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# Methodology Development for a Comprehensive and Cost-Effective Energy Management in Public Administrations

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## 1. Introduction

Energy saving represents one of the most relevant research areas because of the several environmental, economical and legislative motivations, especially in the public sector. In fact, the current international legislation aims to incentivize the activity of energy saving and the use of renewable energy sources in this area. The European Union, while recognizing public administration buildings as a large source for potential energy saving, also assigned to them the role of promoters of energy saving.

The SET PLAN constitutes a support to the 20/20/20 objectives and some European Directives clearly assign to the Public Administration (PA) the strategic role to promote energy efficiency in buildings (EU Directive 2006/32/CE) and to underline that the public buildings (occupied by the Public Administration and open to the public) have to be an example and a reference for the citizens in concrete activities in energetic certification and display campaigns (EU Directive 2002/91/CE). In this scenario an effective energy management procedure becomes unavoidable to reach the imposed targets. Energy management, in fact, is a well structured process that is both technical and managerial in nature. In (Kannan & Boie, 2003) the authors provide a guideline for entrepreneurs in implementing energy management in an industrial field. Using techniques and principles from both fields, energy management monitors, records, investigates, analyzes, changes, and controls energy using systems within the organization. It should guarantee that these systems are supplied with the energy they need as efficiently as possible, at the time and in the form they need and at the lowest possible cost (Petrecca, 1992).

Accordingly, an important figure is the energy manager (a compulsory figure in organization featuring an energy consumption above certain limits, introduced in the Italian legislative system since 1991) (art. 19 law 10/91). Nevertheless, in the public sector he hardly succeeds in reaching important results because of the absence of powerful methodologies and analysis instruments. Energy management procedures in public sector have been illustrated in different work (Na Wei et al., 2009, Feng Yan-Ping et al., 2009, Zia & Devadas, 2007), focusing on the concept of monitoring and metering consumptions. In the final report

“Energy Performance Benchmarking of Ontario’s Municipal Sector” of the Local Authority Services Ltd. (Association of Municipalities of Ontario) and in the report “Case Studies on Municipal Energy Initiatives” of the Commission of Environmental Cooperation, 2010 various attempts to create energy management system are described. In every case there is the absence of common guidelines and the tendency of proceeding with quick fixes, not integrated operations.

Currently about two-thirds of the global energetic consumptions are attributable to the urban areas, which also result as the major Green House Gas (GHG)-emitters with a critical environmental impact. In fact about the 50% of the global population lives in urban areas and they are responsible of the 60-80% of the global GHG-emissions (Dawson, 2007). For these reasons urban areas become important actors on the global decisions about energetic issues (see the C20 and C40 Cities Climate Leadership Group, Clinton initiative, ICLEI, Climate Alliance etc.) (Dawson, 2007).

The concept of Urban Carbon Management originates from these considerations and in many studies it is possible to find interesting energy-efficiency benchmarks developed as valuable tools for governments in managing energy consumption. Olazabal et al., 2008 developed the concept of urban ecosystem with particular attention to energy flows. Bennett & Newborough, 2001, illustrate a model of energy auditing in urban areas highlighting the role of involved people, areas in which the conurbation is divided and required data. The main employed indicators are the Energy Flow Accounting (EFA), the Life Cycle Assessment (LCA) (Tjahjadi, 1999) and the Energy Footprint (EF) (Plan de uso sostenible de la energia y prevenciòn del cambio climatico de la ciudad de Madrid, 2008). All these approaches are interesting for their aspects of generality and for their action in large systems but they take into account the whole city and not only the public administration subset.

Attempts to define energy benchmarks for single users, for example schools are carried out, taking into account specific technical and constructive characteristics of the buildings (Hernandez et al., 2008) or comparing different reference specific consumption (Filippin, 2000). Similar consideration are made for public office buildings, creating a calculated dataset (Nikolaou et al., 2009), using the Energy Use Intensity (EUI) (Chung & Hui, 2009) or applying the data envelopment analysis (Lee, 2008). These studies allow the definition of indicators of the energy performance of particular types of buildings. Nevertheless the proposed approaches are very specific and absolutely not general.

Other two important examples come from the Energy Star® and the Carbon Trust, two government organizations with the aim of incentivizing studies and methodologies for promoting energy efficiency and energy saving from households appliances to the building sector, through a labeling process (Energy Star®) or the definition of benchmark and Good practice (Carbon Trust). In the presented method the indicators for the more detailed level (the efficiency ratios) are revised starting from the ones defined by Energy Star® (in the “ENERGY STAR® Performance Ratings – Technical Methodology”, 2007) and Carbon Trust (Good Practice Guide 306, 2001).

In this chapter a comprehensive and innovative methodology for analyzing the energy performance of Public Administrations is illustrated. It takes into account an intermediate field: a local government consisting of different users (buildings and services as public lighting) with different peculiarities. At the same time this field doesn’t comprehend all the productive sector of a city (agricultural, industrial, residential and service) as seen in the urban carbon management. The focus is on a specific sector (public administration), a subset of the city as a whole, but extremely heterogeneous. This approach has been developed in a

general way in order to be applied to every kind of public organization, filling the gap with the industrial applications (Andreassi et al., 2009a, 2009b) and developing a specific methodology for PAs. Besides this method succeeds in obtaining results starting from a condition of a shortage of data. Differently from Chung et al, 2006 or Bohdanowicz & Martinac, 2007, who define indexes with very detailed information, in this approach we establish our considerations starting from general data commonly available.

To structure this method into a model of analysis, a process consisting in four phases has been developed: the collection of data and information, the benchmark evaluation, the creation of consumption models, the definition of the measures of improvement of the users performance. In particular for realizing the benchmark evaluation phase, a system of composite indicators for mapping the energy performances in different and successive levels of detail is proposed. A case study will demonstrate the methodology reliability.

In conclusion this methodology can be applied to different types of municipalities and allows obtaining immediate and clear results about energy behavior, even more significant results can be when applied to public infrastructures (buildings and services) managed by small-medium municipalities, which usually feature great inefficiencies in the energy management and energy costs forming a consistent part of their budget.

This methodology has been applied and verified in an Italian contest but for its general approach can be adapted to the different European realities; in every case in fact there are approximately the same legislative ties, the same types of users with the same needs and issues. For these reasons the general guidelines of the methodology can be adapted to every specific case.

2. The public administration

Public administration can be defined as a group of users which supply services to the citizenry, as the public buildings (schools, offices, sport buildings, health buildings, etc.), the public lighting, the transport system and the industrial service infrastructures (the waste water and garbage treatment plants) regardless of whether they are paid directly by the Public Administration or by other service companies. In Italy the energy cost (VAT exclusive) is about 5% of a Public Administration’s balance. Figure 1 shows the energy costs

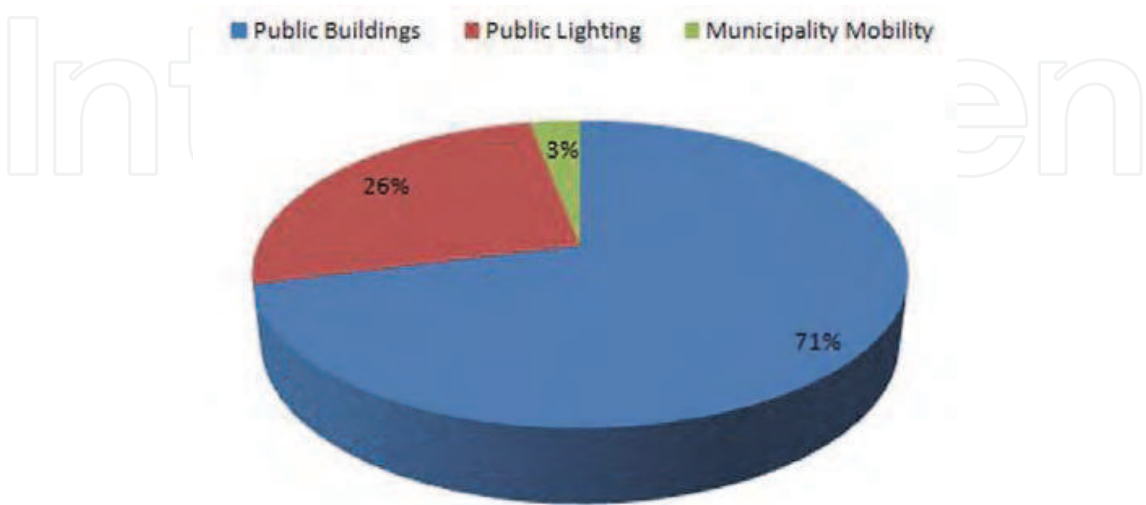


Fig. 1. Allocation of energy costs (example municipality with 200.000 inhabitants)

distribution of an Italian municipality of about 200 000 inhabitants (Picchioluto, 2006): the most relevant cost is attributable to the public buildings, while the public lighting becomes preponderant in smaller towns (constituting about the 60% of the total energy costs).

In this paper the different users are classified in the following groups (or typologies):

- public lighting;
- schools;
- city hall and other offices;
- sports and recreation buildings (gyms, swimming pools, etc.);
- small health care buildings.

Technical structures as waste water and garbage treatment plants are neglected as this study is addressed to small-medium size administrations in which these plants are not common. All these groups, of course, are extremely heterogeneous and are characterized by different consumption trends. Furthermore, also the correspondent users can present different energy use modalities.

To study a so-complex system, a division of the PA into the following three levels is proposed:

1. the administration on the whole;
2. the administration sectors (formed of the same type users);
3. the single users.

This structure allows rationalizing the study and investing the resources more efficiently and effectively.

There are some aspects that emerged during the realization of this study about the Italian situation of the municipalities which need to be underlined. First of all, the consideration given to the energy cost in general is very limited and it's difficult to find in the organization the responsible figure with the correct knowledge about these themes. This situation is very common in Italian Public Administration, due to a lack of knowledge and skills in the activity of energy management and consequently a gap with the advanced and restrictive European Energy policies is determined.

The installed power could be very large and comparable to the industrial organizations but the control about the invoiced consumptions isn't well developed.

Very often municipalities have to face numerous energetic bills, with different types of contracts and even contractors. The accounting system is often not rationalized (especially with the electrical consumption), with a measurement system which is developed over the years, without a rationalization. Databases of the historical consumptions and the structural changes happened in the different users are rarely available because of the insufficient sensitivity to the energy management.

Considering the energy cost of a municipality we have to underline that the payment falls on the citizenry which faces these operating costs with the local taxation system. A correct management of the energy resources has also positive effects directly on the citizenry which can understand the importance of the savings in a practical way. Last important aspect is the growing interest of the public opinion on the environmental issue that should incentivize the creation of an energy management system. The present methodology can succeed in facing them practically and support responsible in energy matter in these type of organizations.

### 3. The methodology

#### 3.1 The four phases of the analysis

First of all, the present approach required the definition of some energy benchmarks to evaluate the energy performance of the various users and to identify the anomalies in the



way of consuming. Then, this approach allows modeling the PA energy consumption in function of its major affecting factors (i. e. energy drivers), as population, temperature, daylight length etc. The resulting models can be used to resolve the previously identified anomalies and to predict the future trends of the energy usage.

Finally, there is the definition of the energy management activities to improve the users efficiency and to minimize energy consumption. To structure these activities into a model of analysis, a process consisting in four phases has been developed (see Figure 2):

1. data and information collection;
2. benchmark evaluation;
3. consumption models creation;
4. measures of users performance and improvement definition.

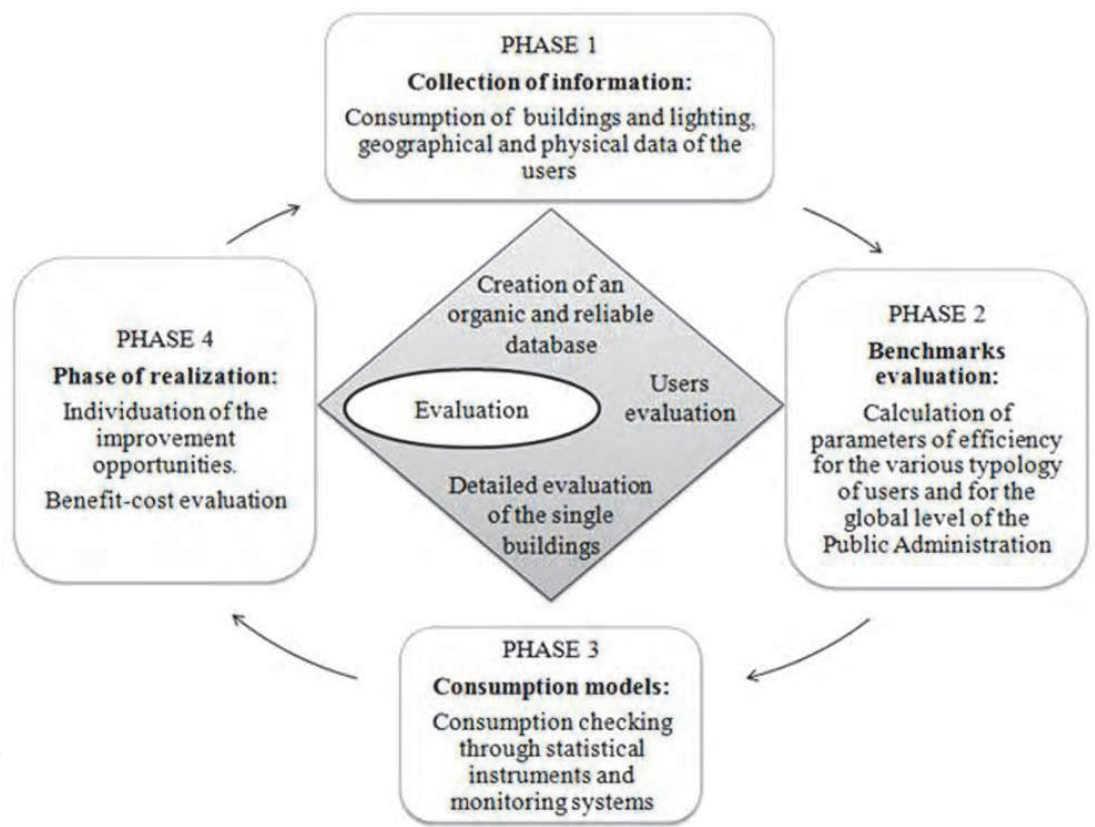


Fig. 2. The four phases of the model

This approach can constitute a guide, a standard procedure, for the energy management activities in a Public Administration supporting who try to rationalize the energy performance of a public organization. One of the most important advantages offered by the presented approach is the capability to obtain results also starting from a condition of poor information. The first step of the procedure is the collection of very general information of the municipality, as those reported in Table 1. A complete list of users information, comprehensive of the total annual energy consumption and the gross heating surface of each user has to be added to these general data.

These data allow assessing the energy performance of the municipality and the various sectors just identified. For a more detailed evaluation, forms to be compiled with all the necessary data for every typology of users have been elaborated, in order to characterize

them and calculate the efficiency indexes. Table 2 reports only an example of these forms, used to describe the characteristics of the public lighting.

<b>General information</b>
Surface of the municipality (km²)
Altitude (m)
Road length (m)
Number of inhabitants
Annual Degree Days
Variation of dark hours
Number of houses

Table 1. Collecting information: the general data

The data collected in the first phase are used for the evaluation of the various performance indicators; in this way a complete screening of the energy performance of a municipality can be obtained: the second phase includes the estimate through convenient spreadsheets of the benchmarks at every level of the organization and this gives the possibility to identify the more critical areas and to focus the attention on them.

<b>Public lighting</b>
<b>Technical information</b>
Number of lamps
Number of spot lights
Surface of the municipality (km²)
Annual consumption (MWh)
<b>Lamps characteristics: typology, numbers, power (W)</b>
Incandescent
Mercury-vapor
High pressure Sodium-vapor
Low pressure Sodium-vapor
Fluorescent
Led
<b>Economical characteristics</b>
Economic value of the lamps (€)
Investment in public lighting (from municipality’s balance sheet) (€)

Table 2. Collecting information: Public lighting

The great advantage of this approach is the immediate and easy form in which the evaluation results are obtained: a sort of display for all the municipality areas with the performance evaluation expressed in a symbolic way and a rapid consideration about the room for improvement (Figure 3). For the different levels an efficiency ratio or a user indicator is calculated (and represented with a symbolic color) and a “map” of energy performance is obtained.

The benchmark creation is explained in every methodological aspect in a proper paragraph (3.2): the benchmark is in fact the central tool in the analysis process and in this study innovative energy indicators are developed for this purpose.

The two following steps of the process can be carried out starting from the more critical areas. In this phase it becomes necessary to design a monitoring system net, to obtain more detailed real time data and to define a flexible and effective control and management system.

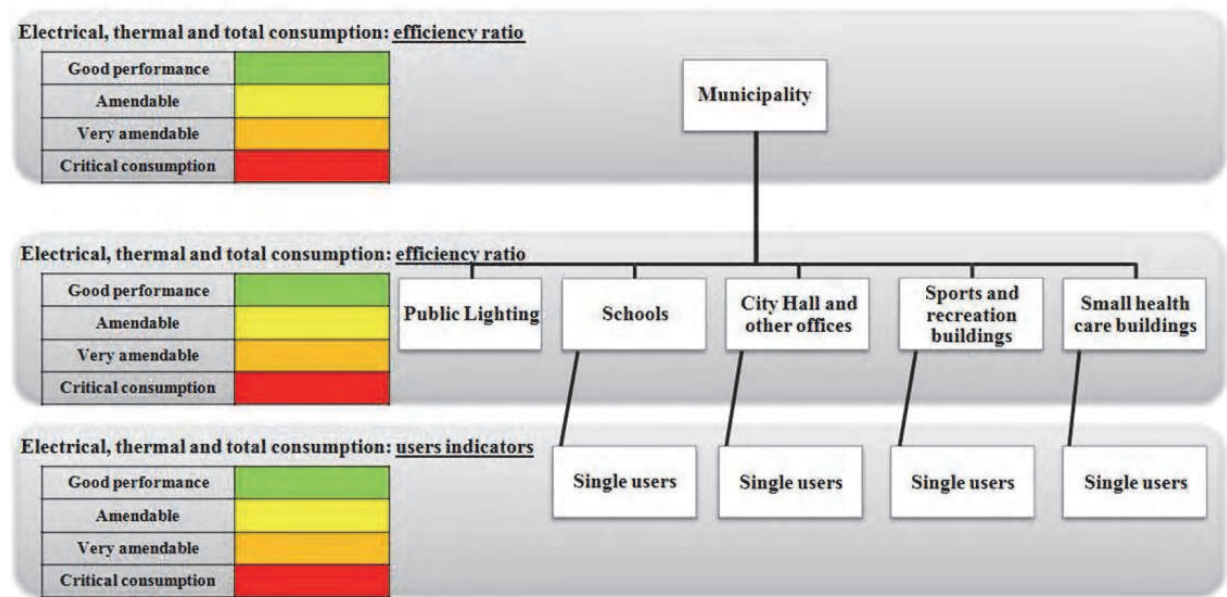


Fig. 3. The energy benchmark system

The availability of more detailed data, not only in an aggregate form as from the energy bills, allows to identify the inefficiencies and to monitor in real time the trends of the consumption. The measurements system integrated with software for the data elaboration creates daily, weekly, monthly and annual consumption profiles; the comparison between the recorded values and the historical profiles allows the individuation of anomalies or changes in the consumption in real time and for all the significant users. The availability of detailed data about the historical consumption also allows an evaluation of the chosen tariff and the choice of a possible alternative (even in this field the room of improvement are next to 10%).

Moreover, the data obtained by a monitoring system can be processed to model energy consumption in time series. The methodologies investigated in this study are essentially:

- regressions;
- neural networks;
- decisional trees.

Tso & Yau, 2007 made an interesting comparison between these approaches suggesting that the regression analysis could be considered the most useful for predicting energy consumption. Generally the popularity of the regression models may be attributed to the interpretability of model parameters and easiness of use. A multiple regression analysis, in fact, can be realized with rapid calculation systems and gives an equation as the following one:

$$Y=a_0+a_1\cdot x_1+a_2\cdot x_2+\dots+a_n\cdot x_n$$

(1)

where  $a_i$  are the coefficients of the  $x_i$  (explicatory variables or energy drivers). Such equation gives the possibility to attribute quotes of consumptions to the various variables and in this



way it is possible to deeply understand the trend of consumption, the affecting variables and their relative importance. The strength of the forecasting models depends on the quality of the used data and on the type of the chosen energy drivers. In public buildings the most useful and suitable drivers are resulted to be the daily Heating and Cooling Degree Days (respectively  $DD_{H,t}$  and  $DD_{C,t}$ ) calculated as in (2) and (3) (where  $T_{ref\_DDc}$  and  $T_{ref\_DDh}$  are different for each type of user, as reported in Table 3 for the specific Italian case and  $T_{mean,t}$  is the daily mean temperature for the day  $t$ ) and dummies variables to represent the day of the week, the month of the year (Pardo et al., 2002, Mirasgedis et al., 2006).

$$DD_{C,t}=\max(T_{ref\_DDc}-T_{mean,t},0)$$

(2)

$$DD_{H,t}=\max(T_{mean,t}-T_{ref\_DDh},0)$$

(3)

Type of building	T <sub>ref</sub> (°C) - Heating (legislative reference)	T <sub>ref</sub> (°C) - Cooling (legislative reference)
Schools	20±2 (Municipal regulations)	26 (UNI 10339:1995)
City hall and other offices	20±2 (Municipal regulations)	26 (UNI 10339:1995)
Sports and recreation buildings (gyms, swimming pools, etc..)	18 (UNI 10339:1995)	24 (UNI 10339:1995)
Small health care buildings	20±2 (Municipal regulations)	26 (UNI 10339:1995)

Table 3. T<sub>ref</sub> and legislative reference for the different type of buildings

The models created and validated by a statistical point of view can be used to put under control the future consumptions, using the CUSUM charts and a system of alerts (Cesarotti et al., 2007).

The final step for the efficiency increase process is the determination of the so called Energy Management Opportunities; the accurate realization of all the previous activities generates the individuation of the anomalies in the way of consumption of all the users, starting from the most critical conditions.

Essentially there are three types of Energy opportunities:

- zero or low cost measures: definition of good practices in using energy;
- investment measures/refurbishment: operations for increasing the efficiency with substantial investment in the energy systems and in the buildings' envelopes;
- non conventional measures: energy certification.

It's clear that this last part of the methodology is the less automatable or standardizable because the choice of energy management or saving opportunities implies an active evaluation by the energy manager and consequently a project analysis which it may be very different depending on the circumstances.

Besides every consideration about the most adapt type of measure has to pair with a complete economic plan, with profit margin, payback and internal rate of return.

3.2 Benchmark creation

After collecting all the necessary information, the energy performance of the municipality through a benchmarking tool can be evaluated.

As previously reminded, for this aim a more complex system of indexes to evaluate an heterogeneous field consisting of very different users is needed. Accordingly, the Energy Star®'s approach has been revised to be adapted to the specific needs and a set of indexes addressed to the entire municipality and every constituting sector has been created. For establishing the energy performance indexes system, a complete dataset has been firstly defined. Generally datasets may result from measurements or simulations. Nikolaou et al., 2009 developed an energy benchmarking dataset at a national level for the office sector through the modeling process of different sample buildings. Differently, in this study all the necessary information about the consumptions and the users' structural characteristics are extracted from a dataset created by measurements in the study "Audit GIS" realized by the Fondazione Cariplo and available in the web. This project consists of over 650 Energy Audits in municipalities located in the North-West of Italy. These data have been collected during a period of two years (2006-2008). The energy audits realized in these municipalities are available on web through a Web-GIS platform: it is possible to navigate the Web-GIS maps and choose the municipalities to examine. A successive menu shows the existent public structures and the reports with the audit results. In particular there are single report with the consumptions and the carbon emissions data, the structural and usage information and the realized or proposed energy saving measures of the single building and the possibility to consult aggregated data in Excel format. In Table 4 is reported a list example of data reported for each user.

AUDIT RESULTS	
Audit date	Audit typology (level of detail)
Buildings characteristics	
Type of construction	Transparent surface (m²)
Destination of use	Daily usage (hour)
Year of construction	Weekly usage (day)
Year of renovation	Yearly usage (hour)
Renovation description	Number of occupant
Thermal gross area (m²)	Climatic Area
Thermal gross volume (m³)	Energy efficiency class
Form factor (S/V)	
Heating system	
Type of plant	Type of fuel
Power (W)	Annual consumption (kWh)
Year of installation	Annual CO <sub>2</sub> emission kg <sub>CO2eq</sub>
Electrical system	
Annual consumption (kWh)	Annual CO <sub>2</sub> emission kg <sub>CO2eq</sub>
Energy saving opportunities	
Description	Annual saving (CO <sub>2</sub> emissions)
Annual saving (€)	

Table 4. Audit result of the project Audit GIS: typical report

In this study, the consumption data and all the other necessary related information are extracted from this dataset even if, for sake of honesty, two weak spots have to be underlined: first of all, these data are elaborated by third and we haven't control about the

presence of error of statistical unreliability; secondly, these municipalities are all concentrated in a relatively small geographical area and of small-medium size.

To increase the database reliability all the included information have been pre-processed, as in the Energy Star®'s procedure ("ENERGY STAR® Performance Ratings – Technical Methodology", 2007) for eliminating outliers, making more robust the statistical analysis and detrending the available datasets (Pardo et al., 2002). In particular, we locate the outliers of the distribution of consumption data through the elimination of all the values which were smaller or bigger than three times the standard deviation of the distribution. Then we elaborate the data through their natural logarithm, for making more robust the analysis and limiting the effects of heteroscedasticity.

After the pre-processing phase, a linear regression between the consumption data and the more significant energy drivers has been realized.

The first defined indexes are finalized to the energy rating of the entire municipality. The necessary data are the total annual electrical (sum of the electrical consumption of all the municipality's users, except the public lighting) and thermal consumption of the administration (sum of the thermal consumption of all the municipality's users): we calculate the mean value of energy consumptions over a period of three years. As energy drivers the sum of the thermal gross areas of the users (*Sur*, expressed in m<sup>2</sup>), the annual Heating Degree Days (*DD*) and the population (*Pop*) are used. The obtained relationships are:

$$\ln(E)=6,72+0,78\cdot\ln(Sur)-0,52\cdot\ln(DD)+0,28\cdot\ln(Pop) \quad (4)$$

$$R^2=0,817 \quad (5)$$

$$\ln(Q)=5,52+0,72\cdot\ln(Sur)-0,09\cdot\ln(DD)+0,33\cdot\ln(Pop) \quad (6)$$

$$R^2=0,868 \quad (7)$$

where *E* and *Q* represent the annual electric and thermal energy consumption, respectively. Clearly there is an anomaly referring to the thermal consumption because the Degree Days coefficient is strangely negative. Furthermore, all the statistical tests (p-value, Test F) confirm the unreliability of this variable. To justify this fact, we can consider that the switching on of the heating systems in the public buildings is automatically settled by law (D.P.R. 26 August 1993 n. 412), depending on the climatic areas. They are geographical areas designed by law on the basis of the annual Heating degree days recorded in a particular year and indicated by letters (A area has the warmest climate, F the coldest).

Therefore, a more correct procedure could be creating a different consumption model for each climatic area. In the data that we elaborate, all the municipalities belong to the climatic areas E and F, so we create models only for these types of municipalities. The following equations have been obtained:

$$\ln(Q)=4,77+0,72\cdot\ln(Sur)+0,34\cdot\ln(Pop) \quad \text{Climatic Area E} \quad (8)$$

$$R^2=0,868 \quad (9)$$

$$\ln(Q)=5,27+0,79\cdot\ln(Sur)+0,2\cdot\ln(Pop) \quad \text{Climatic Area F} \quad (10)$$

$$R^2=0,724 \quad (11)$$

While the model created for the climatic area E is reliable, the one for the climatic area F needs more accurate information because the predicted consumptions are always lower than the one predicted by the other model and it is unacceptable because the Area F has a colder climate. Fig. 4 reports the predicted consumptions for both the climatic areas in ascending order: it's clear that the class F's consumptions are always lower. This problem is due to the availability of a little number of data belonging to the climatic area F. Our approach is however addressed to the creation of different models for every climatic area, obviously taking into proper account a correct number of data.



Fig. 4. Comparison between the model consumption of the climatic area E and F

Then, the ratio between the real consumptions and the predicted ones is calculated. In this way the energy performance of every municipality can be classified through the Efficiency Ratio (ER) defined as follows:

$$ER=\frac{\ln(E_{c,r})}{\ln(E_{c,p})} \tag{12}$$

where  $E_{c,r}$  and  $E_{c,p}$  represent the real and the predicted energy consumption, respectively. The greater is ER, the worst is the PA energy management. The successive step is to fit the results of the efficiency ratio data in a cumulative percentage profile: the result for the total annual electrical consumption is reported in Figure 5. These curves allow determining the performance indexes or attributing the PA to a specific class of consumption. We could decide to assign a score to every municipality corresponding to the complement to 100 of the percentage value of the considered municipality, depending on the ER value. In this study four classes of consumption, identified by efficiency ratio thresholds corresponding to 0.25, 0.50 and 0.75 have been defined. Two positive results can be immediately achieved: on the one hand the attribution to a particular class of efficiency (i.e. labeled by a color) is an immediate result for the municipality and on the other hand this is a powerful approach to compare different municipalities and to assess future targets.

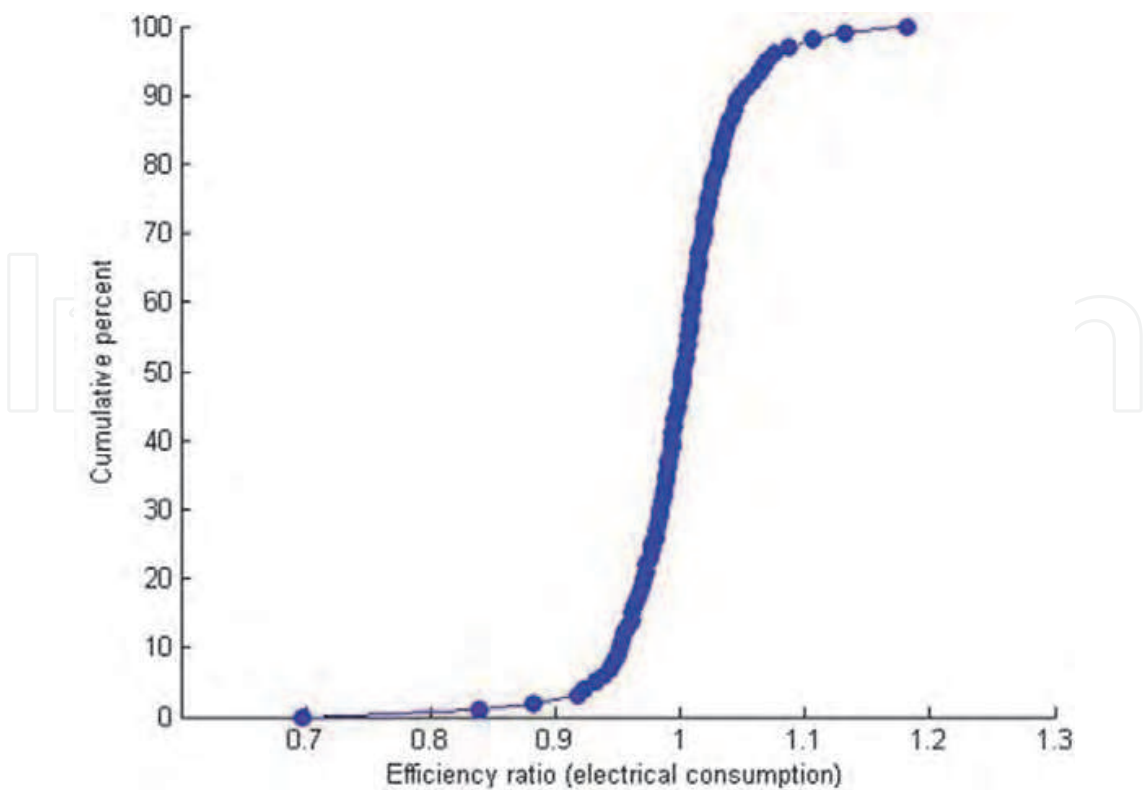


Fig. 5. Cumulative percentage curve for the efficiency ratio of the electrical consumptions

In Table 5 the ER boundary values of the four classes for both electrical and thermal consumption is reported. The final result is a complete and detailed overview about the energy consumption of the administration.

Efficiency ratios-Electrical consumption		Lower limit	Upper limit
Good performance		0.6967	0.9778
Amendable		0.9778	1.0023
Very amendable		1.0023	1.0229
Critical consumption		1.0229	1.1811
Efficiency ratios-Thermal consumption		Lower limit	Upper limit
Good performance		0.8445	0.9835
Amendable		0.9835	0.9998
Very amendable		0.9998	1.0153
Critical consumption		1.0153	1.1257

Table 5. Class of consumption for the municipality

Considering the other two levels, two different approaches have to be distinguished: a top-down or a bottom-up approach. A top-down approach is necessary when the PA has only aggregate data: it's an easy implementable method but it has a great inertia in modifying the benchmark results as a consequence of changes in the way of consuming. On the contrary a bottom-up approach requires detailed information about the user characteristics, which are often not available. Here the present method has been employed to develop indexes for the top-down approach and different benchmarks available in literature for the bottom-up approach are revised.



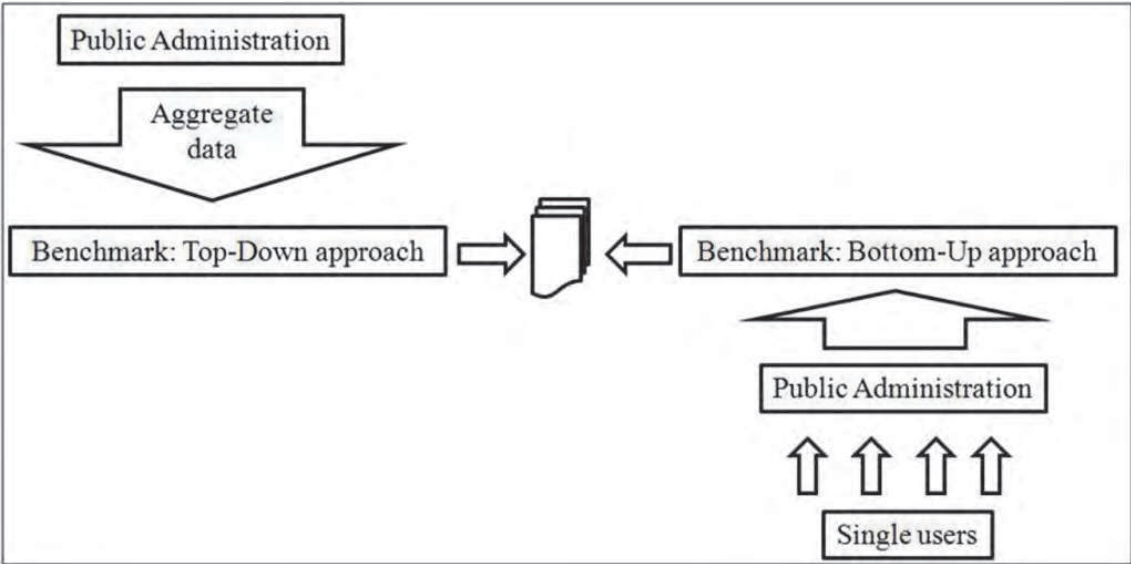


Fig. 6. Comparison between bottom-up and top-down approach

Using the same benchmark procedures for the whole administration, the regression equations for forecasting the electrical and thermal consumptions in each sector of the municipality can be calculated as indicated in paragraph 2. The data used in these cases are the total annual electrical and thermal consumptions for each sector: the mean consumption value is calculated over three years. The considered energy drivers are the sum of heating gross surfaces of the users and the annual Heating Degree Days (general data which can be applied in every organization).

As in the previous case the regression equations and the four classes of consumption are determined.

Then, to validate the approach, a comparison between the results obtained by the efficiency ratios (which classify the performance of the entire sector) and what emerges from the evaluation of the single user indexes is performed. The result (in terms of class of energy performance of the whole sector) of the efficiency ratios should coincide with the mean result of the users indicators.

As indexes for the so-defined bottom-up approach for the single users we decide to revise and adapt to our specific aim some indicators found in literature.

In general these indexes use detailed information to normalize the energy consumption with respect to the climate conditions, the level and the type of usage, the structural characteristics of the buildings or of the plants.

We report an interesting example of this type of comparison, illustrating the case of “schools” but the same reasoning has been made for the other types of users.

The indexes for the schools, defined by the FIRE (Italian Federation for the Rational use of Energy), are the  $IEN_E$  and the  $IEN_R$  (respectively Energetic Normalized Index for electricity and thermal consumption).

These indexes are calculated for every school formulas as it follows:

$$IEN_R = \frac{C_{Ther} \cdot 1000 \cdot F_h \cdot F_e}{DD \cdot V}$$
$$IEN_E = \frac{C_{El} \cdot F_h}{S}$$

(13)

where  $C_{Ther}$  is the annual heating consumption ( $kWh_{therm}$ ),  $C_{El}$  is the annual electrical consumption ( $kWh_{el}$ ),  $F_h$  is a corrective factor concerning the hours of work,  $F_e$  is a

corrective factor concerning the characteristics of the building (form factor  $S/V$ ),  $DD$  are the annual Heating Degree days,  $V$  the heating gross volume ( $m^3$ ),  $S$  the heating gross surface ( $m^2$ ). The FIRE provides three classes of consumption regarding these indexes. For the validation process the  $IEN_E$  and the  $IEN_R$  for a group of 48 schools homogeneously distributed have been calculated and a class of efficiency for every school has been assigned. This result has to coincide with one from the efficiency ratio (that is an efficiency but averaged on the total of schools). In Table 6 the results are reported. As it's clear in the Table 6 the values concerning the thermal consumption show a great correspondence between the two different approaches, instead of the electrical indexes which give very different results in term of assessment of the performance. For understanding this problem we observe the distribution of our sample of data according to the  $IEN_E$  and the  $IEN_R$  and we note that our sample is concentrated in an inefficient evaluation in term of  $IEN_E$ .

Indice			
$IEN_R$	47.92%	29.17%	22.92%
$IEN_E$	12.50%	22.92%	64.58%

Table 6. Distribution in the  $IEN_E$  and  $IEN_R$  classes

To realize a correct comparison we have to adapt our sample of data and re-define the limit values of the  $IEN_E$ 's classes: the  $IEN_E$  is in fact the result of a study of simulation of the energy performance of the schools instead our efficiency ratio gives a correct comparison between the performance of a particular set of data. The scaled limit values are obtained centering our dataset on the  $IEN_E$  values. Finally the pie graphs in Figure 7 show the final repartition of the consumption (respectively thermal and electrical) of 7 schools existing in an example municipality; each school is represented in the pie graphs with the color correspondent of the efficiency class defined by the user's indicator. It's clear that the class with the major incidence in the total consumption is correspondent of the class defined by the efficiency ratio. The same considerations have been developed on the other users typologies, creating indexes allowing the sector's classification and analyzing the most powerful benchmark in literature for the classification of the single users. The results are reported in Table 7. A different approach has been used only for the public lighting where the distinction between sector and user indexes doesn't make practical sense. In this case the most powerful benchmarks come from an Italian research, making a technical and economic evaluation of the lighting system of the municipality.

4. The case study

This method has been applied to the case study of two small towns close to Rome in the region of Lazio, in Italy, called in this paragraph as municipalities A and B. These towns don't present any control in the energy management and for this reason the phase of the real time monitoring net couldn't be insert in this project. The aim of this project has been the mapping process of the energy efficiency of the different sectors and end-users and the evaluation of the possible energy saving opportunities. The phases of project, according the procedure previously described, have been:

1. the data collection;

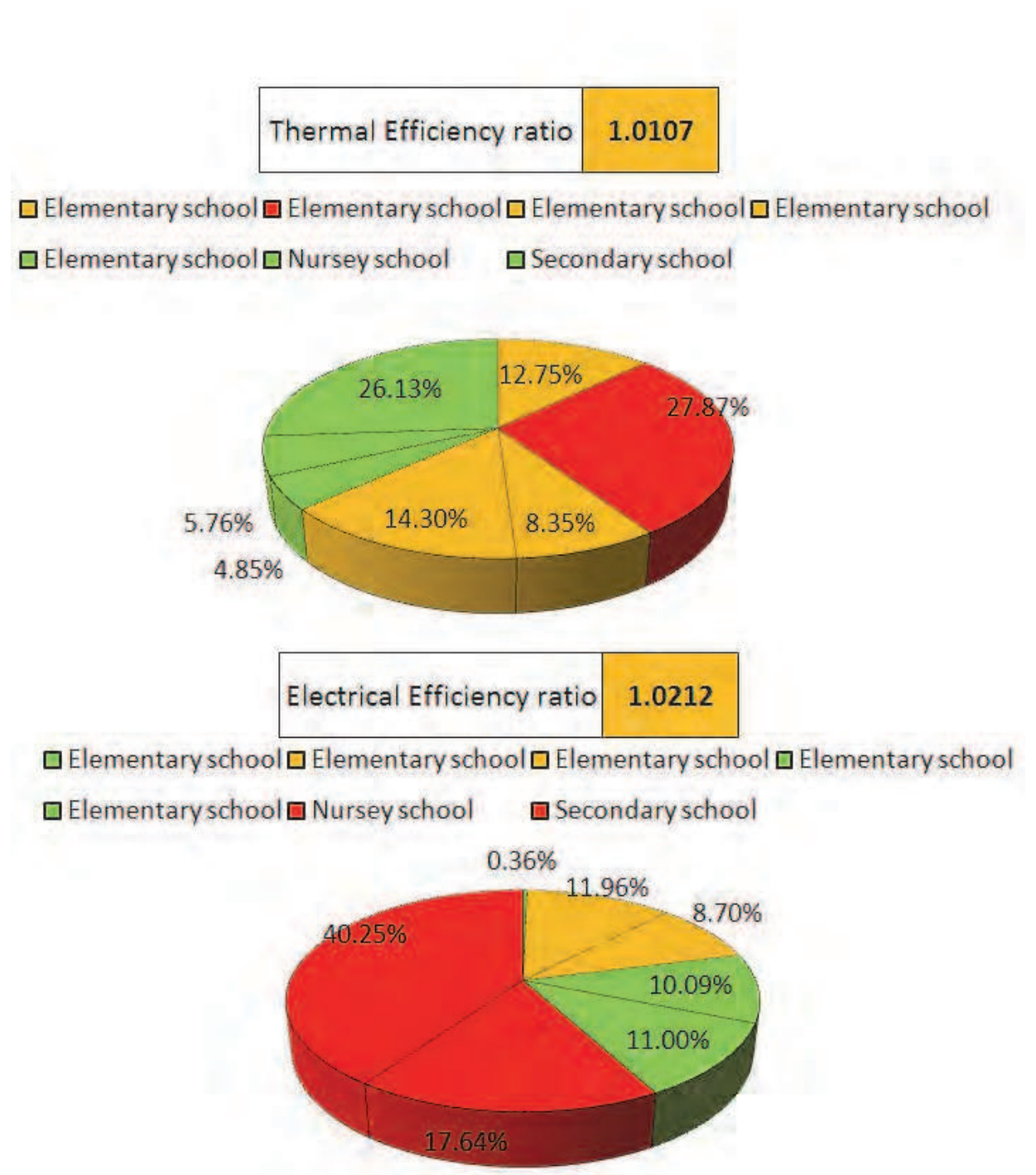


Fig. 7. Comparison between efficiency ratios and users indicators: sector of schools

Typologies of users	Electrical consumption		
	Sector index	Single user index	
		Index	Ref.
Schools	$\frac{\ln(E)}{11.13+0.98\cdot\ln(\text{Sur})-1.035\cdot\ln(\text{DD})}$	$\text{IEN}_E$ (kWh <sub>e</sub> /m <sup>2</sup> )	(1)
City Hall and offices	$\frac{\ln(E)}{14.7+0.94\cdot\ln(\text{Sur})-1.37\cdot\ln(\text{DD})}$	El. benchmark (kWh/m <sup>2</sup> )	(2)
Sports buildings	$\frac{\ln(E)}{9.13+0.86\cdot\ln(\text{Sur})-0.62\cdot\ln(\text{DD})}$	El. benchmark (kWh/m <sup>2</sup> )	(3)
Health buildings	$\frac{E}{426.58+55.10\cdot\ln(\text{Sur})}$	El. benchmark (kWh/m <sup>3</sup> )	(4)
Public lighting	Luminous efficiency (lumen/W) Municipality surface on annual consumption (km <sup>2</sup> /kWh) Number of lighting spots on annual consumption (kWh <sup>-1</sup> ) Mean economic value of the lighting spot (€) Investment on installed power (€/kW)		(5)

Typologies of users	Thermal consumption		
	Sector index	Single user index	
		Index	Ref.
Schools	$\frac{\ln(Q)}{5.51+0.95\cdot\ln(\text{Sur})}$	$\text{IEN}_R$ (kWh <sub>t</sub> /(m <sup>3</sup> ×°C))	(1)
City Hall and offices	$\frac{\ln(Q)}{6.5+0.79\cdot\ln(\text{Sur})}$	Ther. benchmark (kWh/m <sup>2</sup> )	(2)
Sports buildings	$\frac{\ln(Q)}{5.84+0.91\cdot\ln(\text{Sur})}$	Ther. benchmark (kWh/m <sup>2</sup> )	(3)
Health buildings	$\frac{Q}{8\,099.52+300.72\cdot\ln(\text{Sur})}$	Ther. benchmark (kWh/m <sup>3</sup> )	(4)

(1) Guida per il contenimento della spesa energetica nelle scuole, ENEA; FIRE
(2) Good Practice Guide 286, 2000
(3) Energy Consumption Guide 78, 2001
(4) Murray et al., 2008
(5) Facciamo piena luce. Indagine nazionale sull’efficienza nell’illuminazione pubblica, 2006

Table 7. Sectors and users indicators for the municipalities

2. the benchmark evaluation (for both the sector and single users levels);

3. the individuation of anomalies and inefficiencies;

4. the definition of the measures of improvement of the users performance.

For the data collection the forms of the paragraph 3.1 have been used. The first information collected for the towns have been:

- general geographical and demographic information;
- the annual electrical and thermal consumptions of all the municipal structures (and their sum);
- the heating gross surface of all the municipal structures (and their sum).

Table 8 reports the general information of both municipalities and clearly highlights that they are small towns with a cold climate and a limited number of users.

General information	Municipality A	Municipality B
Surface of the municipality (km²)	86.4	61.25
Altitude (m)	600	668
Number of inhabitants	4 787	9 392
Number of houses	2 872	4 506
Annual Degree Days	2 063	2 331
Climatic area	D	E

Table 8. General information of the two municipalities

For the municipality A the individuated structures are:

- 2 schools: a nursery-elementary school and a middle school;
- 1 office: the city hall;
- 3 sports buildings: two football pitches and a tennis pitch;
- 3 leisure buildings: a library and two recreational centres.

For the municipality B the individuated structures are:

- 5 schools: a nursery school, a nursery-elementary school, a middle school, an elementary school and an high school;
- 1 office: the city hall;
- 1 health care building: a consulting room,;
- 4 sports buildings: two football pitches, a rugby pith and a tennis pitch;
- 2 leisure buildings: two recreational centres.

Obviously for both the municipalities the public lighting has been analyzed and evaluated. From this first macroscopic analysis, it can be observed the total absence of renewable energy power plants. Energy is consumed as electrical energy, natural gas and LPG. Basing the analysis of this initial data, some interesting elaboration can be obtained. The proportion between thermal and electrical consumption is reported in Fig. 8 where a preponderance of the electrical consumption for both the municipalities can be observed. The comparison is possible using the conversion factors in TEP (Tons Equivalent of Petroleum)

1 TEP=11628 kWh<sub>thermal</sub>=5347,6 kWh<sub>electrical</sub>

(14)

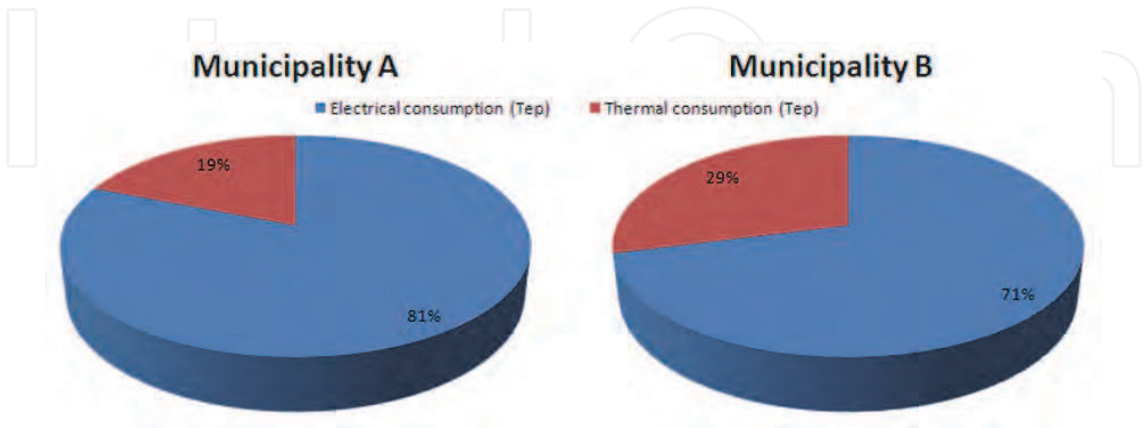


Fig. 8. Consumptions distribution

This is due to the great consumption of the public lighting that, as we previously remembered, usually constitutes a major cost for small municipalities.



The aggregated data allow the evaluation of the energy benchmark of the whole municipality as reported in the Table 9.

	Municipality A	Municipality B
Electrical ER	0.9980	1.0146
Thermal ER	0.9146	0.9594
Total ER	0.9443	0.9747



Table 9. Efficiency ratios of the whole municipalities

Considering the entire municipality, the B town ( $ER_{el}=1.0146$  and  $ER_{th}=0.9594$ ) shows a worst performance compared to our sample of data in terms of electric energy and a better performance in terms of thermal energy, while the town A ( $ER_{el}=0.9980$  and  $ER_{th}=0.9146$ ) is more efficient. In fact, the B results in a “very amendable” class and the A in an “amendable” one for the electrical consumption and they are both in the "good performance" class for the thermal energy usage.

Than the consumptions of the single sectors of the municipalities have been examined. The repartition of energy consumption per sectors for both municipalities has been evaluated, as reported in Figure 9: this analysis confirms the previous consideration. About 50-60% of the whole energy consumption is used for public lighting.

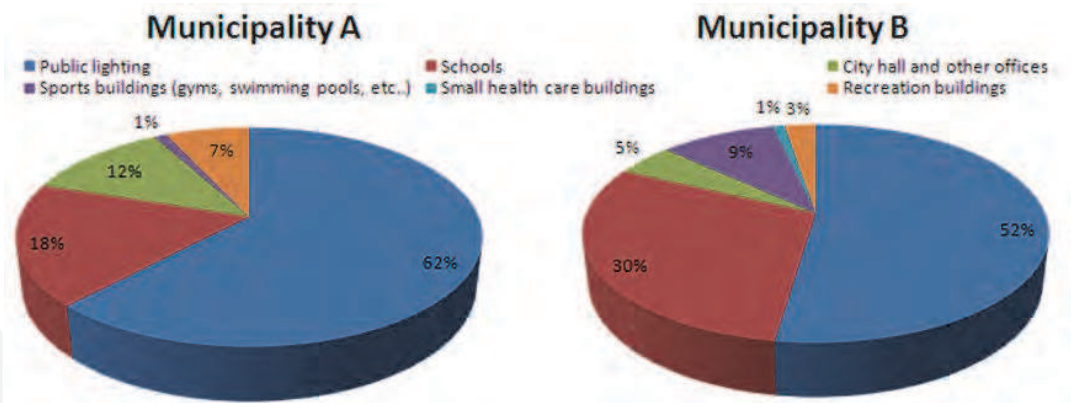


Fig. 9. Repartition of consumption per sector

For each sector the specific consumption (electrical and thermal) have been evaluated and the results are in Figure 10 and Figure 11.

From these graphs interesting considerations may be obtained but not absolute, because an high values not necessary coincide with an anomaly. In particular for the municipality A the most energy intensive sectors are the one of offices and leisure buildings. Differently for the municipality B the most energy intensive sector is constituted by sports buildings. Obviously these are preliminary considerations, for a general overview and characterization of the energy performance of the municipalities.

Successively the thermal and electrical ERs for each sector for both municipalities have been calculated using the general data collected in this phase. The results are reported in Table 10, where different colours have been employed to identify the energy classes.

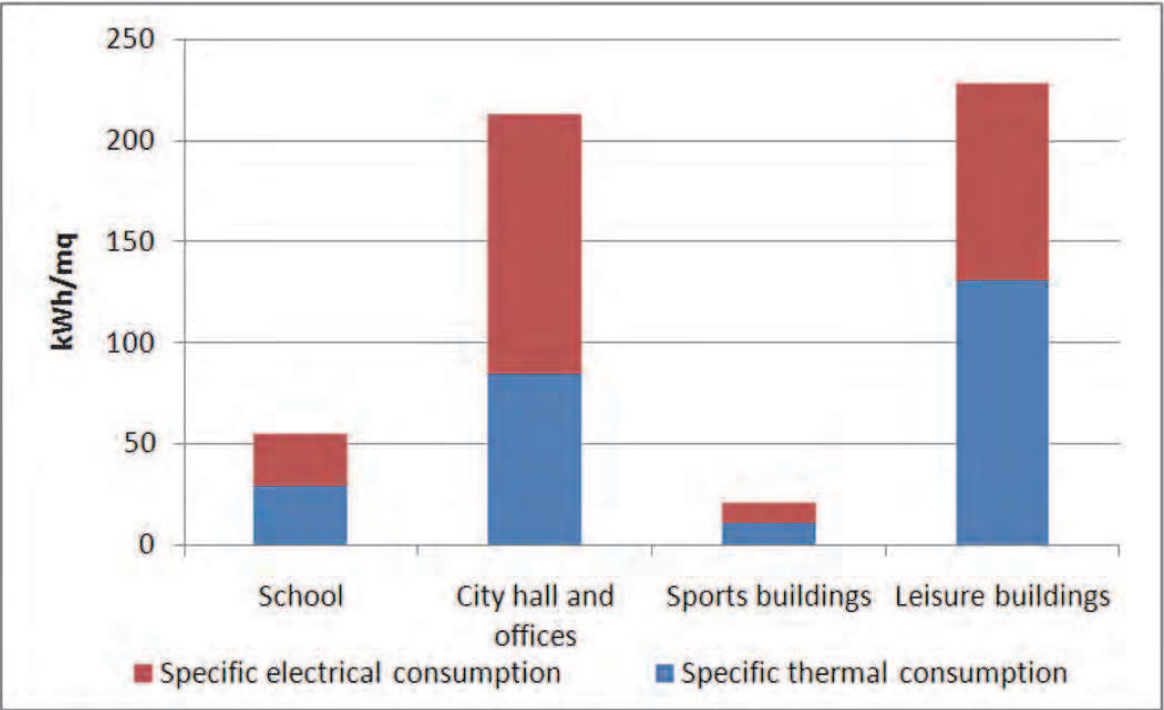


Fig. 10. Repartition specific consumption for the municipality A

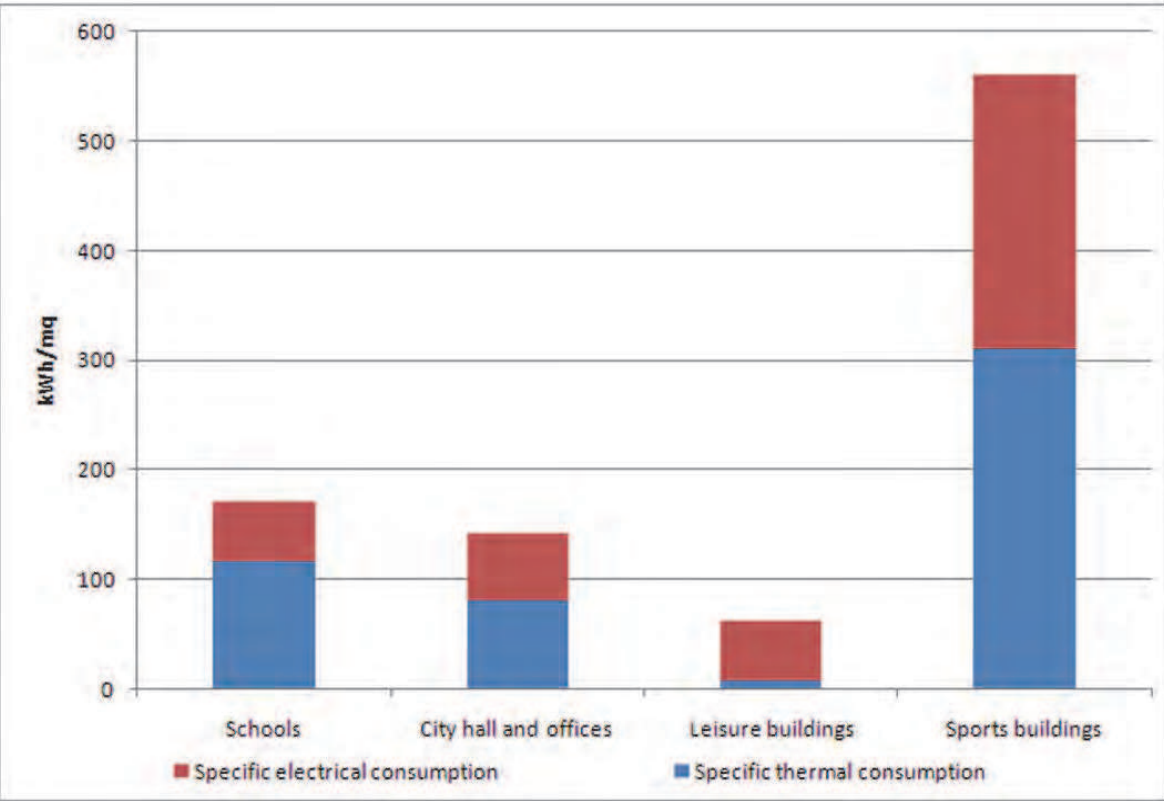


Fig. 11. Repartition specific consumption for the municipality B

By this way, a map of the municipalities performance can be obtained and the more critical areas individuated: the city hall (electrical consumption) for the municipality A and the sports buildings (both thermal and electrical consumptions) and the schools (electrical consumption) for the municipality B.

Municipality A	Electrical ER	Percentage repartition of the electrical consumption	Thermal ER	Percentage repartition of the thermal consumption
Schools	0.9732	44%	0.8934	51%
City hall and other offices	1.0218	38%	0.9475	25%
Sports buildings	0.8516	3%	0.7855	3%
Leisure buildings	0.9919	15%	0.9715	21%
Total	0.998		0.9146	

Municipality B	Electrical ER	Percentage repartition of the electrical consumption	Thermal ER	Percentage repartition of the thermal consumption
Schools	1.0235	52%	0.977	71%
City hall and other offices	0.9714	12%	0.945	9%
Sports buildings	1.1404	24%	1.0391	19%
Leisure buildings	0.9616	12%	0.7484	1%
Total	1.0146		0.9594	

Good performance

Amendable

Very amendable

Critical consumption

Table 10. Efficiency ratios of the two municipalities

A similar evaluation has been made for the public lighting and the results are reported in Table 11: the global index, calculated as linear combination of the other indicators reported in the table, gives a good assessment on the municipality A’s public lighting, but the second and third sub-indexes show the possibility to improve lighting’s performance with a better distribution of lighting spots on the territory or the use of regulation of lighting intensity systems.

A little worst performance is attributed to the municipality B’s plant by the global index; in particular in this case an improvement also of the lamps’ efficiency is necessary. In general this sector isn’t very critical even if we have to remember that it’s the major cost for both the municipalities and for this reason a saving in this area will generate a more substantial improvement.

The first result of this analysis is the individuation of the more critical areas in which concentrate the more detailed evaluations; these are:

- City hall and other offices for the municipality A;
- Leisure buildings for the municipality A;
- Sports buildings for the municipality B;
- Schools for the municipality B;
- City hall and other offices for the municipality B.

Municipality A	Calculated value	Minimal value	Benchmark value	Good Practice
1) Luminous efficiency (lumen/W)	129.91	55.3	86.065	116.83
2) Municipality surface on annual consumption (km²/kWh)	0.00017	0.00018	0.00595	0.01173
3) No. of lighting spots on annual consumption (kWh <sup>-1</sup> )	1.352	0.353	1.469	2.585
Global index	73.82	31.38	49.03	66.69

Municipality B	Calculated value	Minimal value	Benchmark value	Good Practice
1) Luminous efficiency (lumen/watt)	101.49	55.3	86.065	116.83
2) Municipality surface on annual consumption (km²/kWh)	0.000074	0.00018	0.00595	0.01173
3) Number of lighting spots on annual consumption (kWh <sup>-1</sup> )	1.3869	0.353	1.469	2.585
Global index	57.75	31.38	49.03	66.69

Good performance

Amendable

Very amendable

Critical consumption

Table 11. Performance indicators of the public lighting

Through energy audits realized in the single structures and the use of the appropriate form for the data collections, the benchmarks of each user, in order to identify the possible inefficiencies in more detail have been calculated. Only the sector of leisure buildings for the municipality A has been neglected because of the total absence of detailed information about the structures which constitute it.

The results obtained from these indexes on the one hand confirm the validity of our efficiency ratios and on the other hand allow a precise localization of the problem.

Normalized thermal consumption (kWh <sub>term</sub> /m²)	Typical Value	Good Practice
146.54	151	79
Normalized electrical consumption (kWh <sub>el</sub> /m²)	Typical Value	Good Practice
185.51	85	54

Good performance

Amendable

Critical consumption

Table 12. Energy Indicators for offices in the municipality A

The values of the IEN<sub>E</sub> and the IEN<sub>R</sub> for each school allow the individuation of the users where energy saving measures must be applied.

The application of the two first phases of this model and the use of the innovative sector energy benchmarks realize a complete mapping of the energy performances and a first assessment of the possible measures.

Normalized thermal consumption (kWh <sub>term</sub> /m <sup>2</sup> )	Typical Value	Good Practice
309.68	237	162
Normalized electrical consumption (kWh <sub>el</sub> /m <sup>2</sup> )	Typical Value	Good Practice
115.58	56	31.7

Good performance		Amendable		Critical consumption	
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Table 13. Energy Indicators for sports buildings in the municipality B

	IEN <sub>E</sub>	Percentage repartition of the electrical consumptions	IEN <sub>R</sub>	Percentage repartition of the thermal consumptions
Nursery school	115	14.53%	54.4	14.34%
Nursery school-Pantano	100	12.49%	67.1	17.36%
Primary school	24.4	33.54%	8.0	24.21%
Primary school -Pantano	15.9	9.05%	11.0	13.67%
Junior high school	23.1	30.39%	11.3	30.42%

Good performance		Amendable		Critical consumption	
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Table 14. Energy Indicators for schools in the municipality B

Normalized thermal consumption (kWh <sub>term</sub> /m <sup>2</sup> )	Typical Value	Good Practice
90.01	151	79
Normalized electrical consumption (kWh <sub>el</sub> /m <sup>2</sup> )	Typical Value	Good Practice
84.46	85	54

Good performance		Amendable		Critical consumption	
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Table 15. Energy Indicators for offices in the municipality B

It's clear that the successive actions will plan to create a more capillary system of measurements and the creation of the model of consumption for forecasting the trend and individuate changes.

The case study ended with the definition of the more convenient energy saving opportunities, basing this evaluation on the priority ranking previously obtained. Every proposed activity has also an economic plan which is a fundamental support in the decisional process for the realization of the energy saving opportunities.

For individuating the most adapt activity to reduce energy consumptions, a block diagram approach has been used.

In Figure 12 and Figure 13 the decisional process for the individuation of the energy saving opportunities is highlighted, for the more critical sectors with the highest efficiency ratio values (electrical consumption of offices and sports buildings for municipality A, thermal consumptions of sports buildings for municipality B).



The variables which take part of the decisional process are both technical and economic; for example for thermal consumption after the evaluation of the correct dimension and of the efficiency of the boilers (technical consideration) the choice between the use of energy saving equipments (e.g. for the showers) or the installation of solar thermal collectors is necessarily based on the bankroll of the organization.

For this reason the municipality A decides for a more substantial investment and on the contrary the municipality B prefers a low impact energy saving opportunity.

From this reasoning approach the results are the following proposed activities:

1. installation of a solar photovoltaic plant on the city hall structure;
2. installation of energy and water saving equipments in the shower of the sports buildings and substitution of the boiler because oversized after the energy saving equipments installation.

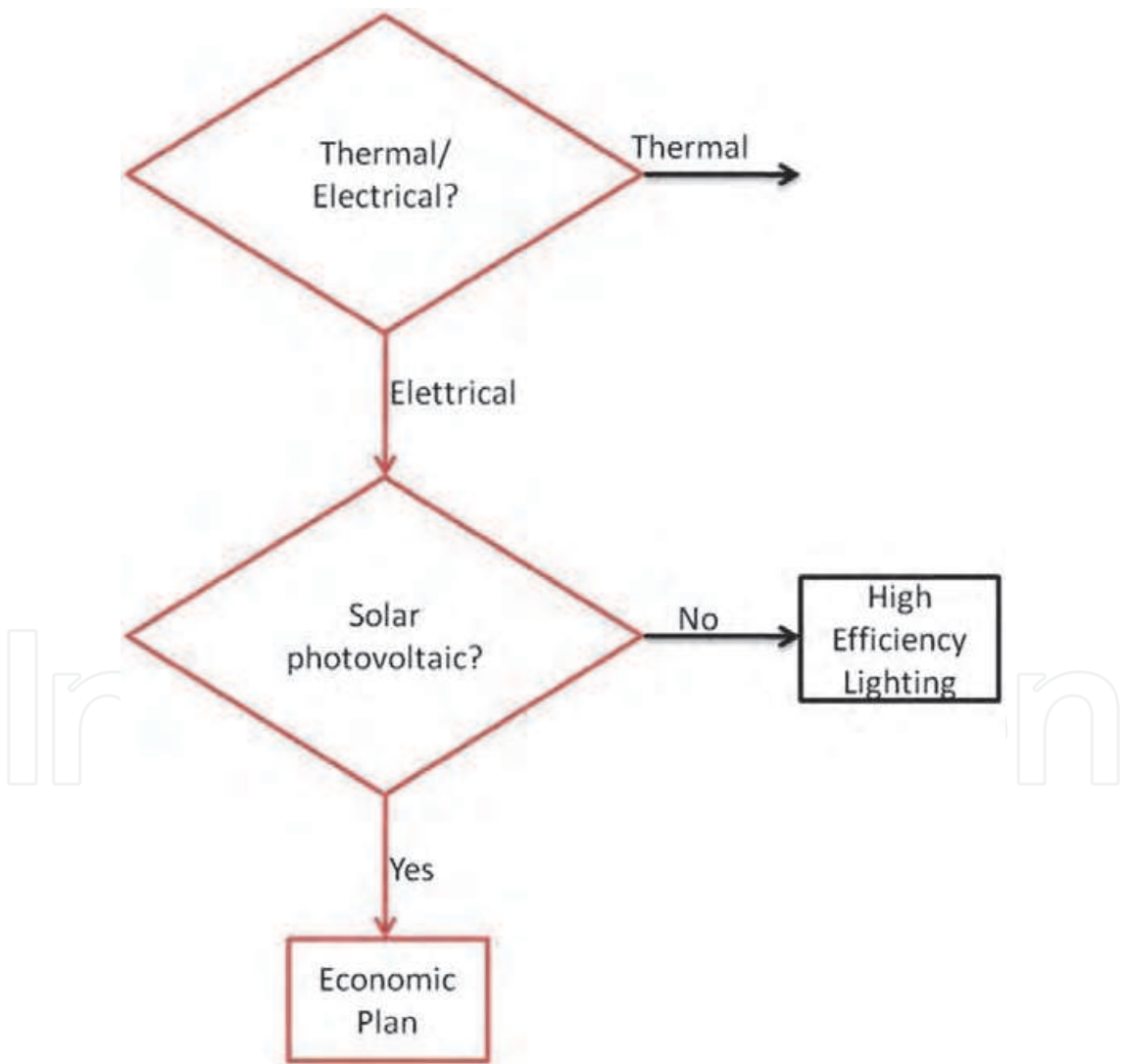


Fig. 12. Block diagram for electrical consumption of offices and sports buildings

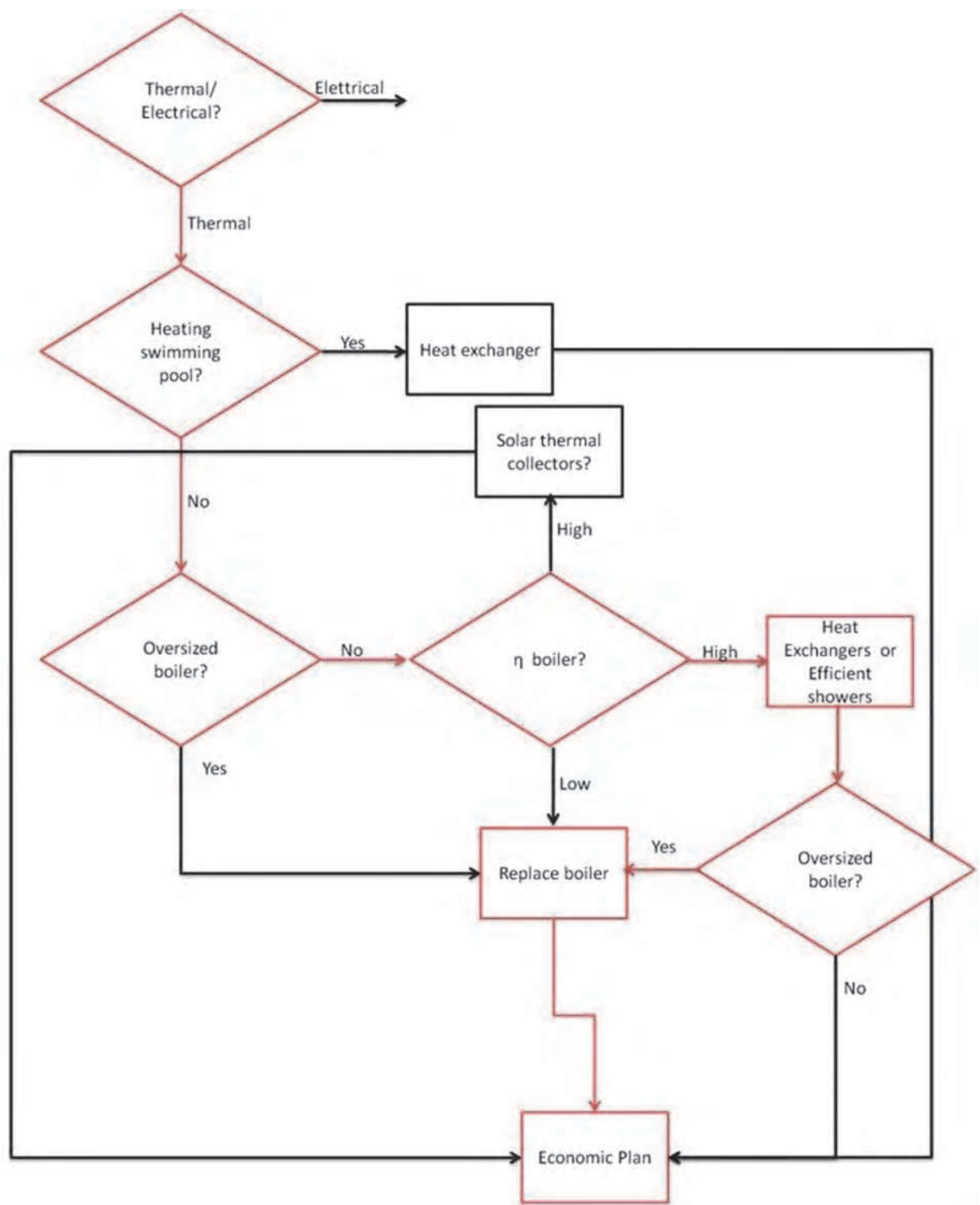


Fig. 13. Block diagram for thermal consumptions of sports buildings

The economic evaluations of these proposed activities are reported in the following figures and tables.

The photovoltaic plant has 5 kW of installed power and through an appropriate software (PVGIS, Potential Estimation Utility) an estimate of the annual producibility is obtained;

then, the Pay Back period, the Net Present Value, and the Internal Rate of Return has been calculated. In Table 16 the data used for the calculation are reported

Module characteristics	Conergy Power Plus 230 Polycrystalline silicon Efficiency: 14.3% Efficiency decrease: 1% per year
Module dimension	Weight: 22 kilos Surface: 1.63 m <sup>2</sup> Thickness: 46 mm
Installed power	5.06 kWp
Slope	33°
Geographical coordinates	41° 41' 28" North 13° 1' 23" Est

Table 16. Data for photovoltaic evaluation

In particular in Figure 14 there is the representation of the PBP, which is of 8.7 years.

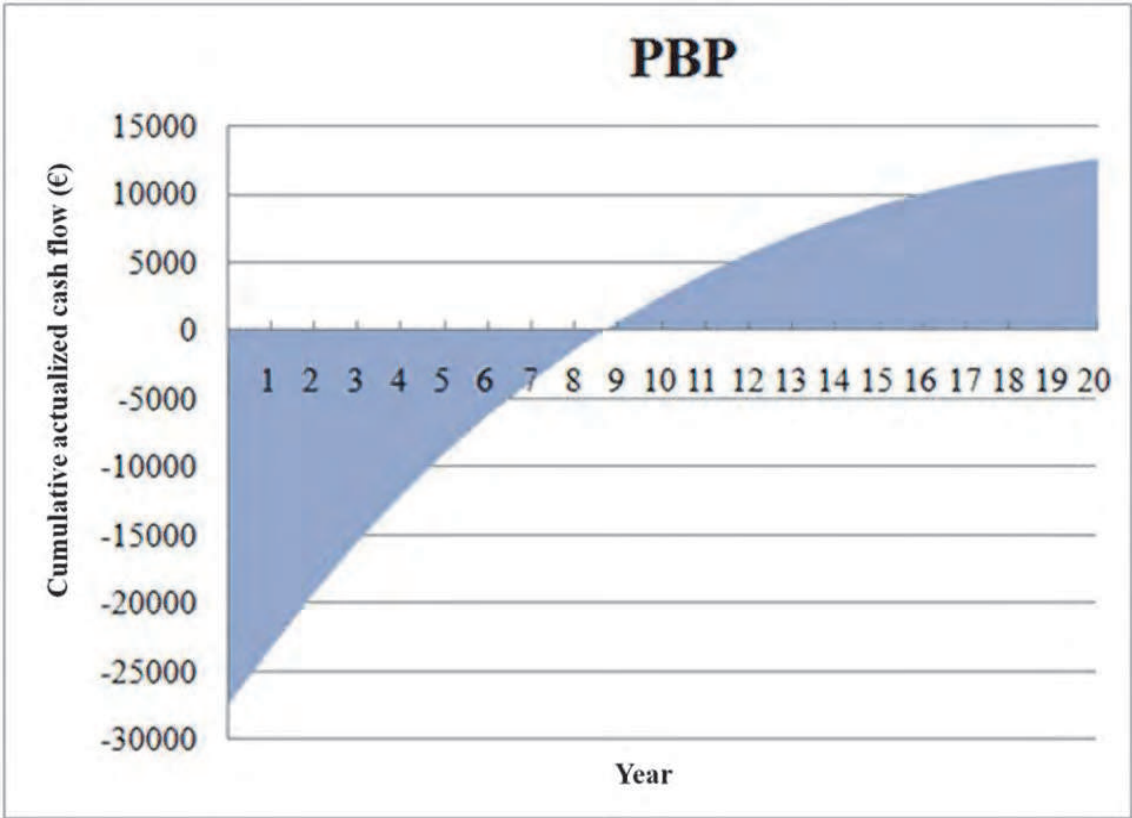


Fig. 14. Pay-Back Period for the photovoltaic plant of the municipality

Instead, for the thermal energy improvements of the sports buildings of the municipality B, the information about the investment are reported in the Table 17. The PBP in this case is lower than 1 year.

Cost installation of two condensing boilers - 32 kW(€)	4 760
Fiscal deduction (%)	55
Final cost of boilers (€)	2 142
Cost of timer (shower) (€)	1 501.5
Final cost of thermal improvement (€)	3 643.5
Previous annual consumption (m <sup>3</sup> / year)	1 8674
Actual annual consumption (m <sup>3</sup> / year)	8 039.2
Annual saving in natural gas consumption (m <sup>3</sup> / year)	10 634.8
Specific cost of natural gas (€/m <sup>3</sup> )	0.442283
Previous annual cost of natural gas (€/year)	8 259
Actual annual cost of natural gas (€/year)	3 556
Annual saving post improvement (€/year)	4 703

Table 17. Investments and savings for the municipalities B: sports buildings

5. Conclusion

A method for the realization of the energy management activities in the Public Administrations (in particular in the local government organizations) has been developed. All the necessary indicators for mapping the energy performance of this kind of organizations are defined: the system of indicators is hierarchical and it is differentiated on the basis of the various levels of detail.

By this way, an assessment on the efficiency of the energy users can be obtained and all the anomalies can be identified.

These indicators are used in an integrated approach which starts from the data collection and terminates with the identification of the main energy management opportunities.

The strength of the approach is the capability to obtain benchmarking evaluation starting from a total absence of energy management approach, a very common situation in Italian municipalities.

The application of this method to a case study of two small Italian towns shows this potentiality to rapidly understand the energy performance of an administration, even if we are starting from a shortage of data.

Even if the designed approach in the case study isn't realized in each phase, the achieved results permit to delineate a map of energy performance of the municipalities, a benchmark evaluation in terms of efficiency classes and the determination of initial and general energy management opportunities for the more inefficient areas (electrical consumption of city hall, thermal consumptions of sports buildings and public lighting).

The successive actions will be addressed to the acquisition of the historical consumption data, the design of monitoring system nets, the determination of predictive models and the creation of an alarm system which keeps under the consumptions.

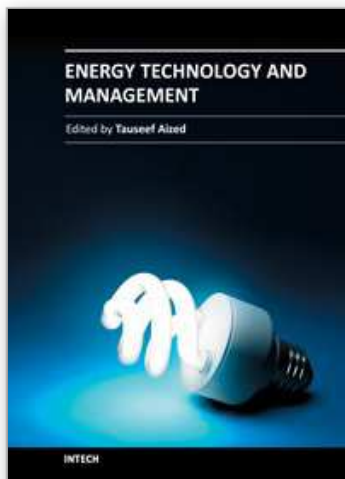
In conclusion, we want to underline that a possible improvement of the method could still be possible if a dataset on national scale would be available, in order to create the most reliable energy indicators.

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## **Energy Technology and Management**

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The civilization of present age is predominantly dependent on energy resources and their utilization. Almost every human activity in today's life needs one or other form of energy. As world's energy resources are not unlimited, it is extremely important to use energy efficiently. Both energy related technological issues and policy and planning paradigms are highly needed to effectively exploit and utilize energy resources. This book covers topics, ranging from technology to policy, relevant to efficient energy utilization. Those academic and practitioners who have background knowledge of energy issues can take benefit from this book.

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