Variability of energy and water consumption of school buildings

R.M.S.F. Almeida
Civil Engineering Department, School of Technology & Management, Polytechnic Institute of Viseu, Portugal

N.M.M. Ramos, M.L. Simões & V.P. de Freitas
Building Physics Laboratory, Civil Engineering Department, Faculty of Engineering, University of Porto, Portugal

ABSTRACT: In developed countries, the building sector is responsible for a very significant share of the total energy consumption. School buildings, since they are places where children are educated and learn to become active members of the society, must be a good example of efficient use of energy and water. In this study, data of the energy and water consumption of 23 Portuguese schools and their main building characteristics and properties was gathered. This information was normalized in order to homogenize the data set and then analysed using advanced statistical tools. The results show a significant variability in the consumption of different schools, even with similar characteristics, suggesting that there may be space to an improvement in its efficiency.

1 INTRODUCTION

In developed countries the building sector is responsible for a very significant share of the total energy consumption. On the 27 countries of the European Union, buildings (residential and services) consume about 40% of total energy use and in Portugal this value is approximately 27% (EUROSTAT 2012). In this context it was published in 2002 the EU Energy Performance of Buildings Directive (EPBD), recently recast in 2010. The main objective of the document is "to promote the improvement of the energy performance of buildings", establishing very ambitious targets (European Union 2010).

The EPBD recast also includes the definition of a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements, that specifies how to compare energy efficient measures in relation to their energy performance and the cost attributed to their implementation and how to apply these to selected reference buildings. Countries must define the reference buildings that should represent the typical and average building stock. Distinct reference buildings will be created according to their category (residential, office buildings, other non-residential) and can be established from a statistical analysis of available real examples data. The reference building should include information on the type of use, floor area, compactness of the building expressed as an envelope area/volume factor, building envelope structure with corresponding U-value, technical services systems and energy carriers together with their share of energy use (European Union 2012).

Regarding school buildings there is in Europe a growing concern and awareness of the need to use strategies, measures and sustainable building solutions in both new and refurbished buildings. However, the unfavourable economic climate we live requires great prudence when it comes to public investment and therefore should be considered alternatives to either reduce operating costs of the non-rehabilitated buildings, either economically optimize the process of rehabilitation. Accordingly, preparing a proposal for the rehabilitation of a school building, in order to improve its energy performance, should include data acquisition, both qualitative and quantitative, of consumption and consequent operating costs, as well as a constructive description of a significant building stock, since this information can be used to characterize the buildings performance in service conditions and to identify potential improvement measures.

The Laboratory of Building Physics of the Faculty of Engineering of University of Porto (LFC-FEUP) conducted a survey of the annual consumption of energy and water on 23 non-rehabilitated schools. The results show significant variability in the consumptions, suggesting that there may be a possibility for reduction. This paper describes the building stock, presents the data obtained in the survey, including a statistical analysis and the first results in the identification of the variables responsible for the variability, and perspective the future works in this investigation.

2 LITERATURE REVIEW

2.1 *Previous studies*

The variability on the energy consumption and, consequently, on the operational costs of school buildings has been subject of interest from several researchers.

Typically the strategies used to gather information on the consumption of school buildings is through the direct contact with institutions, or by sending questionnaires or on request from the government entity that oversees the sector. The data collected is used for the following purposes:

- suggest methodologies for ranking the performance of buildings based on the definition of energy classes;
- propose benchmarks to be included in the regulations or in the energy certification procedure of a particular country;
- define strategies for the identification of efficient rehabilitation measures;
- estimate the consumption of buildings with similar characteristics.

Concerning the methodologies for building rankings, based on a scale of consumption or on the definition of performance classes, commonly used strategies requires a previous statistical analysis of the data. The definition of performance classes can also be suitable for the quantification of reference values (benchmarks).

The annual energy consumption of electricity and natural gas was measured in 15 Argentinian schools by Filippin (2000) and used to estimate and classify the energy efficiency and emission of greenhouse gases, revealing an inefficient use of energy. Benchmark values were proposed and the results compared with similar studies developed in northern hemisphere countries.

Desideri and Proietti (2002) started a research project with the main purposes of promote a methodology for analysis of procedures for a rational use of energy and increment energy saving in Italian school buildings, which included the data collection of energy consumptions to define indicators of consumption and apply them to assess the potential for performance improvement. They concluded that the heating energy demand can be reduced by 48% if all buildings of the same type of construction performed as the best in the class. With the same approach electricity consumption could be reduced by 41%.

Hernandez et al. (2008) proposed to develop energy benchmarks and rating systems, applied to the Irish school buildings, computed from the actual consumption and the calculation of the "Energy Performance Indicator" and compares the results with computer simulation models. The reference values used for the classification were the ones proposed in the prEN 15217 (2005).

Corgnati et al. (2008) performed a field survey in order to collect data concerning the actual energy consumption for space heating of a sample of about 140 Italian school buildings. The information was used to establish a “specific energy performance indicator related to space heating” that could be applied in the definition of benchmark values.

Dascalaki and Sermpetzoglon (2011) exploit the results of a field energy survey in 135 Greek schools for classifying and defining energy consumption benchmarks and subsequently evaluate the relationship between the results and some characteristics of the buildings, such as the geometry and the presence or absence of insulation.

Santamouris et al. (2007) proposes a new energy classification technique, based on intelligent clustering methodologies, supported on the results of a field energy survey in 320 schools in Greece. The cluster analysis allows the identification of performance classes and, within each class, it was suggested a reference value, defined as the center of each cluster, ie, the point where the sum of distances from all data in that cluster was minimized. The results showed that the reference values achieved with this method differ significantly from those obtained with the traditional statistical models based on cumulative frequency distributions. The cluster analysis technique to define performance classes was also applied by Gaitani et al. (2010) with the purpose of identifying the main typical characteristics of the school buildings belonging to each energy class. To this end, a principal components analysis was developed within each class. The ultimate goal was, from these typical characteristics, identify high efficiency proposals for the school buildings rehabilitation.

Energy and indoor environmental audits of energy consumption and indoor air quality were taken by Butala and Novak (1999) in 24 old school buildings in Slovenia in order to perform an economic analysis of possible retrofit measures. The conclusions were that the heat losses are 89% higher than the recommended values and that it is not possible to improve the energy performance, by a more rational energy use, and guarantee good indoor air quality, with low investment costs.

Dimoudi and Kostarela (2009) utilized the values of energy consumption of 9 schools to characterize their performance and to create and calibrate a computer simulation model applied in the identification of potential rehabilitation interventions for reducing consumption.

Information on actual consumption of buildings can also be employed as an instrument of estimating the performance. Stuart et al. (2007) propose a methodology to identify electricity saving opportunities in school buildings based on half-hourly electricity consumption data. The method includes the monitoring of time series data and the identification of patterns in order to predict the performance and possible improvements. Beusker et al. (2012) propose an estimation model for heating energy consumption of schools in Germany based on a strategy of detecting critical parameters in buildings through their correlation with actual consumption. For that it was applied linear and non-linear regression models.

2.2 *Normalization, indexes and variables*

There is no standard procedure for the use of the data collected in energy surveys. It can be found in literature several proposals for the quantities chosen to characterize the consumption, for the procedure applied in the normalization of those quantities, for the indexes employed in the building classification and for the parameters and variables selected to describe the building.

The quantities typically chosen to evaluate the energy performance of buildings include heating energy demand and real consumption data of electricity, gas and other fuels, for heating proposes or as a total value of consumption. There is also some variability in the method elected to compute those quantities. Some studies consider energy related units (J or Wh) and others prefer the economic cost of the consumption.

Quantities need to be normalized in order to allow a comparison between the performance of buildings with different characteristics and locations. This normalization can be carried out regarding to different parameters and variables, such as area, volume, number of students, number of classes, external climate, etc.

Table 1. Relevant studies

Study	Country	Year	Quantity	Unit	Sample (N)	Mean value	Standard deviation
Butala and Novak	Slovenia	1999	Heating	kWh/m^2/year	24	192.8	61.3
				kWh/pupil/year		1521.2	1016.6
			Electricity	kWh/m^2/year		16.0	9.5
				kWh/pupil/year		124.7	97.2
			Both	kWh/m^2/year		207.2	61.4
				kWh/pupil/year		1770.8	1188.5
Filippin	Argentine	2000	Natural gas	MWh/year	15	218.7	135.5
				USD/m^2/year		1.7	0.62
			Electricity	MWh/year		27.7	24.4
				USD/m^2/year		2.1	1.06
			Total	kWh/m^2/year		122.7	41.1
				kWh/pupil/year		441.2	301.7
				USD/m^2/year		3.85	1.26
Desideri and Proietti	Italy	2002	Heating	kWh/m^3/year	28	24.2	19.5
				kWh/pupil/year	29	772.9	456.1
				kWh/class/year		16352,5	9368.2
			Electricity	kWh/m^3/year	13	3.1	1.4
				kWh/pupil/year		111.8	63.0
				kWh/class/year		2413.3	1375.2
Santamouris et al.	Greece	2007	Heating	kWh/m^2/year	320	68	-
			Electricity	kWh/m^2/year		27	-
Hernandez et al.	Ireland	2008	Total	kWh/m^2/year	88	96	50
Corgnati et al.	Italy	2008	Normalized primary energy	kJ/(m^3.ºC.day)/year	117	60	-
Dimoudi and Kostarela	Greece	2009	Heating	kWh/m^2/year	9	123.3	19.0
			Electricity	kWh/m^2/year	6	14.3	3.6
Gaitani et al.	Greece	2010	Electricity	kWh/year	450	25.3	46.9
				kWh/m^2/year	403	14	21
			Oil	litres/year	1037	10.1	14.6
				kWh/m^2/year	901	61	60
Kilpatrick and Banfill	Scotland	2011	Total	MWh/year	21	623.6	270.5
				kWh/m^2/ year		65.5	36.6
Dascalaki and Sermpetzoglon	Greece	2011	Heating	kWh/m^2/year	135	57	-
			Electricity	kWh/m^2/year		12	-
			Total	kWh/m^2/year		69	-
Beusker et al.	Germany	2012	Heating	kWh/m^2/year	105	92.85	28.33
				€/m^2/year		7.44	2.34

Table 1 presents an overview of the most relevant published studies related to the evaluation of school buildings energy performance making use of real consumption data and it is possible to observe the variability in the quantification and normalization of the results. The data of each survey was also analyzed and computed the respective mean value and standard deviation. It was found that the standard deviation values are globally high, which indicates a significant dispersion of the consumptions around the mean value.

Several studies and regulations suggest the use of indexes to evaluate and classify the performance of school buildings, both in design stage and in service conditions. These indexes are typically based on data of consumption and, as so, dependent on the normalization procedure employed (Desideri and Proietti 2002, Hernandez et al. 2008, Corgnati et al. 2008).

3 SCHOOL BUILDINGS CHARACTERIZATION AND METHODOLOGY

The study presented in this article focused on 23 school buildings, situated on the northern coast of Portugal. All are non-rehabilitated buildings, mostly of recent construction, more than 40% of the sample has less than 20 years (Table 2).

Table 2. Distribution according to the year of construction

<1970	1970-1979	1980-1989	1990-1994	≥1995
4	5	4	5	5

The costs of energy and water of each building were obtained from the respective monthly bills, during one year period, provided by the school board. Energy costs includes electricity (heating, lightning, …), gas (cooking and hot water preparation) and oil (hot water preparation).

Buildings were inspected and constructive and operation characteristics recorded, in particular the type of operation (number of students and classes), the geometry, the main constructive elements, facilities, heating and ventilation equipment and systems and the main constructive problems and pathologies. Figure 1 shows the distribution of the school buildings according to the number of students and the floor area.

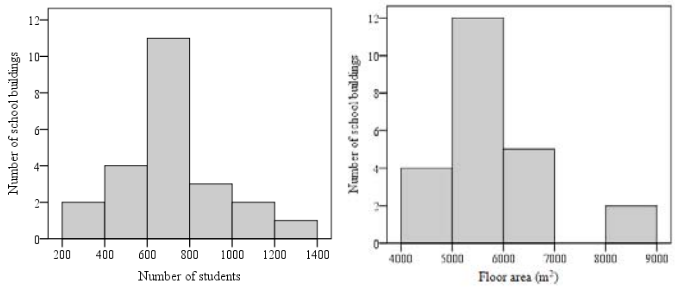

Figure 1. Distribution of the school buildings.

Since the energy performance of buildings is obviously dependent on the characteristics of its envelope, the most relevant properties were quantified: the heat transfer coefficient of the external walls (U_{wall}), roof (U_{roof}) and windows (U_{window}) and the solar energy transmittance of glasses and windows, with and without solar protection ($g_{\perp v}$ and $g_{\perp}'$). A geometric characterization of the buildings was also performed. Table 3 shows the results of the survey and their statistical analysis. In some buildings has not been possible to obtain all the data, therefore it is also presented the size of the sample associated with each variable.

Regarding heating systems, sample can be divided in: (i) Type A schools (five of the analyzed schools had electric heating systems in all classrooms); (ii) Type B schools (individual electric heaters are utilized, usually radiators, in some specific classrooms) (Figure 2).

a) b)

Figure 2. Heating systems. a) Type A schools; b) Type B schools.

Table 3. Building characterization

Parameters	Sample size	Mean	Standard deviation	Minimum	Maximum
Roof area (m^2)	23	2913	897	1400	5200
External walls area (m^2)	13	2111	711	1340	3750
Glass area (m^2)	20	919	538	445	2600
Garden area (m^2)	23	4686	3758	25	15000
Paved area (m^2)	23	10183	4744	1530	19000
U_{wall} ($W/(m^2.K)$)	23	1.31	0.63	0.45	2.60
U_{roof} ($W/(m^2.K)$)	23	2.84	1.11	0.53	3.40
U_{window} ($W/(m^2.K)$)	23	6.06	0.50	4.00	6.20
$g_{\perp v}$ (-)	23	0.82	0.02	0.71	0.82
$g_{\perp}'$ (-)	23	0.25	0.18	0.07	0.48

4 RESULTS

4.1 *Normalization*

The first step was the normalization of the consumption values. The procedure adopted for it was defined after a correlation analysis between variables: number of students, area, electricity annual consumption, gas annual consumption and water annual consumption. Table 4 summarizes the results obtained exposing the Pearson correlation coefficient (r).

Table 4. Correlation analysis

Pearson correlation coefficient		Number of students	Area	Consumption		
				Electricity	Gas	Water
	Number of students	1	**0.682**	0.407	0.091	-0.155
	Area		1	**0.585**	-0.019	0.223
Consumption	Electricity			1	-0.069	0.029
Consumption	Gas				1	-0.108
Consumption	Water					1

The results of the correlation analysis revealed that was only observed a significant correlation between the number of students and the floor area (r=0.682) and between the floor area and the electricity consumption (r=0.585).

Since the electricity consumption corresponds to the most important share in the total operating costs of these schools and the number of students is correlated with the floor area, it was considered that the most appropriate normalization for this sample would be in relation to the floor area.

4.2 *Monthly analysis*

In 7 of the schools studied has only been possible to obtain the annual consumption, so the monthly analysis is thus limited to a sample of 16 buildings. The monthly consumption data was used to identify possible patterns of behaviour that lead to consumption profiles. Figure 3 shows the monthly consumption of electricity and water.

Electricity consumption throughout the year presents a typified pattern, with higher consumption in the winter months, where the necessity of use of artificial lighting and the heating energy demand are higher, and lower consumption in the summer months that usually correspond to the school holidays.

With respect to water consumption the distribution is random, making impossible the identification of a consumption profile. Additionally, is important to refer that some specific data was not available, although not affecting the overall reading of Figure 3. It can be observed that at least no seasonal effect is present.

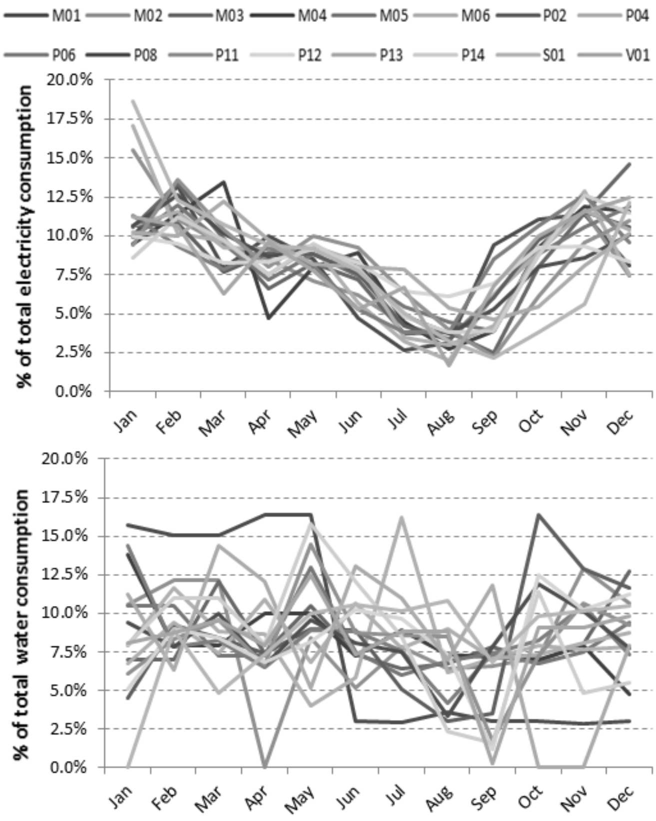

Figure 3. Monthly consumption.

Monthly data of electricity consumption was used to identify a profile of annual consumption, based on the calculation of the monthly average. The profile was computed separately for the five school buildings with heating systems with equipment in all classrooms (Type A schools) and for the rest of the buildings (Type B schools). Similar results were achieved for the two scenarios and, hence, no significant dependence between the consumption profile and the nature of the heating systems was found (Figure 4).

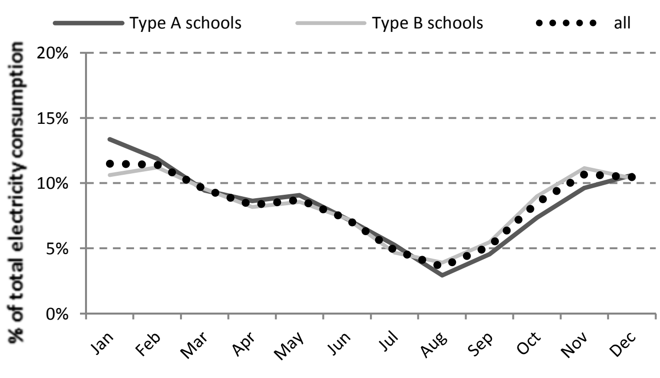

Figure 4. Monthly profiles.

4.3 *Annual analysis*

Table 5 shows the results of the statistical analysis of the number of students, the floor area and the total annual cost of energy (electricity, gas and oil) and water.

It can be concluded that the cost of electricity is the major operational cost of the schools analyzed. The distribution of the annual electricity cost is more homogeneous (C_v = 21%) compared to water (C_v = 72%) and gas (C_v = 57%). Only 4 schools have oil consumption and consequently the sample is too small to be statistically reliable.

Some school buildings have associated sports facilities. Figure 5 plots the distribution of the annual costs of energy and water, normalized relatively to the floor area, highlighting the schools that do not have sport facilities or do not support the consumption costs of energy and water.

In an unexpected manner, the results show that there are no clear evidence of relation between the presence or absence of the sport facility and the costs of energy and water in schools.

Table 5. Statistical analysis of the annual cost

			Cost [€/m^2]				
	Number of students	Area [m^2]	Electricity	Water	Gas	Oil	Total
Sample size	23	23	23	23	23	4	23
Mean	678	5663	3.89	1.45	0.66	0.29	6.05
Median	650	5500	3.98	0.98	0.58	-	6.01
Standard deviation	219	1012	0.83	1.04	0.38	-	1.25
Skewness coefficient	0.828	1.045	-0.35	1.86	1.46	-	0.70
Minimum	350	4035	2.29	0.39	0.20	0.14	3.86
Maximum	1200	8100	5.30	4.76	1.71	0.37	9.39
Coefficient of variation (C_v)	32%	18%	21%	72%	57%	-	21%

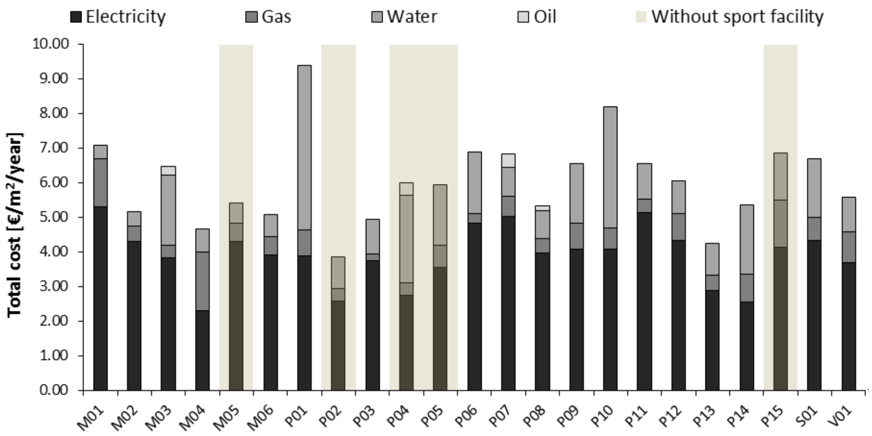

Figure 5. Annual operational costs.

The histograms of the normalized annual costs are illustrated in Figure 6. The distribution of the normalized electricity cost is almost symmetric while water and gas consumptions have right asymmetry.

Another way to statistically analyze the distribution of these samples is using the box-plot representation, where can be observed the outliers of the sample. This form of representation (Figure 7) allows to easily identify situations of abnormally high consumption, for example, the water cost at school P01, clearly superior to the average cost. In fact, the water consumption in this school is so uncharacteristic that conditions the global performance of the school, making it an outlier even when analyzing the total annual costs.

4.4 *Variability analysis*

As stated before, there is no standard procedure for the use of the data collected in energy surveys and, therefore, there is an enormous variability in the normalization procedures, in the units and indexes and in the variables considered. These different approaches makes complicated the process of comparing the values obtained in different studies.

Additionally, the analysis of the variability on the energy and water consumption and, consequently, on the operational costs of a group of school buildings, is important, since it can be a useful management tool for the government entity that oversees the sector. One way to compare the variability of a sample is by calculating the respective coefficient of variation, defined as the ratio of the standard deviation to the mean. The coefficient of variation was computed for the studies presented in Table 1 (those that provide the necessary information) and compared with the study presented in this paper (Figure 8).

The variability found in most of the studies has different magnitudes, ranging from 20% to 80%. The study on Greek schools, with a very large sample, provided even wider values.

Looking at the base data for each study, the variability can, of course, be explained by the variability of the outside climatic conditions in each study. For the Portuguese case, that climatic variability was rather low, the importance of adequate management of the facility therefore arises. An adequate method for grouping schools before deriving benchmarks must consequently be defined.

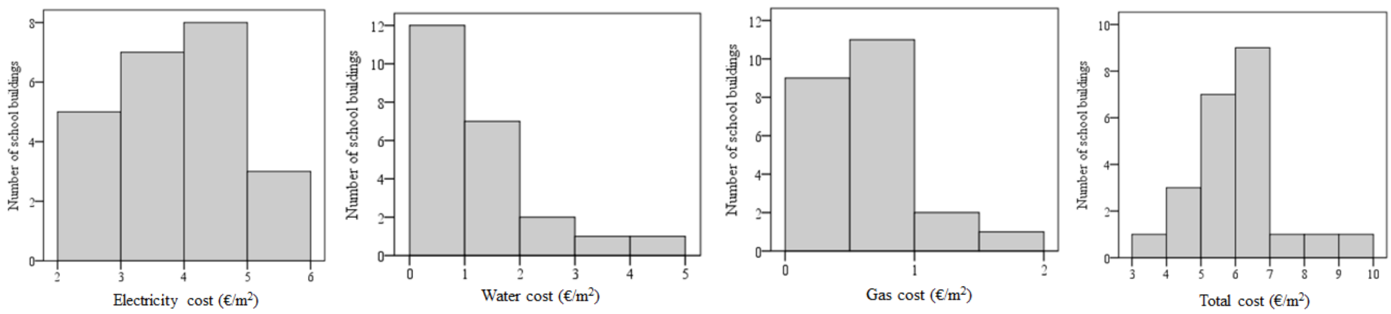

Figure 6. Statistical distribution of the annual costs.

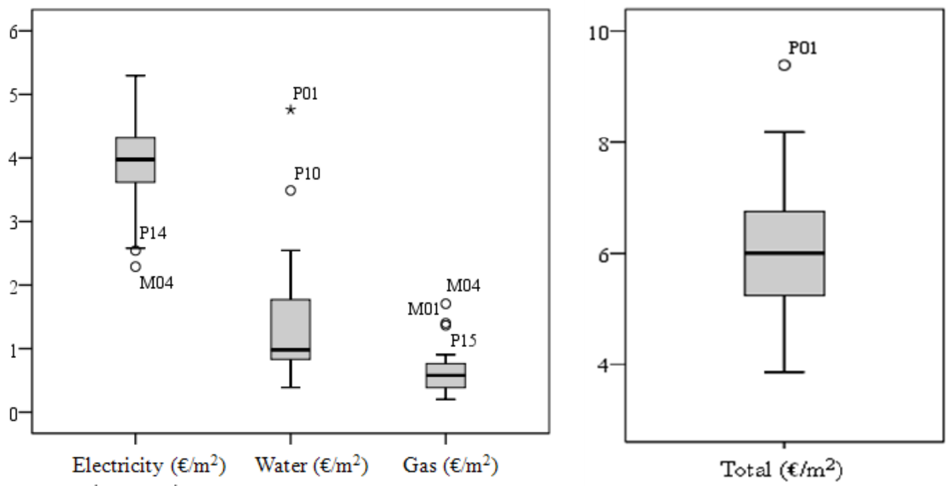

Figure 7. Box-plot of the annual costs.

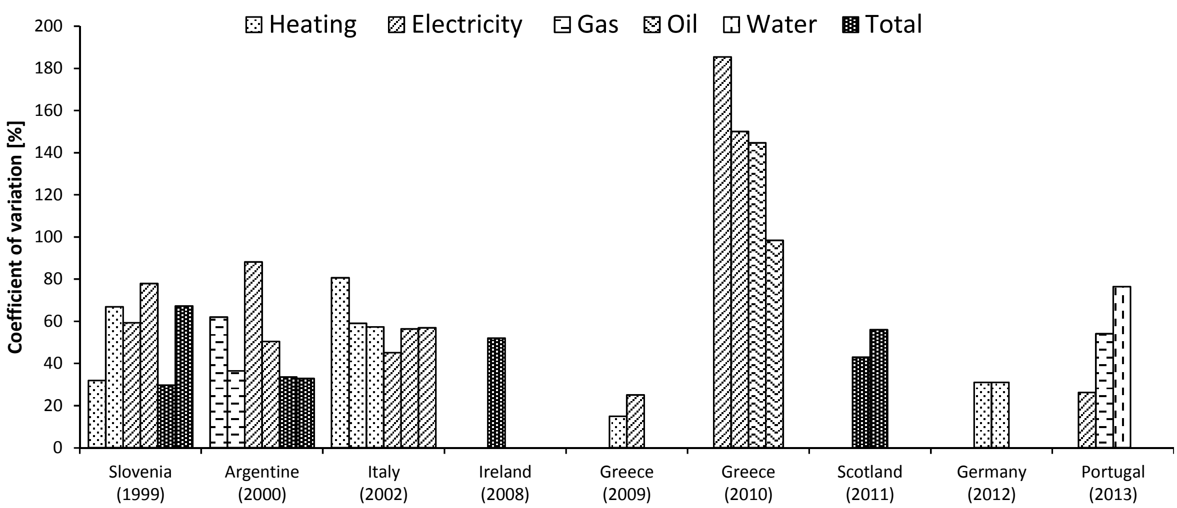

Figure 8. Coefficient of variation.

5 CONCLUSIONS

The data of an energy and water consumption survey, conducted in 23 Portuguese school buildings, was statistically analysed. The following conclusions can be stated:

- monthly consumption, over one year, of electricity, water, gas and oil was recorded. Electricity is the most significant operating cost, followed by water;
- correlation analysis showed that only exists a significant correlation between the number of students and the floor area and between the electricity consumption and the floor area;
- electricity consumption presents a clear seasonal variation, with higher demand in winter months. For the water consumption no pattern was detected;
- the analysis of the average profile of electricity consumption for schools with and without heating system with equipment in all classrooms indicates no significant differences, suggesting their reduced use;
- from the results is not possible to identify a clear relation between the presence or absence of a sport facility and the costs of energy and water;
- the statistical distribution of the normalized annual cost of electricity is almost symmetric while water and gas consumptions have right asymmetry;
- the median value of the total annual costs of energy and water is about 6 €/m^2, 4 €/m^2 for electricity and 1 €/m^2 for water;
- the variability found in similar studies, performed in different countries, can be very different, enhancing the need for a careful computation of all the information regarding these studies.

Using the actual cost of electricity it can be estimated that these buildings have an average consumption of 30 kWh/(m^2.year) which is a low value for school buildings. In situ measurements carried out in these buildings showed that it was only possible to achieve this level of consumption neglecting internal environmental conditions (indoor air quality and thermal comfort) (Almeida and Freitas 2010). For that reason it is essential that there is great prudence in the preparation of the rehabilitation of this schools, since it will most likely result in a significant increase in the energy demand, and consequently in the operating costs of these buildings, and may even, in some circumstances, make the building management unsustainable.

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