wall facade and the temperature difference across it. Thermofluximeter equipment, incorporating embedded thermocouple junctions, is designed to generate an emf signal proportional to the heat flow through the disk. The heat flux meter measures the heat current density (W/m^2), passing through each wall, and together with the recorded temperatures, enabled U-values to be determined. Since most building structures have a significant thermal mass, variations in internal or external temperatures lead to large fluctuations in the heat flow either into or out of the element. In steady state condition internal and external temperatures are constant, so it is easy determine an accurate U-value. In real cases, the steady state conditions do not occur, and it is necessary to evaluate the effect of the variations in temperatures and heat flows so that the U-value would be determined reliably. Measurements were carried out by a Thermozig heat flow meter; temperatures and heat flow were recorded in a data logger every 60 seconds and averaged over hourly intervals. For each session of measurement both temperatures and heat flows were monitored over several days. As in many cases the internal surface was uneven (e.g. wallpapers or pitted plasterboard surfaces) a substrate made of a silicone-clay compound was applied as a substrate to the heat flux meter in order to improve the thermal contact, and hence the accuracy of the measurements. Internal and external temperatures were measured using type T thermocouples coated with fresh solder to provide a low emissivity surface. The (hourly) average heat flows were compared with the corresponding internal and external temperatures in order to carry out the analysis and so determine the thermal transmittance. The U-value was then derived from the sum of the heat flow readings (expressed in W/m^2), with corrections for thermal storage effects, divided by the sum of the temperature difference readings (expressed in K) over the period of the test. The measurement period had to be sufficient that the change in the energy stored in the structure, between the beginning and the end of the measurement period, was relatively small in comparison with the energy that has flowed through the structure during that time. A measurement period of 14 days was considered adequate for the wall constructions which were studied. Successively, the dynamic properties of the building were then evaluated according to the admittance procedure by implementing in a Mathcad [9]code the calculation method reported in the international standard EN ISO 13786. In the admittance procedure two complex quantities are defined, namely a dynamic thermal transmittance Y_{nm} and thermal admittance Y_{nn}. Which represent the ratio of the complex amplitude of the density of the heat flow rate through the surface of the component adjacent to zone "m" to the complex amplitude of the temperature in zone "n", as it is shown in the following equation:

$$Y_{nm} = -\frac{q_m}{\theta_n} \tag{1}$$

With q_m is heat transfer rate density (W/m^2) of the thermal zone "m" and T is temperature (C) of thermal zone "n". Where the dynamic transmittance is given for n≠m and the admittance for n = m. The heat flow rate is assumed positive when entering the surface of the component. We consider that zone "n" is the outside environment and zone "m" the inside environment. Since Y_{nm} and Y_{nn} are complex numbers, each of them may be expressed by amplitude and a phase. Therefore, two parameters may be related to the dynamic thermal transmittance, namely the decrement factor f and the associated time lag Δt_Y that are defined as follows:

$$Y = |Y_{nm}| \tag{2}$$

$$\Delta t_y = \frac{T}{2\pi} \arg(Y_{nm}) \tag{3}$$

2.5. Surveys of the outdoor and indoor environmental conditions

Data loggers and different types of probes were used to carry out the following investigations: survey of the outdoor climate conditions using an external weather station that included hydro-thermal probe, wind speed and direction probe, solar radiation probes; survey of indoor environmental conditions using indoor microclimate stations with hydro-thermal probe and black-globe temperature probe. The surveys of the outdoor and indoor environmental were carried out in winter time for a period of 14 days, at the same time when the U-values were measured.

3. Programmed Interventions

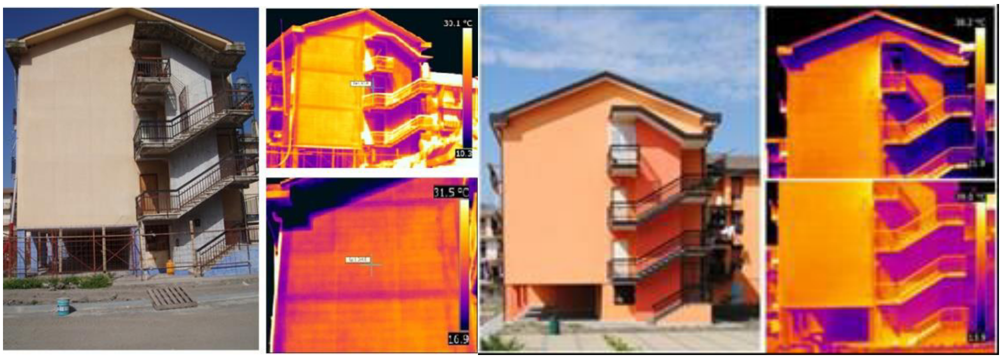
The general objective of the experimentation in progress is to obtain, considering limited extraordinary maintenance, an improvement of energy performance of the buildings [10,11] in full compliance with the available natural resources and ecosystems existing. The intervention program has been realized to achieve maximum environmental comfort for the users of the building and has been pursued with the use of materials and products with low energy consumption during their production, without toxic emissions during their life cycle, with easy maintainability and high recyclability at the end of their life cycle. The programmed interventions on energy and water savings have been the following:

- External thermal insulation composite system (ETICs) that offers the advantages to protect the fabric of the building, improves thermal performance, ensures consistent U-Values, reduces thermal bridging (minimizing condensation and heat loss), reduces thermal stress on the structure, transfers the dew point to outside the structural wall element, improves airtightness of the construction which reduces draughts and heat loss, optimises use of thermal mass (reducing internal temperature fluctuations), improves sound insulation, gives major aesthetic improvements. The exterior insulation system was made of graphite-enhanced EPS (thickness s=40 mm, thermal conductivity λ = 0.031W/mK).
- Centrally Solar Heating system (CSHs) which is a large solar collector integrated with a water-rock accumulation system that is one of the innovative solutions introduced. This system allows to heat or pre-heating the Domestic Hot Water (DHW) of each apartment's accumulation tank, and so offers the advantage of reducing the consumptions of fossil fuels for the energetic needs to produce DHW. In fact, the hot water heater of each apartment will be turned on only when the temperature inside the accumulation tank drops below the temperature set-point.
- Rainwater Harvesting System (RHS) provides an independent water supply, reduces demand on rivers and groundwater. The rainwater harvesting will be used solely for non-potable needs like toilet flushing, laundry washing and landscape irrigation.
- Photovoltaic System (PVs), architectonically integrated in the outdoor common space as a solar "tree", which will offer the advantages to retrain and light up the area with considerable renewable energy production.

To verify the quality of the interventions, the same non-destructive investigations were carried out after the retrofit intervention. As regards the diagnosis of the performance of the Solar Water Heating System, temperature sensors were installed in the boiler of each apartment; temperature and flux sensors in the exit pipe line and in the inlet pipe line of the storage solar system. Surveys of weather conditions were monitored using a meteorological observation system equipped with a solar meter to measure the beam solar radiation, air temperature, relative humidity and precipitation sensor. This last for monitoring the performance of the Rainwater Harvesting System (RHS). The meteorological observation system was programmed to record hourly data and was connected to a data-logger. The energy performances of the building were evaluated, before and after its energetic retrofit, calculating the Energy Utilization Index (EUI) using the Design Builder software [12], which is based on the well tested algorithms of Energy Plus.

4. Effectiveness of building retrofit

The improvement of energy performance, as a result of the proposed actions, were evaluated through numerous experimental analysis as well as the dynamic analysis of the thermal building behaviour carried out by means the software Design-Builder. The theoretical values of the heat transmission rates were calculated (according to UNI EN 12831:2006) before and after the application of the external thermal insulation to the outside wall. This comparison highlights a considerable reduction of the thermal transmittance from 0.470 to 0.319 W/m^{2}K, which produces a reduction of 32% of the thermal losses from the opaque components of the building envelope. Moreover, measurements were carried out to determine the U-values of the external facade before and after the application of the ETICs. These measurements were carried on two different locations of the external facade in order to assess the repeatability of the measurement and to provide a safeguard against equipment failure. In the following, the U-values measured in situ were compared with the calculated ones. Measured and calculated U-values of walls are in very good agreement. U-values were measured as 0.485W/m^{2}K before the retrofit and 0.314 W/m^{2}K after the retrofit, compared to calculate U-values of 0.470W/m^{2}K and 0.319 W/m^{2}K respectively. The comparison between thermo-graphic surveys, before and after the retrofit, shows the improvements of the thermal insulation of the building envelope achieved by the ETICs. After the laying of the ETICs, the thermal bridges were eliminated as showed in figure 2b.



(a) (b)

Fig. 2. Termo-graphic picture (a) before intervention of retrofit (b) after the laying of the ETICs

Another improvement consists in the increase of the thermal storage capacity of buildings. In table 1 are reported the values of the dynamic properties of the building before and after retrofit. It is noted that the performance of dynamic behaviour of the walls is improved with a positive increase of the phase shift and a greater attenuation of the thermal wave.

Table 1. thermal inertia properties according to ISO 13786:2007

	U [W/m²·K]	Y_{nm} [W/m²·K]	Δty [h]
Before Retrofit	0.485	0.193	9.0
AfterRetrofit	0.314	0.019	13.65

The value of the periodic thermal transmittance satisfies the Italian rules that impose a minimum limit value of Y_{nm} = 0.12 W/m²K. The comparison between results of thermo-graphic surveys, before and after the retrofit, shows the improvements of the thermal insulation of the building envelope achieved by the external thermal insulation coating system. In fact after the laying of the ETICs, the radiation pictures show thermal bridges were eliminated (figure 4). To evaluate the global effectiveness of the retrofit intervention it was calculated by Design Builder software the Energy Utilization Index before (EUI_{ante}) and after (EUI_{post}) the retrofit intervention. The following results were obtained: EUI_{ante} = 53.03 kWh/m^{2}y, and EUI_{post} = 30.46 kWh/m^{2}y, with a reduction of this index of about 42,5%. The achieved reduction of primary energy consumption is of about 9.50 MWh/y.

4.1. Centrally solar heating system (CSHs)

Centrally stored hot water preheated the DHW of each apartment, through an heat exchanger [13]. The system (figure 3) has a volume of 20 m^{3}with the solar collector of polycarbonate (τ=0.8) oriented to south (S=80.0 m^2, β=15°). Considering a need for DHW equal to 3.6 MWh, the system will cover 70% of the demand with a savings of 2.52 MWh.

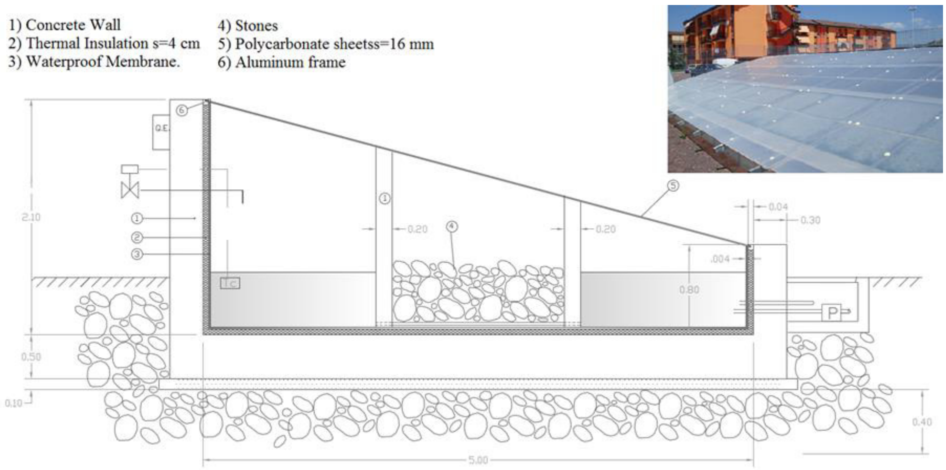


Fig. 3 centralized solar collector unit integrated with a water-rock bed storage

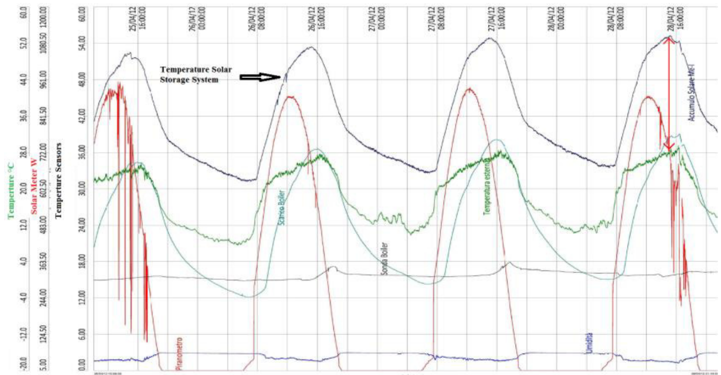


Fig. 4 : trends of temperature of the CSHs in April 2012

Figure 4 shows the temperature reached by the water inside the storage tank for a period of 4 days . Furthermore, we have verified the temperature of the water in the boiler is sufficient to ensure the thermal level necessary for heating domestic hot water.

4.2. Rainwater Harvesting System (RHS)

In multi-family buildings rainwater harvesting allowed meeting a greater percentage of the landscape water demand due to the larger catchment area per square meter of garden available. Large tanks are needed to efficiently meet the garden water demand due to the coincidence of the highest temperatures and the greatest irrigation demand in the driest period of the year. The RHS system supplies water to WC and garden. The total of rainwater collected is 2,402.27 m^3 while the total household consumption for year is 3,634.9 m^3 with a total rainfall of 0.67 m^3 in 2011.

Fig. 5 : rainwater treatment plant

4.3. Photovoltaic solar system (PSS)

The solar trees will be connected to the public electricity grid. Each one is 7.0 meters high and consists of solid steel sculpture in the form of a tree with five branches holding 5 solar panels of 4.0 m^2. There will be installed 10 trees, which can produce about 20.0 MWh/y of electric energy.

Fig. 6 : Photovoltaic solar trees

5. Conclusions

The in-deep study of the energy issues regarding the social housing units analyzed the building envelope and developed a pattern of energy behaviour throughout the building that allows changing the various factor to assess which are the technological components to be amended to improve the energy behaviour. The energy redevelopment permits to obtain :

- savings in consumption of public water of about 2,400 m^3/y.
- savings in primary energy consumption for space heating of about 9.5 MWh/y
- savings in primary energy consumption for DHW of about 2.5 MWh/y
- production of about 20.0 MWh/y of electric energy by RES.

Further comparisons between energy requirements calculated with the software and the real one derived from the bills of energy supplies will validate the obtained results. Then the model simulation of energy behaviour developed can be used to formulate options for action on a larger scale, aimed at reducing energy consumption and at increasing the comfort of residents.
Many times in interventions of maintenance of existing building, especially in social housing, the designer limits himself to consider only architectural, technological and economic criteria. On the other hand, we truly think the design of retrofit of buildings must be approached primarily to achieve satisfactory requirements in terms of safety, comfort of the indoor environment and energy-saving.

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