ENERGY SIMULATIONS FOR ENERGY EFFICIENCY IMPROVEMENT OF AN EXISTING PRIVATE CLINIC IN NORTH ITALY

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ABSTRACT

The present paper analyses an interesting case study of the application of dynamic energy simulation on the energy efficiency improvement process of an existing large hospital building with a starting low level of energy efficiency. Object of the analysis are interventions on the envelope, maximum thermal power requirements and the installation of a cogeneration machine. Great attention is dedicated on the correct sizing of the CHP equipment both in the energy efficiency and economic aspects.

The study is based on the modeling of the existing building as a baseline case and the evaluation of various interventions through dynamic energy simulation. The work proves the usefulness of dynamic energy simulation as an evaluation tool for effectiveness of energy efficiency improvement in refurbishment projects and provides suggestions on the correct sizing of plant and CHP equipment.

INTRODUCTION

The waste of large amounts of heat is an irrational unfortunately widespread practice. In Italy, for example, losses of heat in the thermoelectric conversion amount to over 22 Mtoe/year, 53% of primary energy used. Industry, domestic use, transport, agriculture and marine bunkers losses amount to at least 34 Mtoe/year. If we also consider the waste of heating energy in buildings and the available renewable energy for heating and cooling purposes, it is evident that among losses, waste and renewable sources we are dealing with a huge quantity of thermal energy with an enormous and still underestimated potential (Molocchi, 2011).

The clinic and hospital construction sector is largely similar to that of public or private housing in regards of technical and feasible interventions to achieve the goal of energy saving. It should be noted that in clinics, hospitals and all other structures that are part of this segment, it is not possible trying to achieve energy savings regardless of the comfort aspect, which is fundamental in all areas occupied by people, more so in environments where occupants are not in good health.

Energy simulation plays a very limited role in the average application of energy saving technologies, mainly for the lack of control over when and how a particular analysis should be commissioned and the lack of context specific analysis scenarios; thus often recurring to intuitive selection (de Wilde et al., 1999).

For energy saving components an intuitive selection appears to have additional drawbacks: generally the efficiency of these components cannot be studied in isolation. They are dependent on building characteristics whereas interaction between components can have a substantial effect on the efficiency of each individual component. The impact of climate conditions and occupant behavior add to the complexity and make it almost impossible to predict performance without use of computational tools (de Wilde et al., 2001).

It is therefore essential to support energy efficient design decision with energy analysis able to justify the intervention.

BUILDING DESCRIPTION

The structure of the private clinic building in exam, founded in 1933 as a private clinic, is located in the center of Bergamo (Italy) and consists of various building elements constructed between 1930 and 1970 characterized by having suffered several modifications and expansions through time, all sharing the same low level of energy efficiency.

The following image (Figure 1) represents the urban context in which it is inserted, through the aid of orthophotos so as to analyze the distribution of clinic building parts.

Figure 1 – Top view of the clinic building (Google Earth)

The structure is characterized by a distribution of buildings typical of complexes formed by progressive expansions carried out in different times.

It consists of 7 buildings with different technical and structural characteristics (Figure 2).

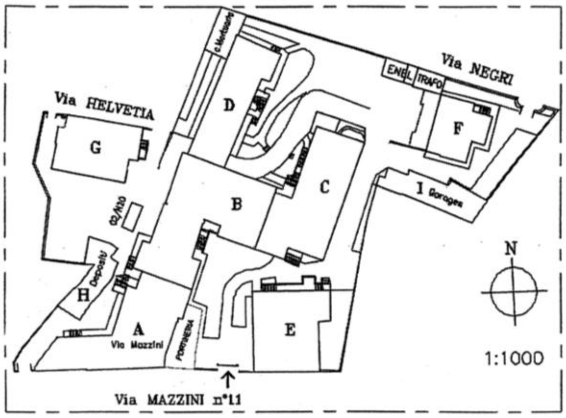

Figure 2 – Clinic complex framework and identification of the main buildings

In particular the core of the clinic (B) can be identified as built around 1930 as a 3 storey building and raised to 5 floors between ‘60 and ‘70 together with the addition of 4 storey blocks A and D and 5 storey block C.

The clinic also consists of some ancillary buildings built in the 30s and subsequently incorporated by the clinic; buildings D,E and F are 4 storey buildings while building G has 3 floors.

Finally the accessory building H can be identified, built in ‘70 and developed on a single floor.

Actual state of building envelope

In relation to the period of construction of the facility and its expansion over time it is possible to characterize the opaque surfaces of the buildings in 3 different categories. The walls built in the 30s are characterized by the average thickness of 40 cm of rock bearing. The portions of walls made in mid ‘60 are made of mixed stone and load-bearing extruded bricks to an average thickness of 35cm, ultimately the walls forming the structures built in 1970 are made of load-bearing hollow bricks with thickness of 40cm. All the walls are plastered on both sides and, also due to lack of subsequent energy requalification on the building, are free of any kind of insulation materials. The walls are then characterized by high thermal transmittance values (ranging from 1.3 to 2.1 W/m^2K) and low values of insulation against air infiltration.

Similarly, the horizontal surfaces between the floors and in contact with the external environment have been realized according to traditional techniques in mixed brick reinforced concrete and do not present any kind of solutions suitable for thermal insulation. The sloping roofs are characterized by layers of wood and tiles and are also devoid of any thermal insulation.

It is also possible to note that the structure has a good state of preservation of external surfaces, except for buildings G and H, which present plaster detachments on different points of the facade.

With regards to the transparent components of the envelope 2 different types of frames can be identified: single-glazed windows with a frame made of wood, mainly concentrated in the structures B, E, G and double glazed windows with standard 3-13-3 air filled double glazing and variable wood or aluminum frame without thermal break mainly concentrated in the A, C and D blocks.

The air distribution system is characterized by a mixture of mechanical ventilation of the premises through single UTAs and uncontrolled natural ventilation through windows.

The air conditioning system, separated from the air distribution system, is characterized by fancoils connected to a water circuit both for heating and for cooling.

The plant generation subsystem of the clinic consists essentially of two 980 kW boilers, type Rendamax 244, connected in cascade with activation priority for the service of heating and production of sanitary hot water that are to serve buildings A, B, C, D, E and G.

The building F, intended for administration offices, is served by two independent boilers and connected to the gas supply with their own counter.

The electrical system, instead, receives the supply in medium-voltage with an available power of 485 kW, connected to it are the two water chillers that supply the air conditioning system for a total cooling capacity of 240kW.

The building is not equipped with detection systems or fuel monitoring tools, but it is still possible to obtain a good estimate of the consumption of natural gas and electricity through the analysis of the available bills of a full solar year, taking into account typical time lag accounting problems.

Solar year 2010 has been chosen as the reference year. Following are the monthly consumptions of natural gas in m^3 for the year 2010 (Figure 3) and the corresponding electricity consumptions in kWh for the same year (Figure 4).

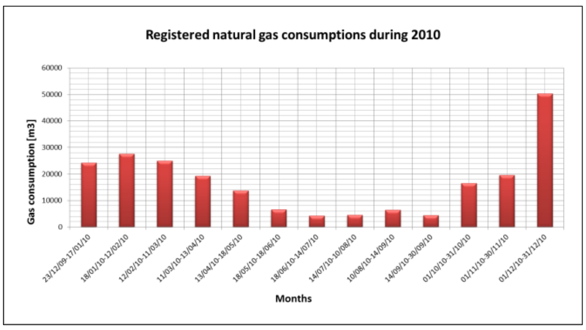

Figure 3 – Trend of 2010 natural gas consumption for the building.

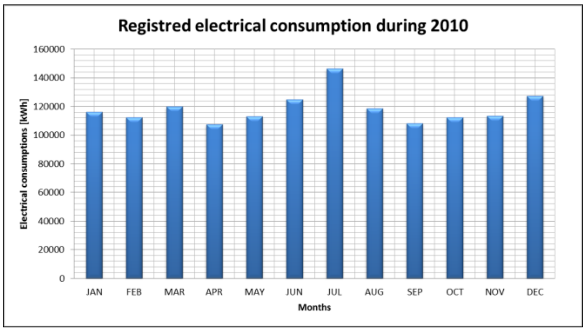

Figure 4 – Trend of 2010 electricity consumption for the building.

Consumption of natural gas are minimal during summer months, reaching about 4000 m^3/month of gas due to the production of domestic hot water, which still requires the activation of the boilers; the peak maxima are recorded in the winter period, when gas consumption soars to 30000 m^3 per month.

The energy value of December is to be considered not significant because of the consumption accounting method applied in this case.

The electricity consumption appear to be, on average, of the order of 120 000 kWh per month, with a power peak of about 150 000 kWh in July, linked with the cooling machines.

Interventions provided on the envelope

Three significant interventions are identified to be performed on the envelope: 1) the coating of the entire building with insulation materials, 2) the replacement of existing windows with high efficiency double glazed windows and aluminum frame with thermal break, and lastly 3) the realization of a greenhouse on the southeast facade of building C.

The state of conservation and energy performance of external walls, with high transmittances and low resistance to air infiltration, are significantly poor.

This, together with the width of these surfaces, approximately 4000m^2 for opaque vertical surfaces and 1500m^2 for horizontal ones, portend as the application of a coat of insulation material constitutes the priority intervention in terms of reduction of energy consumption of the building.

According to the hypothesis to achieve U-values required by current regulations (UNI EN 15251, 2008) such as to have access to tax deductions (Lombardy D.Rg. VIII/8745, 2008) for energy efficiency interventions, equal to 0.34 W/m^2K for vertical elements and 0.30 W/m^2K for horizontal ones, the installation of an outer coating made of expanded polystyrene boards is considered, with a thermal conductivity equal to 0.031W/mK, for a thickness of 10cm on all vertical and horizontal surfaces, the resulting transmittances range from 0.27 W/m^2K to 0.25 W/m^2K complying with considered limits.

It is expected to apply such coatings on the external side of the interested walls with the exception of some particular portions in which the outside placing is prevented by existing constraints.

In these cases it is expected the shift of the insulating layer on the inner side of the walls, having taken care to verify the technical feasibility of this solution. For each vertical element is also verified the absence of interstitial condensation through the application of Glazer formulations (UNI EN ISO 13788, 2003).

It is also estimated that the application of the coating generates increased sound insulation of the walls variable between 0.3 and 0.7 dB.

This intervention also has positive effects on uncontrolled air infiltration, increasing the degree of impermeability of the envelope and thus reducing the infiltration rate by 0.2 volumes/hour.

The glass surfaces currently installed have characteristics of obsolescence in line with those of the envelope, specifically the building currently has two types of windows: single-glazed windows with wooden frame for an average transmittance of 5.5 W/m^2K and a total area of 411m^2 and double glazed windows with mixed wooden and aluminum frames for an average transmittance of 1.978 W/m^2K and a total area of 392 m^2.

The gradual replacement of existing windows is analyzed according to two orders of priority depending on the type of window found by placing high-performance windows with argon filled double glass and aluminum frames with thermal breaks for an average transmittance of 1.108 W/m^2K . It is also expected that this intervention has positive results in terms of increasing the degree of impermeability of the envelope reducing uncontrolled air infiltration by 0.4 volume/hour, and positive feedback in terms of thermal comfort in internal environment through uniformity of the radiant temperatures and acoustic comfort with a remarkable increase of the sound reduction of enclosure. An increase in sound impermeability is also estimated ranging from 6 to 8 dB depending on the windows.

Lastly is presented the construction of a solar greenhouse on the south-east facade of building C, the intervention assumes mainly an aesthetical and architectural connotation permitting the uniformity of the facades, however, an adequate analysis make possible to characterize it also in terms of energy savings. The vertical surface concerned is about 240m^2 and the structure of the greenhouse will be of aluminum, with the possibility of complete opening during the summer period, avoiding overheating problems. Vents are also provided to allow air exchange between indoor areas and the solar greenhouse.

Interventions on Plant systems

Regarding the plant portion of the building as a first step integrative interventions on the existing plant systems are analyzed, specifically a solar thermal panels field for the production of heated water and a solar photovoltaic panels field for the production of electricity are to be considered; separately, in a second phase, the substitution of the existing generators with a CHP machine is to be analyzed.

The solar thermal plant is to be sized to cover more than 50% of the DHW thermal needs arising from the building demand, as required by current regulations for every new building. It is estimated a need of 126.76 l/m^2 per day of hot water, for a total of 11 645 l/day. It is, therefore, predisposed a field of 177.62m^2 of solar collectors with evacuated tube posed on the roof with a tilt angle of 36 ° and connected to a 5000 liters storage tank as to maximize the performance of the system to a value of 41%.

The installation of a solar photovoltaic panels array is also considered, partially integrated on the sloped roof and installed on a special support structure, for a total area of 300m^2 of mono-crystalline silicon modules with estimated efficiencies of 13% exposed to south with an inclination of 36 ° for a total power peak of 41kW installed.

Installation of a cogeneration system

At last the installation of a CHP machine is foreseen, designed for the combined production of electricity and heat. It is essential, for the purpose of a correct sizing of the machine, to be able to couple the thermal and electrical needs of the building with the simultaneous production of the cogeneration, otherwise the investment will not be viable.

Overlaying the pattern of needs for electricity and heat for the winter period it can be seen these demands are found to be sufficiently constant and contemporaneous, this condition let assume a suitable environment for the installation and functioning of a cogeneration system.

The favorable condition that the thermal needs are constantly greater than the electrical requirements during the whole winter period is also present.

This condition also encourages the setting of the cogeneration system in thermal mode, i.e. the co-generator is able to work only when there is enough thermal demand to cover its production, eliminating the potential waste of thermal energy due to the inability to store this energy.

Instead, electricity can be easily stored within the main electricity grid via net metering policies.

To perform a correct sizing of the co-generator becomes of importance the identification of the thermal power curve of the building (Figure 5).

Assuming an operating limit to guarantee acceptable efficiency of the process it is possible to identify the range of operation of the machine, so as to maximize the operating hours of the co-generator, at acceptable efficiencies, as a function of the needs of the structure; the remaining needs should be covered by a backup boiler, in this case already present in the building.

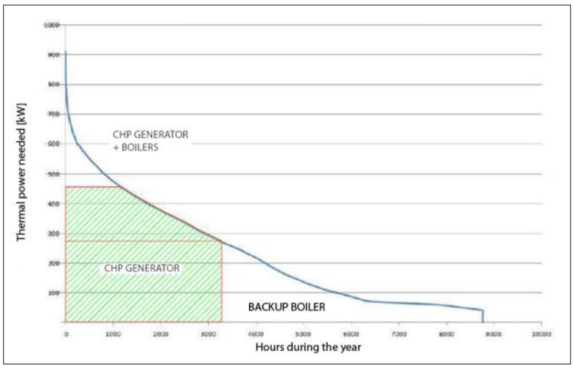

Figure 5 – Example of a thermal power curve and area of operation of the cogeneration system

From a solely energy standpoint, the best CHP machine is represented by the one that maximizes the dashed area in figure 5, which represents the number of operating hours on the x axis and the operating power of the cogeneration system on the y axis.

This assumption does not necessarily represent the best economic choice as cost of installation, maintenance and performance of the machine are to be considered.

It should also be noted how, when sizing, a maximum electrical output of 200 kW is imposed to let the CHP machine access the exchange regime previously introduced with the network.

BASECASE MODEL AND ACTIONS

The simulations intended to evaluate the energetic behavior of the building under examination are performed under dynamic regime by dedicated software; in the specific case, the software DesignBuilder is used, which is a user-friendly interface of the calculation engine EnergyPlus.

The geometrical model is developed starting from existing documentation, therefore, the dimensions and geometrical properties of each building are identified through the help of available plans and field surveys.

The volume and footprint of the structure are defined through the preparation of 31 building blocks for a total volume of 22965m^3 and a total external wall surface of 8864m^2; in addition a number of shading surfaces are modeled such to describe all the shading elements present on the structure as well as the buildings in the vicinity that influence the structure under consideration.

Thermal zones that make up the building are then identified. This division is made according to the principle of uniformity of use conditions of the premises and internal set-points, trying to minimize the number of thermal zones constituting the building but affecting as little as possible on its thermodynamic behavior. A total of 84 thermal zones are identified, of which 74 are subject to occupancy and therefore are thermally controlled.

The individual zones are subsequently characterized in terms of operation, set-points, occupancy, ventilation, electrical load and domestic hot water requirements in 11 different zone types. Each value has been identified by comparing the reference values recommended by current legislation and actual values recorded by the sampling survey in some of the structure's rooms.

The temperature set-point, unitarily defined for the entire structure match at 22.5°C for the heating period and 28°C for the summer. The only exception is of particular rooms such as surgery rooms, characterized by a specific constant set point of 21°C. Each type of zone is then characterized by defining a profile of all set-points and usage values as a function of direct observation of actual behavior of the structure. Each zone is further characterized by values of thermal mass equivalent to the internal partitions not modeled by zone partitioning.

The building envelope is then characterized by the definition of 21 wall types for the opaque components and 3 window types for the transparent components that describe the individual parts of the envelope as previously identified. Depending on the state of conservation of the envelope is also assumed a conventional value of air infiltration equal to 0.7 volumes/hour.

The consumption of domestic hot water is also modeled depending on the intended use of the various areas of the clinic according to standardized patterns of consumption. To allow for a simplified plant modeling is assumed the hypothesis that all the exchange of air in single rooms takes place in a controlled way such as to allow the definition of an air volume exchange function of the number of occupants variable between 10-15 l/s per person and 15 vol/h depending on the intended use of the individual rooms. The plant is then patterned in such a way as to allow the achievement of setpoint conditions provided through the use of fancoils units powered by natural gas boilers and electrical chillers.

To better represent the climatic conditions of recent years and in particular of 2010, chosen as a reference and of which the consumption of the building are known making it possible to carry out a verification and calibration of the model, the annual simulation is parted into two sub-simulations, a "winter" and a "summer" simulation, each one characterized by appropriate climate data from TMY database.

The subsequent verification and calibration of the model as a function of the consumption data available allow the limitation of the errors on the total consumption of up to values lower than 2%.

From the simulation the total consumptions (Figure 6) are identified, equal to 170888m^3 of natural gas and 1397277 kWh of electricity, with a peak power for heating demand equal to 1169kW and a CO_2 production of 1317 tons.

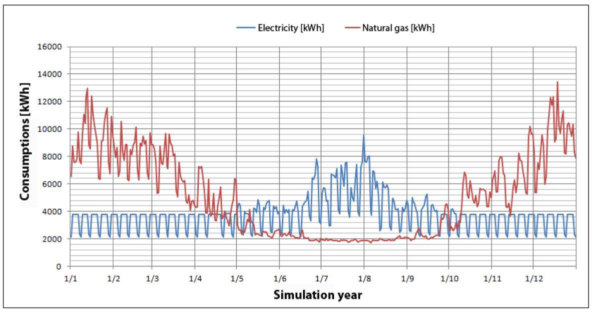

Figure 6 – Total base case electricity and gas consumptions.

This study continues through the progressive integration into the developed model of individual energy efficiency improvement measures previously identified in order to assess their effects in terms of reduced system power consumption, improved indoor comfort and return on investment.

RESULTS:ENVELOPE INTERVENTIONS

The pre-intervention model previously created is progressively modified by inserting the characteristics of individual interventions in the order shown above and proposed in Table I together with the reduction of consumption generated.

Table 1
Gas consumption variations

INTERVENTION	GAS m3	Δ GAS m3	Δ GAS %
Wall insulation	144714	-26174	-15.32
Single glazed w.s	131279	-13435	-7.86
Double glazed	127142	-4137	-2.42
Greenhouse	124739	-2403	-1.41

Note how the increase of the thermal resistance of the opaque surfaces by the application of an insulating coating result in a significant reduction in fuel consumption (-15.32%) as a function of both the previous poor conditions of the envelope and the extension of the surfaces in question. Also significant is the reduction due to the replacement of single-glazed windows, despite the smaller size of the area concerned.

The last two interventions, although characterized by a lower contribution in terms of reduced consumption, must be seen in their dual function of energy savings and improving the architectural uniformities of the facades.

In contrast, the reduction of air infiltration due to the increase of impermeability of the casing, together with the reduction of the transmittance of the envelope cause a slight increase of the summer consumption of 3.45% as described in Table II. This increase is also due to the lack of implementation of interventions aimed at reducing the summer needs. The provision of appropriate shading systems could eliminate this problem.

Table I1
Electrical consumption variations

INTERVENTION	EL. kWh	Δ EL. kWh	Δ EL. %
Wall insulation	1401668	4391	+0.31
Single glazed w.s	1426088	24420	+1.75
Double glazed w.s	1441119	15031	+1.39
Greenhouse	1441119	0	+0.00

The analyzed interventions, in addition to a change in heating and cooling consumption causes a reduction in CO_2 emissions equivalent to 65.5 tCO_2/year, which represent the 4.97% of the pre-intervention production estimated at 1316.7 tCO_2/year.

It should also be noted that the interventions planned cause a significant increase in the indoor comfort of the rooms, in particular, after a careful evaluation in the main rooms of the clinic based on Fanger equations a substantial reduction in the hours of dis-comfort during winter can be seen, reduced by 41% with an average increase in operating temperature of 1°C. This figure, although difficult to quantify economically, is of fundamental importance especially for buildings destined to hospital stay.

RESULTS: PLANT INTERVENTIONS

The evaluation of the effect of the installation of solar thermal collectors is done via the dedicated software Tsol Pro, through which is also done a simple parametric analysis aimed at identifying, once the size of the solar field is established, the optimum volume of the water storage designed to maximize system performance. The result is a storage of 5 m^3 with a system efficiency of 41%.

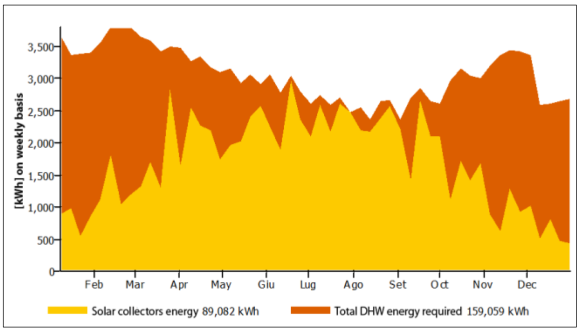

Figure 7 – Energy required for hot water production and energy produced by the solar system.

The installation of solar panels generates a reduction in consumption of natural gas equal to 35699 m^3 which is approximately 21% of total pre-intervention consumption and 56% of consumption linked to the production of domestic hot water (Figure 7). There are no significant effects on electricity consumption. The reduction in the production of CO_2 is quantified in 5.4% compared to the pre-intervention case up to 71 tCO2/year.

The energy generated by the photovoltaic system is calculated by applying simplified equations identifying an annual production of 54203 kWh/year, equal to about 3.88% of the electricity consumption registered in 2010.

Such production is constrained by the limited area of coverage available for the photovoltaic field.

Once the needs of the structure are identified, the curve of thermal power required for the proper sizing of the cogeneration system (Figure 8) can be traced.

The choice falls on a commercially available CHP machine of nominal heat capacity of up to 252kW, minimum heating capacity at constant efficiency of 151.2 kW and 200 kW electric power output for a total cost of € 199'708 plus € 35’000 for installation.

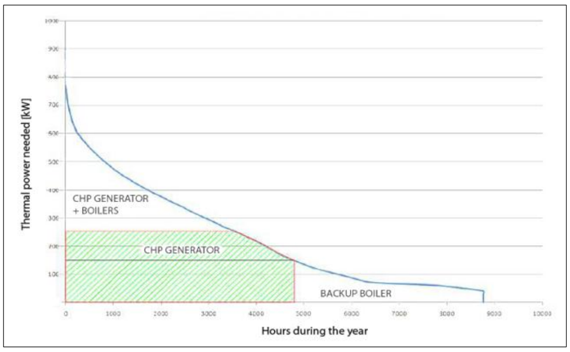

Figure 8 – Thermal power curve and area of operation of the cogeneration system

According to the thermal power curve of the structure, the power characteristics and the period of operation of the identified co-generator it is possible to calculate the changes in fuel consumption identifying an increase in the needs of natural gas equal to 106655kWh/y, or 11’116 m^3, and a reduction in electricity consumptions amounting to 886756 kWhe/y.

Thermal and electrical energy generated by the CHP machine and relative consumptions have been estimated thanks to a specially developed spreadsheet by post-processing simulation results.

CHP gas consumptions and electrical generation have been calculated as a function of thermal needs obtained by the simulation, thanks to the previously mentioned operation schemes and specific machine performance curves a constant efficiency has been identified for the calculations.

Estimated error for this simplification, which does not consider the loss in generation efficiency due to the CHP machine working at partial load, is less than 1.5% on total energy generated, this value has been estimated through performance data curve available in the data sheet of this specific CHP machine.

This variation of the system needs leads to a reduction of primary energy demand of 156 TOE/y, avoiding the emission of 244 tons/y of CO_2 in the atmosphere.

ECONOMICAL ASSESSMENT

In order to perform the economic evaluation of individual interventions a number of characteristic values of the profitability of the investment are calculated such as NPV, IRR and PB.

The NPV indicates the variation of wealth obtained by investing (1):

$$NPV = -R_0 + \sum_{t=1}^{T} R_t/(1+r)^t \quad (1)$$

Each investment is associated with an IRR, which is the discount rate that results in an NPV of zero (2).

$$NPV = \sum_{t=0}^{T} R_t/(1+IRR)^t = 0 \quad (2)$$

Another key parameter in such assessments is the PB, the "breakeven point" of the investment, calculated as follows (3).

$$PB = \min\ t : \sum_{t=1}^{T} R_t/(1+r)^t > 0 \quad (3)$$

The economic evaluation of each intervention is performed by calculating the above parameters over a time horizon of 25 years and assuming an opportunity cost of 3.5%.

The evaluations will be conducted according to the BAU HG scenario that envisages an annual increase in the price of natural gas equal to 8% and electricity prices by 6%.

Also included are all the incentives available in the form of tax deductions (D. lgs 201/2011) of up to € 100’000 for energy requalification projects, tradable white certificates in the energy market and the incentive rates (DM 5 may 2011) intended for the production of energy from renewable sources.

The current price of energy is set at 0.0639 €/kWh for natural gas and 0.17 €/kWh for electricity.

Table III
Economic assessment of single interventions

INTERVENTIONS	COST €	NPV €	IIR %	PB Y
Wall insulation	392’929	242’758	8	15
Single glazed w.s	114’453	174’313	13	9.5
Double glazed w.s	102’411	14’947	5	21.6
Greenhouse	54’540	8’916	5	21.2
Solar thermal	126’853	515’714	22	5.8
Solar photovoltaic	234’242	195’144	10	10

The cost of each provided intervention is identified by an accurate computation and estimated by using the official price lists and quotes.

In Table III a summary page of the characteristic values for the individual interventions is shown.

It is emphasized that each of these planned actions result in a positive NPV and therefore generate wealth, in each case is also found an IRR value greater than 3.5%, thus making it a cost-effective and value generating investment.

Also, the plant investments generally show more cost-effective payback times than interventions that, on the counter, generate reductions on energy demand with the actual values of PB, however, still acceptable. Special case is constituted by the interventions of replacing double glazed existing windows with high efficiency double glazed ones and the realization of the greenhouse, in which the value of PB would not advise the investment, these interventions have, as already mentioned, the valence of uniformity and aesthetic improvement, but as shown are still cost-effective (Figure 9).

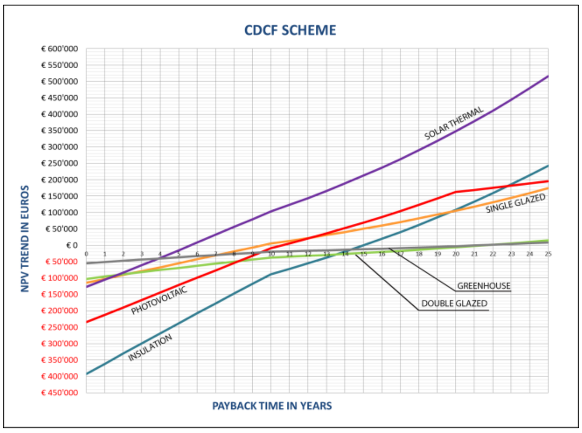

Figure 9 - graphical IRR and PB representation of the various interventions

Next, the values related to the sum of all previous interventions are reported in addition to the replacement of existing generators with the installation of a CHP machine, in this case the economic assessment is performed on a horizon of 20 years (Table IV).

Table IV
Global economic assessment of the interventions

INTERVENTIONS	COST €	NPV €	IIR %	PB Y
PREVIEOUS ACTIONS	1’025’430	796’126	11	9.7
CHP machines	234’708	1’245’239	33	4
TOTAL	1’260’138	2’027’771	16	7.1

It is immediately evident that the intervention of installation of a co-generator proves highly more convenient from the economic point of view than any other intervention analyzed, this fact is due on the one hand to the correct sizing carried out for the CHP equipment, on the other to the strong incentives currently provided for these projects, just consider the special price of natural gas for power generation equal to 0.0425 €/kWh, coupled with the high price of electricity in Italy as well as access to the net metering accounting system which does not require the installation of electric accumulators.

As a matter of comparison, the connection to the district heating system present has been evaluated as an alternative solution, generating a much less interesting investment at the hypnotized price of 0.065 €/kWh, already lower than the actual price, needing a price setpoint of 0.031 €/kWh to be competitive with the installation of a CHP machine.

The same analyses were performed assuming an Energy Service Company (ESCO) intervention, price fixed at 0.05 €/kWh for natural gas and 0.12 €/kWh for electricity, resulting in a NPV of € 3'043'864, an IRR of 19% and a PB of 6.3 years thus making the operation attractive also from an ESCO standpoint.

CONCLUSIONS

The paper proposes a series of analysis and concrete solutions aimed to achieve greater energy sustainability of existing buildings.

Through the application of considered interventions, a total reduction in heating demands of 51.8%, equal to 81848 m^3/year of natural gas, is achieved at the cost of a little increment in cooling loads of 43842 kWhe/year completely counterbalanced by the installation of the photovoltaic array for a total of 54203 kWhe/year generating a reduction on electricity consumption of 10361 kWhe/year.

The installation of a CHP machine, shifting the consumption from electricity to natural gas generate an increase in gas demand equal to 11116 m^3/year and a significant decrease in electricity consumption of 886756 kWhe/year.

The total energy saving are therefore equal to 70732 m^3/year of natural gas and 897117 kWhe/year of electricity. Those energy savings also generates a reduction of 407.6 tons of CO_2 emission in the atmosphere due to energy consumption, equal to 31% of the total CO_2 production of the building.

All those saving are achieved with an improvement in comfort condition with a reduction of 1124 hours of discomfort equal to the increase of 1°C of the operative temperature inside the building.

All the planned interventions are also considered economically favorable with positive NPVs and IIR superior to the cost of capital; for a total of 2’027’771€ of NPV and an IIR of 16% against a total cost of 1’260’138€ and a PB time of 7.1 years.

Nevertheless the importance of a correct and detailed energy analysis of the concerned building is highlighted, which is useful in order to fully identify the entity of the results obtained, both in terms of energy and economic savings.

Through the implementation of an energy analysis it is also considered to have validated the general process illustrated of correct sizing of the CHP machines, ensuring an energetically and economically favorable investment in spite of several real cases, characterized by an inappropriate sizing of the machines, which proved to be failures.

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NOMENCLATURE

NPV, Net present value;
IRR, Internal rate of return;
PB, Payback time;
C_t, Net cash flows at year t;
T, Total considered years;
r, Cost of capital;

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