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Energy Procedia 101 (2016) 542 – 549

Energy Procedia

71st Conference of the Italian Thermal Machines Engineering Association, ATI2016, 14-16 September 2016, Turin, Italy

Evaluation methodology for energy efficiency measures in industry and service sector

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Abstract

Directive 2012/27/EU, transposed in Italy with Decree of 4 July 2014 No102, a common framework of measures for the promotion of energy efficiency in European Union, is an innovative tool for improvement of energy efficiency and also necessary to undertake main objective of European Union (save 20% of primary energy consumption by 2020). Large enterprises and energy-intensive firms, except those having an energy management system (EnMS) according to ISO 50001 or compliant with EMAS Eco-Management and Audit Scheme or ISO 14001 fall under obligations and must be carry out energy audits every 4 years starting by December 2015 having "SMART" requirements: be Specific, Measurable, Accessible, Realistic, Time related. The analysis on a sample of Italian companies, mainly of small and medium enterprises (SME) in industry and the service sector, was conducted. Energy audit was carried out to identify Energy Company Profile, rationalize energy consumption to increase energy efficiency, assessing potential for energy savings and reducing of environmental impact. For any business context a series of energy efficiency measures has been proposed, selecting high profitability energy saving options by applying a priority criterion. Technical and economic indicators were reported on best practices focusing on tertiary sector and also industry. The study, starting from the feasibility assessments, aims to establish a possible correlation between energy performance indicators (EnPIs) and a limited number of parameters of the energy systems, in terms of production, operation and power consumption. Comparative assessment of energy-saving measures provides an useful method for assessing applicability of standard energy-saving measures in similar contexts and cost-effectiveness of solutions, as a function of a limited number of parameters.

Peer-review under responsibility of the Scientific Committee of ATI 2016.

Keywords: Energy efficiency; industry; service sector; energy performance indicators;

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Peer-review under responsibility of the Scientific Committee of ATI 2016.
doi:10.1016/j.egypro.2016.11.069

1. Introduction

The Legislative Decree No.102/2014 acknowledges the European directive 2012/27/UE which defines a series of measures for the promotion and improvement of energy efficiency aimed at reducing the energy final consumption on national territory. To achieve this goal it introduces a series of measures and identifies some tools like Energy Audit (EA) and Energy Management Systems (EnMS). The EA is a systematic procedure capable of supplying a proper knowledge of the energy meter of a building or group of buildings of a business or industrial plant or public/private services and then identify and quantify the energy saving opportunities according to a cost-benefit analysis. The purpose of EA is that of providing a description of energy system of an Organization and then highlighting the possible interventions to improve efficiency and work out the actual saving. Decree 102/2014 makes obligatory the EA every 4 years for a number of subjects: large companies; enterprises with over 250 staff and yearly turnover more than 50 million EUR or total annual balance sheet over 43 million EUR; energy-consuming businesses: manufacturing firms consuming more than 2.4 GWh/year and whose energy cost accounts for at least 3% on the yearly turnover. The Decree obligations, besides the fulfilment of EA, also comprises the implementation of interventions for energy efficiency following their actual spotting. Large enterprises adopting EnMS in compliance with EMAS and ISO 50001 or EN ISO 14001 regulations provided that they include an EA carried out in accordance with Annex 2 of Decree. Although SME are exempted according to this Decree: they can get incentives for the EA and for the adoption of EnMS as well as ISO 50001 certifications through the publication of a specific notice from MiSE (Ministry of Economic Development) [1]. EA must be in compliance with Annex 2 of Decree 102/2014 and with ENEA (Italian National Agency for New Technologies, Energy and Sustainable Economic Development) forthcoming guidelines; carried out by qualified entity: "Società di Servizi Energetici" (ESCo) UNI 11352 certified, Experts in Energy Management (EGE) UNI 11339 certified and energy auditors [2].

2. Energy consumption in industrial and tertiary sectors in EU

Total final energy consumption in industry (EU28) was 272,487 ktoe (2013) [3]. This accounts for 25% of total EU28 final energy consumption (1,103,813 ktoe) in 2013 [3]. Final energy consumption is projected to reduce for most sector groups based on a literature review of economic indicators, market statistics, energy consumption trends. Process heating remains the most significant energy use. There are a good range of economically viable Energy Saving Opportunities (ESOs). Significant innovation is required on current and emerging technologies to realise further industrial energy reduction potential. Market competitiveness remains the strongest driver for energy efficiency solutions. Internal barriers to uptake of ESOs are not well understood. In tertiary sector retail and wholesale trade buildings are the largest consumers of energy among non-residential buildings in Europe. Retail and wholesale trade accounted for 28% of total energy consumption in the non-residential building sector, which amounted to approximately 19 Mtoe (2012) [3]. Electricity consumption accounts for close to 70% of total energy consumption [3]. Accommodation and food service activities accounted for 11% of total energy consumption in the non-residential building sector (2012), amounting to approximately 10.5 Mtoe [3]. Information and communications equipment is estimated to consume approximately 14.7 Mtoe of energy in 2012 [3]. Financial and insurance activities: office buildings are the second largest consumers of energy among non-residential buildings in Europe accounting for 23% of total energy consumption in the non-residential building sector, which amounted to approximately 19 Mtoe in 2013 [3].

Gross inland consumption of primary energy	1.683	MToe
Final energy consumption	1.103	MToe
Total production of primary energy	794	MToe
Energy dependence	53	%

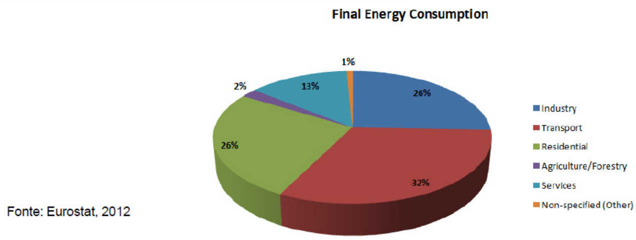

Figure 1 – Final energy consumption in Italy (source: Eurostat, 2012)

3. Energy audits

EA should be programmed according to the following 4 steps to be performed in sequential order: rationalization of energy flows; identification of energy-saving technologies; recovery of wasted power; optimization of energy supply contracts. In planning EA the following aspects to be taken into consideration: specific cost of saved energy; equipments size; hours per year of capacity gear; expected life of equipments; design negligence, implementation, operation of facilities and equipments; cost of money and available budget. The first step, in preparation for the attainment of any objective of rationalization, construction budgets and electrical/thermal energy models appropriate to the context. To build an energy model to make a survey, a census of all electrical (thermal) equipments is necessary. For each user is necessary to find information about: number of units of equipment; installed power; basic load rating; hours/day, day/month and month/year of operation.

4. Measures of Energy Efficiency Performance (MEEP)

Italian industry power consumption is worth about 155,7 TWh/year of which at least 20% wasted using outdated technologies. It is possible to operate on electric motors with 132 TWh/year. The number of electric motors in the industry is about 14.4 million (4.8 million in the service sector). Overall in Italy about 19.1 million is installed of which 12.5 million are electric motors with size below 90 kW. Installing available technology based on high efficiency motors and inverters energy savings allows to reach 25 TWh/year in CO_2 emissions reduction of about 12 Mtonn/year [4]. Interventions are of 2 types: vertical-type, affecting actions directed towards optimization of particular installation within production system (generation of heat for drying, high-efficiency motors, inverters, etc.) and horizontal actions as energy efficiency measures with beneficial effects for the production process (generation systems, contracts optimisation); interventions on electrical systems: peak-shaving, transformer management, power factor correction, conditioning management, pumping systems, distribution systems, lighting, photovoltaic systems [5],[6]; interventions on thermal systems: combustion control, heat recovery systems, other energy rationalization in temperature range in industry, engines fueled by alternative fuels [7], etc.; insulation of steam pipes: normally, the insulation of steam lines within a plant can be partly missing or collapsed (the insulation is designed to reduce thermal losses of at least 90%); space heating: movable barriers to heat leaks, room thermostats with automatic management program, heat recovery. Potential interventions: high-efficiency motors; containment pipeline leaks, decreased intake air temperature, pressure reduction on the compressed air systems; installation of inverter booster pumps; cold accumulation; steam lines insulation; power factor correction; replacing V-belts with toothed belts; install low-loss transformers; heat recovery for boiler feed water; cogeneration; optimization of combustion process in the boiler; rationalization of lighting [8],[9].

5. Methodology for Energy Performance Indicators

A set of independent variable allows for the definition of EnPI and for ongoing measurement and review of energy performance. ISO 50001 states that EnPIs can be a simple parameters, ratio or a complex model. An EnPI represents a value of specific consumption of primary energy, thermal or electrical relating to dimensional parameters (area, kWh/m^2 or volume, kWh/m^3) or not properly technical (kWh/year related to number of personnel, clients, rooms, beds, etc). EnPIs allow the evaluation of energy performance of user through direct comparison to specific limits of Laws on energy with average values for in the same efficiency category. EnPIs definition is first step to define energy consumption of a building/user and provide an overall indication of energy performance and allow to identify the areas of inefficiency to be redeveloped [10].

5.1 Definition of EnPI

The evaluation of EnPI may require the evaluation of large amounts of data that are available if onsite measures can be carried out or on the basis of information not always available (for example, energy bills of the previous 3 years). Without having this data available the only way to define the energy status is carrying out energy measures through an accurate EA. Through a measuring campaign of the main energy and environmental parameters is possible to make a comprehensive and structured database of key data relating to energy consumption. The availability of historical data also allows the characterization of energy systems and clearly identify critical areas to be energy redeveloped. However, on the one hand wide availability of accurate data is necessary to detailed assessment of energy status, the other involves time delay, increasing in costs of conducting EA. In addition with increasing thorough audit level, the benefits are becoming marginal while the costs associated increase faster and faster. The development of a methodology able to identify the relationships between all the measurable variables during the EA, will help identify strictly necessary parameters to the definition of EnPI, without detecting not indispensable parameters to the advantage of the reduction in time and costs.

5.2 Main EnPIs used

The study is focused on the following EnPIs (to be compared with benchmarks): HVAC (Heating, Ventilating and Air Conditioning): heating (EI_w) (kWh_{th}/m^3/year); HVAC: cooling (EI_s) (kWh_{el}/m^3/year); Hot water (EI_{hw}) (kWh_{th}/person/year); Lighting (EI_l) (kWh_{el}/m^2/year); Food refrigeration and storage (EI_c) (kWh_{el}/m^2/year); Lifts (EI_{lift}) (kWh_{el}/m^2/year). These EnPIs account for more than 80% of the building's energy needs in tertiary sector. Some of them, such as EI_w and EI_s are first-level indexes associated with heating and cooling demands and account for the higher percentage of the annual energy bill. Other EnPIs rather have a variable weight in relation to the intended use of the buildings. For example EI_{hw} may have negligible impact on the energy balance of a supermarket but not negligible for a residential building, but can be the opposite for EI_c. All listed EnPIs are of interest as part of the method developed in this study for their evaluation. Tertiary sector, the EnPIs refer to, has shown in recent years an increase in energy consumption higher than the average of the other categories of users. This trend identifies this sector as key driver of future energy demand which, even though characterized by high degree of heterogeneity of consumption centres allows the division of users into different categories: offices/public buildings, schools, hospitals, hotels, restaurants, supermarkets [11].

5.3 Assessment methodology

This analysis will develop a methodology designed to identify relationships between the value of the parameters measured during the energy audit and determine the relationship between EnPIs and some parameters easy to identify and measure. The methodology should make it possible to identify, among all the parameters necessary for the definition of EnPI, those that can be determined by ex post evaluation and not necessarily during the EA with reduction in time and costs involved. This way despite having numeric value of few necessary parameters it will be possible to estimate the value of unavailable parameters analysing and processing few data collected. In addition, in order to assess elementary energy efficiency measures, for which the costs of EA would make difficult the economic feasibility of energy efficiency improvement measure, it would be possible to carry out basic evaluations directly onsite with a minimum use of resources use and reduction in the related costs. The usefulness of the method, rather than possibility to predict the value of main EnPI, is in its implementability as a spreadsheet. In parallel with the development of the method a simulation tool will be assembled that will allow the immediate application of the algorithm and the evaluation of main EnPIs. The method will be developed on two different processing models. The first method has statistical bases, by implementing the inductive reconstruction of the missing parameters starting from those needed to define the energy performance. In fact, for some EnPIs average values characterized by limited standard deviation can be derived with statistical-based approach. In fact, based on the analysis of huge quantities of data from EA, values of some EnPI deviate very little from the mean value of entire population. In practice, for each energy consumption item one start from average value related to the intended use, and through subsequent checks an increasingly more accurate result is obtained. In such cases it is possible to make statistical inference, namely an inductive data processing to derive an empirical function can provide the value of the variable to be determined and for which it is possible to estimate the average error that affects the prediction. The second method is a deductive-based approach and may be used in all cases where first procedure cannot be used (excessive variability of samples). The average value, however, be calculated inductively, would in fact not representative of the population, and it would make little sense to use it as a starting point in the calculation of energy consumption, as in the case of EnPI of heating and cooling demand where numerous factors, including climate-related ones, introduce elements of uncertainty which make a statistical prediction unreliable. In such conditions, this method of investigation is based on macroscopic characteristics of the particular user (type of construction, intended use, size of the building). The assessment of characteristics of systems, energy consumption and construction type will be addressed with deductive approach analyzing the specific context of the building (climatic factors, technical requirements, regulations, etc.). The energy performances of the energy systems are dependent not only on the size of the building, on design, and the intended use. The intended use affects intensity and utilization time of the systems: an office building, for example, requires air conditioning only during working hours and days, while a residential building has to ensure a comfortable climate throughout the day and during whole year. Similarly the structure design influence for example the power size of installations: a building with large glass surfaces has a higher thermal transmittance with respect to a building with bearing walls, and this will require higher thermal powers both for summer air-conditioning and winter heating. The second step of the methodology concerns the definition of energy consumption and EnPI taking into account technical specifications, dimensions, external factors such as environmental ones [12].

6. Simulation of substitution of electric motors with motors with higher efficiency

Energy Simulation Tool (EST) allow to evaluate EnPIs related to annual electricity needs to power electric motors for cooling installations, food refrigeration and storage and handling of elevators. It describes how these EnPIs may find immediate use in the feasibility assessment of energy efficiency actions. In the specific case, the assessment procedure adopted in EST for economic assessment for electric motors substitution will be described [13].

6.1 Case study: simulation of replacement of high efficiency electric motors for compressors

The analysis aims at developing an inductive methodology for identifying the relationship between area, power and average fuel consumption of food refrigeration and storage in supermarkets through regression analysis. The sample analyzed buildings range in size from 700 to 5,000 m^2 of sales area (medium supermarkets). Under 700 m^2 autonomous fresh counters are often found, with higher specific power and for which there is impractical replacement of the compressor motors, for both technical constraints and low economic return. A dependence between the power of compression groups of installed refrigeration equipment and sales areas of its supermarkets was found. The table 1 shows an extract of data used. The COP of each compression group is considered equal to 2.6 (constant value). For each supermarket were considered 4 types of cooling systems, relatively to the study of the link between the surface of the supermarket and power of the compressors: cold rooms for positive temperature (CRPT), cold rooms for negative temperature (CRNT), normal temperature refrigeration plants (NTRP), low temperature refrigeration plants (LTRP). The analysis focuses on a supermarket of 1,500 m^2. For each proposed action, and according to EnPIs estimated in accordance with the methodology, EST provides an estimate value of cooling capacity and annual energy consumption. For refrigeration systems 4 different EnPIs are evaluated: CRPT (9.59 kWh/m^2/year); CRNT (21.71 kWh/m^2/year); NTRP (257.60 kWh/m^2/year); LTRP (116.59kWh/m^2/year).

Table 1: Power of refrigeration systems for investigated supermarkets

Supermarket	Sales area (m^2)	CRNT (kW)	CRPT (kW)	LT (kW)	N (kW)	Total input power (kW)
1	5,000	21	5	108	144	252
2	1,500	8,5	2,8	28	72	100
3	3,000	15	4,2	75	140	215
4	3,200	13,5	4	90	123	213
5	1,950	9,5	3	50	88	138
6	3,800	19	3,75	95	150	245
7	3,400	15	4	95	132	227
8	2,500	11,25	4,2	70	115	185
9	4,300	15	4,12	110	143	253

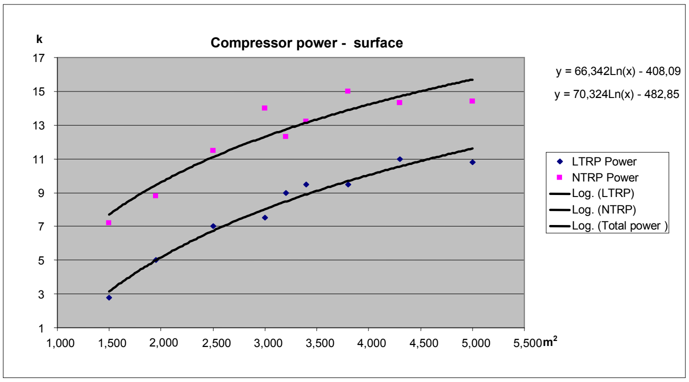

Figure 2: LTRP and NTRP refrigeration systems

The analysis of the data showed a nonlinear dependence between the power of refrigeration systems and the usable area of supermarkets. Trend is described with good approximation by regression curves (equations 1 and 2).

$$kW = 70{,}32 \cdot \ln x - 482{,}85 \text{ (LTRP)} \qquad (1)$$

$$kW = 66{,}34 \cdot \ln x - 408{,}09 \quad \text{(NTRP)} \qquad (2)$$

The decrease in power input with increasing the useful surface for NTRP, is because in large supermarkets fresh counters, large-sized, have a lower surface with respect to the dispersant cooled volume (figure 2).

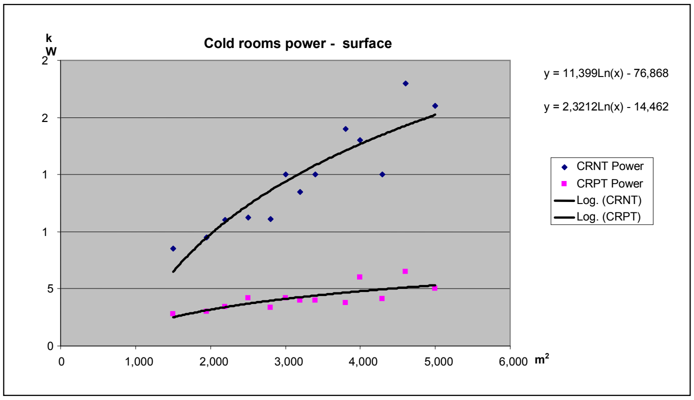

Figure 3: CRPT and CRNT refrigeration systems

Similar results were found for cold rooms (equations 3 and 4):

$$kW = 11{,}39 \cdot \ln x - 76{,}87 \quad \text{(CRNT)} \qquad (3)$$

$$kW = 2{,}32 \cdot \ln x - 14{,}4 \quad \text{(CRPT)} \qquad (4)$$

From obtained regression curve has been possible to integrate their functions in the simulator (figure 3). Selecting intended use "supermarket" the calculation of compressors size is activated and, on the basis of the analyzed data, an estimate on daily and annual consumption is provided. It agrees to share the power required by cooling systems of multiple compressors, avoiding the risk of plant downtime due to any of the pumps breaks, and it allows for partitioning the power delivery by turning off one or more electric motors, allowing the remaining always work in proximity of their rated capacity, and thus the maximum efficiency. As a safety precaution it considers for each installation the presence of at least two compressors between which divide the estimated power. It can still enter the compressors number per system to refine accuracy of EnPI assessment. To estimate annual energy consumption:

$$E_{annual} = \left(\sum_{j=1}^{n} \eta_j \cdot kW_{j-inst} \right) \cdot f \cdot 8{,}760 \qquad (5)$$

- kW_{inst} installed power of the j-th electric motor;
- η_j yield of the j-th electric motor;
- f plant utilization factor, assumed equal to 0.55 (average value of the analysed plants).

From the estimation of annual energy consumption EST allows the assessment of EnPI for each of 4 types of installations considered as $E_{ic}=E_{annual}/Area$. The figure 4 shows EST screenshot on the calculation section of EI_c.

EnPI Food Refrigeration (Food refrigeration)		
Estimated power Cold Rooms NegativeTemperature	27,66	kW
Estimated power Cold Rooms Positive Temperature	6,82	kW
Estimated compressor power Low Temperature Refrigetion Plants	200,23	kW
Estimated compressor power Normal Temperature Refrigetion Plants	161,99	kW
Annual energy consumption Cold Room Negative Temperature	127.047,74	kWh
Annual energy consumption Cold Room Positive Temperature	34.636,22	kWh
Annual compressor energy consumption Normal Temperature Refrigeration Plants	874.230,88	kWh
Annual compressor consumption Low Temperature Refrigeration Plants	711.952,68	kWh
NTRP Compression number	2	
LTRP Compression number	2	
EIc CRNT	13,23	kWh/m2/year
EIc CRPT	3,61	kWh/m2/year
EIc NTRP	91,07	kWh/m2/year
EIc LTRP	74,16	kWh/m2/year

Figure 4 – Screenshot Simulator: Energy consumption relative to a supermarket of 1,500 m^2

The estimated EnPIs are referred to installed capacity and annual energy consumption, and are bound together by such factors as: working hours per day, working days per annum, plant utilization factor. For cold rooms, given the lower specific power of the relative refrigeration systems, it is expected that the system is driven by a single electric motor to be replaced with new high efficiency electric motor. On the contrary, for LTRP and NTRP more flexibility in the intervention is provided for. In the hypothesis of two systems separated and served by different compression groups, the number of electric motors which share the workload is required. In this way evaluating alternative solutions with electrical motors of different size (and yield) and assess economic benefits estimating economic indicators and energy saving (kWh_{saved}/year) is possible. For each motor mechanical power available on the axis and power input was estimated. To avoid overestimation of energy savings after replacing, the efficiency reference values are relative to EFF3 class, 90% of the electric motors on the Italian territory having lower yield values.

Table 2: Estimation of power, energy saving and efficiency

User	Power (kW)	EFF3 motor (%)	Consumption (kWh)	EFF1 motor (%)	Consumption (kWh)
CN	6.50	79.00	32,559	87.00	29,565
CP	2.51	69.20	14,383	81.20	12,258
LT	7.86	81.40	38,244	88.40	35,215
NT	19.27	84.50	90,311	91.50	83,402

EuroDEEM database [14] in EST refers to yields, prices and functional features of high-efficiency motors "EFF 1" for electric power range from 5 to 200 kW, by which an immediate evaluation of the saving in terms of kWh_{saved}/year is possible, and the economic analysis of any intervention by research of higher efficiency electric motor most suitable to the application. Finally, tool is able to calculate incentives according to Technical Sheets of AEEGSI (Authority for Electricity and Gas and Water), as well as energy saving (toe/year) and White Certificates (WC) and the possibility of including or excluding the proceeds of economic incentives enabling the evaluation of further economic savings. For the intervention of replacing electric motor 7 toe and then 7 WC are recognized (1 WC per 1 toe/year of saved energy).

Table 3: Capital budgeting (replacement of electric motors with high efficiency motors in a supermarket of 1,500 m^2)

Cost of intervention (EUR)		10,212.8	
	3 years	**5 years**	**10 years**
Revenues (EUR)	31,773	55,207	122,619
Deductions (EUR)	1,141	1,902	3,804
Incentives (EUR)	0	0	0

Table 4: Financial indicators (replacement of electric motors with high efficiency motors in a supermarket of 1,500 m^2)

	3 years	**5 years**	**10 years**
NPV (EUR)	19.452	84,246	374,717
IRR (%)	58	94	106
PBT (years)		1	

For EnPIs referring to annual consumption of electricity for refrigeration and food storage systems in the supermarket we calculated the main economic indices (PBT, IRR and NPV) relating to the intervention of replacement of electric motors of compression groups with high-efficiency motors (table 5). The substituted motors have sizes of 20 kW (NTRP) and 12 kW (LTRP) with increase in yield of 5% and 7%. PBT is of 1.1 years (table 6).

Table 5: Capital budgeting.

Cost of intervention (EUR)		9,348.9	
	3 years	**5 years**	**10 years**
Revenues (EUR)	24,636	42,861	95,197
Deductions (EUR)	1,755	2,451	4,192
Incentives (EUR)	0	0	0

Table 6: Financial indicators.

	3 years	**5 years**	**10 years**
NPV (EUR)	11,306	60,767	284,967
IRR (%)	40	79	92
PBT (years)		1,1	

6.2 Case study: simulation of replacement of electric motors for the handling elevators. Determination of IE_{lift}

In order to validate the EnPIs related to facilities handling of elevators an office buildings of 10 floors and total area of 4,500 m^2 was chosen. Being known both the number of installed lifts (3 unit) and lift capacity (6 persons), the data were entered in the EST. EI_{lift} are estimated in 1.51 kWh/m^2/year compared with an estimated installed capacity in the 5.36 kW to lift global annual consumption of 6,170 kWh. The estimated powers and the recorded consumption data for the most recent year of utilization are reported in the following table together with the relative errors (table 7). Capital budgeting shows a PBT of 11 years, which is certainly excessive (table 8, 9).

Table 7 - Comparison of the measured data and the data evaluated by the simulator - relative error calculation.

	measured	calculated	Error (%)
Power (kW)	6	5.36	10.6
Energy (kWh)	8,000	6,811	14.8

Table 8: Capital budgeting

Cost of intervention (EUR)		1,320,6	
	3 years	5 years	10 years
Revenues (EUR)	593	1,317	2,198
Deductions (EUR)	510	756	756
Incentives (EUR)	0	0	0

Table 9: Financial indicators

	3 years	5 years	10 years
NPV (EUR)	-4,079	-2,947	374
PBT (years)		11	

Power of installed motor was estimated at 5.36 kW with 77% of yield; the equivalent EFF1 electric motor would have a yield of 85%. Compared to food refrigeration and storage, despite the yield increase of 8%, the low rate use of the lifts strongly penalises annual energy savings.

7. Conclusions

The study, focused on the evaluation of EnPIs, starting from feasibility assessments and aims to establish a correlation between EnPIs and a limited number of parameters of the energy systems, in terms of production, operation and power consumption. The assumption that each power plant is adjusted and sized according to the activity carried out and comply with current technical standards, the algorithm is able to evaluate EnPIs by entering the value of a few parameters such as: intended use; type and size of the building. From data processing, installed power and utilisation factor of the installations are determined. EnPIs values, obtained through deductive procedures, approximations, technical and statistical considerations, will inevitably be affected by errors. Through the tool EST energy consumption can be predicted on the basis of a limited number parameters. Several studies aimed at identifying a set of key performance indicators (KPI) of energy systems to evaluate the effectiveness of energy use that can be usefully introduced into EST for a more precise evaluation of EnPI [15].

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