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Energy audit of an industrial site: a case study

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Abstract

In order to reduce energy consumptions for sustainable and energy-efficient manufacturing, continuous energy audit and process tracking of industrial machines are essential. Compared to other non-residential buildings that have been widely researched, industrial buildings are generally characterized by larger thermal loads, ventilation losses and pollution control requirements. This paper presents the results of a preliminary energy audit carried out on 8 large industrial buildings of a famous car manufacturing holding in Italy. Energy demand for heating varied from 6 to just over 74 kWh/m^3year among the buildings of the site. The energy audit enabled to build a specific factory energy model which has been used in order to analyze the impact of various energy saving actions on the primary energy consumptions of the site. It has been demonstrated that in this specific case the improvement of the building envelopes and the optimization of the performances of the existing HVAC systems can determine a reduction of gas consumption up to 15% per year with a predicted annual economic saving of the order of 100000 €; the total simple pay-back time of the proposed thermal retrofitting is evaluated to be less than 6 years..

Keywords: Energy Audit; Car Industry; Energy Savings; Energy Efficiency

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1. Introduction

The latest European standards in the field of energy efficiency (i.e. 2012/27/EU Directive) [1] point to obtain ambitious goals in terms of the use of renewable sources and energy saving by indicating for all the Member States the obligation to establish a plan for upgrading the energy efficiency of public and private buildings. Starting from 2014, each year at least 3% of the public building surface area shall be retrofitted in order to improve their energy efficiency. Moreover, from December 2015, also the relevant companies will need to undergo an energy audit of their facilities, an audit that must be renewed every 4 years.

Cause to the economic crisis still ongoing, in Italy the total energy consumption in the industrial sector is decreasing during the last six years, from a requirement of 48.9 Mtoe of primary energy in 2006 to 37.4 Mtoe of primary energy in 2012 [2]. However, the impact of the industrial energy consumptions on the total primary energy requirement is equal to 21% and still remains significant. The purpose of the aforementioned EU Directive is mainly to encourage retrofit actions in the industrial sector, which often offers larger energy saving margins respect to the residential sector. For this reason, the EU Directive highlights the compulsoriness of industrial energy audits in order to promote a very efficient tool for monitoring energy consumption and to achieve energy savings by means of the individuation of specific retrofit actions.

An energy audit is the procedure by means of which it is possible to analyze the energy balance of a system in order to define possible improvements of its energy efficiency, to achieve the mitigation of its environmental impact and to reduce energy costs. The main steps of an auditing process have been recently collected and defined in the specific national technical recommendation UNI CEI TR 11428 appeared in October 2011. The auditing procedure is split by the Italian standard in the following steps [3]:

- Complete energy analysis of the system
- Identification of energy waste
- Definition of the retrofitting plan needed to obtain a reduction of energy consumptions
- Implementation of a systematic plan for the development of energy saving projects and monitoring of the results.

In this paper the main results of an energy audit made in the facilities of an important Italian Automotive company is described. In literature there exist other works addressed to the main topic, as for example the work of Gordic et al. [4] in which typical energy consumptions of an automotive industry characterized by a large scale car production were critically analyzed. However, these data are not useful in order to establish reference energy indicators for the Italian company which is the target of the Audit described in this paper because this company is characterized by a low production volume of luxury cars per year and the energy profile consumptions are very different from those generally linked to the generalist car producers.

The data required to develop the energy audit were collected over a period of six months from June 2012 to January 2013. The input data concern the factory layout, the location of thermal and electric plants, the individuation of the main thermal zones in which the whole factory can be partitioned, the data needed for the complete characterization of the existing thermal and electrical plants, the historical trend of the factory energy consumptions and the energy costs through the readings of bills and the monitoring of the indication of the natural gas flow meters installed in the factory. In addition, with the aim to complete the overview of the thermal performances of the factory, an experimental campaign of measurements has been conducted in order to check the real values of the indoor temperature maintained within each building of the factory and to test the thermal characteristics of the main elements of the building envelopes (windows, walls, roof).

As basis of the energy assessment about the factory thermal uses, the natural gas consumptions concerning the last three years 2010, 2011 and 2012 have been used.

2. Energy Analysis of the Plant

The factory analyzed in this paper is located in Emilia Romagna, close to Bologna, and it is very large and complex: it occupies a built-up area of about 70000 m^2, corresponding in a total heated volume of 320000 m^3. The total number of employees of the factory is about 1200. In Figure 1 a schematic lay-out of the whole factory is given.

The factory is divided in several buildings, the most important of which were analyzed during the energy audit. More in detail, the energy audit presented in this paper concerns 8 buildings, each of them characterized by different envelops and heating systems. Only one building is heated by means of a electric heat pump system; the other buildings are heated by burning natural gas.

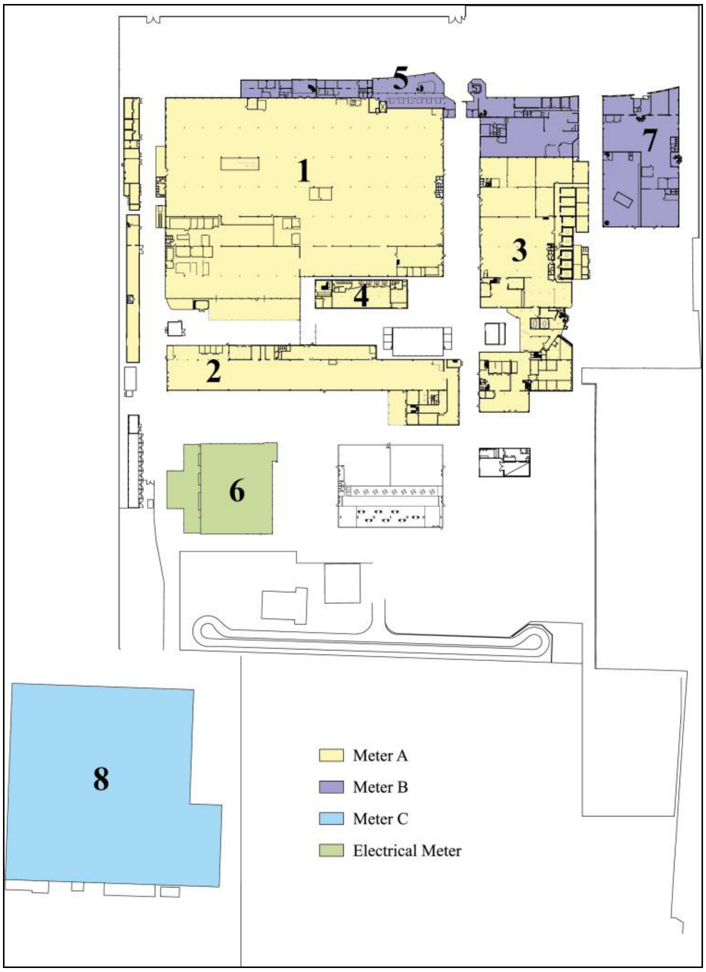

Fig. 1 Layout of the factory; main heated buildings and indication of the corresponding gas and electrical meters.

Within the factory are located 8 different thermal generators but only three distinct gas meters are installed: as evidenced in Figure 1, the gas meter A supplies the buildings 1, 2, 3 and 4, the gas meter B is connected to the buildings 5 and 7, and finally the consumption of the building 8 is registered by the gas meter C. Obviously, the building 6, heated by means of the electric heat pump system, is provided of a specific electricity meter. Unfortunately the thermal layout is very complex: there isn't a correspondence between buildings and thermal plants. For example buildings 2 and 3 are heated by a heat generator, instead building 1 is heated by two different thermal plants. The gas meters A and B record the gas consumption of the car production divisions, while the meter C records the gas consumptions of the R&D division in which carbon monocoques are produced. In order to give an idea about the typical energy consumptions of the factory during 2012 the company has burned a total of about 1.3MSm^3 of natural gas, with a corresponding energy bill of about 650000 €.

2.1 Asset rating evaluation

As first step of the energy audit a standard evaluation of the heating energy consumptions of the main buildings of the factory has been conducted. Accordingly with current Italian standards[5, 6, 7], this kind of evaluation is defined as "*Asset rating*" evaluation and it is considered as the basis for the computation of the energy class of each building. In the Asset rating evaluation a standard use of the buildings is considered by taking into account all the constraints imposed by the Italian standards about the evaluation of the energy class of a building (i.e. a fixed indoor temperature equal to 18 °C for production zones and equal to 20 °C for offices, continuous operation 24h/24h of the heating system, standard assessment of the free thermal gains), standard weather conditions and the real conditions of the envelope elements of each building:

The Asset rating evaluation of the heating primary energy consumptions of each building has been obtained by using a commercial certified software (*MC4 Suite*) by means of which a tridimensional model of each building has been made. In Table 1 the main results obtained in terms of heating primary energy consumptions, of the value of the Energy Performance Indicator (EPi) linked to each heated building and of the Energy Class assigned to each building following the current energy building classification of Emilia Romagna are quoted. By observing the data reported in Table 1 it is evident that strong differences among the standard energy consumptions of the different buildings of the factory there exist; these differences are due to the characteristics of the thermal plants and of the envelopes associated to each building and hence to the year of construction of each building. As an example, building 6 is characterized by a very low specific primary energy consumptions (about 6 kWh/m^3 year); this building is the most recent building added to the factory in 2012 and its envelope and its heating plant have been optimized in order to guarantee low energy consumptions both for heating and cooling. On the other hand, building 5, built in 1999, presents a primary energy requirement for heating of about 74 kWh/m^3 year, one order of magnitude larger that building 6, and this large energy consumption is due to the combined effect of a old heat generation system and of an envelope scarcely insulated from a thermal point of view. An unexpected but interesting result of this asset rating evaluation is that buildings with worst energy performances are those in which the administration is located. In order to explain this fact it is important to observe that in the offices a higher indoor temperature is required (20°C against 18°C of the production zones) and, more important, the ventilation heat losses can be more significant in offices with respect to certain production zones due to the larger renewal air flow rates needed for the maintaining of the hygienic conditions.

Table 1. Asset rating evaluation of the factory energy consumptions for heating

Building	Heating Primary Energy consumptions (MWh/year)	EPi (kWh/m^3 year)	Energetic Class
1	2812.9	21.86	C
2	806.5	27.44	C
3	1185.2	28.82	C
4	255.0	45.80	E
5	3136.9	74.11	F
6	191.7	6.04	A
7	492.9	15.55	B
8	2528.1	26.05	C

The main goal of this preliminary asset rating evaluation has been to individuate for each building the main sources of energy waste. With the only exception of building number 6, all the buildings of the plant present more than one critical point in terms of envelope elements (i.e. high U-value of external walls, thermal bridges) and/or heating plant (low efficiency of the heat generation systems, heating emission, thermal regulation). Common energy waste elements are the thermal losses from the building envelope caused by a low level of walls thermal insulation, thermal losses from windows and skylights, a generalized oversize and oldness of the existing thermal plants (especially burners and generators), and finally the use of ventilation systems characterized by low energy efficiency. In this way, the results obtained during the asset rating evaluation have been used in order to individuate for each building the weak elements of the building envelope and of the existing heating plant for a more rational use of the thermal energy. In addition, the results obtained in this phase enable the comparison of the energy performance of the factory buildings because obtained by considering for each building standard conditions of use.

2.2 Tailored rating evaluation

The estimated energy consumptions obtained for each building with the asset rating evaluation are not directly comparable with the real energy consumptions of the factory, which are available by the periodical reading of the data recorded by the gas and electricity meters because the standard conditions used in the asset rating evaluation are generally far from the real condition of use of the building. In order to obtain a more realistic evaluation of the factory energy consumption, a *Tailored rating* evaluation have been made as suggested by [5,6, 7].

The aim of the tailored rating evaluation is mainly the simulation of the thermal behavior of the factory buildings by taking into account the real conditions of use of each zone in order to obtain a more accurate estimation of the real energy consumption of the buildings. The tridimensional model of each building made by using *MC4 Suite*, adopted during the asset rating evaluation, have been used here by changing the boundary conditions in order to take into account: (i) the real indoor temperature adopted in each productive zone, measured by a series of temperature probes; (ii) the intermittent operating mode of the heating system; (iii) a specific evaluation of free heat gains, in particular for the estimation of the internal heat sources within the production zones.

The tailored rating simulation enables to obtain primary energy consumptions directly comparable with the energy consumption deduced by the reading of the energy meters installed in the factory and this evaluation permits to split the aggregated energy consumption, measured by a single gas meter, among the different buildings connected to the same gas meter. This point is very important for the company in order to have the possibility to subdivide the total energy consumptions among the specific production steps located in each building.

The estimated energy consumptions associated to each building with the tailored rating evaluation are quoted in Table 2. A comparison between the tailored simulation results and the real energy consumption will be shown later.

Table 2. Tailored rating evaluation of the factory energy consumptions for heating

Building	Heating Primary Energy consumptions (MWh/year)
1	603.6
2	165.1
3	214.0
4	55.3
5	807.2
6	154.8
7	339.8
8	587.1

By comparing the data quoted in Table 1 with those of Table 2 it is evident that the primary energy consumptions estimated during the asset rating evaluation are generally larger than those obtained adopting a tailored rating evaluation. For an industrial site this difference can be very large, like in this case, because the real condition of use of the buildings can be very different from the imposed standard conditions adopted during the asset rating evaluation. The main reasons of this large difference are due to: (i) the evaluation of the internal gains, which can be very large in presence of large scale equipments within the production zones and (ii) the adopted operating mode of heating plants since the continuous use (24h/24h) of the heat generators, imposed by the normative for an asset rating evaluation, is generally far from the real management of the heating plants. As an example, the factory heating plants and ventilation systems are usually switched on for 16 hours per day, only during working days, instead of 24h/24h, for all days.

2.3 Evaluation of the Key Performance Indicators

One of the main goal of an energy audit is the definition of a series of synthetic energy indicators in which the total energy consumption of the system under analysis is disaggregated and scaled by considering the typical outputs of the company. These indicators are called Key Performance Indicators (KPI) and they are very useful in order to take under control the functionality of the whole system and to make easier the comparisons with the energy consumptions of other factories which operate in the same field. Unfortunately, a standardized definition of this kind of indicators for all the industrial sectors there not exists. A typical KPI used in the industrial field is defined as the heating primary energy consumption scaled on the number of factory outputs(KPI_a). In fact, it appears reasonable that the energy consumptions of the factory can be correlated directly to the number of outputs produced.

In this case, the company produces two different kind of outputs: cars and carbon monocoques. For this reason two different KPIs (KPI_{a1}, KPI_{a2})have been introduced and calculated.

In Table 3 the trend of the total primary energy consumption, expressed in terms of consumption of kWh of natural gas, scaled on the number of cars and on the number of monocoques produced yearly is shown. It is important to underline that the monocoque's production has started in the second half of 2010, so this year data are not representative, but it has been reported for completeness.

It is possible to note in Table 3 that the primary energy consumption tends to decrease with the increase of the output production. This result can be interpreted as the evidence of a heating primary energy consumption independent from the industrial production volumes.

Unfortunately it is difficult to compare the results obtained in this case with the values of specific energy consumptions obtained during energy audits made on the other car manufacturers. In fact, there are no data regarding the specific consumption of other luxury car manufacturers but only general data on the major American and European automotive industries [8], which are therefore characterized by different production volumes and different industrial lay-outs. As reference, it could be useful to give typical values of the specific energy consumption of these car manufacturers which are of the order of about 2 MWh of primary energy per car, corresponding in about 590 Sm^3/car. In order to complete this information, it is important to remember that in these data all heat energy use (hot water for heating and DHW, industrial steam) are considered.

About the primary energy consumption related to the production of carbon monocoque, because it is a kind of work with high added value and performed by very few producers in the world it is not possible to give other reference values in order to compare with the results obtained in this work and quoted in Table 3.

Table 3. Analysis of specific gas consumption

Year	N° of produced cars per year	Specific gas consumption KPI_{a1} (kWh/car)	N° of produced monocoques per year	Specific gas consumption KPI_{a2} (kWh/monocoque)
2010	1226	2606.2	68	4539.2
2011	1771	2054.3	625	1097.3
2012	2083	1734.3	996	823.8

Another interesting KPI which can be defined in this case, is the KPI obtained by scaling the energy consumption on the weather conditions by using the degree days recorded each year in the site (KPI_b). This indicator shows the energy consumption for heating normalized on the specific external atmospheric conditions; in this way KPI_b becomes independent on the weather conditions recorded each year.

Table 4. Trend of gas consumption for degree day

Year	Degree Days	Meter A KPI_b (kWh/DD year)	Meter B KPI_b (kWh /DD year)	Meter C KPI_b (kWh DD year)
2010	2674	424.1	577.3	/
2011	2523	500.0	670.5	199.3
2012	2652	511.6	608.2	232.6

In Table 4 are quoted the degree days recorded during the winter season during the last 3 years and the energy consumptions calculated by taking into account the indication of the three gas meters of the factory. Because the production of monocoques started during 2010, the corresponding specific gas consumption is not realistic and it is omitted.

From the data quoted in Table 4 it is evident that the primary energy consumption scaled on the degree days is not constant as expected from a theoretical point of view. Unfortunately during these last three years the factory layout is changed heavily: new buildings have been built, other ones have been retrofitted and finally some of them have been turned from production to offices. Because the layout is changed, is impossible to make quantitative evaluations and comparisons among the values obtained during the last three years.

In Table 5 the tailored rating evaluation of the energy consumptions obtained for each building has been scaled on the corresponding degree days used in the simulation; the results are useful in order to disaggregate the energy consumption totalized by the gas meters building by building.

Table 5. Summary of Specific Consumption divided for building

Building	Gas Consumption for degree day KPI_b(kWh /DD year)
1	275.9
2	75.5
3	97.8
4	25.3
5	368.9
6	154.8
7	155.3
8	268.4

The results quoted in Table 5 can be a good starting point for monitoring in the future the energy performance of each building; in order to verify the values of KPI_b linked to each building in the next future the company will install new gas meter in order to check the gas consumption of each building separately.

Finally, KPI_b can be used to make a comparison between simulations results and the real energy consumptions of the factory. In Table 6 is shown the natural gas consumptions scaled on degree days and aggregated for installed gas meter. In the second column are reported the results obtained via *MC4 Suite* simulations and in the third column the corresponding values of the KPI_b calculated by using the indications of the gas meter data.

Table 6. Analysis of Specific Gas Consumption for Degree Days

Meter	Predicted Gas Consumption for degree day from simulations (kWh /DD year)	Gas Consumption for degree day from gas meters (kWh /DD year)	Difference
A	474.5	511.5	-8%
B	524.3	608.3	-16%
C	268.4	232.6	+13%

It is possible to highlight how the predicted values of KPI_b are very close to the real values with a maximum difference of the order of 16%; by considering the complexity of the site this kind of result can be considered encouraging and a good benchmark of the numerical models of the different buildings. The positive benchmark underlines that the energy factory model can be useful in order to analyze the impact of different retrofit interventions on the energy consumptions of the site and for the monitoring of the energy performances of the different buildings.

3. Feasibility Study of Energy Saving Measures

After the benchmark of the energy factory model, the next step of the energy audit has been the definition and evaluation of a coherent energy saving plan for the site. The preliminary audit about the status of the building's envelopes and of the thermal plants has given a precise address to the retrofitting proposal and to the elaboration of the factory energy saving plan. A list of possible interventions has been compiled and for each item a simple feasibility study has been made, with the help of the factory energy model, in order to define the technical and economic suitability of each specific energy saving measure.

In order to evaluate the energy saving obtainable for each proposed measure the numerical *MC4 Suite* model of the system building-thermal plant is used in order to predict the primary energy saving linked to the intervention. After this step, an estimation of the investment costs linked to the measure, according to market prices [9, 10] is made by taking into account all the existing national economic incentives linked to the energy saving actions. Finally the simple pay back time of each energy saving measure is calculated; this parameter can be used in order to assign a priority index to the analyzed energy saving measure. In this case, by following the indications of the management of the company, a classification of the proposed energy saving actions has been made by taking into account the associated value of the pay back time.

The proposed energy saving actions are divided in two groups: actions related to the improvement of the thermal features of the building envelopes and actions linked to the retrofitting of the thermal plants.

Among the actions of the first group (related to the envelope) belongs the improvement of the thermal insulation of the external envelope elements (walls, roofs, floors, windows). Thanks to the factory energy model becomes easy the evaluation of the impact on the energy consumptions of the site of the envelope's retrofit of the different buildings. In many buildings (especially the older ones) the external walls, floors and roof-tops present a scarce thermal insulation. For this reason the improvement of the U-Value of these elements has been tested as possible energy saving action. By considering the application of a mean thickness of an additional thermal insulation layer of about 12-14 cm it is possible to decrease the U-Value of walls and roof-tops of about 80-90%. The buildings interested by this measure are the building 1, 2, 3, 4, 5 and 8 which are the factory's structures more aged. For this action, a total investment cost of about 200000 € has been estimated. The factory energy model highlights that the improvement of the thermal insulation of opaque elements of the envelopes of the older buildings of the site could produce a total primary energy saving of about 225000 kWh per year, with a decrease of the factory energy bill of about 33000 €. However, by spitting this evaluation building by building, it is possible to shown that only in some cases the thermal insulation improvement is economically sustainable.

Another possible energy saving action related to the envelope features is linked to the improvement of the thermal characteristics of the existing windows. For some buildings (i.e. numbers 1, 5 and 8) the ratio between the transparent area (windows and skylights) and the total external area is very large and the transparent elements consist of a single glass layer. By means of the factory energy model the substitution of the existing glasses with double or triple glasses having a low emissivity value has been studied in order to predict the maximum primary energy saving obtainable with this action. This analysis has demonstrated that this kind of action can generate an estimated total energy saving of about 200000 kWh for year, a value very similar to the corresponding one obtained for the improvement of the thermal insulation of the opaque envelope elements, but this action is more expensive: it has been estimated a total maximum cost of about 800000 € for the improvement of the windows which corresponds to a limited yearly economic saving of about 30000 €. The large value of the pay-back time associated to this specific action suggests for this measure a very low priority.

Among the energy saving actions linked to the improvement of the performances of the existing thermal plants the substitution of the old boilers installed in the site has to be mentioned. In fact, the energy simulation made by using the factory energy model has shown that the installed nominal power of the boilers is generally overestimated with respect to the thermal power needed by the site. For this reason, boilers work for most of the time during the winter season at partial loads with reduced performances. Moreover, boilers in many buildings are dated (in some cases they were installed more than 20 years ago). A feasibility study was made about the substitution of the boilers installed in thermal plants of the buildings 1, 3, 4, 5 and 7: in this case the total investment cost is about 280000 €, and the estimated energy saving is about 355000 kWh for year; more important, it has been estimated a cost saving linked to the energy bill of about 53000 € per year.

Another important retrofitting intervention is linked to the optimization of the HVAC systems. Technical standards prescribe the value of the minimal air-change rate for both offices and productive departments. In general, the air conditioning is done by means of specific air treatment units (HVAC) powered by thermal plants in winter and by chillers in summer. In many cases, such as for the conditioning of material processing cabins, the conditioned air flow rate can be very large and the primary energy consumption linked to the air conditioning is non-negligible. The factory energy audit highlighted the possibility to save energy in this field with the adoption of heat recovery units. The use of heat recovery units for each HVAC system installed could determine a total primary energy saving of about 95000 kWh per year, which corresponds to a decrease of energy bill of about 14000 € per year versus a capital cost of about 85000 €. The pay-back time linked to this action is very interesting.

Finally, the measurement of the indoor temperature both in offices and production sites has evidenced a large value of the indoor temperature set-up, up to 5°C over the imposed limits (20°C for offices, 18°C for production sites). By means of the factory energy model the energy saving corresponding to the decrease of the indoor temperature set-up value within the factory buildings has been numerically estimated. This action is very interesting because no capital costs are involved. It has been predicted that the adoption of a lower indoor temperature can determine an interesting primary energy saving (of about 150000 kWh per year) corresponding to a saving cost of about 23000 € per year.

Table 7. Summary of evaluated energy saving measures

Energy Saving Measure	Annual Energy Saving (kWh)	Annual Economic Saving (€)	Investment cost (€)	Annual CO_2 Emissions Saving (ton CO_2)
Buildings insulation	225000	33000	200000	126.7
Windows replacement	200000	30000	800000	115.2
Boilers replacement	355000	53000	280000	201.6
Heat recovery units installation	95000	14000	85000	53.8
Regulation update	150000	23000	/	86.4

A summary of the main energy saving actions analyzed by using the factory energy model with the quantification of savings, costs and other interesting indicators, is quoted in Table 7.

Table 8. Summary of suitable Energy Saving Measures

Building	Energy Saving Measure	Annual Energy Saving (kWh)	Annual Economic Saving (€)	Investment cost (€)	Pay Back Time (years)
Whole Plant	Regulation update	150000	23000	/	0
8	Boiling Replacement	80000	12500	40000	3.2
5	Building Insulation	40000	6000	20000	3.3
1	Boiling Replacement	110000	17000	80000	4.7
1	Building Insulation	36000	5500	29000	5
7	Boiling Replacement	98000	15000	75000	5
8	Heat recovery units installation	58000	9000	50000	5.5
5	Roof-top Insulation	68000	10500	56000	5.5
5	Heat recovery units installation	18000	2700	15000	5.5

In Table 8, the energy saving actions have been divided for buildings and for each action the foreseen pay-back time is indicated. The company considers as acceptable energy saving actions with a pay-back time less than five years; for this reason, in Table 8 only the retrofitting actions characterized by a pay-back time of about 5 years are reported. If all the energy saving actions indicated in Table 8 are actuated, the predicted total annual economic saving is of the order of 100000 €; in this way the natural gas bill is reduced by 15%, with a total simple pay-back time less than 6 years.

4. Conclusions

Energy audit is a powerful tool to achieve interesting energy savings. The reduction of energy costs is a key to improve companies competitiveness and for this reason the realization of an energy audit of industrial sites is not only a specific obligation foreseen by the European Directives but also a real opportunity for the companies.

In this paper the energy audit, limited to the heating plants of the factory, of an industrial site devoted to the production of luxury cars is described. It has been demonstrated how the energy audit enables to collect information which are very useful to define a factory energy model by means of which the energy balance of the site is analyzed. By means of the factory energy model it is possible to study the impact of possible improvements of the site in order to achieve the mitigation of its environmental impact and to reduce energy costs.

A series of possible energy saving actions have been individuated; for each action the primary energy saving per year has been estimated by using the factory energy model. The pay-back time linked to a single action has been calculated; all the interventions with a pay-back time larger than 6 years have been considered as not suitable. The analysis has shown that it is possible to individuate a series of energy saving measures, like thermal insulation of walls and roof-tops, the replacement of old boilers and the use of heat recovery units in the HVAC systems that can produce a saving of about 100000 € per year with a pay-back time less than 6 year. The results of this energy audit have been used by the company for the definition of its energy saving strategy for the next future.

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