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An energy saving solution applied to the final use of electrical and lighting systems of school buildings managed by Perugia Province

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ABSTRACT

In this paper, a study and design of energy conservation actions and the obtention of Energy Efficiency Titles, according to the Italian Ministerial Decree 20th July 2004, applied to lighting and electrical systems in a school district managed by Perugia Province (Italy), is presented.

Specifically, the analysis regarded the replacement of neon lamps with high efficiency ones, and the power factor correction of the electrical system with a lower value. The work was carried out through an energy audit of some school buildings. From the results of this energy audit, project solutions were developed and a technical and economical feasibility study was made.

This study was then extended to the whole school building fleet managed by Perugia Province. The results of this work were validated by a commercial feasibility assessment through an ESCo.

Keywords

Energy audit, energy-saving, school building, lighting system, power factor

1. Introduction

The purpose of this work is to show a study concerning the possible energy-efficiency interventions applied to the electrical and lighting systems in a school district managed by Perugia Province.

The total energy consumption of the Italian schools is 1 million TOE/year circa, which corresponds to 750 million Euros. In this sector, potential energy-savings are estimated to be around 10-20% of the total consumption (100,000-200,000 TOE/year) [1].

Therefore, an analysis aimed at obtaining an energy-saving in this field is interesting [2]. The following procedure to analyse the energetic problem consisted of:

- identifying the factors on which an intervention of energy requalification is possible, altering the environmental comfort only in a positive way;
- establish phases for a correct energetic diagnosis;
- defining the most economically advantageous aimed at energy conservation [3].

A rational use of energy in school buildings has to be promoted, for the huge potential of energy-saving from the improvement of installations [4], and for the following reasons:

- School buildings have high energy consumption, especially with regards to lighting and heating [5]. The size of that consumption is so high to justify an investment.

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- The cultural and the educational impact is interesting and extremely important [6].
- School buildings are places suitable for the adoption and the application of simple and reliable technologies.
- School buildings may have not dis-homogeneous scenarios which need different solutions in the same building, because of [7]:
  - different external light exposure;
  - different window fittings in the same building;
  - different room end uses (classrooms, laboratories, bar) [8].

1. Legislative Framework

On 24th April 2001 the Ministry of Productive Activities with the Ministry of Environment issued two decrees (one for the electrical sector, another one for the gas sector) lately substituted and updated by the two decrees on 20th July 2004 [9], called "Gas Decree" and "Electricity Decree" for the incentivation of energy-saving technologies.

These decrees (issued in the Italian Official Gazette n. 205, 1st November 2004) set a new way of promoting efficient energy-saving technologies, giving to AEEG the task for regulation and management. The goal of the decrees is to obtain national energy-saving of 2.9 million of TOE/year in the first five years; this value is equivalent to the annual increment of the national energy consumption of the 1999-2001 season.

The reduction of total energy consumption will lower green house gas emissions, according to the obligation Italy has signed for the Kyoto Protocol. This will bring economical and social benefits both for the single consumer and for the wider national community. For the former, the reduction of energy bills and the improvement of utility services; for the latter, improvements such as:

- the reduction of energy dependence from foreign countries and more supply safety;
- the reduction of pollution from manufacturing and energy consumption, and even more control of the energy consumption peaks, and the opportunity to lower the risk of blackouts and the costs due to the lack of balance between demand and supply.

The new body of legislation, from January 2005, establishes energy-saving objectives for the electric energy and gas suppliers with more than 100,000 users on 31st December 2001; these must be reached with energy-saving interventions with benefits for the end user for obtaining fixed energy-saving in the following five years. The objective is the ratio between the energy supplied to the end user and the total energy supplied to the country, both counted on the previous year (paragraph 2, art. 4 of DM 20th July 2004 for electric energy supplier, and paragraph 4, art. 3 of DM 20th July 2004 for gas supplier). AEEG data states that 63% of energy-saving (98,000 TOE) must be obtained by electric energy suppliers, and the remaining 37% (58,000 TOE) by gas suppliers. Following the obtained energy-savings, suppliers obtain TEE (also known as "White Certificates") from the GME. A TEE is an energy-saving unit that has the same value of a TOE. The Authority distributes the TEE according to the energy-saving every supplier has done. The Authority verifies and controls the realisation of every project, according to the decrees and actuative rules set by the authority itself [10].

2. User Energy Audit

A study to assess energy consumptions in school buildings managed by Perugia Province and to obtain indications for the definition of energy-saving interventions has been done [11]. The schools chosen for the intervention are mentioned in Table 1, where a number between 1 and 27 is associated to each school for a better view of the following graphs. First of all, data about the energy consumption of the schools have been acquired (Fig.1). These data regarded the main costs each school has to pay for electricity [12], and the power factor value of each school. Different energetic situations of each school building, chosen for relevant consumption and for having a representation of any different construction typology, have been analysed [13]. Electricity bills spanning one year were provided by the Perugia Province's Technical Office. From these bills the following data were obtained:

- electric power absorbed by each building;
- active energy;
- reactive energy;
- power factor.

From these data it is possible to choose the right actions to consider [14]. In this work, the following actions were adopted:

- power factor correction of the electrical system;
- replacement of actual lamps with high efficiency neon lamps.

Table 1. Schools managed by Perugia Province, chosen for the interventions.

N.	*School*
1	I.P.I.A., S. Maria degli Angeli
2	I.T.C.G. "R.Bonghi"
3	I.P.S.I.A., Foligno
4	HS "U.Patrizi" school-rooms
5	HS "U.Patrizi" shed
6	HS "U.Patrizi" branch
7	HS "Franchetti"
8	HS "Plinio il Giovane"
9	Art Institute, Deruta
10	I.P.S.I.A., Foligno
11	I.P.S.I.A. branch, Giano dell'Umbria
12	HS "R.Casimiri"
13	I.T.I.S., Gubbio
14	Art Institute, Gubbio
15	I.P.C., Marsciano
16	HS "Cavour" branch
17	I.T.C. "R. Battaglia"
18	Academy of Music "F. Morlacchi"
19	HS "Cavour Marconi"
20	HS "Cavour Marconi" branch
21	HS "A. Pieralli"
22	HS "A. Mariotti"
23	HS "G.Galilei"
24	Boarding School, Spoleto
25	HS "Fratelli Campani"
26	Art Institute, Spoleto
27	I.T.C.G., Todi

3. Substitutions Of Lamps

Three school buildings were chosen based on their different number of students and construction typology; they represent the 4.5%, in terms of electricity consumption, of all educational institutes managed by Perugia Province. In these three schools, on-the spot assessments were made to identify the actual condition of the lighting system. The majority of the lamps are neon lamps, that, even if they are high efficiency, nowadays are obsolete and cannot offer a satisfactory energy-saving level.

During this study, an Energy Service Company (ESCO or ESCo) was consulted. An ESCo is a commercial business providing a broad range of comprehensive energy solutions including designs and implementation of energy savings projects, energy conservation, energy infrastructure outsourcing, power generation and energy supply, and risk management [15]. The ESCO performs an in-depth analysis of the property, designs an energy efficient solution, installs the required elements, and maintains the system to ensure energy savings during the payback period. The savings in energy costs is often used to pay back the capital investment of the project over a five to twenty year period, or reinvested into the building to allow for capital upgrades that may otherwise be unfeasible.

The ESCo proposed the substitution of the actual neon lamps, which will be recycled in order to reduce environmental impact, with last-generation high efficiency neon lamps, and a dimmer photocell. This replacement does not have initial costs for the customer. Specific consumption of these neon lamps is about 40% lower compared to the actual neon lamps. The dimmer reduces further consumption by 20-25%. A photocell dimmer has a silicon phototransistor which is able, through the frequency of radiations, to recognize visible light from the radiations invisible to human eyes and useless for lighting purposes. From the amount of visible radiation, the photocell is able to set the quantity of light emitted from the neon in order to have a fixed and constant lighting on a work plan. It is important to avoid excessive lighting where it is possible to have good natural illumination in order to avoid excessive consumption.

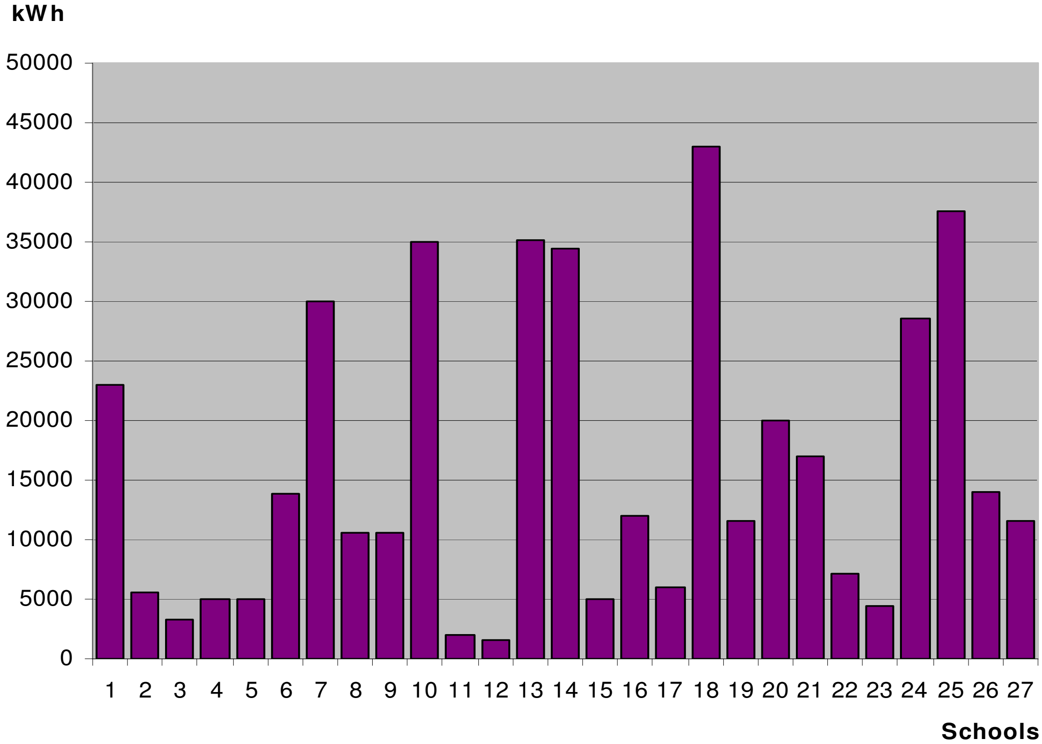

Fig.1: Annual electricity consumption in school buildings managed by Perugia Province.

With an electronic automatic dimmer feeder it is possible to obtain high energy savings under the same lighting conditions. The energy efficiency and the range of automatic variations of light assure, in each time of the day, the lowest energy consumption.

The calculation of energy savings is made by a meter which can collect the consumption of each neon lamp and compare it with the consumption of the old neon lamps. The difference between the two terms represents the energy saving obtained.

Moreover, each neon lamp is connected to the head office by a transceiver. Thanks to this system, it is possible to control all the lighting system; if some neon lamps do not work correctly they will be signalled to the head office.

In this study, we needed to work with a restricted number of school buildings to examine carefully each contest. We decided therefore, with the approval of Perugia Province, to choose three schools, on the basis of the number of students and the construction typology. The three school buildings chosen are as follows:

- technical and commercial institute “Vittorio Emanuele II”;
- high school “A. Mariotti”;
- high school “G. Galilei”.

Their energy consumptions are shown in Fig.2; the typology and number of lamps installed in these schools are summarized in Table 2.

Through the software provided by a lighting company, it was possible to have a first estimate of the energy-saving and of the number of TEE obtainable from this intervention.

For the calculation of energy-saving, the following hypothesis on working times have been made:

- 24 working days in a month;
- 10 working months in a year;
- 8 working hours in a day (1920 hours in a year).

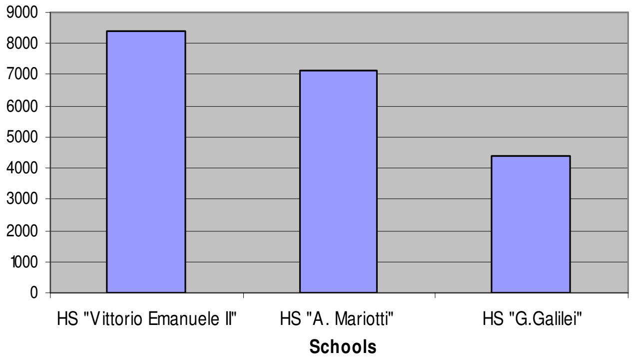

Fig.2: Annual electricity consumption of the three schools chosen for lamp substitutions.

Table 2. Typology and number of lamps installed in the examined schools.

SCHOOL	*N° neon 1x58W*	*N° neon 2x58W*	*N° neon 4x58W*	*N° incandescent lamps*	*Spot-lights*
"A. Mariotti"	101	117	24	8	0
"Vittorio Emanuele II"	26	376	4	72	1
"G. Galilei"	37	278	28	30	0
TOTAL	164	771	56	110	1

With natural lighting, considering the average consumption of 41.8 W for each lamp, it is possible to obtain:

- Average energy-saving of 72.1%;
- 34.27 €/year of economical-saving for each neon lamp.

For the three school buildings chosen we considered 1,930 58 W neon lamps, and their replacement with high efficiency neon lamps allows to obtain 39 TEE.

Using a rough estimate we calculated to obtain 497 TEE from the substitution of neon lamps in all the school buildings managed by Perugia Province.

4. Power Factor Correction

Electrical devices absorb electricity from the network, the quantity of which is due to the electrical characteristics of the devices.

Apparent power is the product between current and voltage, and systems have to be dimensioned using the value of apparent power. Electrical loads consume both real power, which does useful work, and reactive power, which dissipates no energy in the load and which returns to the source on each alternating current cycle. The vector sum of reactive and real power is the apparent power. The ratio of real power to apparent power is the power factor, a number between 0 and 1.

The presence of reactive power causes the real power to be less than the apparent power, and so, the electric load has a power factor of less than 1. The reactive power increases the current flowing between the power source and the load, which increases the power losses through transmission and distribution lines, with additional costs for power companies [16].

Therefore, power companies require their customers, especially those with large loads, to maintain their power factor above a specified amount (usually 0.90 or higher) or be subject to additional charges. Power factor correction brings the power factor of an AC power circuit closer to 1 by supplying reactive power of opposite sign, adding capacitors which cancel the inductive effect of the load.

After an analysis of the electrical consumption for all the school buildings managed by Perugia Province, power factors were calculated for each school [17]. For the school buildings with a low power factor (lower than 0.95) the capacity C of the capacitors that shall be installed to obtain a power factor of 0.95 was calculated.

The angle between real power and apparent power is showed in equation (1):

$$\varphi = arctg\frac{Q}{Consumption} \qquad (1)$$

and the power factor is given by cosφ.

Total capacity of capacitors is calculated from (2):

$$C = \frac{Q_n}{k2\pi f U_n^2} \qquad (2)$$

A power factor correction brings energy savings for power companies, which feed the network a lower power because of better utilization at the final user; the customer does not have to pay additional charges and, finally, the TEE obtained will bring incentives with a short payback time for the users.

From the difference between the value of reactive power before and after the power factor correction, and thanks to some indications from the AEEG, it is possible to calculate the obtainable energy savings; the decrease of consumptions is shown in Fig.3.The TOE obtainable from the power factor correction intervention are summarized in Table 3.

The power factor correction on the 27 school buildings requires a total cost of 12,000 Euros circa, and an economic return, for the selling of the obtainable TEE, of 2,000 Euros, corresponding to the 16% of the starting investment.Such a benefit is obtainable in addition to the savings on electric energy, which have, for this typology of intervention, a pay-back time of 3 years circa [18].

5. Incentives Calculation

From the preparation, execution and evaluation Guidelines for execution for projects (art. 5, paragraph 1, decrees 20th July 2001) and AEEG Deliberation n. 103/03 we can have:

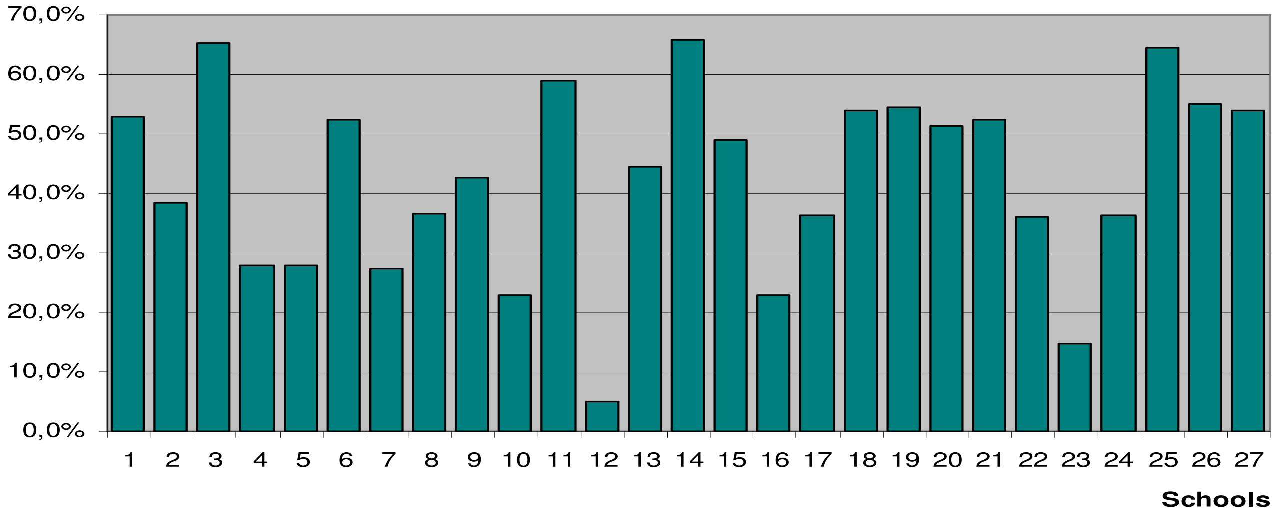

Fig.3: Percentage of energy savings relative to power factor correction.

Table 3. TOE estimated from power factor correction.

School N.	*cosφ*	*Capacitor capacity [kVAR]*	*Charges [€]*	*TOE*
1	0.84	17.5	455	1
2	0.76	10	428	1
3	0.86	10	428	0
4	0.64	10	428	1
5	0.64	10	428	1
6	0.84	10	428	1
7	0.64	17.5	455	6
8	0.74	20	475	1
9	0.79	12.5	442	1
10	0.56	100	1215	9
11	0.87	10	428	0
12	0.83	10	428	2
13	0.8	10	428	3
14	0.89	10	428	1
15	0.83	10	428	0
16	0.57	25	487	3
17	0.74	17.5	455	1
18	0.85	17.5	455	3
19	0.85	10	428	1
20	0.83	20	475	1
21	0.84	10	428	1
22	0.73	12.5	442	1
23	0.41	25	487	2
24	0.74	20	475	4
25	0.89	10	428	2
26	0.85	10	428	1
27	0.85	10	428	1
				48

- *Standard project* for one or more interventions to be evaluated through standard evaluation methods;
- *Analytical project* for one or more interventions to be evaluated through analytical valuation methods;
- *Consumptive project* for one or more interventions to be evaluated with different valuation methods.

It is possible to propose a request of preliminary inspection of conformity, only if there is not any technical card for a standard or analytical evaluation of the interventions. In that case the evaluation of energy savings obtainable must be proposed with a project proposal and a measurement program to be approved by the authority. For lamp substitutions and power factor correction a technical card was produced, so we needed to present a request of preliminary verification to the authority, following the guidelines given by the authority. For year 2008 the AEEG established the TOE priced at 42.99 €.

6. Conclusions

To reduce the energy consumption in school buildings and to experiment new technologies and methodologies for a rational use of energy, some interventions of energy savings are presented in this work, and specifically with special focus on:

- substitution of neon lamps with low consumption neon lamps;
- power factor correction in school buildings with a low power factor.

Table 4. TOE and tons of avoided CO_2 emissions estimated for the two interventions.

Intervention		***Energy-saving [TOE]***	***Avoided emissions [tons of CO_2]***
Power Factor Correction	Power factor correction in 27 schools	48	112.8
Lamps substitution	Substitution of 1,930 neon lamps in 3 school buildings with 1,930 high efficiency lamps	39	91.6
	Substitution of 24,638 neon lamps in all school buildings	498	1170.3

For the first intervention, 3 schools were chosen as a representative sample, and the results obtained have been extended to all school buildings; for the last intervention, 27 school buildings with a low power factor were found.

An energy saving of 546 TEE (or TOE) has been estimated and finally the tons of avoided CO_2 emissions were calculated according to the analysed actions, as shown in Table 4.

present study represents a pilot project, which can be used as a reference point for the drafting of a "local energy plan" for educational buildings, since it coincides with an hypothetical intervention/investment plan, a guiding and coordinating act for those administrations directly or indirectly involved in school building management.

Perugia Province has taken into consideration obtained results to carry out interventions by means of a ten-years local plan.

Its high value lies in the fact that it "acts locally by thinking globally". In fact the realization of these solutions represents a repeatable and practical application of European Directives on energy performance of buildings (2002/91/EC) and on energy end-use efficiency and energy services (2006/32/EC), with particular attention to educational buildings, enhancing as much as possible all the educational aspects of energy saving and efficiency.

7. Acknowledgements

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8. Nomenclature

TOE	Tonne of Oil Equivalent
TEE	Energy Efficiency Title
GME	Electrical Market Manager
AEEG	Italian Authority for Electrical Energy and Gas
DM	Ministerial Decree
HS	High School
I.P.I.A	Professional Institute of Industry and Craftsmanship
I.T.C.G.	Technical and Commercial Institute for Surveyor
I.P.S.I.A.	Professional and Government Institute of Industry and Craftsmanship
I.T.I.S.	Technical and Industrial Government Institute
I.P.C.	Professional Institute for the Commerce
I.T.C.	Technical and Commercial Institute
$\cos\varphi$	Power Factor
Q	Reactive power [kVAR]
Q_n	Nominal reactive power [kVAR]
U_n	Nominal voltage [V]
f	Nominal frequency [Hz]
k	Constant which is 1 for mono-phase plants and three-phase star- connected, and 3 for three-phase plants delta-connected.
ESCo	Energy Service Company

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10. Biographies

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Paolo Sdringola graduated in Environmental Engineering at University of Perugia, Italy in 2006. Ph. D. in Energy Engineering in 2010, currently is employed at the Department of Industrial Engineering, University of Perugia. Main interests and activities are focused on: energy efficiency, diagnosis and energy certification applied to buildings, analysis and simulation of energy-saving solutions, advanced energy systems. He has published papers on these topics in leading journals and conference proceedings.

Marta Millucci studied Mechanical Engineering at the University of Perugia. She has developed her final Master project in biomass gasification processes at the Technische Universität Berlin. She has led projects (KIMbcn Barcelona, Spain) involving scouting of new technologies in energy efficiency sector, solar thermal and photovoltaic energy fields applied to the building sector, and surveys on worldwide technology trends focusing on patents granted by the major research development centers. Her field of interest is the study on new knowledge concerning renewable energies.