Evaluation of energy conservation opportunities through Energy Performance Contracting: A case study in Italy

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Potential opportunities for energy conservation in existing hospitals through Energy Performance Contracting (EPC)

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Abstract

Non-residential buildings like acute hospitals and community clinics contribute to energy consumption and have a negative environmental impact. This is mainly due to the age of the buildings, their poor level of energy efficiency and only a basic maintenance plan. Owing to the very limited money available for public administrators, Energy Performance Contracting (EPC), that entails the involvement of an Energy Service Company (ESCo), can provide the capital needed for investments aimed at increasing energy efficiency. In this paper three acute hospitals and two community clinics in Italy are analysed prior to EPC development in order to assess the economic feasibility of retrofit strategies. The outcome of energy audits carried out in 2014, the analyses of consumption measured over the previous three years, and the assessment of use profiles were all considered for the development of models to break down the overall consumption and to estimate potential savings. As a result, diverse improvement strategies were recommended, including better insulation of envelopes, enhancement of mechanical and lighting equipment, use of renewable energy, better control of systems. Finally, payback periods for the most likely scenarios were evaluated in order to assess the validity of the EPC framework in this application.

Keywords: Energy Performance Contracting; EPC; energy audit; hospitals; energy efficiency; retrofit.

Highlights:

- An energy audit was performed on 5 healthcare buildings.
- Current energy consumption and possible retrofit solutions were evaluated.
- The global retrofit of hospitals allows savings of between 77-79% for natural gas.
- The retrofit of clinics allows savings of between 34-47% for heating and 32-47% for electricity.
- Payback periods (PBP) of energy retrofitting are between 9 and 20 years.

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Nomenclature

EPC	Energy Performance Contracting
ESCo	Energy Service Company
CHP	Combined heat and power generation
EP_{gl}	Global energy performance index (EPh+EPw) [kWh/(m^2·year)]
EP_H	Energy performance index in the heating season [kWh/(m^2·year)]
$EP_{H,L}$	Target energy performance index in the heating season [kWh/(m^2·year)]
EP_w	Energy performance index for domestic hot water production [kWh/(m^2·year)]
GHG	Greenhouse gas [kgCO$_2$/year]
PBP	Payback period [years]
η_{gl}	Heating system global efficiency [-]
S	Overall surface of the envelope [m^2]
V	Overall conditioned volume [m^3]
S_u	Internal floor area [m^2]
U-value	Overall thermal transmittance [W/m^{2}K]
U_w	Overall thermal transmittance of the windows [W/m^{2}K]

1. Introduction

Buildings are responsible for a considerable amount of overall energy requirements and greenhouse gas emissions. The non-residential field is a huge contributor, due to combined heating, cooling, ventilation and lighting loads. In particular, the existing housing stock composed of non-insulated and inefficient buildings, is responsible for a large part of the energy consumption in this sector. For this reason, European Commission guidelines recommend energy refurbishment as a priority for the reduction of energy needs and greenhouse gas emissions. One of the targets of the European Directive 2012/27/UE is to retrofit 3% of the existing public stock, while upgrading it to current legislation [1]. Several proposals regarding the Energy Performance Contracting (EPC) market in Europe have been put into practice, e.g. within the Intelligent Energy - Europe (IEE) programme. ESCos have been identified as key players in the implementation of EPC investments. In fact, EPC is an arrangement between any beneficiary and a provider (e.g. an ESCo), where investments in energy efficiency improvement are repaid in relation to the achievement of a pre-determined target [1]. Thus, technical and economic risks are transferred mainly to the provider, and the beneficiary (e.g. public administration) is involved to a lesser extent. Furthermore, the principle investment is made by the ESCo, whereas the beneficiary is only responsible for paying a regular fee, which is expected to be no higher than the total amount of the real operational costs. This is the most common case, which is valid when the payback time on the investments is shorter than the contract duration. If the payback time is longer than the contract duration, the beneficiary will pay more than the real operational expenses but will reap the benefits of energy savings either throughout the duration of the contract (if they pay less than the operational costs), or soon after the end of the contract.

These issues have already been considered by the scientific community, that assessed retrofit sustainability in the non-residential sector [2-4]. The Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA) drafted an accurate analysis of contractual issues [5]. Other studies [6] focus on the acceptance and success rates of this approach in Europe. Several studies have analysed elements that are likely to jeopardise success [3,7-9]. In fact, there are several marketing and financial, institutional, political and technical risks which cannot be perfectly assessed at the start of the contract and could make it no longer economically viable. Among the technical uncertainties, a thorough understanding of the current energy profile (baseline) and the correct estimation of the energy and economic benefits deriving from the energy retrofit are the most relevant [7-9]. Therefore the evaluation of real energy consumption and the advantages of the energy retrofit are fundamentals parts of the energy audit and the EPC tender. For this reason, one of the most important steps in EPC is correct planning and implementation of a detailed energy audit [10-11].

Numerous studies have investigated the improvement in energy efficiency of hospital buildings and plants through the adoption of retrofit strategies. In particular, researchers have focussed their attention on the current large energy demand of hospitals and healthcare facilities and the advantages of adapting the existing buildings, that are characterised by low efficiency equipment (heating, cooling, ventilation, DHW production, lighting), lack insulation, and offer poor indoor environmental comfort. Considering the complexity of the energy balance and the energy consumption of systems, past research analysed various strategies to reduce the energy demand and costs or to improve the energy efficiency of hospitals. A great number of studies have analysed the energy, economic and environmental benefits provided by the use of heating and cooling systems with a cogeneration or trigeneration system in comparison with traditional heating and cooling plants [12-17]. On the contrary, other research analyses the possibility of applying new generation systems such as fuel cells [18,19] and absorption solar cooling systems [20] or renewable energy plants [21] to obtain energy savings and reduce greenhouse gas emissions. Buonomano et al. [22] carried out dynamic simulations of 4 blocks of an Italian hospital, and showed that the highest savings could derive from retrofitting the heating and air ventilation systems. Ozyogurtcu et al. [23] investigated the energy consumption of different (HVAC) systems used in operating theatres, in the Turkish climate context, and concluded that the best-analysed technologies accounted for a 74% reduction in energy consumption for ventilation, and an associated 48% reduction in economic costs. Rasouli et al. [24] discuss the energy benefits offered by using a heat and moisture recovery system on a variable air volume HVAC system, achieving considerable reductions in energy consumption. Ascione et al. [25] opted for refurbishment of the building envelope. Saidur et al. [26] suggested slight improvements to systems, such as the adoption of variable speed drives. Bujak [27] focussed the energy audit on energy consumption for the production of domestic hot water in a large hospital, in order to provide basic information for predicting the use of alternative solutions, such as renewable energy. Congradac et al. [28,29] presented an analysis of possible energy savings by applying different control techniques, using a mathematical tool which was developed, calibrated and validated to provide a precise estimation of the energy demand for heating and cooling in hospitals. Papantoniou et al. [30] analysed building optimisation and a control algorithm integrated in an existing energy management system of a hospital, with the aim to optimise the energy demand according to the outdoor climatic conditions and occupancy, obtaining significant potential energy savings (36%). Van Schijnndel [31] investigated the optimisation of a hospital power plant, using a mathematical model that implements strategies for the minimisation of costs and / or energy consumption. A common feature of many of the above-mentioned studies is the identification of the best improvement performance scenario, not only from an energy and environmental standpoint, but also from the economic point of view.

This paper will describe the energy audit of 5 hospitals, all targeted for setting up an EPC tendering procedure. Three are acute hospitals, hence quite large, while two are community clinics, and are therefore subject to changeable needs, services and use profiles. These case studies are part of the MARTE project ("Marche Region Technical assistance for healthcare buildings Energy retrofit"), funded by the EU commission within the Intelligent Energy – Europe programme. The main objective of this project is to survey innovative financing strategies to foster energy efficiency investments, e.g. combining MLEI (Mobilising Local Energy Investment) assistance and regional funds ROP – ERDF (Regional Operational Programme - European Regional Development Fund).

2. Methodology

2.1 Evaluation of potential opportunities for energy conservation

The whole process described in this paper meets the requirements posed by the reference standard EN 16247-2 [11], that is relative to the energy audit of buildings. In accordance with that standard, in the first stage the auditors must contact the owner of the audited objects and must agree on the preferred approach to conduct the audit process. To that end, the auditor must invite the owner of the audited objects to a start-up meeting, whose agenda will also include the designation of those members of the owner's staff that will gather information and provide access to the audited objects during on-site surveys. This step is called "collecting data" by the reference standard. Subsequently, energy consumption and costs must be derived from the monthly bills of energy providers (electricity and methane gas in our case study) over the previous three years, whenever feasible. The investigation can be limited to the previous two years in the worst case. In order to investigate all the building parameters relative to size, technical features, equipment and physical performance, on-site surveys, interviews and reference to as-built documentation can be considered. In our application, in a few cases data were not available, hence an estimation of the missing parameters was based on information provided by various technical standards [32,33], by relevant literature, by technical manuals and the expertise of the auditors. Occupancy figures, plant operation and constraints to be accounted for while planning retrofit solutions were mainly inferred from interviews with the owner's management staff and technicians. In fact, as-built drawings were never available, probably because of the age of the audited objects. Therefore, the most important information about envelope stratifications, partitions, floors and windows was gathered through evidence collected during surveys. This fieldwork also allowed the schematic drawings of the building systems to be updated. In some cases, thermal bridges were identified by means of thermography.

The next stage in the audit process deals with the analysis of the energy behaviour of the audited objects. In the case presented in this paper, this analysis was performed by means of whole building simulation models for two reasons. Firstly, these models allowed the most likely energy breakdown to be estimated based on the overall building consumption; secondly, they were set as the benchmarks for carrying out the diagnosis of the buildings in their current state and the simulation of the potential for improvement. To that end, our modelling process involved two main steps:

1. Development and calibration of models by means of data collected relative to the real energy consumption, which were labelled as the "benchmarks";
2. Assessment of the benefits deriving from several hypothesised retrofit solutions, which were calculated as the difference between the benchmark consumption and the (lower) energy consumption after retrofitting.

Once monthly energy consumption data about the audited buildings were available, the energy models to define the benchmarks were developed by means of MC4Suite2013, that is CTI (Italian Thermotechnical Committee) validated software. It is compliant with Italian technical standards UNI TS 11300 parts no. 1 and no. 2 [32,33]. These standards concern design and calculation procedures for the simulation of heating and hot water production systems. The choice of this simulation tool is in line with Italian legislation on energy auditing [34] and energy labelling [35], which does not set real constraints, but allows the auditors to choose whether standardised or dynamic simulation tools work better, depending on the purpose of the energy audit. The standardised simulation tool used in this case was deemed accurate enough for a comparison with the collected energy consumption data. Furthermore, as MC4Suite software [36] is very popular with Italian ESCos, dynamic simulation tools (such as Energy Plus and TRANSYS) were not considered in our application.

A very valuable contribution to the comparison and assessment of potential retrofit strategies was provided by the economic analysis performed for the five case studies. It involved two main steps: firstly, the development of the estimate summary; secondly, the assessment of the expected payback period for each candidate retrofit combination hypothesised within the analyses described in the following section 4. A quantity survey was carried out for all the retrofit combinations, including the breakdown of each retrofit scenario into activities and the estimation of the dimensions of each activity. The accuracy of this step was typical of preliminary drawings. Unit price cost data were then applied to the dimension of each activity, so that the total pricing could be worked out. Cost data were taken from the most popular published source in our region, which is the official database drawn up by the Marche regional authority, called "Prezzario Regione Marche 2014". Those activities for which published unit price costs were not available, were estimated by means of the average between two or more quotations provided by suppliers or vendors. As a result of this process, an estimate summary was determined for each type of candidate retrofit in the following way: the first column contains the description of activities; the second column includes the results of the quantity survey; the third column provides unit prices, and the last column indicates the total price of the activity. The value for each type of retrofitting is obtained by totalling the last column.

Maintenance costs were not considered, because renovation of equipment must imply lower maintenance costs in the future, that will lead to a conservative estimate of the payback period. In fact, a simple payback period (PBP) was estimated, because real interest rates will depend on the source of the money for investments. Therefore, the value of each retrofit solution was divided by the respective annual economic savings, given by the result of the calculations described in section 4. The unit price of fuel and electricity was assessed as the total cost of fuel and electricity throughout the period which the energy audit refers to, divided by the amount of fuel and electricity actually used.

Finally, a report on the results of this energy audit process, including suggestions for energy conservation in the five buildings, was drawn up and presented to the owner of the public company.

2.2 EPC contracting

Energy Performance Contracting (EPC) is usually classified within financial incentives to promote energy conservation [37]. In fact, EPC is a financing technique that uses energy/utility cost savings from reduced energy consumption to repay the cost of installing energy conservation measures. Related energy/utility projects are undertaken by Energy Services Companies (ESCos). In order to be feasible, in the USA the maximum term of an EPC between a beneficiary and a provider has been set at no more than 20 years [38]. Subsidies are sometimes included for amortisation of the EPCloan. The typical procedure is as follows: an ESCo produces a renovation project, by designing and planning energy conservation measures and estimating their potential for reducing utility costs, all calibrated on the baseline utility consumption. The economic viability of this package will be demonstrated by assessing the payback period, whose cash-flow will include expenses due to measurement and verification reports, as well as execution, hardware, financing, construction management and administration costs. The contract will then be signed and energy renovation implemented soon afterwards. In this funding scheme, several advantages have been identified [39]: the ESCo assumes the construction and performance risk for the project; a guaranteed maximum construction cost is provided; the execution of construction is completed in a short time; the ESCo is selected not only as a low-bid contractor, but also as a highly qualified general contractor; audit services are included; measurement and verification services provide the client agency with assurance that equipment will perform for the life of the agreement.

EPC has also been welcomed as the right means to overcome some of the challenges that are slowing down the energy requalification of public buildings [37], namely the lack of public administration staff with a technical background who are capable of designing and managing energy efficiency refurbishment ; variations in energy unit prices that make it difficult to assess the profitability of retrofitting ; lack of budget to sustain such investments; a cumbersome legal, regulatory or institutional framework, that might hamper the implementation of this type of energy conservation action. For these reasons, when the implementation of specific solutions is delegated to the service provider who is an expert in the field, all the technical and administrative barriers can be overcome straightforwardly. In conclusion, the public sector may capitalise and start an ambitious energy efficiency refurbishment project for public buildings.

3. Survey of the existing hospitals

3.1 Description of the buildings chosen as case studies

The case studies considered in this paper were all included in the EU-funded project called “MARTE”, that is coordinated by Marche Region in Italy. The general aim that Marche Region is pursuing by means of this project is to provide MLEI – PDA (Project Development Assistance) to mobilise financing for sustainable energy projects in healthcare buildings. The beneficiary in this case is the public company ASUR, which owns a total of 280 buildings. The project plans to mobilise up to 15 million euros in retrofitting for the EPC pilot project developed by MARTE. A further aim is to create new business models for energy efficiency intervention that can be replicated in other public sectors, and applied to other fields including regional and local authorities. The five case studies involved in the MARTE pilot project are listed in Table 1, and further details will be provided in the next subsections.

< Table 1 to be inserted here >

3.1.1 Acute hospitals

Photos a, b and c in Figure 1 show the case study buildings classified as acute hospitals and listed in Table 1. Case a is the hospital in San Benedetto del Tronto (latitude 42°56'8"88 N – longitude 13°53'11"76 E - altitude above sea level 0 meters), which is a complex of 2 buildings, divided into 6 blocks, that were labelled with letters A-B-C-D-E-F. Block ‘A’ is a single building detached from the main hospital. Block “C” is a historical building (1800s) with architectural constraints. Blocks “A” and “B” were built in the 1970s, while the rest of the blocks were built between 1980-1990. Blocks “A” and “C” consist of 3 storeys while the rest of the blocks consist of 8 storeys. Except for the diagnostic units and operating units, the air change is with natural ventilation due either to the opening of the windows or to infiltration and incidental air leakage. For the diagnostic and operating units, a series of 12 air handling units guarantee the air change. In the whole building, cast-iron panel radiators and fan-coils are installed as heat emitters. Heat generation for heating and DHW is partially achieved with 2 natural gas heat generators (heat power 2400+2400 kW) and partially with a cogeneration plant (heat power 667 kW + electric power 522 kW). The generators and CHP work in parallel, although the CHP is preferably operated. During the summer period, the heat load is low, as only DHW production is required, and for this reason the cogenerator is turned off.

Case b is the hospital in Urbino (latitude 43°43'50"52 N – longitude 12°38'11"40 E – altitude above sea level 485 meters). The building is divided into several blocks built in the 1960s-1970s, except the south block that was completed recently (2007). The hospital has a new heating plant. All the blocks is made up of 8 storeys. Except for the South block, that contains the diagnostic and operating units (8 air handling units), the air change is provided with natural ventilation. Heat generation for heating and for DHW is accomplished using 3 natural gas high efficiency heat generators (heat power 1360 kW + 1360 kW +630 kW). The hospital is also equipped with a new trigeneration system that is currently not in use (cogenerator: heat power 410 kW + electric power 330 kW, absorbing unit: cooling power 1000 kW).

Case c is the hospital in Pergola (latitude 43°33'27"00 N - longitude 12°50'8"88 E – altitude above sea level 265 meters). It is a six-storey building in a single block, with a T-shaped floor plan, built in the 1960s-1970s. The hospital is equipped with one air handling unit used for the air change in the operating theatre, while the others rooms are naturally ventilated in the same way as the previously mentioned hospitals. Heat generation for heating and for DHW is accomplished using 2 natural gas heat generators which were installed in 2004 (heat power 900kW+900 kW).

All three hospitals are characterised by a reinforced concrete frame superstructure except for block C of the building in San Benedetto del Tronto that has a masonry load-bearing structure. The three facilities were built using the traditional technology of external masonry walls and hollow masonry unit partitions. The thermal insulation level of the envelope is quite low, with no insulation or a lack of insulation in the opaque element, aluminium frames without any thermal breaks and single/double untreated glass for the windows. The exception is the south block of the hospital in Urbino that has insulated walls and aluminium windows with a thermal break frame. In all the case study buildings the state of conservation of the building envelopes (external walls, roof and windows) is poor, due to age and the lack of maintenance. All the hospitals are equipped with a hydronic heating system, and cast-iron panel radiators and fan-coils are installed as heat emitters. Currently, no renewable systems are installed in the hospitals.

3.1.2 Community clinics

Photos d and e in Figure 1 show the case study buildings classified as community clinics and listed in the last two lines of Table 1. Case d is “Sant’Elpidio a Mare” community clinic (that hereafter will be referred to as SEM), located near Fermo in Italy. It is a seven-storey building whose occupancy pattern has varied in the past, due to organisational rearrangements, that have determined changes in terms of occupancy levels, number and typology of heated and non-heated thermal zones. It consists of two blocks: the first (A1) was built in the 1970s and hosts all the wards and clinics of the hospital. The second block (A2) was built in the 1980s and connects the rest of the building via a wide staircase, a lift and some waiting rooms. A reinforced concrete frame superstructure bears both blocks of the building. These blocks were built using the traditional technology of external masonry walls and hollow masonry unit partitions. The insulation level of the envelope is quite low, although the performance of block A2 is slightly better, thanks to its better insulated envelope and double-glazed windows. The main scenario considered in the table is relative to the situation in the year 2013, when the medical ward was open on the second floor and most clinics were located on the first floor. The scenario with numbers indicated in brackets is the estimated benchmark, when the surface used will be larger because the second floor will be dedicated to nursing practice and more clinics will be opened on the first floor, ground floor, and first and second floors below grade. As a consequence, the relevant data to be changed in the simulation models are: occupancy of the rooms, use of equipment and lighting, heating system operation in the different thermal zones, weather conditions. On the contrary, the scheme of the heating system was kept unvaried. The whole building is supplied by means of a hydronic heating system, whose central plant is located on the third floor below grade, inside block A1. In the whole building, cast-iron panel radiators are installed as heat emitters, and the circuit is made up of a primary and a secondary circuit. The first contains two boilers and the second distributes hot water to the building. The primary heat generator is a natural methane gas-fired condensing boiler made up of 4 heat exchange modules, each of which has a heat capacity of 115 kW. The secondary boiler is used as a backup, and is a 682 kW methane gas heat generator with high/low/off burner control.

The case study labelled as d in Table 1 is also made up of two blocks. It is located in Petritoli, near Fermo in Italy and consists of a main block, that was built in the 1970s, and an older block which is a historic building. Also in this case, part of the older block is empty, while the main block is entirely in use. Clinics, wards and offices are situated on the first floor below grade, on the ground floor, first floor, second floor and third floor. A reinforced concrete frame bears the main block of the building. Its envelope is built using the traditional technology of external masonry walls and hollow masonry unit partitions, whose insulation level is quite low. The bearing structure of the older block is massive masonry with non-insulated walls typical of fourteenth century architecture in Italy, consisting in the envelope and some interior walls. The remaining partitions are made of hollow masonry units. The values shown in brackets in the last line of Table 1 are relative to the estimated benchmark, as it is expected to be in the future, once a new nursing practice ward has been opened on the second floor of the older block, which is currently unused and hence not heated.

The whole building is supplied by a hydronic heating system, whose central plant is located on the ground floor, in a separate technical room. One cast-iron heating boiler is installed in the central plant, fired with natural methane gas and fitted with on/off burner control. The heat generator has a capacity of 290.7 kW and was installed in the 1990s. Part of the building is heated by cast-iron panel radiators, while the remaining part, specifically on the first floor of the older block, has under-floor heating. The complete circuit is made up of two main circuits: the primary, that includes the boiler, and the secondary, that distributes hot water to the building. This circuit is in turn divided into four sub-circuits. The first supplies the radiators in the main block of the building. The second supplies the panel radiators in the older building, which are regulated by manifold stations. The third sub-circuit supplies the heated floor on the first floor of the older block, by means of several manifold stations spread over the same level. Finally, the fourth part of the secondary circuit provides the building with hot water.

In both buildings there is no mechanical air supply system, hence the indoor air quality is provided by infiltration and incidental air leakage through the building envelope. During on-site surveys, the personnel of the clinic stated that they usually open the windows when they feel that the indoor air quality is no longer acceptable.

< Figure 1 to be inserted here >

3.2 Evaluation of energy consumption

The energy assessment performed for the five buildings encompassed both winter and summer conditions. Firstly, energy figures for heating and hot water were measured in terms of EP index, that is kWh/(m^3·year), referred to the gross volume of the building. The energy consumption was then translated into primary energy. This conversion factor (C.F.) is derived from the knowledge of the amount of energy produced by a unit volume of methane (C.F.=1) and by a kWh unit of electricity (C.F.=2.34).

The consumption figures were then used to calibrate the models developed by means of the MC4Suite2013 software, thereby allowing the behaviour of the buildings to be investigated. More specifically, this tool allowed the overall consumption to be split into sub-components and therefore constituted the basis for simulating the benefits provided by the renovation measures that will be described in section 4. This software implements calculation methods based on European and Italian standards, and accepts input about the building location, local weather, use, occupancy level, building element types, stratifications, and physical characteristics. Its archives can be adjusted and enhanced by users. Once the spatial model is built, it must be broken down into thermal zones. Heating and hot water systems are then built and associated with the various thermal zones.

< Table 2 to be inserted here >

3.2.1 Acute hospitals

For the three acute hospitals, the evaluation of real energy consumption was carried out both through the analysis of consumption in recent years and through the simulation of the building under real conditions. The aim was to provide real information (Ep index based on collected data) and a numerical model based on real input, that could simulate the "baseline" scenario which was subsequently used to estimate the energy benefit which can be derived from retrofitting. The numerical model was built using the real geometry characteristics of the building envelope and equipment. On the contrary, the occupancy profile and the air change rate due to natural ventilation were estimated, on the basis of the assessment questionnaires completed by the users. The model was calibrated with the real energy consumption of natural gas over the last few years. Since the electricity consumption is due to multiple uses (lighting, medical equipment, etc.) and the data were global, it was not possible to proceed with a validation of the electric energy consumption of the auxiliary devices of the heating system.

The data regarding the benchmarks of the acute hospitals are summarised in the first three lines of Table 2.

3.2.2 Community clinics

The two community clinics required the development of two benchmarks, because the public company owner (ASUR) has proposed changes to the intended use of parts of the buildings. More specifically, SEM will be equipped with more clinics. Both buildings will be equipped with a new geriatric nursing unit. Therefore, in this case two steps were required for the benchmark analysis:

1. development of the preliminary benchmark, as already explained in sub-section 2.1, that mirrors the current situation;
2. projection of the benchmark considering the future arrangement of the buildings, because some of the volume of the clinic is currently empty and is therefore not heated, whereas, in the near future (before signing the new EPC), these rooms will be dedicated to health care activities, mainly concerning nursing clinical practice.

This second step led to the development of a benchmark for the envisaged use of the buildings, hereafter referred to as "estimated benchmark". The data regarding the benchmarks of the community clinics are summarised in the last two lines of Table 2. In the case of community clinics, the figures in brackets refer to the estimated benchmarks, i.e. those concerning future scenarios, while all the other values are relative to the present situation. The benchmark models were calibrated against the energy consumption measured in 2013, although slight variations were noticed over the last three years, with the only exception of SEM, some parts of which were being refurbished. It should be noted that a more intensive use of the clinics, according to the estimated future scenario benchmarks, will improve the overall energy performance. All the indexes are below the thresholds recommended by the relevant current legislation (shown in the "$EP_{H,L}$" column).

4. Potential opportunities for retrofit

4.1 Energy saving strategies

The first four columns in Table 3 list the most advantageous combinations of retrofit measures and the respective energy savings that would be determined by the adoption of these energy conservation solutions. The measures chosen differed considerably according to the type of building: acute hospitals require extensive renovation, whereas community clinics can be retrofitted using low cost solutions. This choice was dictated by the public company owner (ASUR) whose administrators realised that the biggest investment should be made on large hospitals, because the energy saved per unit volume will be higher than in the case of small hospitals. As a consequence, the smallest building will be retrofitted using low cost solutions that require limited investments. Table 3 shows the energy reduction brought about by retrofitting, which was first assessed in terms of primary energy and, when relevant, was subsequently split into the amount of cubic meters of methane and the amount of electrical energy saved per year.

4.1.1 Acute hospitals

The renovation proposed for the three acute hospitals was somewhat similar for the envelope while it was different for the equipment. In fact, for Urbino the heating system was new and the trigeneration plant was already installed but not used, and for this reason this part of the hospital was not subject to refurbishment.

As far as the hospital in San Benedetto del Tronto is concerned, the whole envelope is old and poorly insulated and for this reason complete retrofitting was hypothesised except for block C that is subject to architectural constraints as regards the external facades. In particular, an external insulation using 0.20 m thickness of expanded polystyrene was hypothesised for the envelope, in order to reduce the U-value of the wall (from a mean value of 1.36 W/m^{2}K to 0.18 W/m^{2}K) and to minimise the structural thermal bridges. Together with the walls, the roof was refurbished with a 0.20 m thick external insulation of expanded polystyrene (U-value from a mean value of 0.89 W/m^{2}K to 0.17 W/m^{2}K). The renovation of all the windows was also proposed, comprising the insulation of the internal boxes of the roller blinds. The new windows are made with low-emissivity argon gas-filled double glazing with a warm edge (U_w from a mean value of 4.5 W/m^{2}K to 1.4 W/m^{2}K). The window frames are in aluminium with a thermal break. The benefits determined by this choice had an impact on reducing both the transmitted thermal losses and air infiltration, thanks to the improved air permeability performance. No intervention is hypothesised for the ground floor, because it would be difficult and financially onerous to carry out and hardly convenient from the cost-benefit point of view.

Replacing the heat generators with new condensing boilers fired with natural methane gas is also hypothesised, as well as the substitution of the other devices in the heating plant (including the DHW production devices). Refurbishment of the heating plant included substituting the pump and the integration of Variable Frequency Drives. The cogeneration system was retained, since it is not very old and the energy efficiency is quite high. The installation of a control system (climatic in the heating plant and with a thermostat for each zone or room, depending on feasibility, was also hypothesised for the heating equipment. The heat emitter and the pipes were not subject to renovation.

A similar hypothesis of energy retrofit was proposed for the hospital in Pergola, except for the cogeneration plant. The external insulation with 20 cm thick expanded polystyrene led to a reduction in the U-value from 0.71 W/m^{2}K to 0.16 W/m^{2}K for the walls and from 0.50 W/m^{2}K to 0.15 W/m^{2}K for the horizontal roof. The substitution of the windows, using materials with the same characteristics as mentioned above for Urbino, led to a reduction in U_w from 6.2 W/m^{2}K to 1.3 W/m^{2}K. In addition, for the hospital in Pergola, a thermal solar system was hypothesised in order to satisfy the demand for DHW production, using solar collectors with an overall surface of 80 m^2 and a 3000 l volume solar tank.

For the hospital in Urbino renovation was hypothesised only for the building envelope. The external insulation of the opaque elements, with the same thickness and materials as mentioned above, led to a reduction in the thermal transmittances from 1.43 W/m^{2}K to 0.17 W/m^{2}K for walls and from 1.80 W/m^{2}K to 0.19 W/m^{2}K for roofs. The overall transmittances of the windows (Uw) decreased from 6.5 W/m^{2}K to 1.3 W/m^{2}K.

The heating system was not involved in the refurbishment because the whole plant, including the control and monitoring devices, had been changed a few years before.

Despite the fact that the heating and DHW distribution system is poorly insulated and therefore causes high heat dispersion, no action was suggested because most of the pipes are behind the walls or beneath the floor and are therefore difficult to replace.

4.1.2 Community clinics

The renovation solutions that were designed for the two community clinics are somewhat similar, although their application to each hospital differed according to their peculiarities. The renovation which involved both buildings is relative to: replacement of windows, improved control of the heating system, retrofitted lighting and solar panels for hot water production.

In the case of SEM, all the windows of block A1 are old and therefore need to be replaced. This involves almost 320 m^2 of new glazed surface (double glazing and aluminium frames), whose average thermal transmittance will decrease from 4.6 W/(m^2·K) to 2.4 W/(m^2·K). In the case of the community clinic in Petritoli, about 477 m^2 of glazed surface will be replaced with new windows whose average transmittance will be reduced from 3.37 W/(m^2·K) to 1.15 W/(m^2·K). The benefits determined by this choice had an impact on reducing thermal losses through the envelopes due to air infiltration, thanks to the improved air permeability performance.

Another solution concerning the heating system of both buildings is related to the integration of Variable Frequency Drives and temperature reset controls for the pumps of the secondary sub-circuits. At present hot water is pumped at a constant flow rate. In the future scenario the water flow rate will vary according to the real heating needs and weather conditions, whose feedback can be considered by the temperature reset control and by sensors monitoring the return water temperature. This new control system will reduce the overheating that is currently caused by the absence of air temperature monitoring at room level. In addition, adjustable pumps will be integrated in the manifold station, that is in block A2 in SEM, and in the old block in Petritoli.

Solar panels for the production of hot water were also designed to be located close to the technical rooms of the central plants. On the whole they will cover a total surface of 133 m^2 and will satisfy most of the hot water requirements throughout the year in the case of SEM, whereas about 50 m^2 of solar panels will be installed to satisfy part of the hot water requirements in the case of Petritoli. The only drawback is that more electricity will be required due to the installation of an additional pump.

Another type of renovation concerns the lighting system. All the fluorescent lamps, which at the moment are in the corridors and in the rooms with high occupancy rates, will be replaced with led lamps driven by a Digital Addressable Lighting Interface (DALI) control system. Replacement of the existing lamps with led devices was considered for the rooms with a lower occupancy level. To that end, models developed in Relux were calibrated against present consumption and energy savings for the future scenarios were estimated.

In the SEM case study, the current arrangement of the piping of the primary circuit of the heating system is responsible for huge thermal losses. This is due to the considerable distance between the technical room of the central plant and the other technical room where the branches of the secondary system originate. The pipe of the primary circuit is about 100 m long and has no insulation at all. Hence, the replacement of the existing pipe with a new insulated one, to be located on the third floor below grade will determine a great reduction in the distribution losses of the heating system. Despite the limited impact of this solution, the combination of measures listed for SEM in Table 3, will determine thermal and electrical energy savings as great as 34% and 48%, respectively.

In the Petritoli case study the heat generator is quite old, therefore its replacement with a new condensing system (460 kW total power), fired with natural methane gas was assumed. Insulation of the floor between the attic and the third floor of the main building was also designed. On the whole, the combination of all the above-mentioned measures would bring the present consumption down by almost 50% in terms of heating consumption and by 33% in terms of electric power consumption.

4.2 Energy and economic analyses

Each yearly percentage reduction in energy consumption (i.e. thermal and electrical power) was turned into its monetary value, multiplying it by the unit price of natural methane gas and electrical power. In this way it was possible to calculate the annual cost reduction shown in the sixth column of Table 3. This value was compared with the initial investment listed in the fifth column, which is the result of the estimate of quantities described in sub-section 2.1. Hence, the simple payback period was assessed, as already explained in the same sub-section 2.1.

4.2.1 Acute hospitals

In the case of acute hospitals, once the kind of intervention and estimates of quantities had been evaluated, the unit costs were mainly drafted from the official database drawn up by the Marche regional authority. Since some processing cannot be assessed accurately without a detailed survey and an executive project, and unit costs are not present in the database, a rough cost estimate was made (i.e removal and replacement of air handling units and other plants on the roof). The proposed retrofitting led to a considerable reduction in energy consumption (77-79%) and GHG emissions (771-813-315 tCO_2/years). The aim and the obligation to bring the existing buildings into line with the value of energy performance indicated in current legislation (thermal transmittance of the envelope and overall efficiency of the heating system) lead to high levels of energy performance, although the cost-benefit ratios are not always optimal, as demonstrated by the PBP parameter. In fact, the simple payback period obtained (Table 3) ranges between 13 and 20 years, which is quite long (especially 20 years for the hospital in Pergola) and does not allow the initial investment to be repaid with fuel and electricity savings during the duration of the EPC contract.

4.2.2 Community clinics

In the case of community clinics, once the estimates of quantities had been calculated, the unit costs were mainly drafted from the official database drawn up by the Marche regional authority, as reported in sub-section 2.1. Only in a few cases, the database could not help with this task, and hence the unit costs were derived as the average between two or more quotations provided by suppliers or vendors. This was the case of the led lighting system with the DALI control and of the devices for controlling the secondary circuits, in both buildings. The simple payback periods listed in Table 3, ranging between 9.3 and 11.6 years, were derived from these estimates. They are therefore comparable with the duration of EPC contracts, as indicated in the literature cited in sub-section 2.2.

< Table 3 to be inserted here >

5. Discussion

The energy and economic analyses of the building surveys were conducted through the evaluation of real energy consumption, the set-up of a numerical calibrated model and the estimation of the benefits provided by retrofitting the hospitals and the community clinics. The assessment carried out supplies basic information for the future EPC tender, so as to allow the ESCo to have information about the achievable energy and economic savings.

The refurbishment strategies proposed for the acute hospitals and community clinics are different, because the current condition and use of the buildings varies, as does the future scenario indicated by the ASUR. In particular, two types of possible energy efficiency strategies were analysed: the first envisaged an overall retrofit of large complex buildings of considerable strategic importance for the public administration, while the second contemplated specific measures to improve the energy efficiency of community clinics, through the control and management of equipment, but without huge investments.

One important aspect which allows a correct energy audit is the presence of data on energy consumption and costs, and the characteristics of the equipment in the building. In fact, the first step in the evaluation was data collection and the construction of the baseline, that required complete and correct data for calibrating the evaluation model. Furthermore, the data acquired are global values measured at the power meter, with no separation between different uses and devices, and this could lead to significant errors, which do not permit the consumption of different devices to be identified in detail, and do not provide hourly profiles of the energy demand.

The evaluation of real energy consumption allows a reference value to be identified for the energy performance of the buildings with respect to the "standard" indicated in Italian legislation ($EP_{h,l}$ index). The comparison between the energy performance index for heating in the building surveys and the respective legal energy performance limit gives an idea of the poor energy performance of the buildings analysed. In fact, the energy consumption for heating is 310-405% and 135-205% greater than the limit for the acute hospitals and the community clinics, respectively, thereby demonstrating the considerable scope for energy performance improvement. Part of the energy inefficiency is due to low efficiency of the heating equipment. In fact the heating system global efficiency index (Table 2) is between 59.3-73.7% with no significant difference between clinics and hospitals. This parameter is due to the global efficiency of the systems (production, distribution, control, emission and auxiliary devices) that make up the heating equipment. Common to all the buildings analysed is their low efficiency caused by a poorly insulated distribution system and the lack of efficacy or absence of a control system.

For the acute hospitals the retrofit of the building envelope through external insulation and the replacement of the windows, together with the renewal of the heating system, leads to an important 77-79% reduction in energy consumption, with annual cost savings of €358,000 for the hospital in San Benedetto del Tronto, €218,000 for the hospital in Urbino, and €110,000 for the hospital in Pergola. The economic evaluations for these hospitals are made considering the purchase costs of natural gas. Further savings are due to the reduction in both the electricity consumption of the auxiliary devices and the maintenance costs. This means that, in comparison with the assessment, the real situation could lead to further cost savings. The Payback period index (PBP) for the acute hospitals is between 13-20 years. These values are longer than a normal EPC contract (max 10 years), and therefore mean that in order to be economically convenient, the ESCos need some form of incentive or subsidy provided by the property owner. The public administration which in this case is the owner, could have a further benefit in terms of a reduction in GHG emissions, and hence a clear economic advantage considering the reduction target set by the European Union.

On the contrary, for the community clinics the energy savings achieved are 33.9-47.4% in heating and 32.4-47.4% in electricity with annual cost savings of €32,000-40,000. Although the energy savings obtained are lower than those achievable in acute hospitals, clinics have a shorter PBP (approximately 9-11 years). This demonstrates that limited refurbishment of the most energivorous devices and components is more affordable than overall restructuring.

However, these limited measures do not allow the building to be adapted to the current energy levels required, and therefore fuel and electricity consumption remains high.

The results obtained are subject to uncertainties due to several factors, some of which are attributable to the energy and economic assessment. In particular there are risks related to incorrect prediction of the energy savings due to wrong evaluation of the baseline or to an inaccurate prediction of the energy savings. The difference between the results that could be reached and measured after retrofitting compared with the predicted value, could be due not only to the assessment method but also to unexpected factors such as: equipment performance, degradation, lifetime, changes inuse and occupancy of the buildings. In addition to the technical uncertainties, there are economic factors that could modify the real scenario, such as: interest rates, energy costs, tariff structures, tariff levels, and labour costs. The above-mentioned factors cause uncertainty and could jeopardise the success of the EPC. To reduce this risk, both a specific analysis to identify the problems inherent to the EPC and an analysis of possible corrective action are suggested.

6. Conclusion

The assessment presented in this paper showed that although the analysed buildings require enormous amounts of energy for space heating, domestic hot water and other electric supplies, suitable refurbishment can enhance their performance and reduce their energy consumption by up to 77% in those cases where “high cost investments” (acute hospitals) were hypothesised. Savings are no lower than 35-40% for the “low cost investment” refurbishment, that was adopted for community clinics. As far as the first kind of intervention is concerned, despite the huge expected energy savings, the PBP is quite long (15-20 years). As regards the second type of action, the PBP (9-11 years) is almost compatible with the duration of Energy Performance Contracts. For that reason, and in order to make the investment convenient from the economic and financial points of view, it must be supported by some type of subsidy, as has already been stated in literature [37,38]. One of the most popular types of third party support involves public incentives, which could be sized either on the effective energy reduction (white certificate) or on the environmental benefits that can be pursued. This approach would also be useful to correctly account for the huge environmental benefit that is determined by energy consumption reduction, as shown in the seventh column of Table 3. In fact, energy reduction will come as an advantage not only to the owner, but also to society in general.

The method proposed in this paper was based on regular energy analyses, that can easily be repeated and verified, so that any candidate bidding for an EPC tender can quickly evaluate the benefits deriving from any other variation in the basic proposed investment. Despite that, oversimplification is not suitable for this kind of analysis, because it could lead to the inability to properly consider some services.

As a final remark, buildings potentially suitable for retrofitting and energy requalification should be equipped with a monitoring system for energy and thermal parameters, so as to speed up data collection for energy auditing procedures. The same system would also be useful for monitoring and controlling the real performance of renewed systems.

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References

[1] Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC.

[2] Xu P, Chan EXW, Visscher HJ, Zhang X, Wu Z. Sustainable building energy efficiency retrofit for hotel buildings using EPC mechanism in China: analytic Network Process (ANP) approach. J Clean Prod, Available online 8 January 2015.

[3] P. Lee, P.T.I. Lam, W.L. Lee, Risks in Energy Performance Contracting (EPC) projects, Energy and Buildings, Volume 92, 1 April 2015, Pages 116-127, ISSN 0378-7788, http://dx.doi.org/10.1016/j.enbuild.2015.01.054.

[4] Pätäri S, Sinkkonen K. Energy Service Companies and Energy Performance Contracting: is there a need to renew the business model? Insights from a Delphi study. J Clean Prod 2014;66:264-71.

[5] Zabot S, Di Santo D. Guida ai contratti di prestazione energetica negli edifici pubblici, Report Ricerca di Sistema Elettrico, ENEA, 2013, http://editors.enea.it/it/Ricerca_sviluppo/documenti/ricerca-di-sistema-elettrico/edifici-pa/2012/rds-2013-150.pdf

[6] Bertoldi P, Rezessy S, Vine E. Energy service companies in European countries: Current status and a strategy to foster their development. Energ Policy 2006;34:1818-32.

[7] Hu Jinrong, Zhou Enyi, Engineering Risk Management Planning in Energy Performance Contracting in China, Systems Engineering Procedia, Volume 1, 2011, Pages 195-205, ISSN 2211-3819, http://dx.doi.org/10.1016/j.sepro.2011.08.032.

[8] Dong Qian, Ju'e Guo, Research on the energy-saving and revenue sharing strategy of ESCOs under the uncertainty of the value of Energy Performance Contracting Projects, Energy Policy, Volume 73, October 2014, Pages 710-721, ISSN 0301-4215, http://dx.doi.org/10.1016/j.enpol.2014.05.013.

[9] P. Lee, P.T.I. Lam, F.W.H. Yik, E.H.W. Chan, Probabilistic risk assessment of the energy saving shortfall in energy performance contracting projects–A case study, Energy and Buildings, Volume 66, November 2013, Pages 353-363, ISSN 0378-7788, http://dx.doi.org/10.1016/j.enbuild.2013.07.018.

[10] EN 16247-1:2012 Energy audits – Part 1; Generael requirements.

[11] FprEN 16247-2:2014 Energy audits – Part 2; Building.

[12] P. Arcuri, G. Florio, P. Fragiacomo_A mixed integer programming model for optimal design of trigeneration in a hospital complex. Energy 32 (2007) 1430–1447

[13] D. Ziher, A. Poredos, Economics of a trigeneration system in a hospital, Applied Thermal Engineering 26 (2006) 680–687

[14] Denilson Boschiero do Espirito Santo, An energy and exergy analysis of a high-efficiency enginetrigeneration system for a hospital: A case study methodologybased on annual energy demand profiles, Energy and Buildings 76 (2014) 185–198

[15] Alexandre Salem Szklo, Jeferson Borghetti Soares, Maurício Tiomno Tolmasquim, Energy consumption indicators and CHP technical potential in the Brazilian hospital sector, Energy Conversion and Management, Volume 45, Issues 13–14, August 2004, Pages 2075-2091, ISSN 0196-8904, http://dx.doi.org/10.1016/j.enconman.2003.10.019.

[16] G.K. Alexis, P. Liakos, A case study of a cogeneration system for a hospital in Greece. Economic and environmental impacts, Applied Thermal Engineering, Volume 54, Issue 2, 30 May 2013, Pages 488-496, ISSN 1359-4311, http://dx.doi.org/10.1016/j.applthermaleng.2013.02.019.

[17] C.J. Renedo, A. Ortiz, M. Mañana, D. Silió, S. Pérez, Study of different cogeneration alternatives for a Spanish hospital center, Energy and Buildings, Volume 38, Issue 5, May 2006, Pages 484-490, ISSN 0378-7788, http://dx.doi.org/10.1016/j.enbuild.2005.08.011.

[18] Bizzarri G, Morini GL. New technologies for an effective energy retrofit of hospitals. Applied Thermal Engineering 2006;26(2e3):161e9.

[19] Bizzarri G, Morini GL. Greenhouse gas reduction and primary energy savings via adoption of a fuel cell hybrid plant in a hospital. Applied Thermal Engineering 2004;24(2e3):383e400.

[20] T. Tsoutsos, E. Aloumpi, Z. Gkouskos, M. Karagiorgas, Design of a solar absorption cooling system in a Greek hospital, Energy and Buildings, Volume 42, Issue 2, February 2010, Pages 265-272, ISSN 0378-7788, http://dx.doi.org/10.1016/j.enbuild.2009.09.002.

[21] Mikko Kantola, Arto Saari. Renewable vs. traditional energy management solutions e A Finnish hospital facility case, Renewable Energy 57 (2013) 539e545

[22] Buonomano A, Calise F, Ferruzzi G, Palombo A. Dynamic energy performance analysis: Case study for energy efficiency retrofits of hospital buildings. Energy 2014;78:555-72.

[23] [a20] Gamze Ozyogurtcu, Moghtada Mobedi, Baris Ozerdem, Economical assessment of different HVAC systems for an operating room: Case study for different Turkish climate regions, Energy and Buildings, Volume 43, Issue 7, July 2011, Pages 1536-1543, ISSN 0378-7788, http://dx.doi.org/10.1016/j.enbuild.2011.02.013.

[24] Mohammad Rasouli, Soheil Akbari, Carey J. Simonson∗, Robert W. Besant, Energetic, economic and environmental analysis of a health-care facility HVAC system equipped with a run-around membrane energy exchanger. Energy and Buildings 69 (2014) 112–121

[25] Ascione F, Bianco N, De Masi RF, Vanoli GP. Rehabilitation of the building envelope of hospitals: Achievable energy savings and microclimatic control on varying the HVAC systems in Mediterranean climates. Energ Buildings 2013;60:235-8.

[26] Saidur R, Hasanuzzaman M, Yogeswaran S, Mohammed HA, Hossain MS. An end-use energy analysis in a Malaysian public hospital. Energy 2010;35:4780-5.

[27] Janusz Bujak (2010) Heat consumption for preparing domestic hot water in hospitals, Energy and Buildings 42 (2010) 1047–1055

[28] V. Congradac, B. Prebiracevic, N. Jorgovanovic, D. Staniˇsic, Assessing the energy consumption for heating and cooling in hospitals, Energy and Buildings 48 (2012) 146–154.

[29] Velimir Čongradac, Bogdan Prebiračević, Nebojša Petrovački, Methods for assessing energy savings in hospitals using various control techniques, Energy and Buildings, Volume 69, February 2014, Pages 85-92, ISSN 0378-7788, http://dx.doi.org/10.1016/j.enbuild.2013.10.023.

[30] Sotiris Papantoniou, Dionysia Kolokotsa, Kostas Kalaitzakis, Building optimization and control algorithms implemented in existing BEMS using a web based energy management and control system, Energy and Buildings, Volume 98, 1 July 2015, Pages 45-55, ISSN 0378-7788, http://dx.doi.org/10.1016/j.enbuild.2014.10.083.

[31] A.W.M. Van Schijndel, Optimal operation of a hospital power plant, Energy and Buildings 34 (10) (2002) 1055–1065.

[32] UNI TS 11300-1: 2014. Energy perforance of buildings. Part 1: Evaluation of energy need for space heating and cooling.

[33] UNI TS 11300-2: 2014. Energy performance of buildings. Part 2: Evaluation of primary energy need and of system efficiencies for space heating and domestic hot water production.

[34] Decreto Legislativo 30 maggio 2008, n. 115 - "Attuazione della direttiva 2006/32/CE relativa all'efficienza degli usi finali dell'energia e i servizi energetici e abrogazione della direttiva 93/76/CEE" G. U. n. 154 del 3 luglio 2008 (in Italian)

[35] Decreto Ministeriale 26/6/2009 – Ministero dello Sviluppo Economico Linee guida nazionali per la certificazione energetica degli edifici - G.U. 10/7/2009 n. 158 – in vigore dal 25/7/2009 (in Italian)

[36] MC4Suite Software. Website: http://www.mc4software.com/ (Access on: 8 September 2015).

[37] US Department of Housing and Urban Development – Office of Public and Indian Housing, Guidance on Energy Performance Contracts - Notice: PIH-2011-36 (HA), issued on July 8th, 2011.

[38] Washington State Department of Enterprise Services, Energy savings performance contracting – Guidelines for Public Agencies in Washington State, March 2012.

[39] EPEC – European PPP expertise centre, "Guidance on energy efficiency in public buildings", available on-line at: http://www.eib.org .

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Figure. 1. Pictures of (a) San Benedetto del Tronto; (b) Urbino; (c) Pergola; (d) Sant'Elpidio a Mare and (e) Petritoli.

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Object: paper submission to Energy and Buildings - special issue: “**Building Retrofit: Energy conservation, Comfort and Sustainability**”

Dear editors,
we are submitting our paper for consideration for publication by the Journal “Energy and Buildings”.

The submitted version of our paper is unpublished material, because it was worked out as an extension of the paper that we submitted at the IBPC conference in Torino that was held in June 2015.

The title of our paper is:

Potential opportunities for energy conservation in existing hospitals through Energy Performance Contracting (EPC)

by: Paolo Principi, Roberto Fioretti, Alessandro Carbonari, Massimo Lemma

Should you need other information, please do not hesitate to contact me
With best regards

The corresponding author

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Figure 1a

Figure 1b

Figure 1c

Figure 1d

Figure 1e

Highlights:

- An energy audit was performed on 5 healthcare buildings.

- Current energy consumption and possible retrofit solutions were evaluated.

- The global retrofit of hospitals allows savings of between 77-79% for natural gas.

- The retrofit of clinics allows savings of between 34-47% for heating and 32-47% for electricity.

- Payback periods (PBP) of energy retrofitting are between 9 and 20 years.

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Table 1

Id (City/Town)	Climate Zone [Italian leg.]	Degree days	Number of floors	S_u [m^2]	V [m^3]	Ratio S/V	Time of construction
San Benedetto del Tronto	D	1593	8	36863	159422	0.27	1960s-1980s
Urbino	E	2545	8	21018	87238	0.38	1960s-1990s
Pergola	E	2264	6	8195	34026	0.43	1970s
Sant'Elpidio a Mare	D	1874	7	2360 (3444)	10580 (15239)	0.41 (0.32)	1970s-1980s
Petritoli	D	2058	5	2184 (3229)	10866 (16292)	0.56 (0.48)	1970s-1980s

Table 1. Climate zone, geometry and time of construction of acute hospitals and community clinics.

Table 2

Id (City/Town)	Methane [kWh/m^3·y]	Electricity [kWh/m^3·y]	EP$_H$ [kWh/m^3·y]	EP$_{H,L}$ [kWh/m^3·y]	EP$_w$ [kWh/m^3·y]	η_{gl} [%]
San Benedetto del Tronto	57.2	26.0	30.3	7.4	2.4	62.3
Urbino	69.2	40.7	68.7	13.6	3.7	60.7
Pergola	62.7	18.3	59.3	13.3	1.9	73.7
Sant'Elpidio a Mare	49.0	12.9	34.0 (39.2)	14.4 (13.1)	19.4 (9.8)	45.8
Petritoli	41.4	7.5	33.3 (52.2)	10.9 (9.4)	10.9 (6.3)	59.0

Table 2. Results of the benchmarking analyses.

Table 3

Id (City/Town)	actions	EP_H [kWh/m^3·year]	energy reduction [%]	initial investment [k€]	cost reduction [k€/year]	GHG reduction [kgCO_2/y]	PBP [year]
San Benedetto del Tronto	retrofit of whole envelope and heating generation and control system	7.60	77	4600	358	771000	13
Urbino	retrofit of whole envelope and control system. Starting CHP.	15.44	79	3150	218	813825	15
Pergola	retrofit of whole envelope and heating generation and control system	12.40	79	2180	110	315000	20
Sant'Elpidio a Mare	window replac., new heating system control, lighting and solar panels	19.4	(heating) 33.9% (electric) 47.4%	370.4	32	120384	11.6
Petritoli	window replac., roof insul., new heat generation and control, lighting and solar panels	20.9	(heating) 49.8% (electric) 32.4%	370	39.8	127730	9.3

Table 3. Post-retrofit scenarios relative to the five hospitals